DEPARTMENT OF THE ARMY
TULSA DISTRICT, CORPS OF ENGINEERS
1645 SOUTH 101ST EAST AVENUE
TULSA, OK 74128-4609

WICHITA RIVER BASIN PROJECT REEVALUATION
RED RIVER CHLORIDE CONTROL PROJECT

U.S. Army Corps of Engineers
Tulsa District

DRAFT
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ECONOMICS APPENDIX

EXECUTIVE SUMMARY

The Economics Appendix to the Main Report of the Wichita River Basin General Reevaluation Report contains information and data used in the economic evaluation of constructing collection and disposal features in the Wichita River Basin for control of naturally occurring chlorides at Area VII on the North Fork of the Wichita River and Area X on the Middle Fork of the Wichita River. Area VIII collection facilities on the South Fork of the Wichita River, along with Truscott Brine Disposal Lake, were completed in 1987. This evaluation is in response to a 1997 request from the Assistant Secretary of the Army (Civil Works) to complete a General Reevaluation of the Wichita River Basin that would reexamine the economic feasibility and environmental impacts of completing chloride control features at the remaining salt source areas. The purpose of the economics appendix is to describe the methods and procedures for evaluating construction of chloride control facilities at Areas VII and X in the Wichita River Basin. In order to evaluate the economic feasibility of completing these collection and disposal facilities, the potential costs and benefits for chloride control are calculated. Reduction in the 491 tons per day of chlorides emitting from the upper Wichita River Basin would allow more beneficial use of improved water quality for municipal, industrial, and agricultural purposes.

The appendix is divided into several parts.

Part I is an Overview describing economic evaluation concepts. Adverse quality characteristics may limit water use and impose a penalty cost on the user. Penalty costs are additional costs required to treat the water to acceptable levels and the damages that would occur to users from using poor quality water. Total dissolved solids (TDS), chlorides (Cl), and sulfates (SO_4) are commonly used as indicators of the suitability of water for designated users. Based on Environmental Protection Agency public health standards, the recommended maximum levels in drinking water of those indicators are 500 mg/l for TDS, 250 mg/l for Cl, and 250 mg/l for SO_4. The features of Wichita River Basin chloride control attempt to limit the amount of chlorides entering the stream thereby improving the quality of water for beneficial purposes. Water users suffer damages when they incur an unnecessary expenditure to remove undesirable constituents before they can use water and/or their equipment is damaged because of the water's poor quality. Since this penalty cost is a measure of the damage incurred, comparison of penalty costs without and with the water quality improvement project provides a measure of National Economic Development (NED) water quality benefits. The conceptual basis for defining potential agricultural irrigation benefits of improved water quality is similar to that for municipal and industrial users. Agricultural benefits are measured by the average percent crop yield reduction due to irrigation of the crop without and with the project. This procedure is incorporated into the crop optimization model discussed in the agricultural portion of this report.

Part IIA of the Economics Appendix is a description of water demands, water resources, and water management strategies for Region B of the Texas State Water Plan, which includes the Wichita River Basin. The information and data described for Region B includes water demands, sources of supply, net needs, and future water management strategies for that area. Water management strategies include utilization of Lake Kemp water to supplement water requirements for the Wichita Falls area. Chloride control is part of the Texas State Water Plan along with

development of reverse osmosis (RO) treatment facilities for Wichita Falls. Reverse osmosis plant construction is currently underway in Wichita Falls for utilization of Lake Kemp water.

Part IIB is a summary description of Region C of the Texas State Water Plan for the North Texas area, including the Dallas-Fort Worth region. The description indicates water demands, sources of supply, net needs, and future water management strategies for that area. Lake Texoma water is being utilized to a limited extent due to its poor quality. North Texas Municipal Water District (NTMWD) currently blends Lake Texoma water. Greater Texoma Utilities Authority (GTUA) provides the city of Sherman treated water, using the electrodialysis reversal (EDR) desalinization process. Also included is a brief description of the area in Louisiana that may be affected by chloride control and that currently uses Red River water.

Part III describes the municipal and industrial economic evaluation and derivation of costs of Wichita/Red River water under existing conditions and with control at Areas VII and X. The costs of treating Red/Wichita River water using the RO and EDR processes and the damage cost of using the water without and with the project are calculated.

Part IV describes a reach-by-reach evaluation for municipal and industrial users of Red/Wichita River water. In this analysis, existing and potential use of Wichita/Red River water was first identified through the Texas State Water Plan for Regions B and C. Three sources of water supply, Lake Kemp, Lake Texoma, and the Red River in Louisiana, are identified as either existing or potential sources. In the Wichita River Basin, the city of Wichita Falls has plans underway to utilize Lake Kemp water. Some blending occurred in 2000 during the ongoing drought due to the significant reduction in water supply storage in Lake Arrowhead and Lake Kickapoo. By 2003, the city of Wichita Falls will treat Lake Kemp water by RO desalinization. West Texas Utilities has contracted for 20,000 acre-feet of Lake Kemp water and currently uses about 8,100 acre-feet. Existing municipal and industrial water use from Lake Texoma was identified for the GTUA and the NTMWD, with potential municipal and industrial water use for Grayson County. Long-range potential water use from Lake Texoma may also occur in other areas in the region, such as in the Tarrant Regional Water District (Fort Worth) and the Dallas Utilities Authority (DUA) service areas. However, the water plan does not specifically allocate water from Lake Texoma to those providers. In Louisiana, existing use of Red River was identified for Bossier City and Willamette Industries, both on the Red River.

In past economic evaluations when allocating water supplies to demands, demands are satisfied based on priority of use and least costly source. Priority of use meant that municipal and industrial water demands would be met first. The least costly source was chosen based on per unit cost, in terms of dollars per thousand gallons. Since then, considerable effort has been made by State and local entities to plan for future water needs. Therefore, the analysis must consider the water source as identified by the user and evaluated by the regional planning groups, and as described in the Texas State Water Plan. These entities may be assumed to have a local or regional perspective of their willingness to pay for additions to water supply. The order of priority of use is established as municipal, then industrial, which would include steam-electric power first based on contractual agreements. Storage and ownership of water for agricultural use is important at Lake Kemp where the Wichita County Water Improvement District is one of the reservoir owners. As discussed previously, the least costly source from a cost per thousand

gallon perspective may not be appropriate for an individual entity especially since the high capital cost, often in the hundreds of millions dollars, make an alternative cost prohibitive for a water entity. This evaluation will discuss each water provider or user in terms of the amount of water currently being utilized and projected to be utilized in the future based on the Texas State Water Plan. Water quality benefits are calculated when Red/Wichita River water is used with or without the project. The benefit is measured as the quality cost of water, either the cost of treatment to an acceptable standard or the damage cost as a result of no treatment, without the project as compared to with the project. A water supply benefit is calculated if Red/Wichita River water is used only with the project and is the difference in values between the cost of Red/Wichita River water with the project and the value of the next least costly alternative with the project. Induced benefits occur if additional water is used with the project above that which is used by the project without the project. Future without-project conditions assume that current use of Red/Wichita water source would not be abandoned for another source. If future net needs exceed the ability of a current source to meet those needs, then the next least costly source would be used. Municipal and industrial benefits are calculated by reach for each major water provider that currently uses or plans to use the Wichita River and/or the Red River as a source of water supply. Existing use of the river occurs in Louisiana by the city of Bossier City and an industrial user at Campti, Louisiana. Although the impacts of Wichita Basin chloride control are slight this distance from the chloride control points, potential economic benefits are developed for the plans under consideration based on differences in the TDS concentration-duration curves for the without and with project condition. No water use from the Red River for municipal and industrial purposes in Arkansas and Oklahoma occurs at the present time. Other sources of water supply are generally of better quality and are utilized in the basin. In Texas, where recurrent shortages of water occur in some regions, use of Lake Texoma water and Lake Kemp water currently exists and is expected to continue to occur in the future. Full utilization of existing surface water may be less costly and result in fewer environmental impacts than developing a new source of surface water supply. Table ES-1 summarizes the municipal and industrial benefits by reach and plan.

Part V describes the agricultural irrigation evaluation and potential irrigation benefits for improved water quality with different water availability constraints. The current economic analysis is based on a mathematical model for agriculture that includes land, water, and salinity constraints. The concept of salinity control at the source areas includes disposal of brines at the existing Truscott Brine Lake, or diversion to other stream locations as proposed by the U.S. Fish and Wildlife Service in the fall of 2001. Deep well injection was not feasible in this area due to the lack of suitable geologic formations in which to inject the brines. To estimate average annual benefits, existing conditions with Area VIII completed are compared to project alternatives with Area VII or Area X completed or with both Areas VII and X completed. This agricultural evaluation was first completed in September 2000. Revisions to crop budgets and water availability were made in September 2001, and interest rate changes were made in December 2001 to 6-1/8% for Fiscal Year 2002. The agricultural analysis in 2000 considered two optimization scenarios. First, the model limited current irrigated acres to 15,000 (current level); however, with the project, model optimization occurred. An analysis based on best management practices and optimal net returns with and without the project, known as the optimal to optimal condition scenario, was also conducted.

TABLE ES-1

SUMMARY OF MUNICIPAL AND INDUSTRIAL BENEFITS BY PLAN

	Demand Center	Quantity Demanded (mgd)	Plan 3 Area X ($1,000)	Quantity Demanded (mgd)	Plan 4 Area VII ($1,000)	Quantity Demanded (mgd)	Plan 5 Areas X & VII ($1,000)
1	Bossier City/Municipal & Industrial	10	$24.0	10	$72.2	10	$96.3
	Industrial/Manufacturing	12	$3.9	12	$15.6	12	$23.4
5T-GTUA	GTUA-Sherman EDR	10	$22.8	10	$68.3	10	$91.0
5T-GRAY	Grayson County	5	$9.4	5	$29.5	5	$38.9
5T-NTMWD	North Texas Municipal Water District						
	Blend Lake Lavon & Lake Cooper	46.5	$281.4	48.7	$899.4	49.7	$1,048.4
9-WICHFALL	Wichita Falls						
	10 mgd RO/EDR with dam	10	$107.3	10	$523.5	10	$842.1
9-INDUSTRY	Steam-electric Oklaunion	0.3	$2.8	0.3	$11.0	0.3	$19.3
Total M & I		88.8	$439.4	91	$1,551.9	92	$2,144.0

Texas A&M and other conducted previous agricultural economic analyses in 1980, 1992, and 1997. The economic study conducted in 1980 was an analysis of the chloride control project for the entire Red River Basin (Runkles et al.). Since then, there have been several updates using the basic soils and yields of the 1980 study, such as Lacewell et al. (1992) and McCarl et al. (1997). The updates were based on water availability and salinity with and without a project. Also, new crop enterprise budgets with updated prices were used to refine the economic model. In 1992, the economic optimization model was first expressed in the General Algebraic Modeling System (GAMS) software to make future updates more effective and efficient.

The crop yields, costs, and returns were based on current crop enterprise budgets for the region as developed by the farm management specialist in Vernon, Texas. The economic analysis was based on water quantity and salinity estimates developed by the U.S. Army Corps of Engineers, Tulsa District and as estimated by the Texas Agricultural Experiment Station (TAES). The economic model for evaluating the agricultural implications of salinity control in the Wichita River region has been developed and applied. This model, which includes stochastic elements, has been applied to a set of data jointly provided by the TAES Blacklands Research Center at Temple, Texas, and the U.S. Army Corps of Engineers. This report discusses some of the major differences between this analysis and previous analyses of the Red River project, including discussion of a mixture of new assumptions, new modeling approaches, and new data used in the analysis. Most of the information and data presented is from the September 2001 TAES report. Interest rate changes in December 2001to 6-1/8% from 6-3/8% are presented as the final benefit carried forward for cost-benefit comparisons.

The current analysis required a different modeling framework due to the incorporation of uncertainty. In particular, the model that was used was stochastic programming with a recourse or discrete stochastic programming model (Dantzig 1955; Cocks 1968; Ziari et al. 1995). Within this modeling framework, acreage and irrigation installation decisions are made before the value of uncertain states like salinity and prices are known. In particular, irrigated acres are chosen before the year's cropping season, salinity, or crop prices are known. In turn, leaching water requirements, prices, and salinity affected yields become known after the cropping decisions are made. This is the same method used for analysis in the Edwards Aquifer region of Texas and in many other projects (Dillon 1991; Williams 1996; McCarl et al. 1993; and Schaible, McCarl, and Lacewell 1999). Also, the period of analysis was changed to include 2005-2105 with the same conditions assumed in place from 2055-2105.

Three allocation schemes impacting economic Reaches 7 and 12 as provided by the U.S. Army Corps of Engineers, Tulsa District were as follows:

Scenario One:	71,500 acre-feet of water available 100% of the time
Scenario Two:	100,000 acre-feet of water available 89% of the time
	50,000 acre-feet of water available 11% of the time
Scenario Three:	120,000 acre-feet of water available 82% of the time
	60,000 acre-feet of water available 16% of the time
	30,000 acre-feet of water available 2% of the time

All analyses include Reaches 5 and 6 with 70,000 acre-feet of water available in each reach 100% of the time. The rationale for development of these scenarios is discussed in the Hydrology Appendix.

For the study area, there are about 15,000 acres irrigated in a base case. With improved water quality, it is expected that irrigated acres will increase. To have a set of expected benefits attributable to the project, two sets of comparisons were analyzed for the three scenarios above. The comparisons were:

Scenario One: Optimal to Optimal. This refers to running the GAMS model allowing optimal or profit maximizing acres of each crop (irrigation and dryland) to come into solution for current conditions and conditions with the salinity project.

Scenario Two: 15,000 to Optimal. This refers to running the GAMS model allowing only 15,000 irrigated acres for the current conditions situation, but using the optimal (profit maximizing) acres of irrigated crops for the with-project conditions.

For the Optimal to Optimal and the 15,000 to Optimal comparisons above, all three scenarios of irrigation water allocation conditions will be included. Thus, there are six runs of the GAMS model with associated results.

The GAMS model represents a very powerful method for modeling using external files. For the analysis, there are data requirements related to land, water, crop yield and impact of salinity on yield, and crop enterprise budgets.

Land in each soil type for each reach was derived from U.S. Department of Agriculture soils maps for the study area. Most of the acreage is located in Reach 7, with 30,723 dryland, 5,482 irrigated, and 9,133 in irrigated pasture. Total land available for the study is 99,827 acres.

The following designations are used in the summary tables in the main body of the report.

Opt-Opt	=	Optimal base solution compared to optimal with-project solution
15K-Opt	=	15,000 acre irrigated base solution compared to optimal with-project solution
Wat1	=	71,500 acre-feet of water available 100% of the time
Wat2	=	100,000 acre-feet of water available 89% of the time, 50,000 acre-feet of water available 11% of the time
Wat3	=	120,000 acre-feet of water available 82% of the time, 60,000 acre-feet of water available 16% of the time, 30,000 acre-feet of water available 2% of the time

Six separate estimates for acres irrigated were done conforming to the three scenarios for water availability and the two scenarios on current conditions (current versus optimal). In all cases, the principal reaches irrigated are Reaches 5 and 7. Reaches 7 and 12 are related in that these two reaches share water available and the most profitable receives the water. The principal crop irrigated in all cases is alfalfa, with some tomatoes and bermuda.

Table ES-2 presents the expected average annual benefits to irrigated agriculture across all reaches for the Wichita Salinity Control Project. Naturally, the average annual benefits mirror the total present value of benefits. For Plan 3, benefits range from $1.4 to $3.34 million, for Plan 4 from $0.194 to $1.481 million, and for Plan 5 from $1.98 to $4.511 million. Clearly, based just on the agriculture component of measuring benefits to the project, Plan 5 is far superior.

TABLE ES-2
AVERAGE ANNUAL BENEFITS IN MILLION DOLLARS

	Plan 1	**Plan 3**	**Plan 4**	**Plan 5**
Opt-Opt, Wat1 - Full Water Always Available	-0.038	1.405	0.194	1.980
15k-Opt, Wat1 - Full Water Always Available	-0.061	2.340	1.247	3.289
Opt-Opt, Wat2 - Limited Water 11% of the Time, Full the Rest	-0.080	1.708	0.131	2.726
15k-Opt, Wat 2 - Limited Water 11% of the time, Full the Rest	-0.079	3.044	1.468	4.062
Opt-Opt, Wat3 - Limited Water 16% of the time, and No Water 2%	-0.084	2.008	0.145	3.175
15k-Opt, Wat3 - Limited Water 16% of the time, and No Water 2%	-0.083	3.344	1.481	4.511

These results indicate that more water can be profitably used in the study area for as total water available is increased, benefits increase. Also, there is support that improved water quality is a benefit to agriculture bringing increased yields. The primary crop produced was alfalfa, with some bermuda and a small acreage of tomatoes.

Several issues and market factors impact the economic analysis. Some major factors included in the analysis are:

- The location of land available for irrigation has significantly shifted east from that in past studies. In particular, the majority of the land available for irrigation is located in reaches where the change in salinity is not great relative to crop tolerance for salinity. This means the yield differences in those regions for project conditions is not dramatic. In previous appraisals, there was substantially more potential irrigable acreage available in reaches that received a very large projected reduction in salinity loads and, therefore, exhibited large changes in the potential for agricultural irrigation. Our reexamination, based on the Geographical Information System and ownership patterns, showed irrigated crop production in the uppermost reaches was not viable.

- Over the 15 or so years that this project has been appraised, agriculture has been subjected to a cost price squeeze, and the profitability of agriculture has not been great. In the project region, the observed irrigated acres have fallen largely due to economic conditions. This occurred even though the first project works were put in place. Much of this current situation of depressed prices is resolved due to the use of normalized prices.

Reviewing the expected annual net returns for Plan 5 gives insight into the dynamics of the region. Benefits are estimated at $3.31 million in 2005 then increase slowly to $11.79 million by 2055. This is due mainly to a long-term crop yield increase that is incorporated into the model (Lacewell et al. 1992).

The principal regions for irrigated production are 5 and 7, particularly for Plans 3, 4, and 5. Irrigated acres are projected to increase dramatically for Plans 3-5, going from 15,000 to over 50,000 acres in Plans 3 and 5 and 24,000 acres in Plan 4. This leaves about 40,000 acres available but not irrigated in Plans 3 and 5. Current irrigated acres of 15,000 were set as an upper limit in the model for Plans 1 and 2. Large irrigated acreage increases with the project (Plans 3-5) are shown for Reaches 5 and 7. Reaches 9 and 11 show no irrigated acres.

For this analysis, the potential irrigated crops were cotton, wheat, sorghum, alfalfa, tomatoes, sweet corn, and bermuda. The principal crop produced is dryland alfalfa for Plans 1 and 2, with about 15,000 acres of irrigated alfalfa (See Table 5-41). However, with the project completed as defined in Plans 3-5, nearly 50,000 acres shift from dryland alfalfa to irrigated alfalfa in Plans 3 and 5. There are some minor acreages of sweet corn and tomatoes. In 2015, the solution is not dramatically different from 2005, giving stability to cropping patterns.

Total irrigated acreage under each plan is relatively stable. Uncertainties as far as 50 years in the future and certainly 100 years are speculation at best. At this point, the benefits of the project using normalized prices and realistic assumptions suggest strong benefits through irrigated agriculture.

An alternative approach to estimating net benefits involves a comparison of estimated optimal cropping patterns and irrigation decisions without project (current conditions) and with project, rather than limiting irrigated acres for current conditions to 15,000. In this case, using water availability and salinity values estimated by the Corps of Engineers, the present value of total returns to land increases only $5.21 and $6.58 million for Plan 1 and Plan 2, respectively (less than 3%). Plans 3, 4, and 5, naturally, are unchanged. This is reflected in average annual net benefits of $3.17, $0.05, and $5.21 million for Plans 3, 4, and 5, respectively. This is not a major difference from the base assumption.

Finally, **Part VI** summarizes the economic benefits and costs for the different alternatives. Control and disposal plans were developed for 14 alternatives in formulation of the NED plan. Net benefits and benefit-to-cost ratios were developed for each alternative to determine the plan with the greatest net benefits that would become the recommended NED plan. After completion of project formulation by Tulsa District, the USFWS proposed an additional 12 alternatives that were evaluated in December 2001.

Based on the period of record, 1962-1998, the selected plan will remove 1,080 tons/day of TDS from the upper reaches of the Wichita River Basin. Of this 1,080 tons/day, 409 tons/day of chlorides will be removed. This represents 83% of the chlorides at the source areas. Wichita River chloride control has the potential to remove 31% to 82% of the TDS load and 34% to 82% of the chloride load from the Wichita River Basin. Of particular interest in the upper Wichita River Basin is the project's impact on Lake Kemp. Under natural conditions, the chloride

concentrations at Lake Kemp equal or exceed 696 mg/l 99% of the time and are greater than 1,312 mg/l 50% of the time. With implementation of the selected plan, chloride concentrations will equal or exceed 166 mg/l 99% of the time and will be greater than 318 mg/l 50% of the time. This represents a 76% reduction in chloride concentration at Lake Kemp. The Red River Basin has an estimated total chloride load of 3,300 tons/day. The selected plan will remove 409 tons/day resulting in a 12% reduction in total chloride load for the Red River Basin. The concentration-duration study revealed that under natural conditions, the chloride concentrations at Lake Texoma equal or exceed 196 mg/l 99% of the time and is greater than 345 mg/l 50% of the time. With implementation of the selected plan, chloride concentrations will equal or exceed 147 mg/l 99% of the time and will be greater than 309 mg/l 50% of the time. This represents a 10% reduction in chloride concentration at Lake Texoma.

A summary of the benefits and costs of the plans selected for final formulation are shown below:

FINAL FORMULATION COSTS
OPTIMAL TO OPTIMAL AGRICULTURE
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits M&I ($1,000)	Annual Benefits Ag ($1,000)	Total Benefits ($1,000)	Net Benefits ($1,000)	BCR
Area VII Pump to Truscott (Future Dam Raise), VIII As Is, X Pump to Truscott								
7A	$50,032.0	$1,341.0	$4,809.0	$2,144.0	$3,175.0	$5,319.0	$510.0	1.11
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$35,377.0	$987.0	$3,364.0	$1,552.0	$2,008.0	$3,560.0	$195.0	1. 06

FINAL FORMULATION
EXISTING TO OPTIMAL AGRICULTURE
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits M&I ($1,000)	Annual Benefits Ag ($1,000)	Total ($1,000)	Net Benefits ($1,000)	BCR
Area VII Pump to Truscott (Future Dam Raise), VIII As Is, X Pump to Truscott								
7A	$50,032.0	$1,341.0	$4,809.0	$2,144.0	$4,511.0	$6,655.0	$1846.0	1.38
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$35,377.0	$987.0	$3,364.0	$1,552.0	$3,344.0	$4,896.0	$1,531.0	1. 46

Only three USFWLS plans were shown to have positive net benefits as shown below:

USFWS/TPWD ALTERNATIVE ECONOMICS
OPTIMAL TO OPTIMAL

Alternative	Total Project Cost ($1,000)	Annual O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits			Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG (opt-opt)* ($1,000)	Total ($1,000)		
Alternative 4A1—Pump Area VII to Raggedy Creek, Area VIII as is, Area X abandon	$27,000.00	$259.10	$2,073.98	$534.40	$1,383.00	$1,917.40	-$ 156.58	0.92
					$1,711.00	$2,245.40	$ 171.42	1.08
					$2,012.00	$2,546.40	$ 472.42	1.23
Alternative 4A2—Pump Area VII to Paradise Creek, Area VIII as is, Area X abandon	$43,300.00	$374.37	$3,284.90	$534.40	$1,383.00	$1,917.40	-$1,367.50	0.58
					$1,711.00	$2,245.40	-$1,039.50	0.68
					$2,012.00	$2,546.40	-$ 738.50	0.78
Alternative 4B1—Pump Areas VII and X to Raggedy Creek, Area VIII as is	$50,500.00	$620.44	$4,014.90	$861.30	$1,986.00	$2,847.30	-$1,167.60	0.71
					$2,733.00	$3,594.30	-$ 420.60	0.90
					$3,181.00	$4,042.30	$ 27.40	1.01

USFWS/TPWD ALTERNATIVE ECONOMICS
EXISTING TO OPTIMAL

Alternative	Total Project Cost ($1,000)	Annual O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits			Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG (opt-opt)* ($1,000)	Total ($1,000)		
Alternative 4A1—Pump Area VII to Raggedy Creek, Area VIII as is, Area X abandon	$27,000.00	$259.10	$2,073.98	$534.40	$1,217.00	$1,751.40	-$ 322.58	0.84
					$1,648.00	$2,182.40	$ 108.42	1.05
					$2,037.00	$2,571.40	$ 497.42	1.24
Alternative 4A2—Pump Area VII to Paradise Creek, Area VIII as is, Area X abandon	$43,300.00	$374.37	$3,284.90	$534.40	$1,217.00	$1,751.40	-$1,533.50	0.53
					$1,648.00	$2,182.40	-$1,102.50	0.66
					$2,037.00	$2,571.40	-$ 713.50	0.78
Alternative 4B1—Pump Areas VII and X to Raggedy Creek, Area VIII as is	$50,500.00	$620.44	$4,014.90	$861.30	$2,186.00	$3,047.30	-$ 967.60	0.76
					$2,634.00	$3,495.30	-$ 519.60	0.87
					$3,221.00	$4,082.30	$ 67.40	1.02

Plans 7a for control of chlorides at Area VII and X, and Plan 8a for control of chlorides at Area VII were formulated as two separate alternatives that should be carried forward to final formulation. Control of chlorides at Area X alone was not economically justified in the early plan formulation phase of the study. Although Plan 7a has the greatest net NED benefits and is the selected plan, the difference between the two plans indicates whether Area X is justified based on a last added basis as summarized below.

SUMMARY OF COSTS, BENEFITS, AND BCR BY PLAN

		Plan 7a	**Plan 8a**	**Area X Last Added**
First Cost		$50,032,000	$35,377,000	$14,655,000
O&M		$1,341,000	$986,500	$354,500
Total annual Cost		$4,808,901	$3,364,462	$1,444,400
Benefits	Existing to Optimal	$6,655,000	$4,895,900	$1,759,100
	Optimal to Optimal	$5,319,000	$3,559,900	$1,759,100
Net Benefits	Existing to Optimal	$1,846,100	$1,531,400	$314,700
	Optimal to Optimal	$510,100	$195,400	$314,700
BCR	Existing to Optimal	1.38	1.46	1.22
	Optimal to Optimal	1.11	1.06	1.22

TABLE OF CONTENTS

Page

PART I - OVERVIEW

INTRODUCTION 1-1

ECONOMIC EVALUATION CONCEPTS 1-1
- Water Quality Considerations 1-1
- Federal Policies 1-2
- Water Quality Improvement and the National Economic Development Account 1-2
- Conceptual Basis for Economic Evaluation 1-3
  - Municipal and Industrial Water Users 1-3
  - Agricultural Users 1-4

PRIOR STUDIES FOR ECONOMIC EVALUATION 1-7

PLAN EFFECTIVENESS 1-8

STUDY AREA 1-9
- Development of the Study Area 1-9

REACHES OR IMPACT AREAS 1-14
- Municipal and Industrial 1-14
  - Hydrologic Constraints 1-16
  - Legal Constraints 1-16
  - Economic Constraints 1-16
- Agricultural Evaluation 1-16
- Recreation Evaluation 1-16

WATER USERS 1-18
- Municipal Users 1-18
- Industrial Users 1-18
- Steam-Electric Users 1-19
- Agricultural Users 1-19

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

STUDY ELEMENTS 2-1

REGIONAL WATER DEMAND AND SUPPLY OVERVIEW 2-2
- Previous Studies 2-2
- Current Study 2-2

DESCRIPTION OF REGION B 2-2

ECONOMIC ASPECTS OF REGION B 2-5
- Land Use 2-7
- Climate Data 2-7
- Ecology and Wildlife 2-9
- Current Population and Demographic Data 2-9

POPULATION AND WATER USE PROJECTIONS 2-11
- Amendments to 1997 Water Plan 2-11
- Region B Overview 2-12
- Populations Revisions for Cities 2-12
  - City of Holliday 2-12
  - Lakeside City 2-13
  - City of Seymour 2-13
  - City of Byers 2-13
  - City of Henrietta 2-13
  - City of Petrolia 2-14
  - City of Bowie 2-14
  - City of Nocona 2-14
  - City of Saint Jo 2-14
  - City of Iowa Park 2-15
  - City of Wichita Falls 2-15
- Population Revisions for Counties 2-15
  - Archer County 2-15
  - Baylor County 2-16
  - Clay County 2-16
  - King County 2-17
  - Wichita County 2-17
- Region B Population Growth 2-17
- Summary of Population 2-18
- Per Capita Use 2-20

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

Revised Water Use Projections 2-20
Revised Municipal Water Use Projections 2-20

TOTAL WATER USES IN REGION B 2-22

WATER PROVIDERS IN REGION B 2-24
Major Water Providers 2-24
Water Use Demand Centers 2-24
Summary of Existing Local and Regional Water Plans 2-25
Summary of Recommendation in the State Water Plan 2-29

MUNICIPAL WATER USE 2-29

MANUFACTURING (INDUSTRIAL) WATER USE 2-30

STEAM-ELECTRIC POWER GENERATION 2-32

MINING WATER USE 2-33

AGRICULTURAL IRRIGATION WATER USE 2-34

LIVESTOCK WATER USE 2-37

EVALUATION OF EXISTING WATER SUPPLIES OVERVIEW 2-37
Water Supply and Use 2-37
Groundwater 2-38
Existing Surface Water Supply 2-43

EXISTING WATER SUPPLY RESERVOIRS 2-43
Greenbelt Lake 2-43
Lake Pauline 2-43
Lakes Kemp and Diversion 2-46
Santa Rosa Lake 2-47
Lake Electra 2-47
North Fork Buffalo Creek Reservoir 2-48
Wichita System 2-48
Lake Kickapoo 2-48
Lake Arrowhead 2-49
Lakes Olney and Cooper 2-49

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

Lake Nocona 2-49
Lake Amon G. Carter 2-50
Miller's Creek Reservoir 2-50
Other Lakes and Reservoirs in the Region 2-50
Lake Wichita 2-50
Lake Iowa Park 2-50

SEDIMENTATION AND RESERVOIR YIELDS 2-51

RESERVOIR WATER RIGHTS AND CONTRACTS 2-52

STREAM SUPPLIES 2-52

GROUNDWATER SUPPLIES 2-58
General Description 2-58
Seymour Aquifer 2-58
Blaine Aquifer 2-59
Trinity Group 2-59

GROUNDWATER AVAILABILITY AND RECHARGE 2-59

RELIABILITY OF LOCAL SUPPLIES 2-63

INTERBASIN AND INTERREGION TRANSFERS 2-64

ALLOCATION OF EXISTING SUPPLIES 2-64

COMPARISON OF WATER DEMANDS TO CURRENT SUPPLIES, TEXAS STATE SENATE BILL 1, REGION B 2-71
Current Supply 2-71
Regional Demands 2-72
Comparison of Supply and Demand 2-72

EFFECT OF WATER QUALITY ON SUPPLY 2-80
Municipal Water Systems with Existing or Potential Quality Concerns 2-80
Nitrate Concerns 2-81
Arsenic Concerns 2-83
Salinity Concerns for Lake Kemp and Diversion Lake 2-83
System Limitations 2-85

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

System Operations and Reliability 2-86
Summary of Regional Needs 2-89
Entities with Supplies in Excess of Needs 2-89

IDENTIFICATION, EVALUATION, AND SELECTION OF WATER MANAGEMENT STRATEGIES, TEXAS STATE SENATE BILL 1, REGION B 2-92
Identified Regional Needs and Evaluation Procedures 2-92
Regional Needs 2-92
Evaluation Procedures 2-94

CITY OF WICHITA FALLS 2-96
Background 2-96
Water Demands 2-97
Current Water Resources 2-97
Review of Alternative Water Supply Strategies 2-98
Description of Potentially Feasible Alternatives 2-98
Alternative WF-1: Wastewater Reuse 2-100
Alternative WF-2: Water from Lake Kemp/Diversion Reservoirs 2-101
Alternative WF-3: Construct Lake Ringgold Reservoir 2-103
Regional Water Treatment (Desalination) Plant Alternative (Lake Kemp/Diversion Reservoirs) 2-104

CITY OF VERNON 2-105
Background 2-105
Water Demands 2-106
Current Water Resources 2-106
Review of Alternative Water Supply Strategies 2-106
Description of Potentially Feasible Alternatives 2-108
Alternative V-1: Treated Surface Water from Wichita Falls 2-108
Alternative V-2: Raw Surface Water from Lake Kickapoo 2-108
Alternative V-3: Groundwater from Round Timber Ranch Well Field 2-108
Regional Water Treatment Plant Alternative (Lake Kemp/ Diversion Reservoirs) 2-110
Analysis of Viable Strategies 2-110
Alternative V-1: Treated Surface Water from Wichita Falls 2-110
Alternative V-2: Raw Surface Water from Wichita Falls 2-111
Alternative V-3: Groundwater from Round Timber Ranch Well Field 2-113
Regional Water Treatment (Desalination) Plant Alternative (Lake Kemp/Diversion Reservoirs) 2-115

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

HINDS-WILDCAT AND LOCKETT WATER SUPPLY SYSTEMS 2-115
Hinds-Wildcat Water Supply System 2-115
Quantity, Reliability, and Cost 2-116
Environmental Factors 2-117
Impacts on Water Resources and Other Water Management Strategies 2-117
Impacts on Agriculture and Natural Resources 2-117
Other Relevant Factors 2-117
Lockett Water Supply System 2-117
Alternative L-1 Pipeline from Vernon to Lockett 2-117
Alternative L-2 Nitrate Removal System 2-118

CITY OF ELECTRA 2-120
Background 2-120
Water Demands 2-121
Current Water Resources 2-121
Lake Electra 2-121
River Well Field 2-121
Review of Alternative Water Supply Strategies 2-122
Alternative E-1: River Well Field 2-122
Alternative E-2: Construct New Raw Water Pipeline and RO Plant 2-124
Alternative E-3: Buy Treated Water from Wichita Falls 2-125
Regional Water Treatment Plant Alternative 2-125
Analysis of Viable Strategies 2-125
Alternative E-1: River Well Field 2-125
Alternative E-2: New Pipeline From Lake Diversion/Advanced Treatment at Central Plant 2-127
Alternative E-3: Buy Treated Water From Wichita Falls 2-129
Regional Water Treatment Plant Alternative 2-130

THALIA WATER SUPPLY CORPORATION 2-130

REGIONAL WATER TREATMENT PLANT ALTERNATIVE (LAKE KEMP/ DIVERSION RESERVOIRS) 2-131
Background 2-131
Water Demands 2-131
Facilities Description 2-132
Quantity, Reliability, and Cost 2-132
Environmental Impacts 2-135
Impacts on Water Resources and Other Water Management Strategies 2-135

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

Impacts on Agriculture and Natural Resources 2-136
Other Relevant Factors 2-136
Impacts on Water Resources and Other Water Management Strategies 2-136

RECOMMENDED WATER MANAGEMENT STRATEGIES 2-136
City of Wichita Falls 2-138
City of Vernon 2-138
Hinds-Wildcat System 2-138
Lockett System 2-138
City of Electra 2-138
Chloride Control Project 2-139

SUMMARY OF DROUGHT CONTINGENCY PLANS 2-139

RECOMMENDATIONS INCLUDING UNIQUE ECOLOGICAL STREAM SEGMENTS, RESRVOIR SITES, LEGISLATIVE & REGIONAL POLICY ISSUES, TEXAS STATE SENATE BILL 1, REGION B 2-140
Introduction 2-140
Discussion of Regional Issues 2-140
Chloride Control Project 2-141
Brush Control Program 2-141
Recharge Enhancement 2-142
Weather Modification 2-142
Increase Conservation Storage for Lake Kemp 2-142
Designation of Unique Steam Segments and Reservoir Sites 2-142
Unique Steam Segments 2-143
Reservoir Sites 2-143
Discussion of Regulatory and Legislative Actions 2-143
Regulatory Review of Nitrate MCL 2-143
Funding for Comprehensive Studies 2-144

SUMMARY OF REGIONAL RECOMMENDATIONS 2-144

KNOX COUNTY WATER SUPPLY PLAN 2-145
City of Benjamin 2-146
Knox City 2-146
Description of Supply 2-146
Options Considered 2-146

TABLE OF CONTENTS (Continued)

Page

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

Water Supply Plan 2-147
Costs 2-147
City of Munday 2-147
Description of Supply 2-147
Options Considered 2-147
Water Supply Plan 2-147
Costs 2-147
County-Other Category 2-148
Manufacturing 2-148
Steam-Electric 2-148
Mining 2-148
Irrigation 2-148
Description of Supply 2-148
Options Considered 2-148
Water Supply Plan 2-149
Costs 2-149
Livestock 2-149

PART IIB - WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA

OVERVIEW 2-151

DESCRIPTION OF REGION C 2-151

ECONOMIC ACTIVITY IN REGION C 2-153

WATER-RELATED PHYSICAL FEATURES IN REGION C 2-153

CURRENT WATER USES AND DEMAND CENTERS IN REGION C 2-153

CURRENT SOURCES OF WATER SUPPLY 2-153

WATER PROVIDERS IN REGION C 2-154

AGRICULTURAL AND NATURAL RESOURCES IN REGION C 2-154

TABLE OF CONTENTS (Continued)

Page

PART IIB - WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA (Continued)

SUMMARY OF THREATS AND CONSTRAINTS TO WATER SUPPLY IN REGION C 2-155

WATER-RELATED THREATS TO AGRICULTURAL AND NATURAL RESOURCES IN REGION C 2-156
- Population and Water Demand Projections 2-156
  - Methodology for Projections of Population and Water Demand 2-156
  - Population Projections 2-157
  - Water Demand Projections 2-157
- Analysis of Water Supply Currently Available to Region C 2-162
- Comparison of Current Water Supply and Projected Water Demand 2-164
  - Comparison of Supply and Demand 2-164

SOCIOECONOMIC IMPACTS OF NOT MEETING PROJECTED WATER NEEDS 2-166

EVALUATION AND SELECTION OF WATER MANAGEMENT STRATEGIES 2-167

GOALS OF THE PLANNING PROCESS 2-167

TYPES OF WATER MANAGEMENT STRATEGIES CONSIDERED 2-168

METHODOLOGY FOR EVALUATING WATER MANAGEMENT STRATEGIES 2-168

RECOMMENDED WATER MANAGEMENT STRATEGIES FOR MAJOR WATER PROVIDERS 2-169

RECOMMENDED WATER MANAGEMENT STRATEGIES BY COUNTY 2-175

LIVESTOCK DEMANDS 2-181

CONSISTENCY WITH THE REGIONAL WATER PLAN 2-181

REGULATORY, ADMINISTRATIVE, LEGISLATIVE, AND OTHER RECOMMENDATIONS 2-182

PLAN APPROVAL PROCESS AND PUBLIC PARTICIPATION 2-183

REGIONAL WATER PLANNING GROUP 2-183

TABLE OF CONTENTS (Continued)

Page

PART IIB - WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA (Continued)

OUTREACH TO WATER SUPPLIERS AND REGIONAL PLANNING GROUPS 2-183

OUTREACH TO THE PUBLIC 2-183

PUBLIC MEETINGS AND PUBLIC HEARINGS 2-184

IMPLEMENTATION STRATEGIES 2-184

PART IIC – WATER SUPPLY AND DEMAND - LOUISIANA AND ARKANSAS

INTRODUCTION 2-184

STUDY AREA 2-185

BACKGROUND 2-187
- Reach 2 2-188
  - Potential Use of Red River Water 2-188
- Reach 3A 2-189
  - Potential Use of Red River Water 2-189
- Current Usage of Red River Water 2-190
  - Reach 1 2-190
  - Reach 2 2-190
  - Reach 3A 2-190

SOURCES OF WATER 2-191
- Summary of Existing Sources By Reach 2-191
  - Reach 1 2-192
  - Reach 2 2-193
- Inventory of Existing and Potential Water Sources By Reach 2-194
  - Reach 1: Primary Study Area 2-194
  - Reach 1: Secondary Study Area 2-200
  - Reach 1: Potential Reservoirs 2-200

SCREENING OF WATER SUPPLY SOURCES 2-204
- Methodology 2-204
- Screening 2-205
  - Reach 1 2-206

TABLE OF CONTENTS (Continued)

Page

PART IIC – WATER SUPPLY AND DEMAND - LOUISIANA AND ARKANSAS (Continued)

REACH 1 2-214
Atchafalaya River 2-215
Toledo Bend Reservoir (Secondary Study Area) 2-215
Terrace and Miocene Aquifers 2-215
Castor Creek 2-216
Cypress Black Bayou Reservoir No. 1 2-216
Red River 2-216
Twelve-Mile Bayou 2-216

REACH 2 2-217

REACH 3A 2-217

PART III – PROJECT EVALUATION MUNICIPAL AND INDUSTRIAL – EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST OF RED RIVER WATER

OVERVIEW 3-1

BACKGROUND 3-1

REVIEW OF PAST ASSUMPTIONS 3-3
Treated Water Quality 3-3
Alternative Source Thresholds 3-3
Wastewater Reuse 3-4
The Least Costly Source Will Be Used First 3-6
New Reservoirs Can Be Built to Meet Demand 3-6
Damages 3-7

MUNICIPAL DAMAGE COEFFICIENT 3-7

INDUSTRIAL DAMAGE COEFFICIENT 3-10

ANTICIPATED WATER QUALITY 3-11

EXISTING AND POTENTIAL WATER SUPPLY SOURCES 3-14
Reach 1: Shreveport/Bossier City, Louisiana 3-14
Existing Water Supplies 3-14

TABLE OF CONTENTS (Continued)

Page

PART III – PROJECT EVALUATION MUNICIPAL AND INDUSTRIAL – EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST OF RED RIVER WATER (Continued)

Potential Water Supplies 3-16
Reach 5-NTMWD: North Texas Municipal Water District (Collin County, Texas) 3-17
Existing Water Supplies 3-17
Potential Water Supplies 3-19
Reach 5-GTUA and GRAY/DEN: Sherman/Denison, Texas, Area 3-20
Existing Water Supplies 3-20
Potential Water Supplies 3-21
Reach 5-DAL: Dallas Water Utilities (including Denton County, Texas) 3-21
Existing Water Supplies 3-21
Potential Water Supplies 3-23
Reach 5-TRWD: Tarrant Regional Water District (Tarrant County, Texas) 3-24
Existing Water Supplies 3-24
Potential Water Supplies 3-25
Reach 8: Wichita Falls, Texas 3-27
Existing Water Supplies 3-27
Potential Water Supplies 3-29

TRANSPORTATION COSTS FOR POTENTIAL WATER SUPPLY SOURCES 3-29
Reach 1: Shreveport/Bossier City, Louisiana 3-30
Reach 5-NTMWD: North Texas Municipal Water District 3-31
Reach 5-GTUA and GRAY/DEN: Sherman/Denison, Texas 3-31
Reach 5-DWU: Dallas Water Utilities including Denton County, Texas 3-32
Reach 5-TRWD: Tarrant Regional Water District (Tarrant County, Texas) 3-32
Reach 8: Wichita Falls, Texas 3-33
Comparison to the State Water Plan 3-33

TREATMENT METHODS AND COSTS 3-33
Current Desalination Applications in the Red River Basin 3-36
Greater Texoma Utility Authority 3-36
West Texas Utilities 3-37
Estimated Treatment Costs 3-38

BLENDING 3-47

ALTERNATIVE TREATMENT LEVELS 3-55

TABLE OF CONTENTS (Continued)

Page

PART IV – MUNICIPAL AND INDUSTRIAL BENEFIT EVALUATION

INTRODUCTION 4-1

ALLOCATION OF SUPPLIES TO DEMANDS 4-1

LOUISIANA 4-2
- Reach 1 – Bossier City/Industry 4-2
- Reach 1 – Industry 4-3

TEXAS 4-4
- Reach 5T - GTUA/Sherman Greater Texoma Utility Authority 4-4
- Reach 5T - Grayson/Denison-Grayson County Water Supply Project 4-6
- Reach 5T - NTMWD – North Texas Municipal Water District 4-8
- Reach 5T - DWU – Dallas Water Utilities 4-13
- Reach 5T - TRWD – Tarrant Regional Water District 4-13
- Reach 9 - Lake Kemp – Wichita Falls 4-13
- Reach 9 - Oklaunion – West Texas Utilities 4-18

SUMMARY OF MUNICIPAL AND INDUSTRIAL BENEFITS 4-21

PART V – AGRICULTURE

INTRODUCTION 5-1
- Scope of Agricultural Evaluation Studies 5-1

DESCRIPTION OF AGRICULTURAL STUDY AREA 5-1
- Agricultural Study Area 5-1
- Topography 5-2
- Agricultural Reaches or Impact Areas 5-4

ANALYSIS OFLAND COVER/LAND USE CHANGES FOR 1977-1997 5-6

LAND COVER/LAND USE CHANGE DETECTION 5-6
- Materials 5-8
  - Image Data 5-8
  - LANDSAT TM Data 5-8
  - LANDSAT MSS Data 5-8
  - Aerial Videography 5-8
  - Vector Data 5-8

TABLE OF CONTENTS (Continued)

Page

PART V – AGRICULTURE (Continued)

Methodology 5-8
Accuracy Assessment 5-9
Results and Conclusions 5-9
Recent Cropping Practices 5-14
May TM Scene Classification 5-16
October TM Scene Classification 5-17
Summary 5-18
Land Uses and Irrigated Area Trends 5-18
Crops 5-23
Soils 5-28
The Wichita County Irrigation System 5-33
Implications for Project Design and Evaluation 5-38
Implications for Agriculture in Reaches 10 and 11 5-39
Wichita River Above Lake Kemp 5-39
Lake Kemp Model 5-39
Irrigation in Reaches 7 and 12 5-40
General Concepts 5-40
Crop Salinity Tolerances 5-41
Irrigation Water and Leaching Requirements 5-44
Limitations of Amount of Irrigation Water Available, Reaches 7 and 12 5-47

AGRICULTURAL IRRIGATION ECONOMIC ANALYSIS 5-50
Overview 5-50

ALTERNATIVE PLANS 5-50

INPUT DATA AND ASSUMPTIONS 5-51

REACH DEFINITIONS 5-51

SOIL DELINEATION 5-54

LAND AVAILABLE 5-54

IRRIGATION MODES NARROWED TO LOW ENERGY PRECISION APPLICATION ... 5-54

CONSIDERATION OF LIFT ZONES ELIMINATED 5-55

USE OF ALTERNATIVE SALINITY LEVELS 5-55

TABLE OF CONTENTS (Continued)

Page

PART V – AGRICULTURE (Continued)

METHODOLOGY FOR SOIL-WATER CONDUCTIVITY 5-56

REVISED LEACHING FRACTION 5-58

STOCHASTIC COMMODITY PRICES 5-58

CROP BUDGET 5-59

ANALYTICAL MODEL 5-59

DISTRIBUTION OF BENEFITS 5-60

ECONOMIC UPDATE 5-60
- Introduction 5-60
- Basic Scenarios 5-60
- Irrigation Allocation Alternatives 5-60
- Comparison 5-61
- Input Data 5-61
- Land Availability 5-61
- Water Availability 5-61
- Yield Reduction Curves 5-63
- Crop Enterprise Budgets 5-64
- Crop Prices 5-66
- Results 5-67
- Acres Irrigated 5-67
- Water Use 5-68
- Crop Yield Reductions 5-73
- Economic Implications 5-74
- Total Value By Plan 5-74
- Total Net Benefits 5-75
- Average Annual Benefits 5-76
- References 5-78

TABLE OF CONTENTS (Continued)

Page

PART VI – SUMMARY OF BENEFITS AND COSTS BY ALTERNATIVE

INTRODUCTION 6-1

PLAN EFFECTIVENESS 6-1
Summary 6-1
Plan Effectiveness at the Source Areas and by Alternative Plan 6-2
Plan Effectiveness at Lake Kemp 6-3
Plan Effectiveness at Lake Texoma 6-4

SUMMARY OF AVERAGE ANNUAL BENEFITS BY PLAN 6-5

SUMMARY OF AVERAGE ANNUAL COSTS BY ALTERNATIVE 6-6

SUMMARY OF USFWS/TPWD ECONOMIC FEASIBILITY 6-22

SUMMARY OF BENEFITS, COSTS, AND BCR BY PLAN: INCREMENTAL EVALUATION 6-25

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES

PART I – OVERVIEW

1-1 Plan Accomplishment at the Source Area, Wichita River Basin 1-9
1-2 Reach Designations - Red River Basin 1-14

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS

2-1 Market Value of All Agricultural Products Sold 2-5
2-2 Number of Oil and Gas Wells 2-6
2-3 1996 County Payrolls 2-6
2-4 Percentage of Land Use by County 2-7
2-5 Monthly Averages and Records for Wichita Falls 2-8
2-6 Temperature Extremes and Average Rainfall 2-8
2-7 County Populations 2-10
2-8 1990 Demographics – Breakdown by Income and Education 2-10
2-9 1990 Demographics – Breakdown by Occupation 2-11
2-10 Region B County Population Totals 2-19
2-11 Per Capita Water Demand Projections, TDWB 1997 Plan 2-21
2-12 Per Capita Water Demands Calculated Using the RWPG Population and Water Use Projections 2-22
2-13 Regional Demand Centers 2-25
2-14 Survey Results Regarding Water Plans 2-25
2-15 Water Providers and Users in Region B 2-27
2-16 Firm Yields for Lakes in Region B 2-38
2-17 Water Rights Holders and Their Usage 2-42
2-18 Summary of 1997 State Water Plan Yield Studies 2-44
2-19 Updated Reservoir Yields For Region B 2-45
2-20 Estimated Sedimentation Rates and Projected Capacities 2-51
2-21 Summary of Reservoir Water Rights in Region B 2-53
2-22 Summary of Existing Water Supply Contracts 2-54
2-23 Stream Water Rights 2-56
2-24 Stream Available Supply 2-57
2-25 Groundwater Availability – Region B 2-62
2-26 Availability in Blaine Aquifer by TDS 2-62
2-27 Groundwater Historical Use 2-63
2-28 Allocation of Existing Supplies – Region B 2-65
2-29 Comparison of Supply Versus Demand by County – Year 2000 2-75
2-30 Comparison of Supply Versus Demand by County – Year 2050 2-76

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART IIA – WATER SUPPLY AND DEMAND – REGION B – WICHITA FALLS (Continued)

2-31 Difference of Supply and Demand by User Group 2-77
2-32 Identified Supply Needs for Region B 2-80
2-33 Water Systems Not Compliant With Primary Drinking Water Quality Standards 2-81
2-34 Secondary Drinking Water Standards and Salinity Levels of Lake Kemp 2-84
2-35 Peak Day Demands 2-85
2-36 Water User Groups with System Limitations 2-87
2-37 Safe Yield Analysis for the Wichita System 2-88
2-38 Water User Groups with Supply In Excess of Needs of 1,000 Acre-Feet/Year 2-90
2-39 Comparison of Water Demands with Current Supplies by Major Water Provider 2-91
2-40 Regional Supplies Not Allocated to a User Group 2-92
2-41 Water Users with Identified Needs 2-94
2-42 Knox County Surplus/(Shortage) 2-146
2-43 Water Management Strategies Considered for Knox City 2-146
2-44 Water Management Strategies Considered for the City of Munday 2-147
2-45 Water Management Strategies Considered for Knox County Irrigation 2-148
2-46 Recommended Plan Costs by Decade for Knox County Irrigation 2-150

PART IIB – WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA

2-47 Major Water Providers in Region C 2-154
2-48 Adopted County Population Projections for Region C 2-158
2-49 Adopted County Water Demand Projections for Region C 2-160
2-50 Adopted Water Demand Projections for Region C By Type of Use 2-160
2-51 Comparison of Water Demand With Current Water Supplies By Major Provider – Municipal and Manufacturing Water 2-166
2-52 New Supply From Water Management Strategies and Estimated Capital Costs for Region C Major Water Providers 2-174
2-53 Potential New Reservoirs For Region C Water Supply 2-176
2-54 Capital Costs for Region C Recommended Water Management Strategies 2-180
2-55 Potential Use of Red River Water by Large Municipal Systems: Reach 1 2-185
2-56 Potential Use of Red River Water by Large Municipal Systems: Reach 2 2-189
2-57 Current Usage of Red River and Alluvium 2-190
2-58 Summary of Existing Water Sources: Reach 1 2-192
2-59 Summary of Existing Water Sources: Reach 3A 2-194

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART IIB – WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA (Continued)

2-60 Existing and Potential Surface Water Sources: Reach 1, Primary Study Area 2-195
2-61 Existing and Potential Groundwater Sources: Reach 1, Primary Study Area 2-197
2-62 Existing and Potential Surface Water Sources: Reach 1, Secondary Study Area 2-201
2-63 Potential Reservoirs: Reach 1, Primary Study Area 2-202
2-64 Potential Reservoirs, Reach 1, Secondary Study Area 2-203
2-65 Screening Criteria for Supply Sources..... 2-205
2-66 Summary of Supply Sources to be Used for Cost Computations 2-205
2-67 Screening Evaluation of Supply Sources 2-207

PART III – PROJECT EVALUATION MUNICIPAL AND INDUSTRIAL – EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST FO RED RIVER WATER

3-1 Water Quality Thresholds for Alternate Water Supply Sources..... 3-4
3-2 Combined Municipal Damage Coefficient 3-9
3-3 Industrial Damage Coefficient..... 3-11
3-4 Average Daily Water Use Per Industry 3-11
3-5 Weighted Average TDS Concentrations Expected Loading 3-13
3-6 Weighted Average CI Concentrations Expected Loading 3-13
3-7 Weighted Average SO_4 Concentrations Expected Loading..... 3-14
3-8 Existing and Potential Water Supply Sources, Reach 1 3-17
3-9 Existing and Potential Water Supply Sources, Reach 5-NTMWD..... 3-20
3-10 Existing and Potential Water Supply Sources, Reach 5-GTUA and GRAY/DEN.....3-21
3-11 Existing and Potential Water Supply Sources, Reach 5-DAL 3-24
3-12 Existing and Potential Water Supply Sources, Reach 5-TRWD 3-27
3-13 Existing and Potential Water Supply Sources, Reach 8 3-29
3-14 Alternate Source Costs..... 3-30
3-15 Municipal Cost of Red River Water, Natural Conditions..... 3-40
3-16 Municipal Cost of Red River Water, Area VIII Only Conditions 3-41
3-17 Cost of Red River Water, Areas VIII & X Only Conditions 3-42
3-18 Cost of Red River Water, Areas VII & VIII Only Conditions 3-43
3-19 Cost of Red River Water, Areas VII, VIII, & X Conditions 3-44
3-20 Industrial Cost of Red River Water, Natural Conditions..... 3-45
3-21 Industrial Cost of Red River Water, Area VIII Only Conditions 3-45
3-22 Industrial Cost of Red River Water, Areas VIII & X Only Conditions..... 3-45

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART III – PROJECT EVALUATION MUNICIPAL AND INDUSTRIAL – EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST FO RED RIVER WATER (Continued)

3-23 Industrial Cost of Red River Water, Areas VII & VIII Only Conditions 3-45
3-24 Industrial Cost of Red River Water, Areas VII, VIII, & X Conditions 3-45
3-25 Expected Safe Blendable Quantities, Normal Operating Conditions 3-49
3-26 Maximum Blendable Quantities, Drought Operating Conditions 3-50
3-27 Blended Cost of Red River Water, Natural Conditions 3-51
3-28 Blended Cost of Red River Water, Area VIII Only Conditions 3-51
3-29 Blended Cost of Red River Water, Areas VIII & X Only Conditions 3-52
3-30 Blended Cost of Red River Water, Areas VII & VIII Only Conditions 3-53
3-31 Blended Cost of Red River Water, Areas VII, VIII, & X Conditions 3-54

PART IV – MUNICIPAL AND INDUSTRIAL BENEFIT EVALUATION

4-1 Municipal Costs of Red River Water By Plan, Reach 1, Bossier City 4-3
4-2 Municipal Water Quality Benefits By Plan 4-3
4-3 Industrial Damage Costs By Plan 4-4
4-4 Industrial Water Quality Benefits By Plan: Reach 1 4-4
4-5 EDR Flows By Plan - GTUA-Sherman 4-4
4-6 EDR Treatment Costs for Reach 5 - GTUA-Sherman 4-5
4-7 Total Costs By Plan for Reach 5 - GTUA-Sherman 4-6
4-8 Water Quality Benefits By Plan, Reach 5 - GTUA-Sherman 4-6
4-9 EDR Flows By Plan for Grayson County 4-6
4-10 EDR Costs By Plan - Reach 5 - Grayson/Denison 4-7
4-11 Summary of Costs By Plan - Reach 5 - Grayson/Denison 4-8
4-12 Water Quality Benefits By Plan, Reach 5 - Grayson/Denison 4-8
4-13 Alternative Source Costs, Reach 5 – North Texas Municipal Water District 4-9
4-14 Water Demand By Category, 2000-2050, Reach 5 – North Texas Municipal Water District 4-10
4-15 Blendable Quantities and Total Cost By Plan, Reach 5 – North Texas Municipal Water District 4-10
4-16 Wichita River Basin Chloride Control Allocation Based on Blending Options, Lake Lavon and Lake Cooper Blend Only, No Treatment, Municipal Less Manufacturing 4-11
4-17 Total Municipal and Industrial Average Annual Benefits By Plan, Reach 5 – North Texas Municipal Water District 4-12

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART IV – MUNICIPAL AND INDUSTRIAL BENEFIT EVALUATION (Continued)

4-18 Quantities of Water, RO/EDR Treatment, Reach 9 – Wichita Falls 4-14
4-19 RO/EDR Treatment Costs By Plan, Reach 9 – Wichita Falls 4-15
4-20 Summary of Total Costs By Plan, RO/EDR Treatment 4-16
4-21 Summary of Total Costs By Plan, Blended Water 4-16
4-22 Summary of Municipal Benefits, Wichita Falls, With Plan 5 4-17
4-23 Municipal and Industrial Benefits, RO/EDR Treatment, Reach 9 – Wichita Falls 4-17
4-24 Municipal and Industrial Benefits, Blendable Normal, Reach 9 – Wichita Falls 4-17
4-25 Quantities of Water Required By Plan – Reach 9..... 4-19
4-26 RO/EDR Costs By Plan, Reach 9 – Industry..... 4-20
4-27 Average Annual Benefits, Reach 9 – Industry..... 4-20
4-28 Power Water Quality, Reach 9 – Oklaunion..... 4-21
4-29 Summary of Municipal and Industrial Benefits by Plan..... 4-22

PART V – AGRICULTURAL

5-1 Vegetative Cover Type Descriptions 5-9
5-2 Area Under Agricultural Cover Type By Decade..... 5-10
5-3 Area Under Hardwood Cover Type By Decade 5-11
5-4 Area Under Shrubland Cover Type By Decade..... 5-12
5-5 Area Under Grassland Cover Type By Decade 5-13
5-6 Ground Truth Sample Point Composition 5-16
5-7 May TM Scene Preliminary Classification Acreages..... 5-16
5-8 Predicted Wheat Acreages by Reach, May TM Scene Classification 5-17
5-9 October TM Scene Preliminary Acreage Classifications 5-17
5-10 Predicted Crop Acreages by Reach, October TM Scene Classification 5-18
5-11 Summary of Areas of Major Land Uses in the HCU's in the Study Area..... 5-21
5-12 Distribution of Irrigated Land By County 5-21
5-13 Irrigated Areas as Reported by Census, TWDB, CBMS, and MIADS 5-22
5-14 Areas of Major Land Uses in the Evaluation Reaches 5-24
5-15 Estimated Area of Crops Harvested in Five HCU Areas in 1992..... 5-27
5-16 Soils Recommended to be Representative Soils on Cropland and Pastureland in Evaluation Reaches..... 5-32
5-17 Crop Yield Responses to TDS Concentrations in Soil Water..... 5-43

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART V – AGRICULTURAL (Continued)

5-18 Plan I and Plan III Median Value Irrigation and Leaching Water Requirements in Reaches 7 and 12 5-45
5-19 Summary of Estimates of Water Supplies Available Through The WCWID Canal With No More Than Four Events In 27 Years When Either The Maximum Capacity Of The WCWI Canal Is Exceeded Or The Minimum Storage of 30,000 Acre-Feet Is Experienced In Lake Kemp For More Than 7 Consecutive Days 5-49
5-20 Chloride Control Alternative Plans 5-51
5-21 Reach Definitions 5-52
5-22 Expected Stream Flow Events and Associated Probability 5-58
5-23 Crop Price Deviations Percent Change From Base Price 5-59
5-24 Land Available By Soil Type and Reach 5-62
5-25 Water Available By Reach and Assumption 5-63
5-26 Yield Reduction Curves By Crop 5-64
5-27 Crop Budgets, Detailing Costs – Year 2001 5-65
5-28 Crop Price and Discount Rate Assumptions Used 5-67
5-29 Acres Irrigated for 2005 and 2055 Across All Reaches By Scenario 5-68
5-30 Water Use by Reach, Plan, and Scenario for 2005 and 2055 For Optimum Versus Optimum Full Water to Reaches 7 and 12 5-69
5-31 Water Use by Reach, Plan, and Scenario for 2005 and 2055 For 15,000 Acres Current Versus Optimum With Full Water to Reaches 7 and 12 5-70
5-32 Water Use by Reach, Plan, and Scenario for 2005 and 2055 For Optimum Versus Optimum With 100,000 Acre-Feet Available to Reaches 7 and 12 5-71
5-33 Water Use by Reach, Plan, and Scenario for 2005 and 2055 for 15,000 Irrigated Acres For Current Condition Versus Optimum With Project Assuming 100,000 Acre-Feet Available to Reaches 7 and 12 89% of the Time 5-72
5-34 Water Use by Reach, Plan, and Scenario for 2005 and 2055 for Optimum Versus Optimum With 120,000 Acre-Feet Available to Reaches 7 and 12 82% of the Time and Other Limits 5-73
5-35 Water Use by Reach, Plan, and Scenario for 2005 and 2055 for 15,000 Irrigated Acres for Current Conditions Versus Optimum With 12,000 Acre-Feet Available to Reaches 7 and 12 82% of the Time and Other Limits 5-74
5-36 Total Present Value of Net Returns to Irrigated Agriculture From 2005-2055 For Six Scenarios in Million Dollars 5-75
5-37 Total Present Value of Net Benefits to the Wichita Salinity Control Project From 2005-2055 For Six Scenarios in Million Dollars 5-75

TABLE OF CONTENTS (Continued)

Page

LIST OF TABLES (Continued)

PART V – AGRICULTURAL (Continued)

5-38 Average Annual Benefits to the Wichita Salinity Control Project for Six Scenarios in Million Dollars 5-76

PART VI – SUMMARYOF BENEFITS AND COSTS BY ALTERNATIVE

6-1 Plan Effectiveness Percent Control at Source Areas 6-2
6-2 Plan Effectiveness Percent Control by Plan 6-2
6-3 Lake Kemp Concentration-Duration Data 6-3
6-4 Lake Texoma Concentration-Duration Data 6-5
6-5 Summary of Average Annual Benefits by Plan, Optimal to Optimal Agricultural Benefits 6-6
6-6 Summary of Average Annual Benefits by Plan, Existing to Optimal Agricultural Benefits 6-6
6-7 Wichita River Basin Chloride Control Total Project and Annual Costs By Plan, FY 2002 Current Estimate October 2001, 6-1/8% 6-7
6-8 Average Annual Costs By Plan 6-15
6-9 Average Annual Costs, Benefits, Net Benefits, and BCR, Optimal to Optimal Agricultural Benefits 6-16
6-10 Final Formulation Costs Optimal to Optimal Agriculture 6-18
6-11 Average Annual Costs, Benefits, Net Benefits, and BCR, Existing to Optimal Agricultural Benefits 6-19
6-12 Final Formulation Existing to Optimal Agriculture 6-21
6-13 Summary of Municipal and Industrial Benefits by Plan 6-22
6-14 USFWS/TPWD Alternative Economics Optimal to Optimal 6-23
6-15 USFWS/TPWD Alternative Economics Existing to Optimal 6-24
6-16 Summary of Costs, Benefits, and BCR By Plan 6-25

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES

PART I – OVERVIEW

1-1 Municipal and Industrial Benefit Concept 1-5
1-2 Agricultural Benefit Concept 1-6
1-3 Reach Subdivisions and Study Area 1-10
1-4 Wichita Falls Region 1-12
1-5 Dallas Region 1-13
1-6 General Agricultural Study Area 1-17

PART IIA – WATER SUPPLY AND DEMAND - REGION B – WICHITA FALLS

2-1 Vicinity Map Region B 2-3
2-2 Surface Water Map 2-4
2-3 Projected Population for Region B 2-18
2-4 Projected Water Use for Region B 2-23
2-5 1990 and 2000 Region B Water Use 2-24
2-6 Total Municipal Water Use for Region B 2-30
2-7 Projected Manufacturing Water Use for Region B 2-31
2-8 Projected Agricultural Irrigation and Livestock Water Use for Region B 2-34
2-9 Major Aquifers in Region B 2-40
2-10 Blaine Aquifer 2-41
2-11 Actual Water Use by Category in Region B in 1990 and 1996 2-42
2-12 Distribution of Current Supplies 2-71
2-13 Supply and Demand for Region B 2-72
2-14 Irrigation Supply and Demand for Region B 2-73
2-15 Municipal Supply and Demand for Region B 2-73
2-16 Steam-Electric Power Supply and Demand for Region B 2-74
2-17 Region B Vicinity Map 2-93
2-18 City of Wichita Falls Planning Alternatives 2-99
2-19 City of Vernon Planning Alternatives 2-109
2-20 City of Electra Planning Alternatives 2-123
2-21 Regional Planning Alternatives 2-133
2-22 Preferred Water Management Strategy 2-137

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES (Continued)

PART IIB – WATER SUPPLY AND DEMAND – REGION C – DALLAS/FORT WORTH AND LOUISIANA

2-23 Region C 2-152
2-24 Historical and Projected Population for Region C 2-159
2-25 Projected Water Demand for Region C by Type of Use 2-161
2-26 Projected Total Water Availability for Region C 2-163
2-27 Comparison of Total Supply With Demand for Region C 2-165
2-28 Overall Comparison of Supply and Demand for Dallas Water Utilities With the Recommended Water Management Strategies 2-170
2-29 Overall Comparison of Supply and Demand for Tarrant Regional Water District With The Recommended Water Management Strategies 2-172
2-30 Overall Comparison of Supply and Demand for North Texas Municipal Water District with The Recommended Water Management Strategies 2-173

PART IIC – WATER SUPPLY AND DEMAND – LOUISIANA AND ARKANSAS

2-31 General Location of Reaches 1, 2, and 3A 2-186
2-32 Surface Water Features 2-209

PART III – PROJECT EVALUATIN MUNICIPAL AND INDUSTRIAL – EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST OF RED RIVER WATER

3-1 Municipal and Industrial Study Area and Reach Subdivisions 3-5
3-2 Wichita River Basin Project Features 3-12
3-3 Shreveport / Bossier City Water Sources and Transportation Systems 3-15
3-4 North Central Texas Water Sources and Transportation Systems 3-18
3-5 Wichita Falls Area Water Supplies and Transportation Systems 3-28
3-6 Conventional Surface Water Treatment and EDR Water Treatment Flow Diagrams ... 3-34
3-7 Reverse Osmosis and Electrodialysis Reversal Treatment Processes 3-39
3-8 North Central Texas Transportation of Red River Water 3-46

TABLE OF CONTENTS (Continued)

Page

LIST OF FIGURES (Continued)

PART V – AGRICULTURE

5-1 Location of the Study Area 5-2
5-2 Area Under Agriculture 5-10
5-3 Area Under Hardwoods 5-12
5-4 Area Under Shrubland 5-13
5-5 Area Under Grassland 5-14
5-6 Crop Ground Truth Sample Points 5-15
5-7 Wichita County Water Improvement District No. 2 5-35
5-8 Evaluation Reaches 5-53

TABLE OF CONTENTS (Continued)

Page

LIST OF CHARTS

1 Elevation Zones in the Wichita-Red River Chloride Control Project Study Area 5-3
2 Counties and Hydrologic Cataloging Unit (HCU) Watersheds Involved in the Wichita-Red River Chloride Control Study 5-5
3 Agricultural Evaluation Reaches 5-7
4 Major Land Use Groups in the Wichita-Red River Salinity Control Project Study Area 5-21
5 Areas of Land Uses in the Potential Benefit Reaches of the Wichita-Red River Chloride Control Study 5-23
6 Areas in Cropland, Pasture, and Orchards in the Wichita-Red River Salinity Control Project Study Area 5-25
7 Cropland, Pastureland, Hayland, and Orchards in the Benefit Evaluation Reaches in the Wichita-Red River Salinity Study 5-26
8 Soil Map for the Wichita-Red River Salinity Control Project Study Area 5-29
9 Properties of Some Soils Which Limit Their Potential for Producing Crops 5-31
10 Compare Daily Water Flows at Mabelle, Southside Canal, and Wichita River near Kamay 5-37
11 Compare Probabilities of Water Flow at Southside Canal with Flows at the Mabelle Gage Upstream 5-38
59 Crop Yield Responses to Electrical Conductivity in Water in Soil in Lower Root Zone 5-42
60 Crop Responses to TDS in Water in Soil in Root Zones Near Wichita Falls 5-43

TABLE OF CONTENTS (Continued)

Page

LIST OF APPENDICES

PART V – AGRICULTURAL

Appendix A – Description of Economic Model

Appendix B Irrigated Acres

Appendix C Irrigation Water Used

Appendix D Salinity Yield Reductions

Appendix E Yearly Benefits by Decade

Appendix F Total Present Value of Benefits

PART I - OVERVIEW

INTRODUCTION

This appendix contains information and data used in the economic evaluation of constructing collection and disposal features in the Wichita River Basin for control of naturally occurring chlorides at Area VII on the North Fork of the Wichita River and Area X on the Middle Fork of the Wichita River. Area VIII collection facilities on the South Fork of the Wichita River, along with Truscott Brine Disposal Lake, were completed in 1987. This evaluation is in response to a 1997 request from the Assistant Secretary of the Army (Civil Works) to complete a General Reevaluation of the Wichita River Basin that would reexamine the economic feasibility and environmental impacts of completing chloride control features at the remaining salt source areas. Reduction in the 491 tons per day of chlorides emitting from the upper Wichita River Basin would allow more beneficial use of improved water quality for municipal, industrial, and agricultural purposes.

This appendix is divided into six parts.

- Part I is an Overview describing economic evaluation concepts.
- Part II is a description of water demands, water resources, and water management strategies for Region B of the Texas State Water Plan. The Texas State Water Plan includes the Wichita River Basin.
- Part III is a summary description of Region C of the Texas State Water Plan for the North Texas area, including the Dallas-Fort Worth region. The description indicates water demands, sources of supply, net needs, and future water management strategies for that area. Also included is a brief description of the area in Louisiana that may be affected by chloride control.
- Part IV describes the municipal and industrial economic evaluation and derivation of costs of Wichita/Red River water under existing conditions and with control at Areas VII and X.
- Part V describes the agricultural irrigation evaluation and potential irrigation benefits for improved water quality with different water availability constraints.
- Finally, Part VI summarizes the economic benefits and costs for the different alternatives.

ECONOMIC EVALUATION CONCEPTS

Water Quality Considerations

Adverse quality characteristics may limit water use and impose a penalty cost on the user. Penalty costs are additional costs required to treat the water to acceptable levels and the damages that would occur to users from using poor quality water. Total dissolved solids (TDS), chlorides (Cl), and sulfates (SO_4) are commonly used as indicators of the suitability of water for designated users. Based on Environmental Protection Agency (EPA) public health standards, the

recommended maximum levels in drinking water of those indicators are 500 mg/l for TDS, 250 mg/l for Cl, and 250 mg/l for SO_4. Texas water quality standards are 1,000 mg/l TDS, 300 mg/l Cl, and 300 mg/l SO4. The features of Wichita River Basin chloride control attempt to limit the amount of chlorides entering the stream thereby improving the quality of water for beneficial purposes.

Adverse quality characteristics limit in-stream or in-transit value of the water. Conversely, the stream serves as a disposal system by transporting both natural and man-made water contaminants. These contaminants are not degradable. Their relative strength is a direct function of the dilutive supply of available water. In other words, their elimination at a given point leads to improved water quality throughout the downstream system. The relative degree of improvement at any point reflects the proportion of the total load that has been removed. The distribution of potential benefits is therefore widespread. Evaluation of the net water quality improvement benefits requires a determination as to whether the sum of the reduction in penalty costs by using poor quality water and the increase in in-transit values offset the cost of improving the quality of the stream flow.

Federal Policies

Planning for Federal water resource projects is based on the Principles and Guidelines (P&G) promulgated in 1983 by the U.S. Water Resources Council and set forth in the Planning Guidance Notebook (Engineer Regulation [ER] 1105-2-100) dated April 2000. The Planning process is also grounded in the laws that apply to the Civil Works Program and the Corps of Engineers missions. The P&G allow the formulation of reasonable alternatives that are responsive to national, State, and local concerns. Plans recommended for implementation must reasonably maximize net National Economic Development (NED) benefits and be consistent with protecting the Nation's environment in accordance with national environmental statutes, applicable executive orders, and other Federal planning requirements. This is the Federal objective. Project plans must be formulated to alleviate problems and take advantage of opportunities in ways that contribute to the Federal objective. Contributions to NED include increases in the net value of the national output of goods and services or increases in economic efficiency, expressed in monetary units, of goods and services that are marketed as well as those that may not be marketed. The national environment is protected when damage to the environment is eliminated or avoided and important cultural and natural aspects of our heritage are preserved (ER 1105-2-100, Chapter 2, Planning Principles, page 2-1). The existing condition may have environmental outputs with unquantifible economic value. Support of a chloride tolerate ecosystem is an environmental output of the current stream condition. The economic value of that ecosystem is theoretically captured in any project related mitigation.

Water Quality Improvement and the National Economic Development Account

Alternative plans that are complete, effective, efficient, and acceptable must be formulated and must reasonably maximize net NED benefits and protect the environment. Mitigation of adverse affects must be part of any plan. Economic gains and potential losses were both evaluated. Completeness is the extent to which a given plan provides and accounts for all necessary investments or other actions to ensure realization of the planned effects. This may

require relating the plan to other types of public or private plans if the other plans are crucial to realization of the objective, i.e., State water plans, use of Lake Kemp by the city of Wichita Falls. Effectiveness is the extent to which a plan alleviates the specified problems and achieves the specified opportunities, i.e., percent control at the source area. Efficiency is the extent to which an alternative plan is the most cost-effective means of alleviating the problem and realizing the opportunities, consistent with protecting the environment, i.e., NED benefit-to-cost analysis. Acceptability is the workability and viability of the plan with respect to acceptance by State and local entities and the public, and compatibility with existing laws, regulations, and public policies, i.e., regional planning groups buy in and Red River Authority (RRA) support as the local sponsor (P&G, page 7).

Alternative plans may include a range of measures that can, over time, balance water demand with water availability. This includes reducing the demand for water, improving efficiency in use, reducing losses and waste, improving land management practices to conserve water, and increasing the available supply of water. Nonstructural measures, including modifications of public policy, management practice, regulatory policy, and pricing policy, should be included as well (P&G, pages 6-7). The city of Wichita Falls and Wichita County Water Improvement District No. 2 (irrigation) are co-owners of Lake Kemp and have such policies in place.

To facilitate the evaluation and display the effects of alternative plans, four accounts are established in the P&G - the NED account, the environmental account, the regional account, and the other social effects account. Only the NED and the environmental accounts are required by the P&G. The NED account is presented in this appendix of the Reevaluation report. Beneficial effects in the NED account are increases in the economic value of the national output of goods and services in a plan. The general measurement standard of the value of goods and services is the willingness of users to pay for each increment of output from a plan. Since it is difficult to measure the actual demand situation, the total value of the output of a plan may be based on four alternative measurement techniques. These techniques are the willingness to pay based on actual or simulated market price, change in net income, cost of the most likely alternative, and administratively established values (P&G, pages 8-9). Willingness to pay and the cost of the most likely alternatives are two measures considered in this evaluation.

Conceptual Basis for Economic Evaluation

Municipal and Industrial Water Users. Water users suffer damages when they incur an unnecessary expenditure to remove undesirable constituents before they can use water and/or their equipment is damaged because of the water's poor quality. Since this penalty cost is a measure of the damage incurred, the comparison of penalty costs without and with the water quality improvement project provides a measure of NED water quality benefits. The total cost to a non-agricultural user of Wichita/Red River water without/with the project is composed of costs for:

1) Pretreatment and desalinization treatment facilities,
2) Operation and maintenance of these facilities,
3) Disposal of extracted waste materials from desalinization,

4) Damages resulting in repair or replacement of equipment, such as water heaters, piping, etc., and
5) Transportation or conveyance costs to the user.

The amount of damage that will occur or the degree of treatment necessary is dependent on the concentration of undesirable constituents. The concentrations of these constituents vary daily with the variations summarized in concentration-duration curves representing a reach. Exhibits B and C in the Formulation Appendix show the concentrations for TDS, Cl, and SO_4 for the reaches for natural conditions, without-project conditions (Area VIII completed), and for three with-project conditions (Area VII complete, Area X complete, and both Areas VII and X complete). Duration curves were developed for each affected reach to show the variation in terms of the percentage of time that specified concentration levels were exceeded. The determination of costs for Wichita/Red River water is based on these water quality concentration-duration curves for each plan, without and with the Wichita Basin project.

There is an upper concentration (threshold value) of a constituent in water that can be tolerated by a municipality or industry using the water, before damages occur. Figure 1-1(a) indicates that when the concentration of a constituent is below the threshold value, the user will suffer some damage proportionate to the concentration of the constituent. When the concentration exceeds the threshold value, the user may be willing to pay for treatment costs to improve the quality of water to the threshold level or may be willing to sustain additional damages, whichever cost is less. Treatment of Wichita/Red River water or damages caused by use of this water is based on the water quality equal to the average water quality of alternative sources within a reach. Figure 1-1(a) presumes that the concentration is constant. In reality, the concentration is not constant, but varies by duration. Therefore, the concentration must be related to the percentage of time the given concentration occurs or is equaled and exceeded, as shown in Figure 1-1(b). The total annual costs incurred by a user can be developed based on the previous curves. The relationship of total annual costs, treatment, and damage for municipal and industrial users that occurs over the full range of concentration-duration without and with the project is shown conceptually in Figure 1-1(c).

Agricultural Users. The conceptual basis for defining the potential agricultural irrigation benefits of improved water quality is similar to that of municipal and industrial users. Figure 1-2(a) shows the percentage of crop yield reduction expected when that crop is irrigated with water of a given quality that contains varying levels of chlorides. Salt-free water would result in a 0% yield reduction. Similarly, crop yield reduction by crop is related to concentration-duration curves of water quality variability without and with the project (Figure 1-2(b)). These sets of curves are used to develop percent yield reduction versus percent of time the concentration is equaled or exceeded (Figure 1-2(c)). Integration of areas under the curves gives a measure of the average percent crop yield reduction due to irrigation of the crop without and with the project. The difference or area between the curves is a measure of the benefits attributed to water quality improvement as crop yields are affected. This procedure is incorporated into the crop optimization model discussed in the agricultural portion of this report.

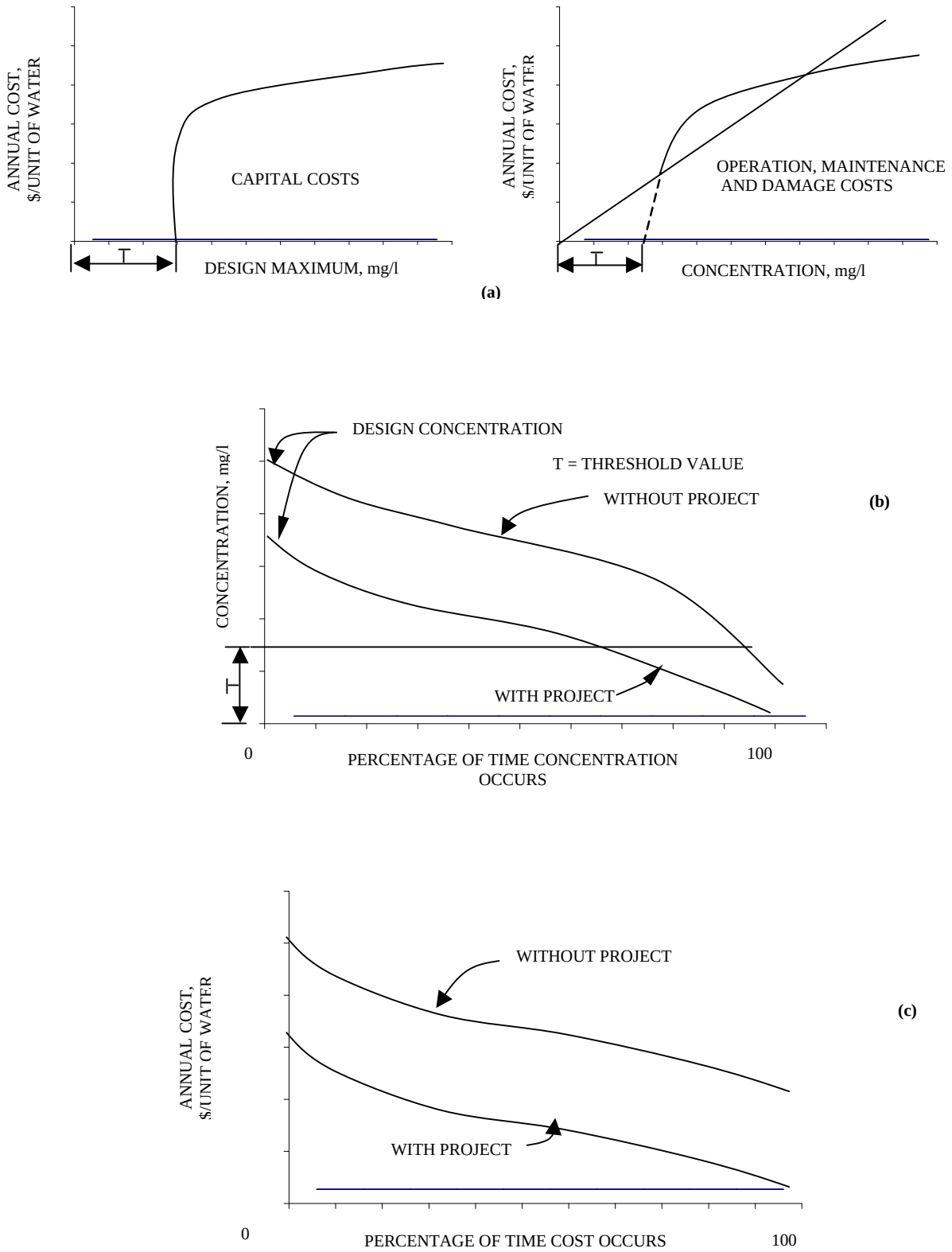
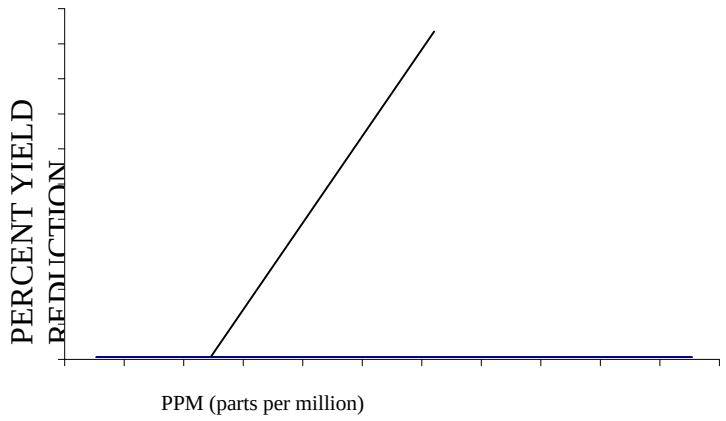
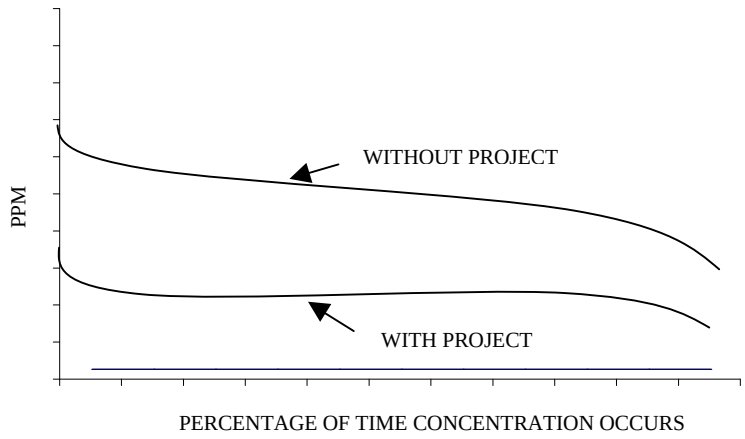


Figure 1-1 (a)(b)(c). Municipal and Industrial Benefit Concept



(a)



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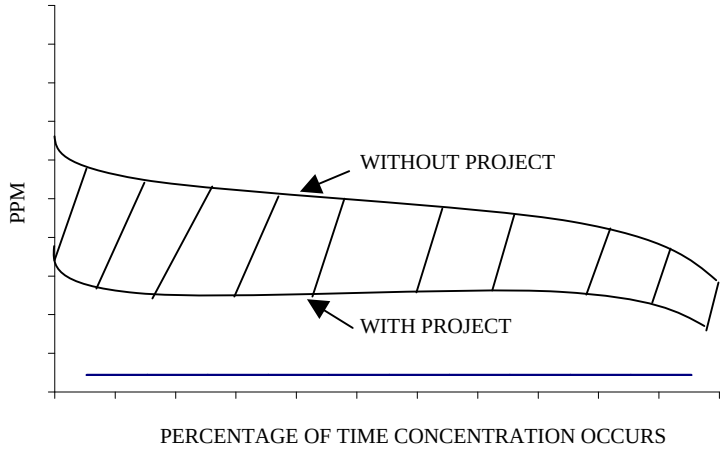


(c)

Figure 1-2(a)(b)(c). Agricultural Benefit Concept

PRIOR STUDIES FOR ECONOMIC EVALUATION

Previous Tulsa District reports that have economic evaluations or economic-related information about chloride control in the Red River Basin are:

1. U.S. Army Corps of Engineers, Tulsa District, "Water Quality Control Study – Part II: Survey Report on Arkansas-Red River Basins; Texas, Oklahoma, and Kansas", March 1968.

2. U.S. Department of the Army, Corps of Engineers, Tulsa District, Tulsa, OK, "Arkansas-Red River Basin Chloride Control, Texas, Oklahoma, Kansas (Red River Basin), Design Memorandum No. 25, Phase I - Plan Formulation", Volumes I and II, July 1976.

3. U.S. Army Corps of Engineers, Tulsa District, "Supplemental Data to Arkansas-Red River Basin Chloride Control, Red River Basin, Design Memorandum No. 25, General Design, Phase I - Plan Formulation", Volumes I and II, November 1980.

4. U.S. Army Corps of Engineers, Tulsa District, "Limited Reevaluation Report (LRR), Red River Chloride Control Project", revised June 1993.

5. U.S. Army Corps of Engineers, Tulsa District, "Red River Chloride Control Project Supplemental Assessment Report", to the Environmental Impact Statement, February 1997.

6. U.S. Army Corps of Engineers, Tulsa District, "Evaluation of Wichita River Basin Completion, Red River Chloride Control Project", October 1997.

General Design Memorandum (GDM) No. 25 describes the plan formulation and presents engineering, environmental, and economic data for the Red River Basin Chloride Control Project. During review of that document, additional or supplemental data were requested to quantify the project's benefits. The Office of the Chief of Engineers provided specific guidance for the economic reanalysis (item 3 above) in a letter dated December 6, 1978. The Supplemental Data report to the GDM established the concepts and methodologies for the economic analysis. The 1993 LRR was prepared at the direction of the Assistant Secretary of the Army for Civil Works (ASA [CW]) in a memorandum dated September 12, 1992. The purpose of the LRR was to identify the current benefits of the project, since the Red River Chloride Control Project was authorized for construction and about a decade had passed since the previous economic evaluation.

The last two reports, the Supplemental Assessment Report (SAR) and the Evaluation of Wichita River Basin Completion report (items 5 and 6), looked only at specific items of interest as directed by the ASA (CW) in memoranda dated September 20, 1996, and September 9, 1997, respectively. The SAR identified and explored in a preliminary fashion the feasibility of desalinization, mixing/blending, and partnership options for consideration by the ASA (CW). The *Evaluation of the Wichita River Basin Completion* report was a quick, informal economic analysis of completing only the Wichita River Basin features of the Red River Chloride Control Project. These reports were constrained in scope by budget and time considerations. In addition

to these Corps reports, the Tulsa District contracted with various contractors to prepare many other technical reports in support of findings in the Corps reports. The agricultural analysis of chloride control has been conducted by Texas A&M University, Texas Agricultural Experiment Station (TAES) since 1978. These reports and studies are listed in the bibliographies of the Corps reports.

PLAN EFFECTIVENESS

The objective of the Wichita River Basin project study is to select a plan to provide the most practical means of improving the quality of water for beneficial uses. Removal of salt was found to be the key element in achieving the study objective.

To evaluate the technical effectiveness of the selected plan, two areas were chosen as checkpoints: Lake Kemp on the Wichita River, a major tributary of the Red River; and Lake Texoma on the main stem of the Red River. Lake Kemp is pertinent to this evaluation, while Lake Texoma would be an important checkpoint for chloride control in the remaining Red River Basin. The U.S. Public Health Service standard for municipal water supply is 250 mg/l for Cl. The EPA drinking water standard limits are 500 mg/l for TDS, 250 mg/l for Cl, and 250 mg/l for SO_4. Many smaller communities (less than 50,000 inhabitants) in the Red River Basin do not currently meet this limit, and all groundwater in the Red River Basin exceeds this limit. The State of Texas has established its own water quality limits of 1,000 mg/l for TDS, 300 mg/l for Cl, and 300 mg/l for SO_4; however, many communities are looking to improve their treated water quality. Therefore, the EPA limits remain a better indication of the desired water quality.

The tentatively selected plan is very effective in accomplishing the objective of improving the quality of Wichita River water, and to a lesser extent, Red River water below the confluence of the Wichita and Red River. The natural chloride loads and the percent of chlorides controlled by the selected plan *at the source area* are presented in Table 1-1 for each salt source in the Wichita Basin along with those in the remaining Red River Basin. Man-made salt pollutants are mainly oil field sources and are being controlled by the State of Texas. The Wichita River Basin contributes about 22% of the total natural chloride load in the Red River Basin. With Areas VIII, VII, and X in place, about 409 tons per day of the approximately 491 tons per day chloride emission in the Wichita Basin, or about 83% of chlorides, will be controlled. Evaluations prior to the current study estimated about 360 tons per day, or 80%, would have been controlled. Detailed information on plan effectiveness is described in the Formulation Appendix and at the end of this appendix.

TABLE 1-1

PLAN ACCOMPLISHMENT AT THE SOURCE AREA
WICHITA RIVER BASIN

Salt Source Area	Natural Chloride Load (tons/day)			Proposed Plan Chloride Control	
	Wichita	Red		(tons/day)	(percent)
V (Estelline Springs)		60			
VI		510			
VII	**244**			**195**	80
VIII	**189**			**165**	87
IX		342			
X	**58**			**49**	84
XI		220			
XIII		350			
XIV		150			
XV		120			
Subtotal by Basin	**491**	1,752		**409**	83
Total Natural Sources			2, 243		
Minor Natural and Man-made Sources			1,119		
Total Red River Basin			3,362		

Note: Wichita River Basin, Area VIII operational in 1986. Ring dike at Estelline Springs (Area V), operational since January 1964, controls 240 of the total 300 tons per day chloride emission.

STUDY AREA

Development of the Study Area

The generalized study area is the Red River Basin (Figure 1-3). Two study areas used in the evaluation are the municipal and industrial study area and the agricultural irrigation study area. Counties located adjacent to the Wichita/Red River in Texas, Oklahoma, Arkansas, and Louisiana could potentially be economically affected by Wichita River Basin chloride control. These counties represent the most probable area of economic impact. The county line was generally used to delineate the boundaries of the study itself, since baseline information relevant to the study, such as population projections, is published by political units. The area was modified for data collection and in the benefit-to-cost analysis based on previous chloride control studies that evaluated the municipal, industrial, and agricultural benefits of the proposed chloride control project. Prior studies were identified as the 1980 Supplemental Data report, the 1993 LRR, the 1997 SAR, and the 1997 Wichita Basin report.

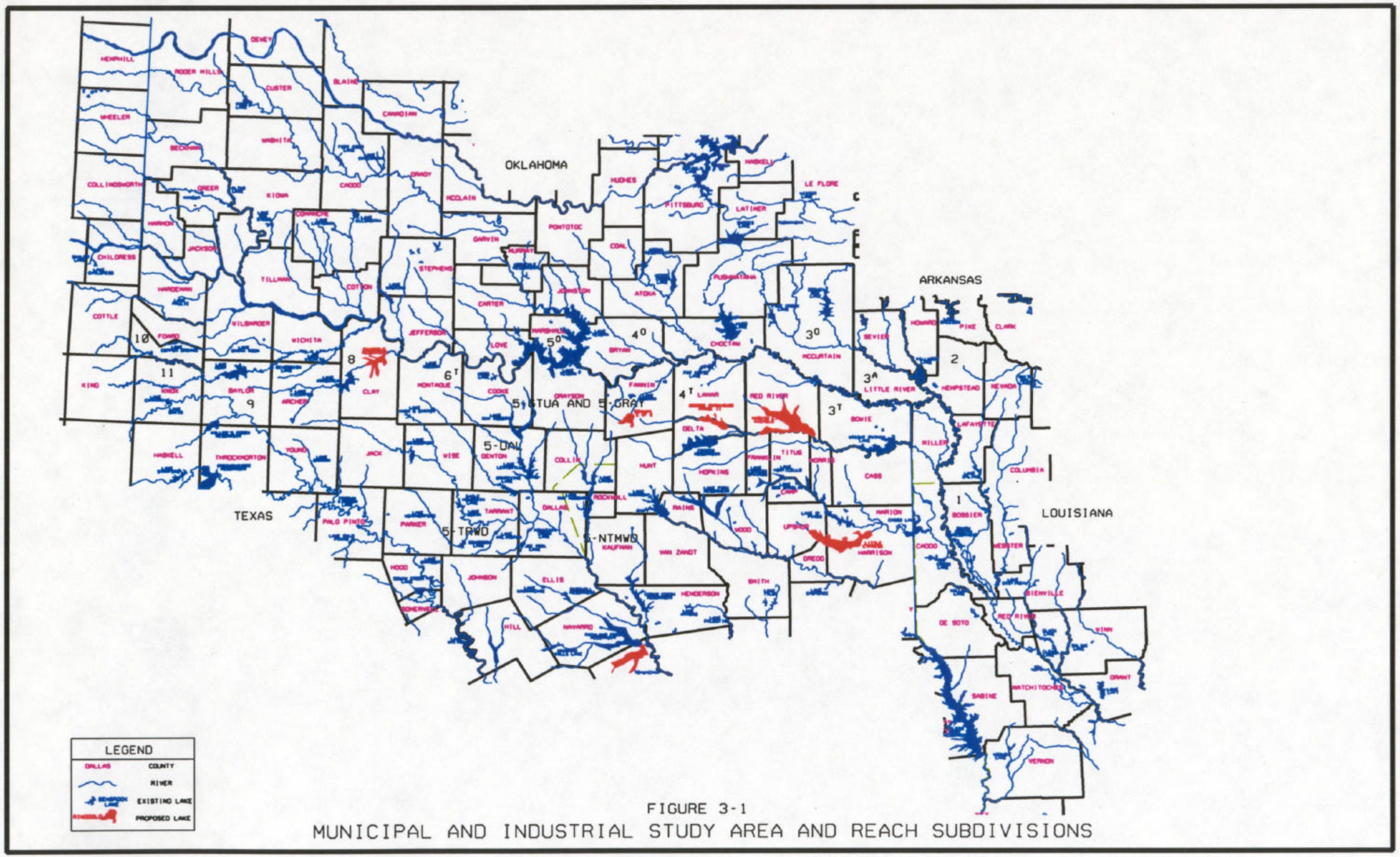


FIGURE 3-1
MUNICIPAL AND INDUSTRIAL STUDY AREA AND REACH SUBDIVISIONS

The municipal and industrial study area was defined by identifying existing and potential users of Wichita/Red River water as presented in the Texas State Water Plan, Region B (Wichita Falls region) and Region C (Dallas region). Figures 1-4 and 1-5 show these two regions, respectively. The third region is in Louisiana where use of Red River water occurs at Bossier City and at an industrial facility in Campti, Louisiana. The agricultural study area will be discussed in the agricultural evaluation section. The upstream limit of the study area is just below the salt source areas where project effects begin to occur. This is relevant for the agricultural evaluation. The downstream limit is the confluence of the Red River with the Mississippi River. Two major lakes, Lakes Kemp and Diversion on the Wichita River and Lake Texoma on the main stem Red River, are the focus of this evaluation.

Water users are interested in obtaining good quality water from the least costly source. The cost of water includes development of the source, transportation of water to the use area, treatment before use, and distribution or conveyance to the ultimate user. These costs vary, depending on the source (groundwater or surface) being developed, the length and type of transportation system (pipeline, channel, stream, conveyance), and the method and degree of treatment required. The large capital costs of developing a new source of water supply may make it unlikely that a single potential user has the capital available to invest in that source. Consequently, it is more likely that several users would develop a resource. It must be kept in mind that the lowest per unit cost may be the least costly source alternative on a per unit basis; however, the project cost for construction and environmental mitigation may make that source cost prohibitive and unaffordable in the near term. Use of Wichita/Red River water is usually most practical for those counties adjacent to the river. There is some distance from the river where it is no longer economically feasible to consider the river as a practical source of water supply. This distance is a function of the proximity of alternative sources as well as the volume of water supplied and the population served. Larger water users will generally find it more attractive to transport water longer distances than smaller users.

The basis for municipal and industrial evaluation of water demand, water supply, and net need has been refined from previous evaluations. Through the 1997 Senate Bill 1, the State of Texas now requires a regional planning effort that will be incorporated into the State Water Plan for 2002. The results of that 3-year effort are regional water plans that were completed for the most part in the fall of 2000. Extensive data gathering and evaluation efforts on a region-by-region basis and development of regional water management strategies occurred. For this evaluation, the study area was refined to include existing major water users and potential users of Wichita/Red River water according to the water plan. Major water users were those identified as current users of Wichita/Red River water in the Texas State Water Plan and current users of Red River water in Louisiana, including Bossier City. In Region B, the Wichita Falls area has been identified as a user of Lake Kemp/Diversion water based on planned construction of a desalinization facility as well as a steam-electric power plant owned by West Texas Utilities at Oklaunion, Texas. Furthermore, Wichita Falls blended Lake Kemp water for a limited time during the recent drought. In Region C, existing users of Lake Texoma water are the Greater Texoma Utility Authority (GTUA-Sherman) and the North Texas Municipal Water District (NTMWD). The GTUA desalinizes Lake Texoma water by the Electrodialysis Reversal (EDR) process, and the NTMWD blends Lake Texoma water with Lake Lavon.

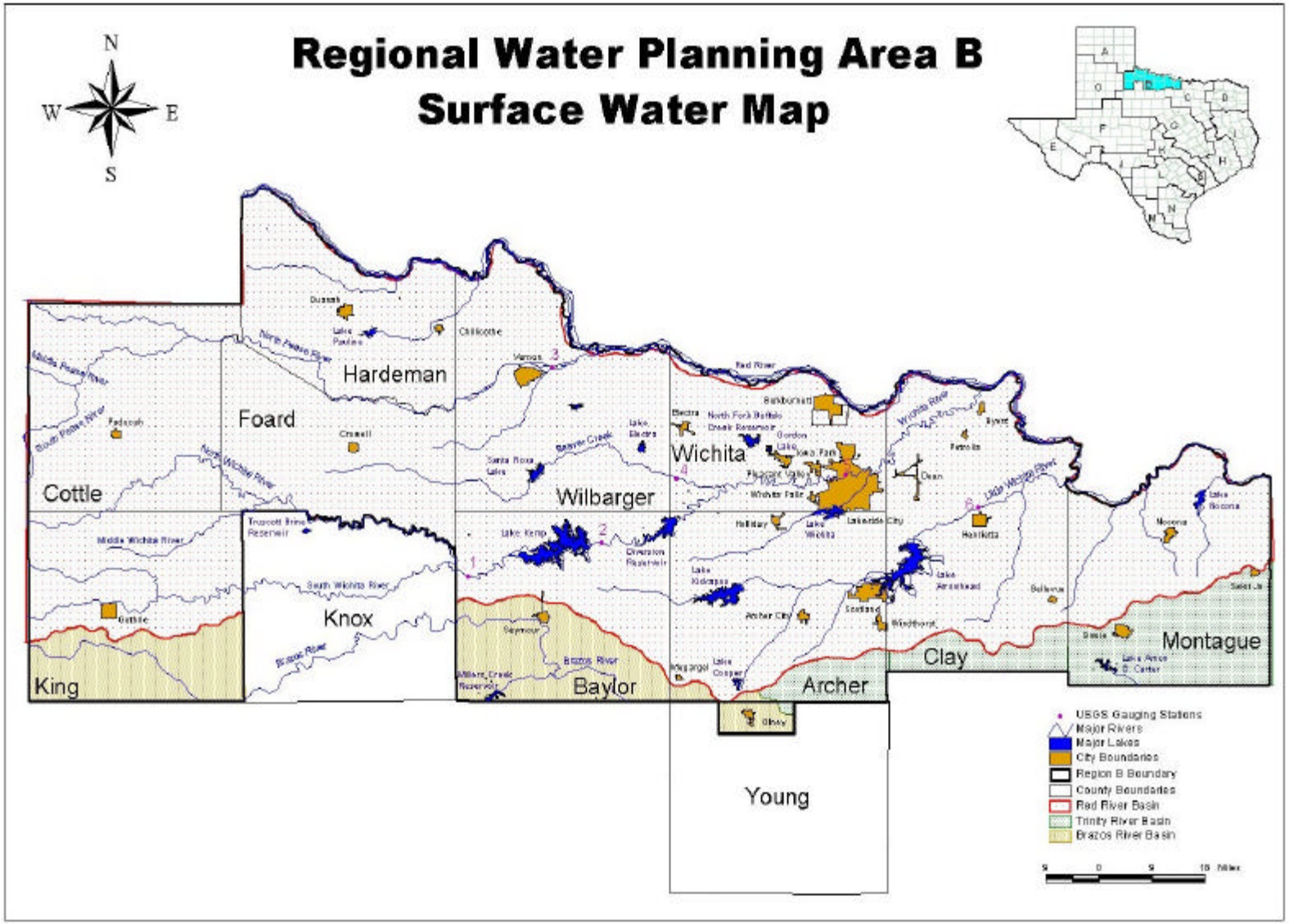


Figure 1-4. Wichita Falls Region.

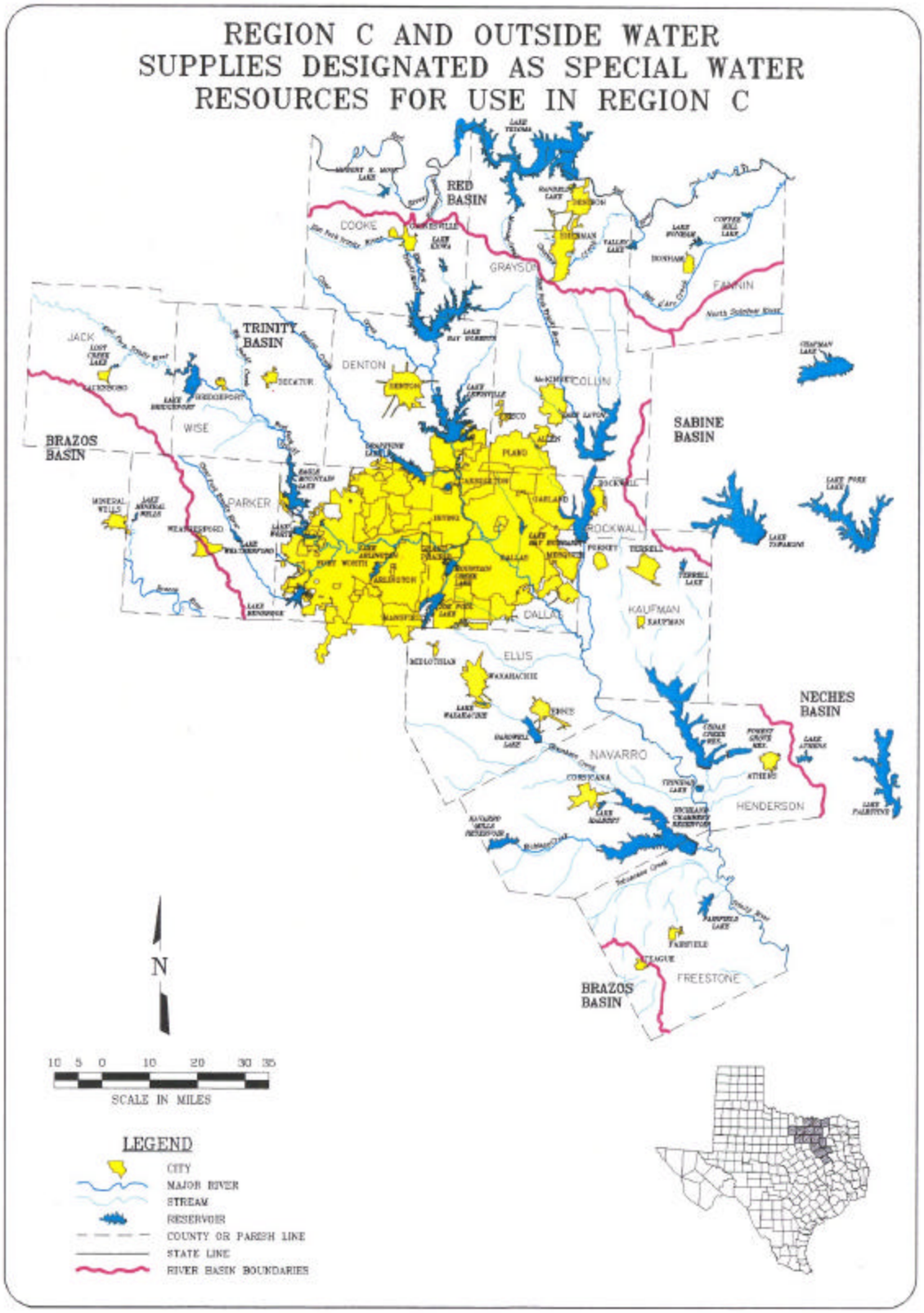


Figure 1-5. Dallas Region.

REACHES OR IMPACT AREAS

Municipal and Industrial

To facilitate data collection and analysis for municipal and industrial users of Wichita/Red River water, the Wichita/Red rivers were subdivided into segments or reaches (impact areas). See Figure 1-3. These reaches are similar to those designated in previous economic reports, such as the LRR, with some modifications. Modifications to previous reach designations were made to make clearer the existing source of water, such as Lake Kemp (Reach 9), Lake Texoma (Reach 5), and the Red River in Louisiana (Reach 1). In addition, the existing or potential user of water from that source, such as Wichita Falls or the GTUA, may be incorporated into the reach designation. The boundaries of the reaches were determined by considering hydrologic, legal, and economic constraints. Table 1-2 shows the reach designation, stream, counties (parishes) within the reach, and the existing/potential user of water from the Wichita/Red Rivers. Reaches with no existing/potential user were screened out of the evaluation process. The purpose of the reach designation is to develop a cost of Wichita/Red River water to calculate project benefits and assess whether future water use would come from the river or alternative sources. The cost of river water depends on concentration-duration curves without and with the project.

TABLE 1-2

REACH DESIGNATIONS - RED RIVER BASIN

Reach	River/Lake	Counties (Parishes)	Existing/Potential User
1	Red River	Bossier, Louisiana (LA)	Bossier City
		Natchitoches, LA	Willamette Industries
		Avoyelles, LA	
		Caddo, LA	
		Grant, LA	
		Rapides, LA	
		Red River, LA	
2	Red River	Hempstead, Arkansas (AR)	
		Lafayette, AR	
		Miller, AR	
3-A	Red River	Little River, AR	
3-O	Red River	McCurtain, Oklahoma (OK)	
3-T	Red River	Bowie, Texas (TX)	
		Red River, TX	
4-O	Red River	Bryan, OK	
4-T	Red River	Fannin, TX	
		Lamar, TX	

TABLE 1-2 (Continued)

Reach	River/Lake	Counties (Parishes)	Existing/Potential User
5-O	Lake Texoma	Marshall, OK	
5-GTUA	Lake Texoma	Grayson, TX*	Greater Texoma Utility Authority (GTUA)-Sherman
5-Gray/DEN	Lake Texoma	Grayson, TX*	Denison and Grayson County
5-NTMWD	Lake Texoma	Collin, TX*	North Texas Municipal Water
		Dallas, TX*	District (NTMWD)
		Kaufman, TX*	
		Rockwall, TX*	
5-DAL	Lake Texoma	Collin, TX*	Dallas Water Utilities (DWU)
		Dallas, TX*	
		Denton, TX	
		Kaufman, TX*	
		Rockwall, TX*	
5-TRWD	Lake Texoma	Tarrant, TX*	Tarrant Regional Water
		Ellis, TX	District (TRWD), Fort Worth,
			Trinity River Authority (TRA)
6-O	Red River	Jefferson, OK	
		Love, OK	
6-T	Red River	Cooke, TX	
7	Red River	Cotton, OK	
8	Wichita River	Archer, TX	Wichita Falls system
		Clay, TX	
		Montague, TX	
		Wichita, TX	
9	Lake Kemp	Baylor, TX	Wichita Falls system
		Wilbarger, TX	
10	North Fork	Foard, TX*	
	Wichita River		
11	South Fork	Knox, TX	
	Wichita River		

Hydrologic Constraints. The major constraint for identifying reach boundaries was hydrologic, such as the location of major tributaries and stream gaging stations, and changes in water quality. Changes in water quality as a result of inflow from tributary streams may result in distinct variations in water quality in the Wichita/Red Rivers. Development of hydrologic data in the form of concentration-duration curves for TDS, Cl, and SO_4 by reach enable the economic benefit analysis to be accomplished, as explained in the concept/ methodology portion of the report.

Legal Constraints. Since Federal, State, and local laws can influence water allocation and use, consideration was given to transport of water across state boundaries. The Red River Compact between the States of Oklahoma and Texas establishes current legal boundaries for water transport. In addition, the State of Oklahoma has refused to support solutions to water quality problems when those solutions involve projects within Oklahoma as part of the Red River Chloride Control Project.

Economic Constraints. These constraints were discussed above as data collection along county lines and by major water user. Demographic data used to develop water demand data are often developed along county, city, and in some cases, water system boundaries, whereas data on the availability and use of water supply are usually available by contracted user, who often supplies water to other entities in various counties and rural areas.

Agricultural Evaluation

Reach designations for the agricultural evaluation have been changed from previous evaluations. Figure 1-6 shows the general agricultural study area. Former Reach 8 has been changed to Reaches 7 and 12. There is no longer a Reach 8 for the agricultural evaluation to avoid any confusion with the former Reach 8. Reach 7 is the Wichita River from its mouth upstream to Lake Diversion and all the land lying within 50 feet in elevation above the Wichita River and also lying below the elevations associated with the Wichita County Irrigation District (WID) canals. Reach 12 is the land between the mouth of the Wichita River and Lake Diversion that lies within 50 feet of the elevation above the main canals of the WID. In the current evaluation, Reaches 5 and 6 are now separated by the Montague-Clay County line, whereas, previously Reaches 5 and 6 were separated by the Grayson-Cooke County line. There is also no irrigation from Lake Texoma (Reach 5 in the municipal and industrial analysis), only above the upper limits of Lake Texoma. The reaches significant for the agricultural evaluation are those below Lake Kemp (Reach 9), which are Reaches 5, 6, 7, and 12. Concentration-duration curves were matched to the appropriate reaches. These designations are described in detail in the agricultural analysis section.

Recreation Evaluation

An evaluation of the potential recreation impacts to Lake Kemp was conducted as part o this study. Some members of the public and agencies have express concern about the changes in water quality in the Wichita River and its impact on water-based recreation. Changes in water quality may result in changes in the clarity, or turbidity, of bodies of water popular with recreation users. Lake Kemp is a resource accessible only through private property; however,

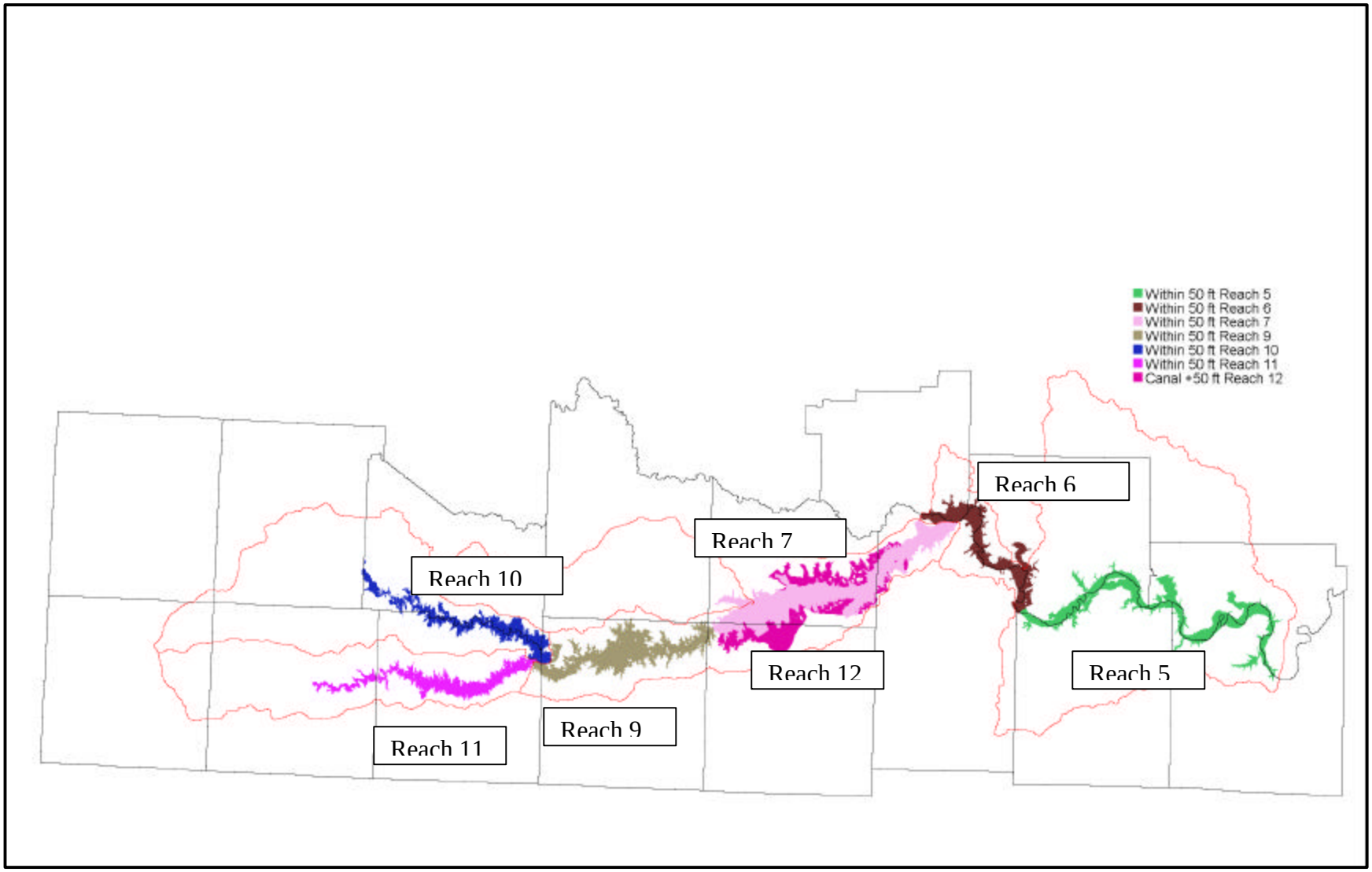


Figure 1-6. General Agricultural Study Area.

visitors use the lake for recreation. In response to concerns about recreation at the lake, the Corps contracted with Texas Tech University Department of Range, Wildlife, and Fisheries Management to assess the economic value of recreation at Lake Kemp and potential impacts to the value of recreation because of projected related changes. The study estimated the impacts of Lake Kemp recreation expenditures in the areas surrounding the lake. Based on projected differences between pre- and post- project turbidity, the impact to recreation use and the value of recreation under the with-project condition is below a level that can be identified by recreation users.

WATER USERS

The four main types of water users in the study area are municipal, manufacturing (industrial), steam-electric, and agricultural irrigation. Mining and livestock are other water users.

Municipal Users

A municipal user is a public or private entity, such as a municipality or water district, that represents an area of concentrated demand and provides a water supply system for public consumption to meet residential; commercial; industrial, including manufacturing; and public demands for water. The approach used in this evaluation is to be consistent with data and information developed for the Texas State Water Plan 2000 by major user groups and counties. The major municipal water groups evaluated in Texas are: Wichita Falls, Greater Texoma Utility Authority (Sherman), North Texas Municipal Water District, Dallas Water Utility, Tarrant County Regional Water District, Fort Worth, and the Trinity River Authority. In Louisiana, Bossier City is the only known municipal water supply entity that currently uses Red River water.

Industrial Users

Industrial (manufacturing) water users include those with self-supplied water sources and those that depend on public supplies. Since nearly all manufacturers in the region obtain their water from public systems, this evaluation will be of the municipal systems that supply water to manufacturing industries. Some manufacturers may have their own on-site treatment process even though they obtain their water from municipal systems, or they may be on their own well water systems. In Texas State Water Plan 2000, information was compiled on supply and demand for water by sector. Manufacturing water demand represents only about 6% of historical (1996) total demand for all water in Region C, and about 8% of municipal demand. In Region B manufacturing demand for water represents about 2% of total water demand and about 8% of municipal demand (Reference Region C, Volume I, page 2.14, Table 2.6 and Region B, Chapter 4, page 8, Table 4-3.) In Louisiana, only one known manufacturing facility currently uses Red River water. Water use for mining, mainly oil and gas extraction processes, is discussed as a separate category in the State water plans.

Steam-Electric Users

Steam-electric users are power plants that utilize water to operate steam-driven turbines for generation of electricity. At the present time, only one steam-electric plant (Oklaunion) is known to use Lake Kemp water.

Agricultural Users

Agricultural water users are those individuals or businesses engaged in farming activities that use available water for irrigation to increase crop yield and income. The agricultural evaluation conducted by Texas A&M University discusses potential agricultural benefits from using Wichita/Red river water above Lake Texoma. Livestock water use is discussed in the Texas Water Plan.

PART IIA –WATER SUPPLY AND DEMAND - REGION B - WICHITA FALLS

STUDY ELEMENTS

This municipal and industrial evaluation will focus on major water purveyors for Region B (Wichita Falls) and Region C (Dallas) in Texas and existing Red River water users in Louisiana. Six major study elements of regional water demand and supply were identified for the municipal and industrial evaluation. Those study elements are: 1) establish demand; 2) identify alternative water sources, both existing and future; 3) determine future net need; 4) analyze water use with and without the project and discuss water management strategies; 5) calculate the benefits for the Wichita River Basin project; and 6) evaluate the sensitivity of the analysis.

Establishing need and identifying alternative water sources allowed the screening out of counties in Oklahoma and Arkansas; parishes in Louisiana (except Bossier Parish); and counties in Texas, except those that could reasonably be supplied from either Lake Texoma or Lake Kemp. The screening process used in the 1993 LRR and in previous reports was reviewed. Sources of supply had to be consistent with the current Texas State Water Plan. Since detailed studies, evaluations, and public involvement occurred during development of the Water Plan over the last several years, consistent with NED evaluation procedures, that information was relied on in this evaluation. Thus, sources of data to establish demand, supply, and net need for water are the Region B and Region C portions of the Texas State Water Plan 2000; known existing use of water from the Wichita/Red River in Oklahoma, Arkansas, and Louisiana; and previous studies conducted by the U.S. Army Corps of Engineers, Tulsa District. Alternative water sources are identified in the Texas State Water Plan and in "Investigation of Existing and Potential Sources of Water Supply and Cost of Red River Water", Wichita River Basin Reevaluation, dated April 2001, Volumes I and II, by Huitt-Zollars, Inc.

The analysis of water use without and with the project depends on the sources and costs of water supply and estimates of existing and future water needs. Whether a specific source is utilized to meet needs depends on the adopted regional management strategy that takes into account existing contracted sources of water supply and the cost, quantity, and quality of potential sources of water supply. The costs assigned to water supply sources, including the Wichita/Red Rivers, allow computation of benefits. These benefits are measured as either an improvement in water quality, i.e., a reduction in treatment and damage costs without and with the project, or the cost of the least costly alternative, depending on the regional management strategy. The Wichita/Red Rivers, including Lake Kemp and Lake Texoma, are considered existing and alternative water supply sources for analytical purposes. Existing and planned additional uses of these sources of water supply are described in the water plans. The Texas Water Plan describes in detail how the consensus water demands are developed for the regions. Alternative projections are presented in those reports, and conservation measures are incorporated into those projections.

REGIONAL WATER DEMAND AND SUPPLY OVERVIEW

Previous Studies

The most recent comprehensive Tulsa District report that describes historic, existing, and projected water use and sources of water in the study area is the 1993 Limited Reevaluation Report (LRR). In the 1993 LRR, the methodology used to develop forecasts of water use utilized the Institute of Water Resources Municipal and Industrial Needs (IWR-MAIN) forecasting system. Survey data of over 300 municipal systems were used to calibrate the model to 1980 water use data. OBERS Series E projection rates were then used to forecast future water use by county (parish) in the region for different categories of water use. Conservation measures were incorporated into the model to account for system loss prevention programs and conservation-oriented water pricing policies. Future water demands utilizing this method resulted in differences compared to what was reported in the 1997 Texas water plan projections.

Current Study

Regional planning groups were created by the Texas Water Development Board (TWDB) to implement the planning process for the Texas State Water Plan. These regional planning groups have a commonality of water resource demands, supplies, needs, and shared water management strategies. Most regions share a common river basin or source of water for a major water provider. The two regions in Texas used in this analysis are Region B, whose principal city is Wichita Falls, and Region C, the Dallas metro area. A general description of the region, its economic and demographic base, and its ecology is followed by a discussion of regional water demand and supply and water management strategy adopted by the planning group. The Region B plan is presented in this report since the project area lies within this region, and the plan presents a comprehensive discussion of water resource problems and needs. Some minor revisions have been made for clarification purposes and year 2000 Census data have been added in certain tables, when available.

DESCRIPTION OF REGION B

Senate Bill 1 of the 75th Texas Legislature was passed in 1997 to set the process of developing a comprehensive water plan to be completed in 2002. To accomplish this task, the state was divided into 16 regional water planning groups. Region B is comprised of ten entire counties and a portion of one county (Young) in north-central Texas. Specifically, those counties are Archer, Baylor, Clay, Cottle, Foard, Hardeman, King, Montague, Wichita, Wilbarger, and the city of Olney in Young County. Figure 2-1 shows Region B and the cities, towns, and counties it encompasses. The focus of this evaluation will be on the Wichita Falls area.

Region B lies mainly in the Red River Basin; however, southern portions of Archer and Clay counties lie in the Trinity River Basin, and southern portions of Archer, Baylor, and King counties lie in the Brazos River Basin, as shown on the Surface Water Map in Figure 2-2. Knox County, Reach 11, was included in the Brazos region, Region G, since most of that county lies in the Brazos River Basin, although the South Wichita River intersects the northernmost half of the

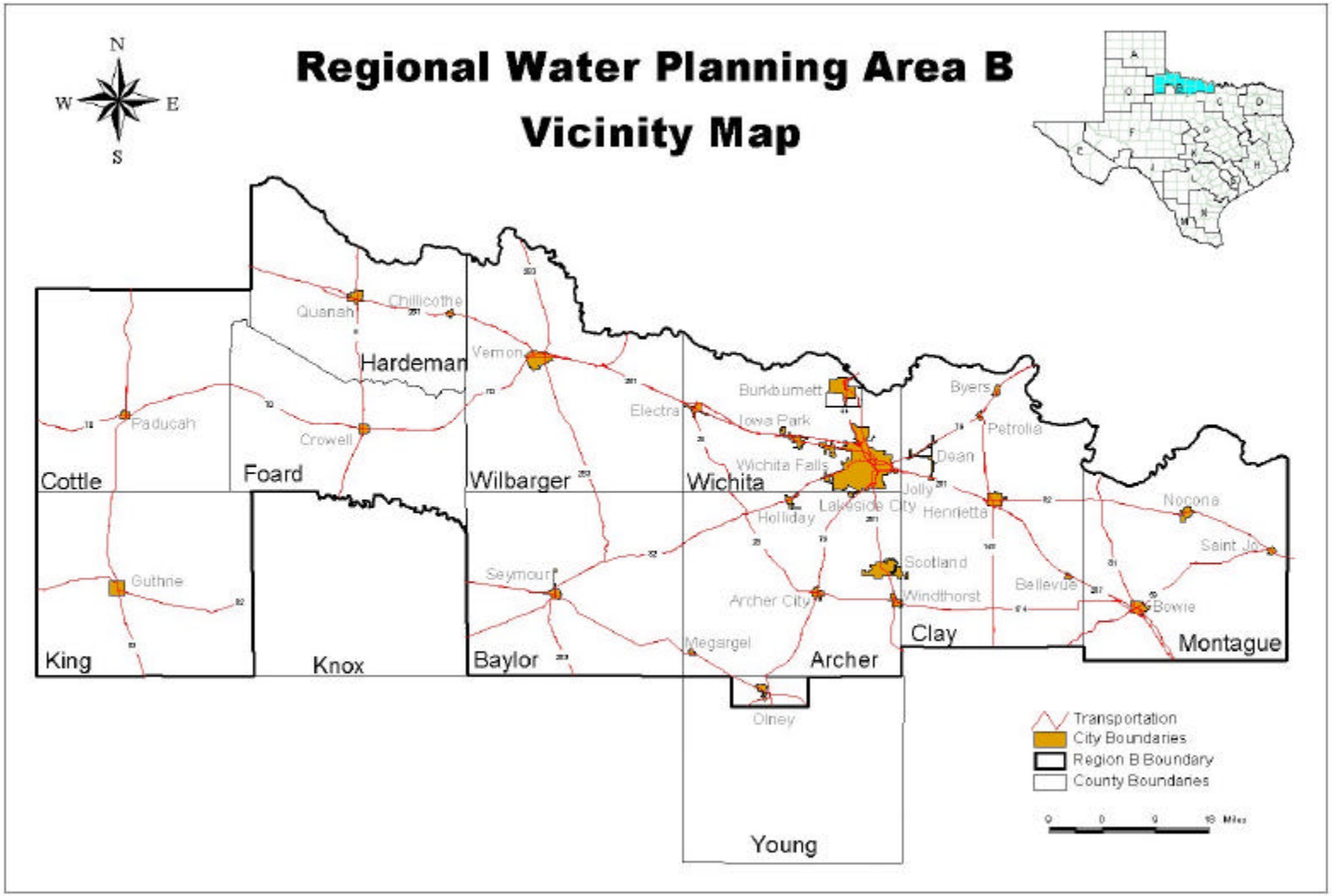


Figure 2-1. Vicinity Map Region B.

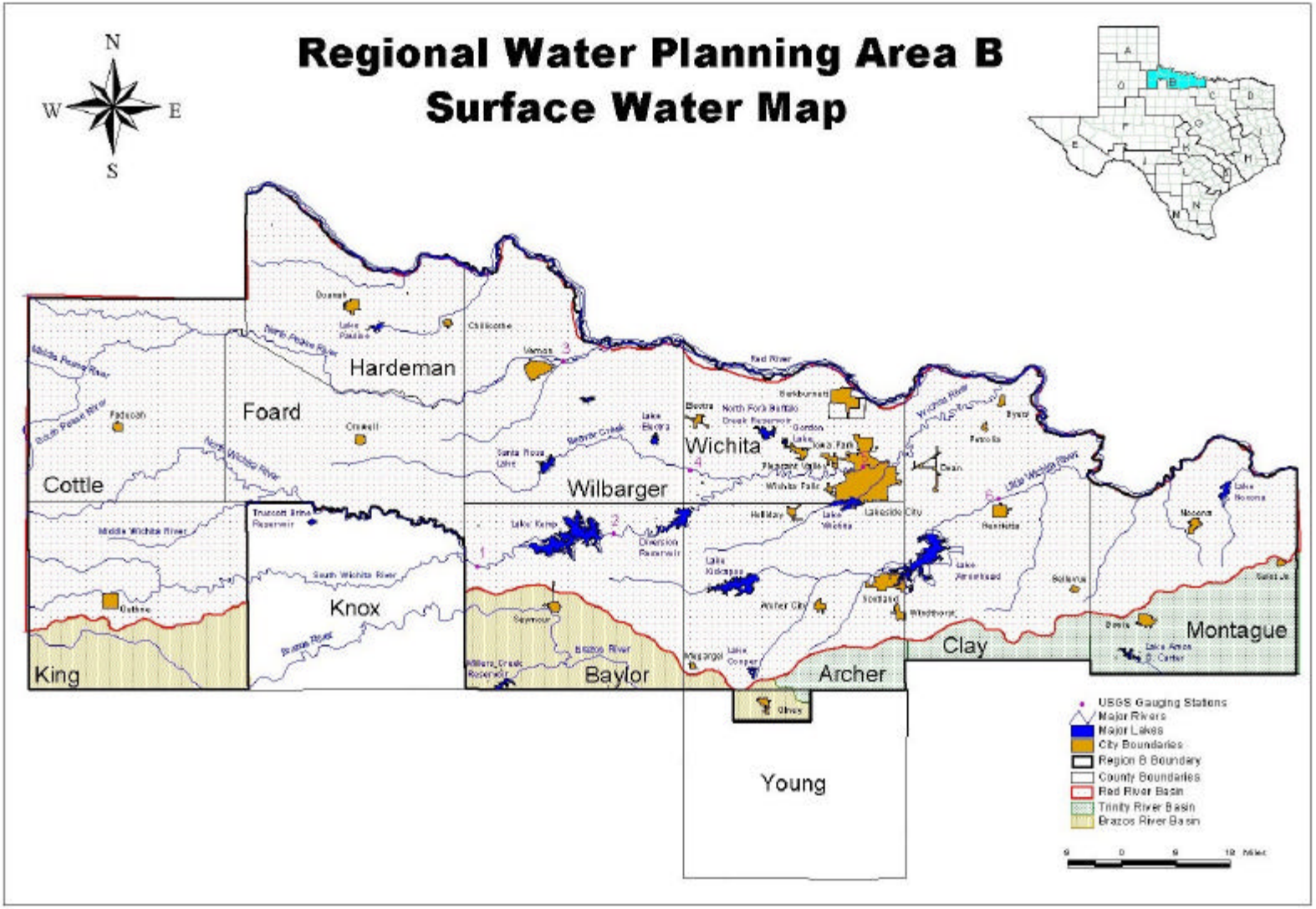


Figure 2-2. Surface Water Map.

county. Knox County is discussed separately and is in the chloride control study area. Knox County has relatively small municipal systems that rely on groundwater and are unlikely to utilize Lake Kemp water as a water source for economic (cost) reasons. Since the chloride control areas and Truscott Brine Lake lie in Knox County, information for Knox County is included following the Region B material.

ECONOMIC ASPECTS OF REGION B

The main components of the region's economy are farming, ranching, and mineral production. As Table 2-1 shows, the market value of all agricultural products sold in the region is substantial, and the availability of water has a direct impact on this industry.

TABLE 2-1

MARKET VALUE OF ALL AGRICULTURAL PRODUCTS SOLD

County	Value ($1000)	Percent
Archer	63,394	21
Baylor	38,007	13
Clay	37,592	13
Cottle	14,753	5
Foard	11,108	4
Hardeman	15,887	5
King	6,598	2
Montague	29,559	10
Wichita	21,861	8
Wilbarger	33,237	11
Young	23,193	8
Total	**295,189**	**100**

The Texas Railroad Commission reports that Region B has over 33,000 producing oil wells and over 600 gas wells. Table 2-2 provides a tabulation by county of current oil and gas wells.

TABLE 2-2

NUMBER OF OIL AND GAS WELLS

County	Oil Wells	Gas Wells
Archer	6,949	4
Baylor	472	1
Clay	2,319	81
Cottle	52	47
Foard	172	34
Hardeman	303	0
King	995	38
Montague	2,749	48
Wichita	11,820	4
Wilbarger	2,301	2
Young	5,058	379
Total	**33,190**	**638**

The service infrastructure is also strong. Some services offered throughout Region B include agribusiness, oilfield service, grain, fiber, and food processing. Wichita County, the most populous county in the region, is the retail trade center for a large area. Sheppard Air Force Base and medical services also are big contributors to the economy of Wichita County. The region boasts a variety of manufacturing, including oilfield equipment, clothing, building products, plastics, electronics, wood products, and aircraft equipment. Table 2-3 depicts the payrolls of each county in 1996.

TABLE 2-3

1996 COUNTY PAYROLLS

County	Annual Payroll ($1,000)
Archer	13,109
Baylor	13,211
Clay	17,721
Cottle	7,302
Foard	4,339
Hardeman	19,122
King	N/A
Montague	54,686
Wichita	960,436
Wilbarger	83,542
Young	105,266

N/A = Not available.

Land Use

Region B includes some of the largest ranches in the state, including the Waggoner Ranch in Wilbarger County and the Four Sixes Ranch in King County. It has over 1 million acres of croplands and over 3 million acres of open range. Table 2-4 shows land use percentages for each county in the region (data for Montague County were unavailable). Percentages under the heading "Conservation" represent lands that had been croplands, but that have been converted to the Conservation Reserve Program (CRP). The CRP subsidizes farmers and landowners to convert highly erodible farmland to permanent grassland for a period of 10 years.

TABLE 2-4

PERCENTAGE OF LAND USE BY COUNTY

County	Crops	Federal	Conser -vation	Pasture	Range	Urban	Water	Transpor -tation	Total
Archer	16.2	<0.1	1.0	1.6	77.0	0.9	2.2	1.1	592.7
Baylor	29.0	<0.1	1.6	1.7	61.2	0.7	4.9	0.8	576.5
Clay	19.3	<0.1	0.6	6.1	67.9	1.6	3.1	1.5	708.6
Cottle	14.7	<0.1	12.7	0.9	65.3	0.3	2.1	0.6	578.6
Foard	21.2	<0.1	14.9	-	62.4	-	0.6	0.9	452.1
Hardeman	37.5	<0.1	15.4	0.4	42.2	1.2	1.7	1.6	444.7
King	9.7	<0.1	2.3	0.4	86.4	0.0	0.5	0.6	584.9
Montague	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wichita	40.5	1.1	1.5	3.8	38.7	9.9	1.5	3.0	391.9
Wilbarger	37.2	1.1	7.3	6.7	46.6	<0.1	0.9	1.3	612.9
Young	30.6	1.1	0.8	2.7	61.0	1.6	2.1	1.3	595.4

N/A – Not Available

Typical crops in Region B include cotton, coastal bermuda, wheat, alfalfa, peanuts, grain sorghum, watermelons, pecans, peaches, and various other fruits. Cattle for beef and dairy production are the major component of the livestock industry, with sheep, swine, and equine also present. The agricultural section of this study discusses land use and cropping patterns that are pertinent to the chloride control project.

Climate Data

The best word to describe the weather of Region B is volatile. It has the ability to change from one extreme to another in a short period of time. Annual precipitation can also vary greatly from year to year. Average annual rainfall for the region is 27.4 inches; however, the extremes range from 47 inches in 1919 to 12 inches in 1896. Table 2-5 shows monthly averages and records for the Wichita Falls area, and Table 2-6 lists temperature extremes and average rainfall for each county in the region.

TABLE 2-5

MONTHLY AVERAGES AND RECORDS FOR WICHITA FALLS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High Temp. (F)	52	57	66	76	83	92	97	96	87	77	64	55
Low Temp. (F)	28	32	41	50	59	68	73	71	64	52	41	31
Dew Point (F)	28	31	37	47	58	64	65	64	60	50	38	30
Precipitation (In)	1.04	1.46	2.21	3.01	4.07	3.52	1.72	2.48	3.82	2.74	1.54	1.29
Snowfall (In)	2.0	2.0	1.9	0.9	Trace	0.0	0.0	0.0	0.0	Trace	0.3	1.1
Wind Speed	11.2	12.1	13.4	13.1	12.1	12.1	11.2	10.4	10.5	10.7	11.4	11.2
Monthly Rec's	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
High Temp. (F)	87	93	100	102	107	117	114	113	108	102	89	88
Low Temp. (F)	-12	-8	6	24	36	50	54	53	38	21	14	-7
Precipitation (In)	4.48	6.80	5.38	8.50	13.22	9.63	11.86	11.05	10.23	11.77	7.34	6.12

TABLE 2-6

TEMPERATURE EXTREMES AND AVERAGE RAINFALL

County	Temperature (degree F)		Annual Rainfall (inches)
	January Mean Minimum	July Mean Maximum	
Archer	29	98	29.3
Baylor	26	97	27.3
Clay	26	97	31.9
Cottle	25	96	22.3
Young	26	96	30.6
Foard	24	97	23.9
Hardeman	23	97	24.5
King	24	98	23.8
Montague	31	98	32.9
Wichita	28	97	28.9
Wilbarger	25	97	25.7

The region is obviously drier in the western areas and has more rainfall in the eastern and southern counties.

Since 1930, the entire state has experienced seven major droughts. Two of these droughts occurred in 1996 and 1998. A drought in this region has entered its third year, with water conservation measures imposed in the Wichita Falls service area. It has been predicted that between 15% and 30% of Texas farmers will quit the business this year (2002) due to recent droughts. This fact is particularly significant for Region B since agriculture is a major contributor to the economy of the region.

Ecology and Wildlife

Most of Region B lies in the area known as the “Rolling Plains” with the exception of Montague County, which lies in the "Oakwoods and Prairies" area. The Texas Parks and Wildlife Department describes the “Rolling Plains” region as a “gently rolling plain of mesquite and short grass savanna.” Mesquite brush, prairie grasses, and sandstone outcroppings generally characterize the open range. Cottonwood, hackberry, and saltcedar brush can be found near most rivers and streams. This vegetation is important to the survival of both resident and migratory birds. It is evident by the widespread mesquite, however, that overgrazing, soil erosion, and the lowering of the groundwater table have all contributed to the decline of native grasslands. The topography of the region gently slopes to the east and southeast. The Red River and its major tributaries drain most of the region; however, tributaries of the Brazos and Trinity rivers drain extreme southern reaches of the region.

The “Rolling Plains” region of Texas is not usually thought of as an area rich in wetland habitats. However, the region is actually very important to both migrating and wintering waterfowl. In fact, many species of migrating shorebirds, raptors, and other birds stop over in the region to feed and rest on the available wetlands.

Over 40 species of water-dependent reptiles, amphibians, and mammals live in the study area. This includes minks, muskrats, and beavers, snakes, turtles, salamanders, and frogs. Fish species present in the study area include drum; carp; buffalo; bluegill; sunfish; largemouth, white, spotted, and striped bass; white crappie; flathead, blue, and channel catfish; and walleye. Lake Kemp supports a notable striped bass fishery. Some endangered species are also present across the region.

Copper Breaks State Park, located 12 miles south of Quanah in Hardeman County, contains 1,889 acres and a 70-acre lake. The park has abundant wildlife, and, according to the 1998 Texas Almanac, is home for part of the official Texas Longhorn herd.

The Environmental Impact Statement (EIS) discusses in detail the ecology of the region and the fish and wildlife environment of the project impacted area.

Current Population and Demographic Data

In general, most of the population is concentrated in eastern portions of the region, with over one-half located in and around Wichita Falls. In 1996, the total population of the region was reported to be 201,984, with the largest population center, the city of Wichita Falls, being 100,501 or 50% of the total. The population of Wichita Falls according to the 2000 Census was 104,197. The second largest city in the region was Vernon with a population of 12,481 in 1996 and 11,660 in 2000. The January 1, 1998, estimated population density of the region ranged from a high of 200 persons per square mile (Wichita County) to a low of less than 1 person per square mile (King County). The regional population is forecast to increase by 10% over the study period. Table 2-7 shows the 1990 census population by county and the corresponding estimated population in 1998. Tables 2-8 and 2-9 give a more in-depth breakdown of regional demographics.

TABLE 2-7

COUNTY POPULATIONS
(Based on 1990 and 2000 Census)

County	Area (sq. mi.)	1990 Population	2000 Population	% Change	Density (people/sq. mi.)
Archer	910	7,973	8,854	9.0	10
Baylor	871	4,385	4,093	-1.3	5
Clay	1,098	10,024	11,006	8.5	10
Cottle	901	2,247	1,904	-6.3	2
Foard	707	1,794	1,622	3.2	2
Hardeman	695	5,283	4,724	-5.2	7
King	912	354	356	-5.4	<1
Montague	931	17,274	19,117	5.3	21
Wichita	628	122,378	131,664	4.6	210
Wilbarger	971	15,121	14,676	1.5	15

Note: The City of Olney is not included in this table.

TABLE 2-8

1990 DEMOGRAPHICS – BREAKDOWN BY INCOME AND EDUCATION

County	Median Family Income	Percentage of Population That		
		Has High School Diploma or Better	Has Bachelor's Degree or Better	Has a Family Income Below Poverty Level
Archer	$29,617	72.2	12.3	8.9
Baylor	25,747	63.6	10.3	16.3
Clay	27,901	68.9	11.1	9.1
Cottle	21,799	51.8	10.7	22.1
Foard	22,105	62.2	11.2	15.7
Hardeman	24,705	62.8	11.0	14.8
King	29,000	78.2	24.5	7.4
Montague	22,948	63.6	10.2	15.1
Wichita	28,799	75.1	16.5	12.5
Wilbarger	25,603	62.9	12.7	15.5
Young	26,563	60.7	11.2	11.9
Average	$25,890	65.6	12.9	13.6

TABLE 2-9

1990 DEMOGRAPHICS – BREAKDOWN BY OCCUPATION

County	Percentage of Population that Works in						
	Agriculture	Manufacturing	Trade	Finance	Health	Public	Unemployed
Archer	11.7	9.2	20.5	4.8	7.6	4.2	4.0
Baylor	11.6	7.8	23.5	5.0	10.0	3.9	6.0
Clay	9.9	13.0	19.4	4.5	9.0	4.6	5.0
Cottle	26.1	1.2	15.8	3.4	6.2	6.0	5.9
Foard	21.3	8.3	10.4	4.6	11.9	6.6	5.3
Hardeman	15.9	12.5	20.3	4.2	10.8	1.9	8.8
King	41.1	0.0	12.5	2.1	0.0	7.3	2.0
Montague	5.5	19.9	19.9	3.4	7.7	4.0	5.6
Wichita	1.6	15.2	23.1	5.3	11.6	5.1	7.1
Wilbarger	9.1	11.9	16.8	3.6	20.4	2.5	5.3
Young	6.4	13.8	18.5	4.4	8.1	3.5	5.9
Average	14.6	10.3	18.2	4.1	9.4	4.5	5.5

POPULATION AND WATER USE PROJECTIONS

Amendments to 1997 Water Plan

This report has been prepared in accordance with the requirements of Texas State Senate Bill 1 (SB1). Subsequent to the passage of SB1, "Guidelines and Data Requirements for Addressing Revisions of the Consensus - Based Population and Water Demand Projections Senate Bill 1" were published by the TWDB.

The rules promulgated for implementing SB1 direct the Regional Water Planning Group (RWPG) to use the consensus-based population and water use projections that were developed for and used in preparing the 1997 State Water Plan. Specifically, the rules state:

Section 357.5 Guidelines for Development of Regional Water Plans.

(d) *Use of population and water demands. In developing regional water plans, regional water planning groups shall use:*

(1) state population and water demand projections contained in the state water plan or adopted by the board after consultation with the Texas Natural Resource Conservation Commission and the Texas Parks and Wildlife Department in preparation for revision of the state water plan; or

(2) in lieu of paragraph (1) of this subsection, population and water demand projection revisions that have been adopted by the board, after coordination with the Texas Natural Resource Conservation Commission and the Texas Parks and Wildlife Department, based on changed conditions and availability of new information. Within 45 days of receipt of a request from a

regional planning group for revision of population or water demand projections, the executive administrator shall consult with the requesting regional water planning group and respond to their request.

The RWPG for Region B presented a request to the TWDB for several changes to the 1997 State Water Plan projections in population and water. All requests were documented as required by the guidelines and were approved by the TWDB. The proposed revisions to the population and water use projections have been documented. The results of those changes are the basis for this report.

Region B Overview

The 11 north Texas counties of Region B include Archer, Baylor, Clay, Cottle, Foard, Hardeman, King, Montague, Wichita, Wilbarger, and a portion of Young. These counties have a year 2000 consensus-based total population projection of 197,282. In 2050, that population is estimated to grow to 207,660, a 5.26% increase. The RWPG is herein submitting information to document a projected total population of 197,793 in 2000, with a 9.7% increase to 2050 giving a total projected population of 216,914.

Region B contains only one city larger than 100,000, which is Wichita Falls. The other communities in Region B are smaller and more rural in nature with incomes that are dependent on agriculture and, to a lesser extent, the oil industry. Consequently, the population for the region is projected to have only a moderate increase for the next 50 years, from 201,984 people in 1996 to 216,914 in 2050, or a 7.5% increase.

The latest population data from the Texas State Data Center provided information regarding 1996, 1997, and 1998 for the cities and counties in the region. In addition, questionnaires were mailed to virtually every water provider in the region, including the water supply corporations (WSC), municipal utility districts (MUD), river authorities, and small communities, to verify population estimates.

Information was requested and provided by those entities regarding water meters and water usage for the past 8 years. The entities also included information regarding future or ongoing expansions to their systems. All the data were used to make population and water use projections. The proposed population and water use data for Region B are summarized and each request for revision is documented according to the requirements of the TWDB in the next sections of this report.

Population Revisions for Cities

City of Holliday. Population projections have been increased because the city of Holliday has experienced a higher growth rate over the last decade than was shown in the 1997 Consensus Water Plan (1997 Plan). Information from the Texas State Data Center indicates that the 1998 population of Holliday was 1,564. This number was used as the projected 2000 population, and the same changes were applied as were used in the 1997 Plan. The actual year 2000 Census count was added below the tables, when available.

City of Holliday Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	1,475	1,509	1,558	1,556	1,554	1,520	1,469
RWPG		1,564	1,613	1,621	1,609	1,575	1,524
2000 census		1,632					

Lakeside City. Lakeside City, a bedroom community adjacent to Wichita Falls, has experienced slow but steady growth over the last 10 years. The 1997 Plan showed an increase from 865 in 1990 to 1,004 in 2000. The Texas State Data Center gives the 1998 population as 1,048. Based on this information, the population through 2020 has been revised upward, but knowing that the city boundary expansion will be limited, the population from 2030 to 2050 has been held constant and below the 1997 Plan estimate.

Lakeside City Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	865	1,004	1,081	1,258	1,455	1,653	1,831
RWPG		1,100	1,177	1,350	1,400	1,400	1,400
2000 census		984					

City of Seymour. The Texas State Data Center gives the 1998 population of Seymour as 3,074. That number was used as the projected population for 2000, and then the changes of the 1997 Plan were applied.

City of Seymour Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	3,185	2,958	2,828	2,462	2,177	2,102	2,031
RWPG		3,074	2,944	2,578	2,293	2,218	2,147
2000 census		2,908					

City of Byers. The Texas State Data Center gives the 1998 population of Byers as 556. That number was used as the projected population for 2000, and then the changes shown in the 1997 Plan were applied.

City of Byers Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	510	522	512	493	481	489	499
RWPG		556	546	527	515	523	533
2000 census		517					

City of Henrietta. The Texas State Data Center has the 1997 population of Henrietta as 3,082 and the 1998 population as 3,100. The city projects their 2000 population to be 3,112. Water meters in the city have increased from 1,342 in 1990 to 1,452 in 1998, or about 1.02% per year. Therefore, the city's population projections have been revised to show a positive trend using a conservatively low rate of about 0.5% per year through 2030 and a decreased rate from 2030 to 2050.

City of Henrietta Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	2,896	2,764	2,696	2,537	2,293	2,044	1,795
RWPG		3,112	3,268	3,431	3,602	3,750	3,800
2000 census		3,264					

City of Petrolia. The 1998 population of Petrolia, as given by the Texas State Data Center, was 834. This is the population used as the base for 2000, and the changes as shown in the 1997 Plan have been applied thereafter.

City of Petrolia Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	762	783	763	728	695	691	693
RWPG		834	814	779	746	742	744
2000 census		782					

City of Bowie. From 1990 to 1998, the population of Bowie increased from 4,990 to 5,350, according to the Texas State Data Center. That indicates a growth rate of approximately 1.0% per year. However, in the last couple of years the rate has decreased some. For this report, the 2000 population has been held at 5,350, a small decrease in population is shown from 2000 to 2010, and a slight positive trend is predicted from 2010 to 2050. The city anticipates that migration into the city from the metroplex area of Dallas-Fort Worth and Denton will increase the population in later years. The effects of that migration have already occurred in Decatur just 28 miles east of Bowie.

City of Bowie Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	4,990	4,874	4,774	4,677	4,476	4,281	4,076
RWPG		5,350	5,250	5,300	5,350	5,400	5,450
2000 census		5,219					

City of Nocona. The Texas State Data Center lists the 1998 population of Nocona as 3,171. This is a positive growth trend from 1990, which had 2,870 people in the city. The population of 3,171 is shown as the population for 2000, with a fairly flat growth rate shown through 2050.

City of Nocona Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	2,870	2,814	2,798	2,794	2,752	2,686	2,622
RWPG		3,171	3,180	3,190	3,200	3,190	3,190
2000 census		3,198					

City of Saint Jo. The Texas State Data Center shows the 1998 population of Saint Jo as 1,130. This report uses 1,130 as the base for the 2000 population, and then applies the same changes as shown in the 1997 Plan.

City of Saint Jo Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	1,048	1,084	1,102	1,134	1,163	1,166	1,169
RWPG		1,130	1,148	1,180	1,209	1,212	1,215
2000 census		977					

City of Iowa Park. In 1998, Iowa Park's population was 6,864 according to the Texas State Data Center. This report uses that number for the 2000 population and projects population through 2050 using the same changes as the 1997 Plan.

City of Iowa Park Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	6,072	6,488	6,833	7,154	7,356	7,512	7,671
RWPG		6,864	7,209	7,530	7,732	7,888	8,047
2000 census		6,431					

City of Wichita Falls. The city of Wichita Falls Planning Division prepared a study in 1997 called "Growth Trends". In that report, city growth trends from 1986 through 1996 were analyzed, and the population was estimated at 103,312 as of August 1, 1997. This was based on tracking plats, new construction, utility connections, public school enrollment, and natural change (births and deaths). The 1990 population was 96,259, so the city has enjoyed an increase of about 1.2% per year. For this report, a smaller increase to 2000 was applied to project a population of 103,713. The changes in population as shown in the 1997 Plan were then applied for the decades through 2050.

City of Wichita Falls Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	96,259	101,424	106,688	111,590	114,558	116,828	119,143
RWPG		103,713	108,977	113,879	116,847	119,117	121,432
2000 census		104,197					

Population Revisions for Counties

Archer County. The RWPG is projecting that Archer County will have about 1,616 more people in 2050 than is estimated in the consensus-based projection. The new projections are based on the following:

- The city of Holliday has been shown previously to be growing faster than anticipated;
- Lakeside City will grow faster than shown through 2020;
- The 1996 population for Archer County is higher than the 2000 consensus-based population by 1,428;
- Six other water providers in Archer County were surveyed, including the Baylor WSC, Archer County MUD No. 1, the city of Megargel, the city of Scotland, the Windthorst WSC, and the Wichita Valley WSC. Based on the latest water meter count for those entities and an average of about 2.3 people per meter, populations and

growth rates were established to get a more accurate accounting of the "other" rural population.

Archer County Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	9,613	8,185	8,453	8,494	8,428	8,243	7,969
RWPG	9,613	9,215	9,523	9,809	9,794	9,708	9,585

2000 actual 8,854

Baylor County. Consensus-based population projection shows Baylor County declining in population by over 31% from 2000 to 2050. However, the 1997 population estimate from the Texas State Data Center was 4,313 and in 1998 it was 4,326. So a continued small increase is projected to 2000 with the decline beginning in the following decades. The RWPG projected decline is 25.8%. Seymour, the largest city in the county, has been shown to have a larger population than was estimated, and the Baylor WSC is also growing in rural Baylor County. The Baylor WSC recently bid a new expansion project, and they are calculating that total water meters will increase from 610 in 2000 to 750 in 2050. The increase in those two entities accounts for the 405 additional people shown by the RWPG in Baylor County in 2050.

Baylor County Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	4,385	4,110	3,929	3,420	3,025	2,921	2,822
RWPG		4,110	3,929	3,598	3,353	3,288	3,227

2000 census 4,093

Clay County. Clay County joins Wichita County on the east and is experiencing population growth due to its proximity to Wichita Falls. The consensus-based projection shows a 42% decrease in total county population from 2000 to 2050 while the RWPG projection is for 32% positive growth in those 50 years. This difference is explained by:

- A 1996 population of 10,566 versus originally projected a 2000 population of 9,610;
- The city of Henrietta has been exhibiting a positive growth rate (previously documented) versus a negative rate predicted;
- A survey of other county water providers, including the town of Bellevue, Blue Grove WSC, Charlie WSC, Dean Dale WSC, Arrowhead Lake WSD, Arrowhead Ranch WSD, and the Friberg-Cooper WSC, provided information regarding existing water meters and projected growth for their systems.

Clay County Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	10,024	9,610	9,305	8,758	7,917	7,056	6,195
RWPG		9,610	9,652	9,650	9,651	9,792	9,849

2000 census 11,006

King County. King County is ranch country and is sparsely populated. The town of Guthrie is the largest in the county, with a 2000 population estimated at 150. However, the community of Dumont in the northwest corner is served water by the Dumont WSD, a part of the Red River Authority of Texas. The King-Cottle WSC also sells water in the county. Based on survey information and water meter projections, the RWPG is estimating that King County will have 287 people in 2050 instead of 165 as shown in the consensus-based plan.

King County Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	354	362	350	325	270	213	165
RWPG		400	397	389	344	313	287
2000 census		356					

Wichita County. The consensus-based population projections show Wichita County increasing in population by 12.8% from 2000 to 2050. The RWPG estimate for Wichita County is an increase of 16.2%. Wichita Falls accounts for about one-half the additional population and has been discussed previously in this report. The city of Iowa Park also has additional population projected. The remainder of the extra people will be scattered throughout the county and have been accounted for using water meter information provided by the other county water providers, including Friberg-Cooper WSC, Horseshoe Bend WSC, the town of Pleasant Valley, Wichita Valley WSC, Dean Dale WSC, the city of Burkburnett, and the city of Electra. The RWPG projections, it should be noted, are in line with consensus-based numbers through 2030. In 2050, the consensus-based projections show a decrease from 2040 while the RWPG shows a 1.9% increase. That divergence from the trend created the largest difference in the two sets of numbers.

Wichita County Population Comparisons

	1990	2000	2010	2020	2030	2040	2050
1997 Plan	122,378	130,193	136,455	142,350	145,473	147,740	146,874
RWPG		130,193	136,455	142,350	145,811	148,553	151,349
2000 census		131,664					

Region B Population Growth

The Region B projected total population growth is shown in Figure 2-3. The projections were determined by:

- Using the latest information published by the Texas State Data Center for city populations;
- Surveying cities, smaller communities, rural water supply corporations, municipal utility districts, and river authorities to determine population based on existing meter counts;
- Using growth trends derived from surveys based on populations and meter counts from 1990 to 1998.

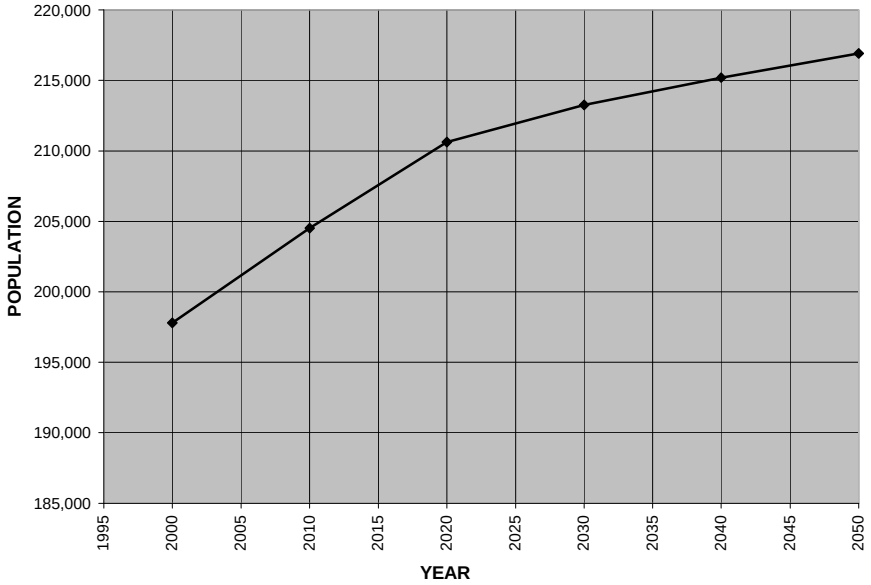


Figure 2-3. Projected Population for Region B.

Projected Population Data Points

	2000	2010	2020	2030	2040	2050
Population	197,793	204,521	210,634	213,261	215,196	216,914
2000 census	198,016					

The city with the highest projected growth rate is Wichita Falls. It is expected to grow by slightly over 20% in the next 50 years for many reasons. Recently, the city annexed additional property north and west of town. The Allred Prison has a construction project in progress to double the size of the facility, the Midwestern State University student population has increased in recent years, and Sheppard Air Force Base continues to expand its training facilities. Other towns that may experience some growth include Lakeside City, Henrietta, Burkburnett, Iowa Park, and Vernon.

Summary of Population

The north-central Texas area that is known as Region B for the SB1 water study is predominantly ranching and farming country. Wichita Falls is the only city that is currently over 100,000 in population. However, this area of Texas is slowly gaining population, and this trend is projected to continue through the planning period in 2050. Table 2-10 summarizes all the TWDB and RWPG proposed county and total regional population projections. The table shows that the RWPG population projections are 1.4% higher than the TWDB projections through 2030, and that by 2050, the RWPG number is about 6.8% higher than the TWDB estimate. Table 2-10 also shows the actual count for the 2000 census.

Tables A-1 through A-3, in Attachment 2-1 at the website, summarize all the population projections for the region through 2050. These projections were made by using the 1996 through 1998 population information provided by the Texas State Data Center in conjunction with questionnaires mailed to every water provider in the region.

TABLE 2-10

REGION B COUNTY POPULATION TOTALS

County	2000			2010		2020		2030		2040		2050	
	TWDB	RWPG	Actual	TWDB	RWPG	TWDB	RWPG	TWDB	RWPG	TWDB	RWPG	TWDB	RWPG
Archer	8,185	9,215	8,854	8,453	9,523	8,494	9,809	8,428	9,794	8,243	9,708	7,969	9,585
Baylor	4,110	4,110	4,093	3,929	3,929	3,420	3,598	3,025	3,353	2,921	3,288	2,822	3,227
Clay	9,610	9,610	11,006	9,305	9,652	8,758	9,650	7,917	9,651	7,056	9,792	6,195	9,849
Cottle	2,139	2,105	1,904	2,076	2,035	1,958	1,921	1,812	1,760	1,638	1,596	1,476	1,443
Foard	1,741	1,741	1,622	1,736	1,736	1,731	1,731	1,667	1,667	1,604	1,604	1,513	1,513
Hardeman	5,265	4,956	4,724	5,382	4,957	5,550	5,008	5,650	5,023	5,749	5,038	5,828	5,047
King	362	400	356	350	397	325	389	270	344	213	313	165	287
Montague	16,583	16,583	19,117	16,243	16,243	15,911	15,911	15,228	15,228	14,566	14,566	13,869	13,869
Wichita	130,193	130,193	131,664	136,455	136,455	142,350	142,350	145,473	145,811	147,740	148,553	146,874	151,349
Wilbarger	15,515	15,515	14,676	16,069	16,069	16,649	16,649	16,982	16,982	17,093	17,093	17,103	17,103
Young*	3,579	3,365	3,396	3,739	3,525	3,822	3,618	3,852	3,648	3,849	3,645	3,846	3,642
Total	**197,282**	**197,793**	**201,412**	**203,737**	**204,521**	**208,968**	**210,634**	**210,304**	**213,261**	**210,672**	**215,196**	**207,660**	**216,914**

* Partial

Per Capita Use

Per capita municipal water use is predicted to gradually decline over the planning period from 187 gallons per capita per day (gpcd) in 2000 to 161 gpcd in 2050 based on water use and population projections. According to the 1997 amended Texas Water Plan published by the TWDB, use for the entire state was shown to be 168 gpcd in 1990 with an increase to 181 gpcd in 2000. In 2050, statewide use is predicted to decline to 157 gpcd. Region B's water use is currently in-line with the statewide average and is expected to decline in the future as predicted with the average. Since a large majority of the region is rural in nature, the percentage of conservation savings for the state as a whole will probably not be realized to the same extent in this area. In the more densely populated areas where new construction is progressing at a faster pace, more water conserving measures can be implemented by requiring newer plumbing fixtures and maintaining tighter controls on overall water use.

Revised Water Use Projections

The TWDB developed their consensus-based water use projections based on a year with below average rainfall and water use conservation measures being implemented over the planning period. Water usage has been categorized for analysis purposes into municipal (MUN), industrial (or manufacturing) (MFG), mining (MIN), agricultural irrigation (IRR), livestock (STK), and steam-electric power (power cooling) (PWR). Reported municipal water use data for 1982 to 1991 were used to calculate annual per capita water use for each city in preparation of the 1997 State Water Plan. Several entities have water demands that differ from the consensus-based projections due to population changes and higher per capita demands derived from later 1996 to 1998 data. A proposed new power plant in Archer County will impact water use in the PWR category, and water delivered by Wichita County Water Improvement District No. 2 (WCWID #2) for irrigation purposes is substantially more than that accounted for in the consensus-based plan. All the requested revisions are documented in the following section.

Revised Municipal Water Use Projections

The TWDB defines municipal water use as residential and commercial water use. Residential use includes single and multi-family residential household water use. Commercial use includes water used by business establishments, public offices, and institutions, but does not include industrial water use.

The two factors used to project municipal water use are population and daily use of water by each person or gpcd. Table 2-11 shows the 1990 calculated and the 2000 through 2050 estimated per capita demands as derived from the TDWP 1997 Plan.

TABLE 2-11

PER CAPITA WATER DEMAND PROJECTIONS
TDWB 1997 PLAN

	1990 Per Capita Demand	2000 Per Capita Demand	2010 Per Capita Demand	2020 Per Capita Demand	2030 Per Capita Demand	2040 Per Capita Demand	2050 Per Capita Demand
Archer City	172	200	191	182	178	174	173
Holliday	122	131	123	116	112	108	107
Lakeside City	108	112	106	99	95	91	90
Seymour	189	213	203	191	190	187	185
Byers	156	147	139	132	128	124	123
Henrietta	170	200	190	180	174	174	173
Petrolia	102	111	105	98	94	90	89
Paducah	207	218	208	197	191	191	190
Crowell	178	223	213	203	199	196	195
Chillicothe	114	139	131	123	120	115	114
Quanah	152	171	162	153	150	146	145
Guthrie	268	458	440	428	418	419	417
Bowie	138	153	145	137	132	130	129
Montague	55	103	95	87	83	83	80
Nocona	155	147	139	132	127	123	123
Saint Jo	129	121	114	107	102	100	99
Burkburnett	130	146	138	131	127	124	123
Electra	139	169	161	153	149	146	145
Iowa Park	114	140	132	124	121	117	116
Wichita Falls	169	191	182	174	170	167	166
Vernon	125	191	182	172	169	165	164
Olney	146	172	163	154	151	147	146
Other Rural	200	279	270	265	267	273	290

In general, the demands are decreasing each decade from 2000 to 2050 due to progressively more and better conservation measures being instituted.

Table 2-12 has the per capita demand factors proposed by the RWPG. The table begins with actual data for the year 1996 as required in Exhibit B - Data and Format Guidelines for SB1 Regional Water Plan - Technical Reports as published by the TWDB. In all cases, data on water use for the past 8 years were gathered from each entity. The year 1996 was a particularly dry year in this region and produced a higher per capita demand. That year was used as a base for the majority of the entities. However, in 1991, the city of Vernon had a peak per capita use at 216 gpcd so that was used as the beginning point for Vernon's calculations. Some cities indicated a trend toward lower usage and were adjusted accordingly. In all cases, progressive reductions were made to account for future conservation measures.

TABLE 2-12

PER CAPITA WATER DEMANDS CALCULATED USING THE RWPG POPULATION AND WATER USE PROJECTIONS

	1996 Per Capita Demand	2000 Per Capita Demand	2010 Per Capita Demand	2020 Per Capita Demand	2030 Per Capita Demand	2040 Per Capita Demand	2050 Per Capita Demand
Archer City	162	155	147	140	136	133	132
Holliday	129	131	125	118	115	113	112
Lakeside City	131	144	137	124	121	119	117
Seymour	203	213	203	190	189	186	185
Byers	145	146	139	132	128	124	123
Henrietta	189	200	190	180	175	172	170
Petrolia	115	111	105	98	97	95	94
Paducah	128	204	194	184	179	176	173
Crowell	158	230	218	206	201	199	197
Chillicothe	185	139	131	123	120	115	114
Quanah	195	171	163	154	150	147	145
Guthrie	381	458	440	428	418	419	417
Bowie	181	182	173	164	159	156	154
Montague	56	103	95	87	83	83	80
Nocona	164	196	186	177	172	169	167
Saint Jo[1]	147	110	99	101	97	96	95
Saint Jo[2]	148	113	95	100	98	97	94
Burkburnett	115	151	144	136	132	130	128
Electra	146	168	160	152	147	145	143
Iowa Park	153	174	162	153	149	146	145
Wichita Falls	192	198	188	178	173	170	168
Vernon	170	206	196	188	185	181	180
Olney	191	194	184	174	170	167	165
Other Rural	142	166	159	153	152	150	153

[1] Saint Jo - portion of city in Trinity River Basin.
[2] Saint Jo - portion of city in Red River Basin.

TOTAL WATER USES IN REGION B

Water use for Region B has been divided into categories for analysis purposes (listed previously). Figure 2-4 shows the amounts of water predicted to be required for these categories through 2050. Water use is shown in acre-feet units, with 1 acre-foot being equivalent to 325,851 gallons of water.

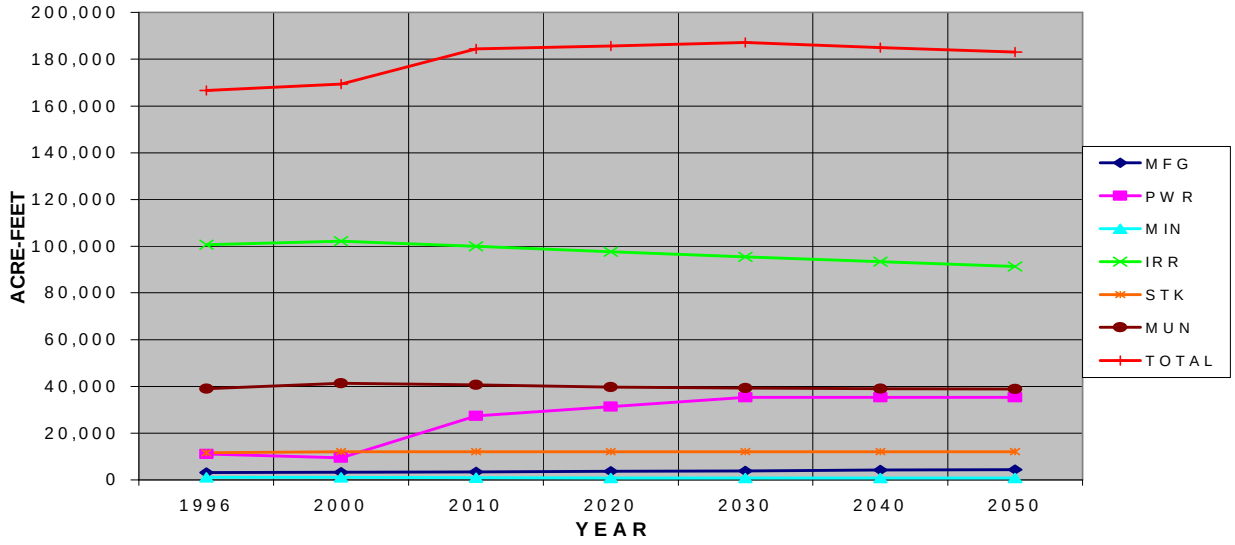
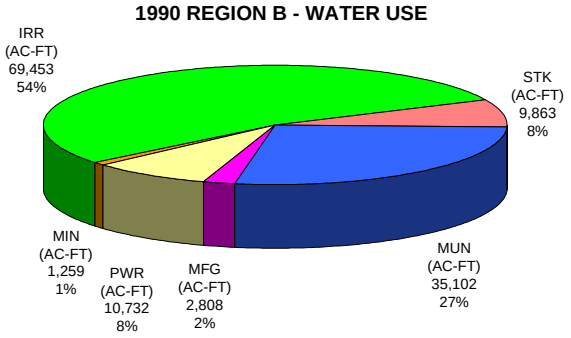


Figure 2-4. Projected Water Use for Region B.

Projected Water Use
(acre-feet)

	1996	2000	2010	2020	2030	2040	2050
MFG	3,230	3,266	3,547	3,755	3,968	4,260	4,524
PWR	11,116	9,460	27,360	31,360	35,360	35,360	35,360
MIN	1,192	1,176	909	845	811	785	792
IRR	100,564	102,106	99,880	97,687	95,522	93,385	91,277
STK	11,574	12,169	12,169	12,169	12,169	12,169	12,169
MUN	38,976	41,395	40,715	39,820	39,373	39,068	39,092
Total	**166,652**	**169,572**	**184,580**	**185,636**	**187,203**	**185,027**	**183,214**

Total water consumption for the region is predicted to increase approximately 10% from 1996 to 2050. Figure 2-5 compares the 1990 water uses to the projected 2050 water uses. The two scenarios in Figure 2-5 show that the composition of water use for this region is not anticipated to change much. However, a proposed new power plant in Archer County will contribute to more than doubling the amount of water required for that category.



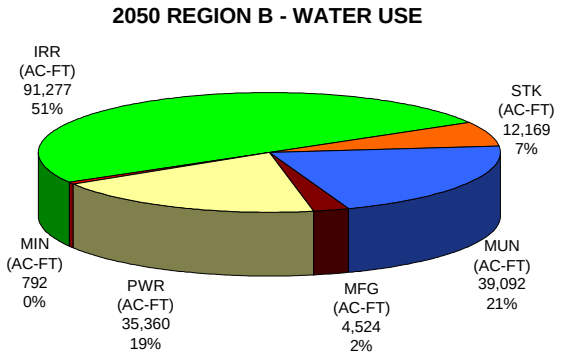


Figure 2-5. 1990 and 2050 Region B Water Use.

WATER PROVIDERS IN REGION B

Major Water Providers

Senate Bill 1 requires that each RWPG designate its Major Water Providers (MWP) and develop data related to those entities. Accordingly, "A MWP is an entity that delivers and sells a significant amount of raw water for municipal and/or manufacturing use on a wholesale and/or retail basis. The entity can be public or private (non-profit or for-profit). Examples include municipalities with wholesale customers, river authorities, and water districts." The MWP's in Region B are:

- Greenbelt M & I Authority
- City of Wichita Falls

Water Use Demand Centers

The city of Wichita Falls is the largest demand center in the region. Other minor demand centers include Seymour, Henrietta, Quanah, Bowie, Nocona, Burkburnett, Electra, Iowa Park, Vernon, Olney, and Archer City. Table 2-13 shows the 1996 and 2000 population of these demand centers along with the 1996 municipal water use

TABLE 2-13

REGIONAL DEMAND CENTERS

County	City	1996 (2000) Population	1996 Municipal Water Use (acre-feet)
Archer	Archer City	1,938 (1,848)	351
Baylor	Seymour	3,059 (2,908)	694
Clay	Henrietta	3,038 (3,264)	642
Hardeman	Quanah	3,300 (3,022)	720
Montague	Bowie	5,389 (5,218)	1,092
	Nocona	3,146 (3,198)	514
Wichita	Burkburnett	11,154 (10,927)	1,443
	Electra	3,397 (3,168)	557
	Iowa Park	6,941 (6,431)	1,192
	Wichita Falls	100,501 (104,197)	21,650
Wilbarger	Vernon	12,481 (11,660)	2,377
Young	Olney	3,365 (3,396)	719

Although population data by city is available from the 2000 census, municipal water use is currently not available.

Summary of Existing Local and Regional Water Plans

In April 1999, surveys were sent to the water providers of Region B to determine, among other things, if they possessed a water conservation plan or a local or regional water plan. Table 2-14 lists the results of those surveys.

TABLE 2-14

SURVEY RESULTS REGARDING WATER PLANS

Water Provider	Existing Drought Contingency Plan?	Existing Water Conservation Plan?	Existing Local or Regional Water Plan?	Special Concerns of the Provider
Archer County MUD	Y	Y	N	Supply
Arrowhead Lake WSD	Y	Y	N	
Arrowhead Ranch Estates	Y	Y	N	
Baylor County WSC	N	N	N	Nitrates
Box CWSD	N	N	N	
City of Archer City	N	N	N	
City of Bowie	Y	Y	N	
City of Burkburnett	N	N	N	Nitrates
City of Byers	N	N	N	Nitrates
City of Charlie	N	N	N	Nitrates
City of Crowell	Y	N	N	Nitrates
City of Dumont	N	N	N	
City of Electra	N	Y	N	Nitrates
City of Henrietta	Y	Y	Y	

TABLE 2-14 (Continued)

Water Provider	Existing Drought Contingency Plan?	Existing Water Conservation Plan?	Existing Local or Regional Water Plan?	Special Concerns of the Provider
City of Holliday	N	N	N	
City of Iowa Park	N	N	N	
City of Lakeside City	N	N	N	Storage
City of Megargel	Y	N	N	
City of Nocona	N	N	N	
City of Nocona Hills	N	Y	Y	Nitrates
City of Olney	N	Y	N	Storage
City of Paducah	N	N	N	
City of Petrolia	N	N	N	
City of Pleasant Valley	N	N	N	
City of Quanah	N	N	N	
City of Saint Jo	Y	Y	N	
City of Scotland	Y	N	N	
City of Seymour	N	N	N	Nitrates
City of Sunset	N	N	N	Storage
City of Vernon	Y	Y	Y	Nitrates
City of Wichita Falls	Y	Y	Y	
Dean Dale WSC	Y	Y	N	
Farmers Valley WSD	Y	Y	N	
Foard County WSD	Y	Y	N	
Forestburg WSC	N	N	N	
Goodlett WSD	Y	Y	N	
Hinds CWSD	Y	Y	N	
Horseshoe Bend WSC	N	N	N	
Lockett WSD	Y	Y	N	
Medicine Mound WSD	Y	Y	N	
Northside WSC	Y	Y	Y	Nitrates
Quanah NE WSD	Y	Y	N	
Ringgold WSD	Y	Y	N	
South Quanah WSD	Y	Y	N	
West Texas Utilities	N	N	N	
Wichita Valley WSC	N	N	N	
Windthorst WSC	N	N	N	

Table 2-14 shows that as of May 1, 1999, most providers did not have a drought contingency or water conservation plan that meets the new requirements of SB1. However, as a part of SB1 planning efforts, most entities developed the plans as required. The city of Wichita Falls and others implemented their drought contingency and water conservation plans in 2000 as lake water levels dropped to near record lows.

Water is provided in Region B by a number of entities. Cities provide most of the water in the region, with the city of Wichita Falls providing the majority. Other major providers include the Red River Authority of Texas and the Greenbelt Water Authority. Wholesale suppliers in the region are the city of Wichita Falls and the Greenbelt Water Authority. Table

2-15 shows a comprehensive listing of the water providers and municipal use for 1996. A more detailed discussion of water use is presented in the next section of this report. It should be noted that these use figures do not include water for irrigation, manufacturing, electrical power, livestock, or mining.

TABLE 2-15

WATER PROVIDERS AND USERS IN REGION B

User	County	River Basin	1996 Demand (acre-feet/year)
Archer City	Archer	Red	351
Holliday	Archer	Red	226
Lakeside City	Archer	Red	149
Seymour	Baylor	Brazos	694
Byers	Clay	Red	86
Henrietta	Clay	Red	642
Petrolia	Clay	Red	104
Paducah	Cottle	Red	239
Crowell	Foard	Red	216
Chillicothe	Hardeman	Red	165
Quanah	Hardeman	Red	720
Guthrie	King	Red	64
Bowie	Montague	Trinity	1,092
Montague	Montague	Red	31
Nocona	Montague	Red	577
Saint Jo	Montague	Trinity	139
Saint Jo	Montague	Red	47
Burkburnett	Wichita	Red	1,443
Electra	Wichita	Red	557
Iowa Park	Wichita	Red	1,192
Wichita Falls	Wichita	Red	21,650
Vernon	Wilbarger	Red	2,377
Olney	Young	Brazos	719
Other Rural			5,496
Total			38,976
Baylor WSC	Archer	Red	18
Archer Co. MUD #1	Archer	Red	110
Megargel	Archer	Red	46
Scotland	Archer	Red	222
Windthorst WSC	Archer	Red	224
Wichita Valley WSC	Archer	Red	212
Archer Co. Other	Archer	Red	10
Archer Co. Other	Archer	Trinity	9
Archer Co. Other	Archer	Brazos	19

TABLE 2-15 (Continued)

User	County	River Basin	1996 Demand (acre-feet/year)
Baylor WSC	Baylor	Brazos	187
Baylor Co. Other	Baylor	Red	27
Baylor Co. Other	Baylor	Brazos	25
Bellevue	Clay	Red	42
Bluegrove WSC	Clay	Red	7
Charlie WSC	Clay	Red	9
Dean Dale WSC	Clay	Red	262
Arrowhead Lake WSD	Clay	Red	95
Arrowhead Ranch WSD	Clay	Red	86
Friberg-Cooper WSC	Clay	Red	83
Clay Co. Other	Clay	Red	522
Clay Co. Other	Clay	Trinity	52
King-Cottle WSC	Cottle	Red	422
Cottle Co. Other	Cottle	Red	10
Foard Co. WSD	Foard	Red	68
Margaret WSD	Foard	Red	12
Thalia WSC	Foard	Red	15
Foard Co. Other	Foard	Red	49
Goodlet WSD	Hardeman	Red	17
Medicine Mound WSD	Hardeman	Red	17
Quanah NE WSD	Hardeman	Red	59
S Quanah WSD	Hardeman	Red	18
Hardeman Co. Other	Hardeman	Red	98
King-Cottle WSC	King	Red	215
Dumont WSD	King	Red	51
King Co. Other	King	Red	2
King Co. Other	King	Brazos	3
Forestburg	Montague	Red	22
Montague WSC	Montague	Red	31
Nocona Hills WSC	Montague	Red	77
Oak Shores WSC	Montague	Red	4
Sunset WSC	Montague	Red	18
Ringgold WSC	Montague	Red	21
Montague Co. Other	Montague	Red	230
Montague Co. Other	Montague	Trinity	614

TABLE 2-15 (Continued)

User	County	River Basin	1996 Demand (acre-feet/year)
Friberg Cooper WSC	Wichita	Red	83
Horseshoe Bend WSC	Wichita	Red	14
Pleasant Valley	Wichita	Red	96
Wichita Valley WSC	Wichita	Red	494
Dean Dale WSC	Wichita	Red	65
Box Com. WSD	Wilbarger	Red	19
Farmers Valley WSD	Wilbarger	Red	28
Harrold WSC	Wilbarger	Red	30
Hinds Com WSD	Wilbarger	Red	26
Lockett WSD	Wilbarger	Red	94
Northside WSC	Wilbarger	Red	31
Odell WSC	Wilbarger	Red	16
Oklaunion WSC	Wilbarger	Red	40
Wilbarger Co. Other	Wilbarger	Red	230

Note: Water use shown is for municipal purposes.

Summary of Recommendations in the State Water Plan

The 1997 Consensus Texas Water Plan anticipates that Region B will have adequate water supplies throughout the planning period. The main recommendation of the Plan is to employ conservation measures to reduce water waste. Also, the heavy dissolved solid and chloride concentrations in the western portions of the region are preventing full utilization of available water resources. To reduce this, the 1997 Consensus Texas Water Plan recommends that the Red River Chloride Control Project, sponsored by the Red River Authority of Texas, continue to be funded and operated.

MUNICIPAL WATER USE

Municipal water use is defined by the TWDB as residential and commercial water use. Residential use includes single and multi-family household water use. Commercial use includes water used by business establishments, public offices, and institutions, but does not include industrial water use. Residential and commercial water uses are categorized together because they are similar types of uses, for example, each category uses water primarily for drinking, cleaning, sanitation, cooling, and landscape watering.

The total municipal water use for Region B is shown to decline from 41,395 acre-feet in 2000 to 39,092 acre-feet in 2050 in spite of a population increase of over 10%. The decrease is anticipated because, as previously mentioned, per capita water use is expected to decrease over the next 50 years. Decreases in water use are expected due to water conservation measures implemented by the cities and individual users, including more efficient plumbing fixtures, better

lawn watering procedures, tighter controls on water losses by water providers, and other conservation measures. The graph of the municipal water use line shown in Figure 2-6 indicates the declining water use trend from 2000 through 2050.

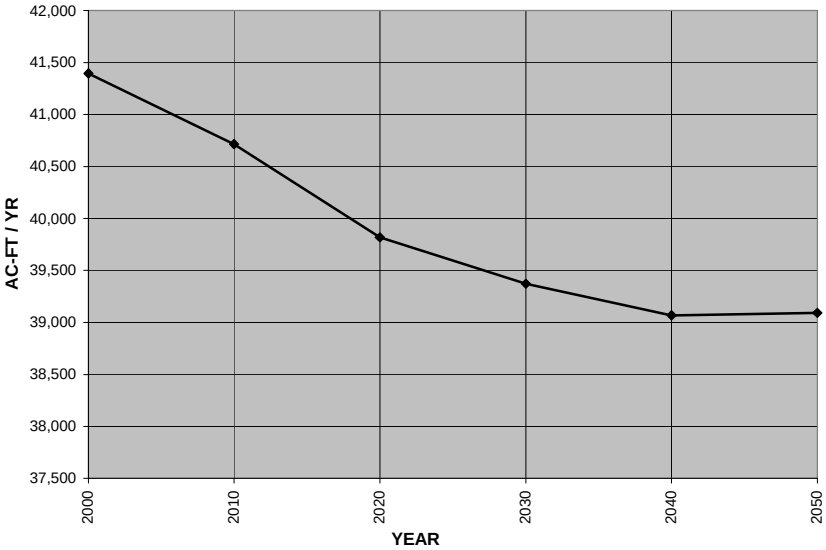


Figure 2-6. Total Municipal Water Use in Region B.

Total Municipal Water
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	42,598	41,923	41,032	40,366	39,757	38,756
RWPG	41,395	40,715	39,820	39,373	39,068	39,092

Since weather has a significant impact on municipal water use, all projections for the future have been based on a below average rainfall year. Water use data were accumulated for water users of the region through research of records at the TWDB, the Texas Natural Resources Conservation Commission (TNRCC), and questionnaires sent to sellers of municipal water. Many estimates of future use have been based on water sold in 1996 as it was a particularly dry period in the north Texas region, and total water use peaked. The total final regional projections, as shown below, compare closely with the 1997 Plan.

MANUFACTURING (INDUSTRIAL) WATER USE

Manufacturing (MFG), or industrial, water use has been defined as water used in the production of manufactured products, steam-electric power generation, and mining activities, including water used by employees for drinking and sanitation purposes. Water use for manufacturing products in Region B is a small percentage, less than 5%, of overall water use in this region.

The majority of MFG water use (over 62%) is in Wichita County by industrial facilities in and around Wichita Falls. Wilbarger, Hardeman, and Montague counties also have facilities that require water in the MFG category. The top six MFG facilities in Wichita County used slightly over 78% of the water in 1998. Those facilities include Vetrotex America, PPG Industries, Stanley Proto Tools, Howmet Corporation, Wichita Falls Castings, and Tranter, Inc. Wilbarger County has Rhodia, Inc., and Wright Brand Foods as major industrial users for that area. Numerous other small industrial users are located in Region B.

Based on the trend of increasing water required for MFG in Region B, an increase from 3,266 acre-feet in 2000 to 4,524 acre-feet in 2050 has been projected. While the percentage increase for MFG water is 38%, the amount of the increase, as considered in the overall regional plan, is much smaller at 9%. Figure 2-7 shows the projections for MFG water use in Region B.

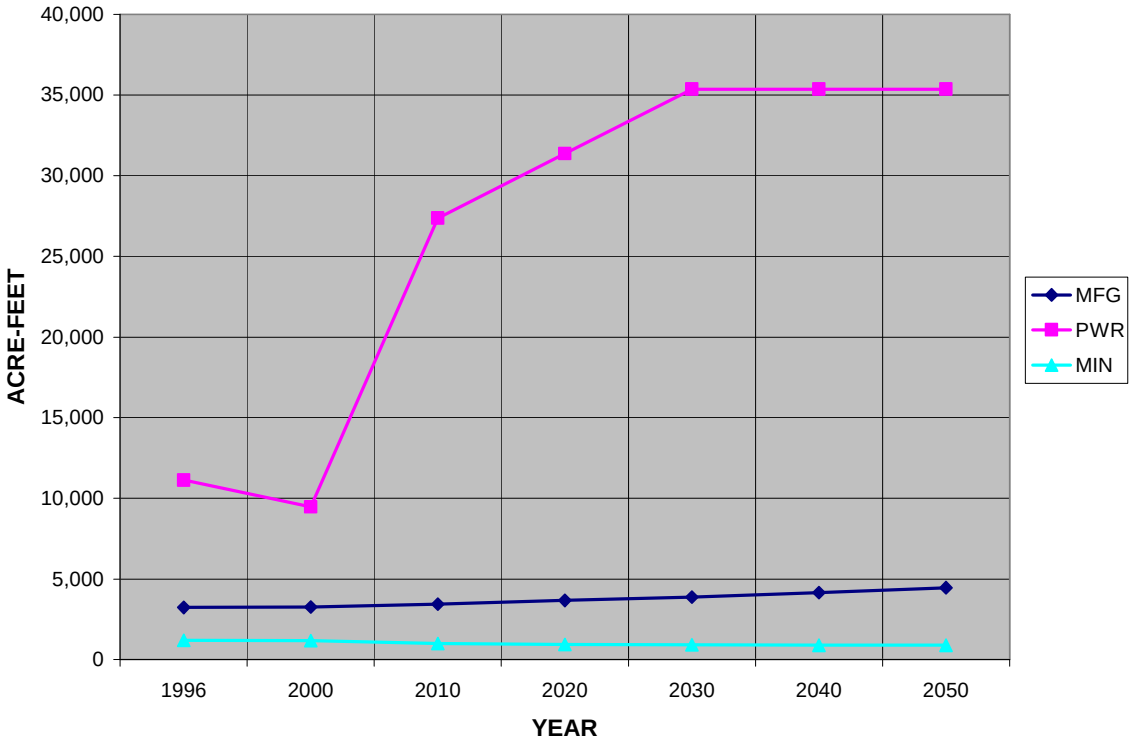


Figure 2-7. Projected Manufacturing Water Use for Region B.

Projected Manufacturing Water Use By Year

	1996	2000	2010	2020	2030	2040	2050
MFG	3,230	3,266	3,547	3,755	3,968	4,260	4,524
PWR	11,116	9,460	27,360	31,360	35,360	35,360	35,360
MIN	1,192	1,176	909	845	811	785	792

Region B will probably have some growth in the number of industrial facilities that locate in that area. That growth will be attributed to reasonable land prices, a good labor market, and above average power and water resources.

As stated earlier, the 1997 Plan projections were based on 1990 data. In 1996, Hardeman County and Wichita County used more water for MFG than was projected for 2000 in the 1997 Plan. The RWPG is requesting that adjustments be made to more accurately depict those water demands as shown below.

Hardeman County Manufacturing Water Demand
Original TWDB Projections
(acre-feet)

1990	2000	2010	2020	2030	2040	2050
225	250	277	301	327	355	383

Hardeman County Manufacturing Water Demand
RWPG Projections
(acre-feet)

1996	2000	2010	2020	2030	2040	2050
347	347	374	398	424	452	480

Wichita County Manufacturing Water Demand
Original TWDB Projections
(acre-feet)

1990	2000	2010	2020	2030	2040	2050
1,922	2,074	2,217	2,343	2,460	2,604	2,746

Wichita County Manufacturing Water Demand
RWPG Projections
(acre-feet)

1996	2000	2010	2020	2030	2040	2050
2,172	2,172	2,315	2,441	2,558	2,702	2,844

STEAM-ELECTRIC POWER GENERATION

Total water use required for steam-electric power generation for Region B is projected to be 9,460 acre-feet in 2000 and to grow to 35,360 acre-feet in 2050. The West Texas Utility Company (WTU) currently has power-producing plants in Wilbarger and Hardeman counties, and there is a small co-generation plant in Wichita Falls associated with the Vetrotex America manufacturing facility. On April 1, 1999, it was announced that Panda Energy International, Inc., of Dallas would break ground on a $200 million, 1,000-megawatt electric generating plant in Archer County. The city of Wichita Falls and the Wichita County Water Improvement District (WCWID) will deliver water for the new plant from Lake Diversion. The plant will require 10 million gallons per day. The water will be conveyed in an existing open irrigation

canal for the majority of the route. Losses due to seepage and evaporation can be anticipated. With the new plant and possible future expansion of the WTU facilities, the water used in this category will be increased substantially over the 50-year planning period. The percentage of water used for power generation in Region B will increase from 8% in 1990 to 19% in 2050.

The RWPG estimates the following PWR water requirements for Archer County where none was shown previously.

Archer County Steam-Electric Power Water Demand
RWPG Projections
(acre-feet)

2001	2010	2020	2030	2040	2050
14,000	14,000	14,000	14,000	14,000	14,000

The TWDB has shown no PWR water demands in Wichita County based on 1990 data, but in 1994, a co-generation plant was constructed in conjunction with the Vetrotex America fiberglass plant. Based on their 1996 water use, the RWPG is projecting the following water demands:

Wichita County Steam-Electric Power Water Demand
RWPG Projections
(acre-feet)

1996	2000	2010	2020	2030	2040	2050
349	360	360	360	360	360	360

West Texas Utilities (WTU) has a coal-fired power plant in Wilbarger County. They have contracted with the city of Wichita Falls and the WCWID for 20,000 acre-feet of water out of Lake Kemp. This water is to be used for current demands and future expansions. Based on data provided by WTU, the RWPG is projecting the following PWR water requirements for Wilbarger County:

Wilbarger County Steam-Electric Power Water Demand
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	8,000	10,000	15,000	15,000	15,000	15,000
RWPG	8,100	12,000	16,000	20,000	20,000	20,000

MINING WATER USE

The oil and gas industry has played a large role in the history and development of the north-central Texas area and is essentially the only "mining" activity in the region. Fresh water has been used in the past to drill wells and in some cases to water flood oil fields. However, as the fields in this area are mature and will not see much more development, water required for production will decline as well. If oil prices remain below the $18 to $20 per barrel level,

production will decrease even more. Based on the current status of the oil industry and recent trends in water required for mining in this region, a decrease from 1,176 acre-feet required in 2000 to 792 acre-feet in 2050 is projected and is shown in Figure 2-5.

The mining activity in Region B is principally for oil exploration and production. Using 1996 data, Montague County is the only county that appears to need more water for mining than is projected in the 1997 plan. The RWPG projections follow:

Montague County Mining Water Use
(acre-feet)

	1996	2000	2010	2020	2030	2040	2050
1997 Plan		583	461	437	429	433	446
RWPG	627	627	593	580	568	571	587

AGRICULTURAL IRRIGATION WATER USE

Irrigation water use is by far the largest water use category in Region B and in the north Texas area. Irrigated crops in the region include cotton, wheat, peanuts, alfalfa, hay-pasture, vegetables, orchards, and others. The total acreage irrigated varies from year to year depending on weather, crop price, government programs, and other factors. Agricultural use accounted for approximately 54% of the water used in 1990 and is projected to be 50% of all the water used in 2050. Figure 2-8 shows the projected agricultural water use.

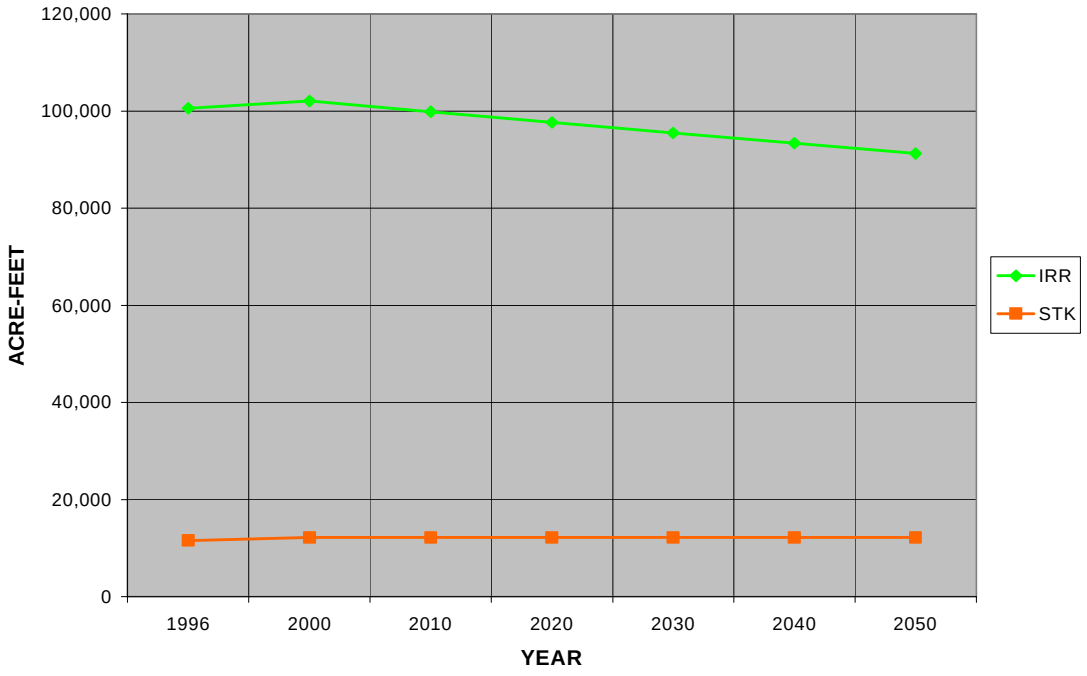


Figure 2-8. Projected Agricultural Irrigation and Livestock Water Use for Region B.

Projected Agricultural Irrigation Water Use

	1996	2000	2010	2020	2030	2040	2050
IRR	100,564	102,106	99,880	97,687	95,522	93,385	91,277
STK	11,574	12,169	12,169	12,169	12,169	12,169	12,169

Wichita County Water Improvement District No. 2 (WCWID #2) is the largest single provider of water for irrigation. It provides water to a large area of Wichita County and to smaller portions of Archer and Clay counties. Lake Kemp is the source of the water that is delivered through Lake Diversion and then into unlined, open irrigation canals. These canals inherently have higher losses than a closed system due to seepage, evaporation, and other factors. The irrigation district has a program in effect that is aimed at gradually constructing a closed underground system near the point of use thereby reducing losses to seepage and evaporation.

A portion of the water used for irrigation in Region B is from groundwater, but the majority of the water used is surface water. In 1996, 63,511 acre-feet of the total 99,764 acre-feet were delivered through the unlined ditches of WCWID #2. However, due to the age and construction of the canal system, approximately 44% of water released into the canal system was lost due to evaporation, seepage, and leaks. A study was prepared for WCWID #2 to determine the costs for installing pipelines in the canals to prevent the losses, and it was shown to be cost prohibitive, approximately $25 million. Note that all surface water diversion losses are included in the water required for irrigation. Some reduction in underground water loss is anticipated due to the use of more efficient irrigation systems and improved irrigation management practices. If chlorides are reduced in the Lake Kemp/Lake Diversion system, property irrigated by WCWID #2 may actually increase.

A gauging station at the head works of the canal system at Lake Diversion measures water delivered from Lake Diversion. Approximately 90% of the water released is used in Wichita County, 5% in Clay County, and 5% in Archer County. In 1998, 74,000 acre-feet were released of which 9,000 went to Lake Wichita to maintain its level. Based on information provided by the WCWID, irrigation water use (including unpreventable losses) is projected for Archer, Clay, and Wichita counties as follows:

Archer County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	291	282	274	266	258	2,500
RWPG	3,600	3,500	3,400	3,300	3,200	3,100

Clay County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	499	489	478	468	458	449
RWPG	4,000	3,900	3,800	3,700	3,600	3,500

Wichita County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	35,643	34,592	33,570	32,587	31,626	30,691
RWPG	60,000	59,000	58,000	57,000	56,000	55,000

Small reductions have been shown progressing from 2000 through 2050, but it is conceivable that with better water quality in Lake Kemp due to the chloride removal project on the watershed, the amount of irrigated acreage could increase.

In Cottle County, irrigation water use in 1990 was 607 acre-feet and in 1996 it was 4,571 acre-feet, so the projections have been adjusted as follows:

Cottle County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	589	572	555	528	522	507
RWPG	4,434	4,301	4,172	4,047	3,925	3,808

Foard County used 3,600 acre-feet of water for irrigation in 1990, and 5,132 acre-feet in 1996. The projections are changed as follows based on that discrepancy:

Foard County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	3,495	3,392	3,293	3,196	3,103	3,012
RWPG	4,978	4,829	4,684	4,543	4,407	4,275

Montague County used 220 acre-feet for irrigation in 1990 and 297 acre-feet in 1996, so the projections have been adjusted as follows:

Montague County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	220	220	220	220	220	220
RWPG	297	297	297	297	297	297

In 1990, a total of 17,744 acre-feet were used for irrigation in Wilbarger County. In 1996, 19,661 acre-feet were reported as being used; therefore, the projections are changed as follows:

Wilbarger County Irrigation Water Use
(acre-feet)

	2000	2010	2020	2030	2040	2050
1997 Plan	17,744	17,218	16,707	16,211	15,730	15,264
RWPG	19,071	18,499	17,944	17,406	16,884	16,377

LIVESTOCK WATER USE

Livestock (STK) production is an important part of the economy in Region B. In 1996, total water used in the region for livestock was 11,574 acre-feet. The use is projected to have a small increase to 12,169 acre-feet in 2000 and then remain level from 2000 to 2050. This represents about 7% of the water used in the region. Figure 2-8 shows these STK projections.

The TWDB has projected the water required for producing livestock based on 1990 usage. The RWPG projections are based on 1996 reported figures. Those projections have been adjusted as follows:

Projected Livestock Water Use
(acre-feet)

	County	2000	2010	2020	2030	2040	2050
1997 Plan	Archer	2,331	2,331	2,331	2,331	2,331	2,331
RWPG	Archer	2,711	2,711	2,711	2,711	2,711	2,711
1997 Plan	Foard	258	258	258	258	258	258
RWPG	Foard	289	289	289	289	289	289
1997 Plan	Hardeman	312	312	312	312	312	312
RWPG	Hardeman	480	480	480	480	480	480
1997 Plan	Montague	1,474	1,474	1,474	1,474	1,474	1,474
RWPG	Montague	1,850	1,850	1,850	1,850	1,850	1,850
1997 Plan	Wichita	610	610	610	610	610	610
RWPG	Wichita	740	740	740	740	740	740
1997 Plan	Wilbarger	1,063	1,063	1,063	1,063	1,063	1,063
RWPG	Wilbarger	1,797	1,797	1,797	1,797	1,797	1,797

EVALUATION OF EXISTING WATER SUPPLIES OVERVIEW

Water Supply and Use

Water providers have continuously striven to develop water resources in Region B so that they can deliver potable water to the people, irrigation water to farmers and ranchers, and water to promote industrial and economic growth. In 1910, the dam at Lake Wichita in Wichita County was completed, signifying the beginning of 90 years of water management for recreation, irrigation, and human consumption for north-central Texas. In 1924, the dam at Lake Kemp was completed, making it one of the largest man-made lakes in the world. The lake was originally designed for flood prevention and water supply; however, soon after construction, it was determined that its water was too saline to drink. This led to the discovery of natural salt-water springs in Foard, King, and Knox counties that have caused the water in the Big Wichita and Pease Rivers to be very difficult to treat for human consumption. Consequently, the water is only used for irrigation and steam-electric power purposes today. This natural phenomenon prompted the Red River Authority to initiate the Red River Chloride Control Project on the Big Wichita River. The building of brine lakes and low-flow dams has reduced the amount of dissolved solids and chlorides in the water. As a result, water from Lake Kemp may be utilized

for other uses. Ten significant lakes and four major streams are used for water supply in the region. Figure 2-2, Surface Water Map, shows the location of the major surface water sources in Region B.

Table 2-16 shows the annual firm yield that a lake or reservoir can produce in a year for each significant lake in Region B.

TABLE 2-16

FIRM YIELDS FOR LAKES IN REGION B

Water Source	County	Lake Firm Yield (acre-feet)	Conservation Capacity (acre-feet)
Amon Carter Lake	Montague	2,600	20,050
Lake Arrowhead	Clay	29,532	262,100
Lake Diversion	Archer/Baylor	1,100	40,000
Lake Electra	Wichita	600	8,050
Lake Kemp	Baylor	116,000	319,600
Lake Kickapoo	Archer/Baylor	16,072	106,000
Lake Nocona	Montague	*1,260	*22,398
Miller's Creek Reservoir	Baylor	N/A	30,700
Olney Lake	Young	1,260	N/A
Santa Rosa Lake	Wilbarger	N/A	11,570

N/A = Not Available.
Sources: Texas Natural Resource Conservation Commission; 1999 Texas Almanac; and *1986 Freese and Nichols, Inc., Report.

In addition to the lakes listed in Table 2-16, some municipalities and water supply corporations obtain their raw water from wells and springs. As of 1980, however, many of the wells and springs have ceased to flow, due mainly to over-pumping of the area's groundwater.

Groundwater

There are two major aquifers, Seymour and Trinity, and one minor aquifer, Blaine, in Region B. The Seymour Aquifer, found mainly in the western portions of the region, provided 151,765 acre-feet of water to the area in 1994. According to the TWDB, 93% of this supply was used for irrigation, and most of the remaining supply was pumped for municipal use by the cities of Vernon, Burkburnett, Electra, and Seymour.

Extreme northern reaches of one of the state's most expansive aquifers, the Trinity Aquifer, lie in western and southern Montague County, the easternmost county in Region B. Water from this area of the aquifer is used mainly for irrigation due to its relatively low well yield. Figure 2-9 shows the location of the major aquifers within Region B.

Figure 2-10 shows the location of the only minor aquifer in Region B, the Blaine Aquifer. The Blaine Aquifer is found only in Cottle, Foard, Hardeman, and King counties of Region B, and nearly 98% of the water pumped from this aquifer is used for agricultural purposes. The

water pumped from this aquifer is highly contaminated with dissolved solids from natural halite dissolution. In addition to natural contamination, significant pollutants are also present in the aquifer as a direct result of oil and gas production.

Region B boasts nearly 150 natural springs and seeps across the area. While some continue to produce water today, many have dried up over time due to over-pumping of the groundwater for municipal, agriculture, industrial, and mining use. While it is important to note that the use of springs for water supply is not common across the region due to excessive amounts of chlorides and dissolved solids, several springs are still utilized for domestic agricultural and mining supply. In addition, the smaller producing springs feed natural ponds and creeks that are habitat for many plants and animals. It should be recognized that any future development of underground sources of water, as well as overuse of existing surface water supplies, may cause a widespread decline in the viability of existing springs. On the other hand, the creation of new surface water supplies, such as lakes, ponds, canals, etc., will serve to replenish the underground water supply, rejuvenate existing or extinct springs, and possibly create new springs and seeps.

Agriculture is the main component of regional water use, accounting for 67% of all water used. Irrigation water is currently provided from Lakes Kemp and Diversion in unlined canals by the WCWID, the major irrigation provider in the region. The WCWID has a program underway to replace existing open canals with piped systems in portions of their service area. A significant amount of irrigation is also provided from groundwater. Irrigation water use in the region is expected to decline to 56% throughout the study period under the without-project condition as more efficient pumping and irrigation techniques and equipment are being implemented across the region. Municipal use is expected to remain relatively constant due to conservation, while commercial and industrial use is expected to increase by nearly 260%. This significant increase is due to a proposed power generation plant in Archer County. The overall increase in water use in the region is projected to be about 10% throughout the study period. Figure 2-11 shows actual water use by category for Region B in 1990 and 1996 as published by the TWDB. The 2050 projections are taken from Chapter 2 of this report.

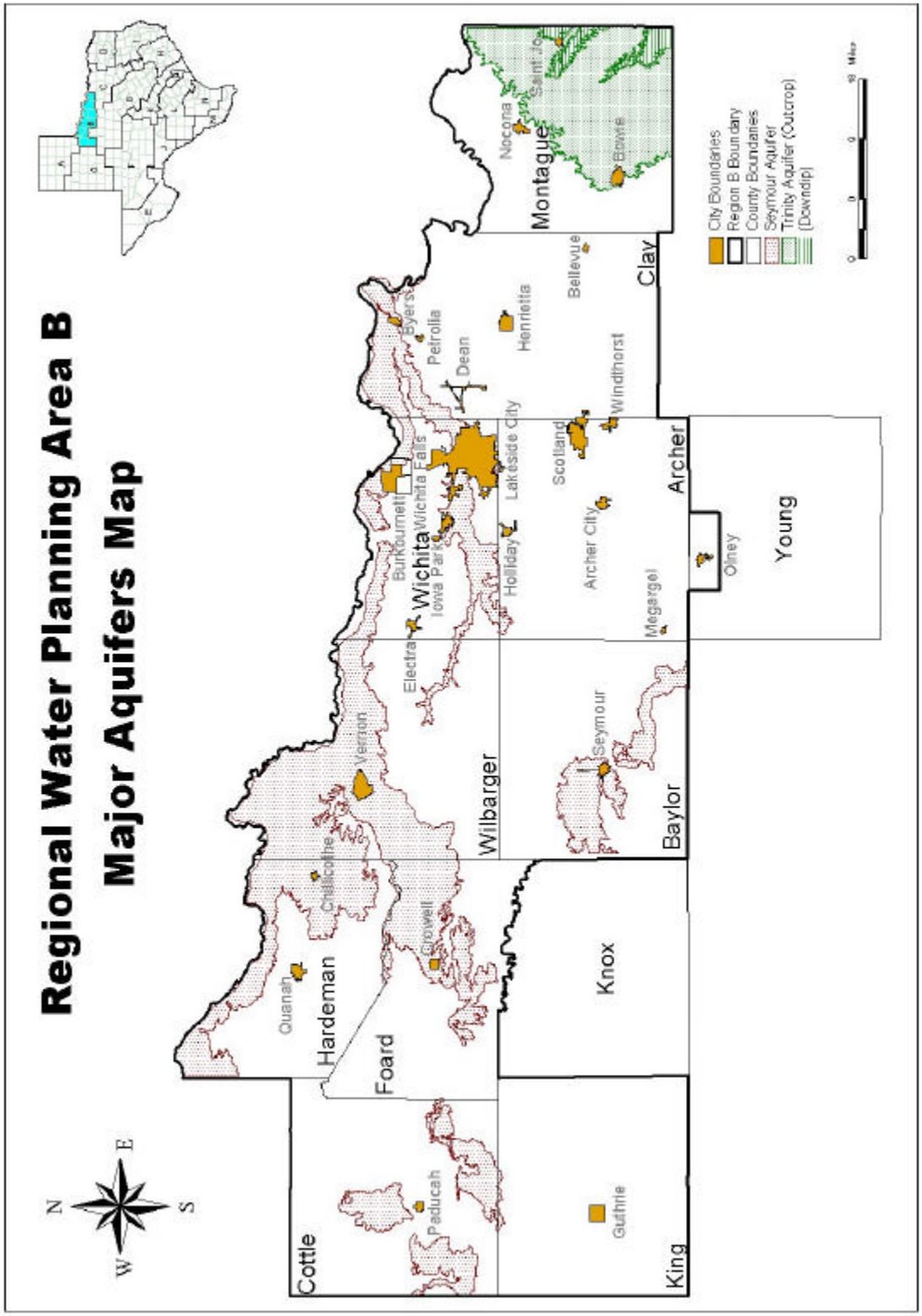


Figure 2-9. Major Aquifers in Region B.

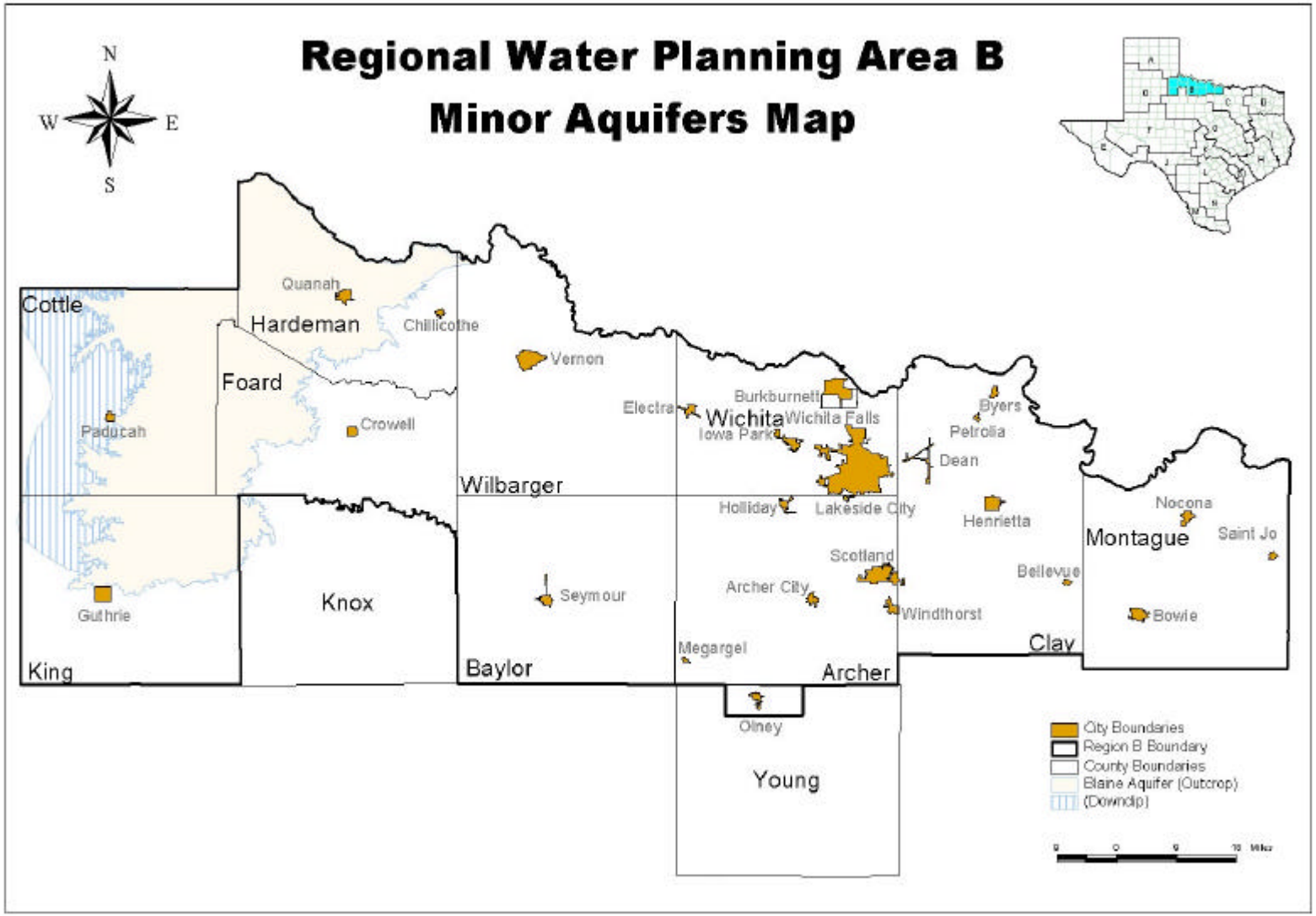


Figure 2-10. Blaine Aquifer.

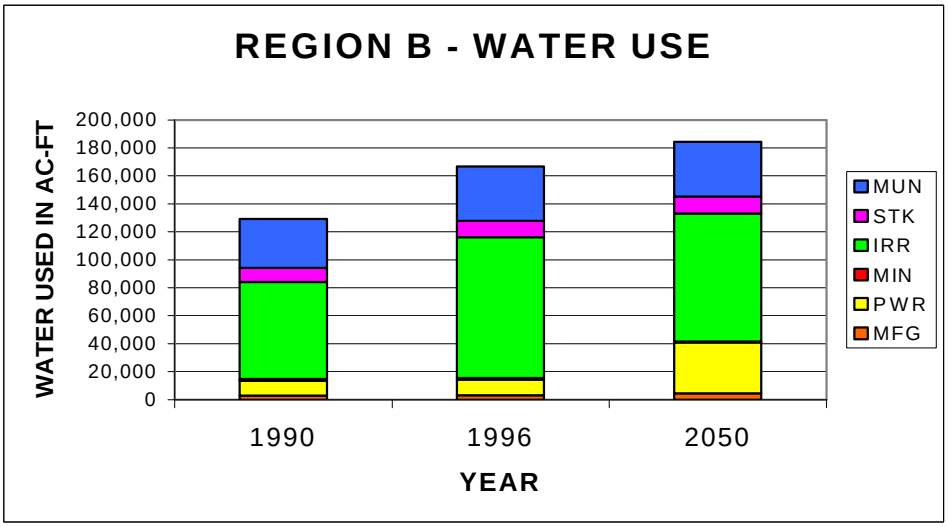


Figure 2-11. Actual Water Use by Category in Region B in 1990 and 1996.

Table 2-17 shows the water rights holders of Region B and their permitted and actual usage.

TABLE 2-17

WATER RIGHTS HOLDERS AND THEIR USAGE

Rights Holder	Water Supply	Permitted Use (acre-feet)	Reported Use		
			1994	1995	1996
A. L. Rhodes	Little Wichita River	3,600	0	0	0
City of Bowie	Amon G. Carter	5,000	1,119	0	1,234
Peba Oil & Gas Co.	Red River	1,600	0	0	0
North Montague County Municipal Water Auth.	Lake Nocona	1,260	597	563	599
Red River Authority	Truscott Brine Res.	3,050	0	0	0
Red River Authority	South Wichita River	8,780	4,838	5,489	5,104
Lonnie D. Allsup	Trib. of Wichita River	2,150	360	360	360
City of Wichita Falls	Holliday Creek	7,950	0	0	0
Wichita County Water Improvement District #2	Lakes Kemp & Diversion	193,000	60,572	50,490	35,720
W. T. Waggoner Estate	Lakes Santa Rosa & Wharton	3,070	324	353	314
City of Electra	Lake Electra	1,400	693	307	440
City of Wichita Falls	Lake Kickapoo	40,000	13,806	12,518	14,498
City of Olney	Lakes Olney & Cooper	1,260	649	604	0
City of Wichita Falls	Lake Arrowhead	45,000	12,604	12,931	14,242
City of Wichita Falls	Little Wichita River	2,350	3,535	3,585	3,898
City of Henrietta	Little Wichita River	1,550	470	0	679
West Texas Utilities Co.	Lake Pauline	7,140	3	0	4

Existing Surface Water Supply

To evaluate the adequacy of supply from existing reservoirs in Region B, a review of the 1997 State Water Plan, previous water planning studies, and historical operations was conducted. In addition, projected sedimentation in the reservoirs over the planning period (2000–2050) was evaluated. This information was used to assess the current firm yields of the reservoirs. Summaries of the 1997 State Water Plan data and the proposed reservoir yields based on this review are presented in Tables 2-18 and 2-19, respectively. For reservoirs whose reported firm yields could not be verified through previous studies, operation studies were conducted provided the data were available. The adequacy of supply for Greenbelt Lake was evaluated by Region A, and the findings are presented in this memorandum. The sedimentation analysis is discussed in Section 3.1.2.

EXISTING WATER SUPPLY RESERVOIRS

Greenbelt Lake

Greenbelt Lake is located in Region A, but water from the lake is used to supply several cities in Region B. The lake is owned and operated by the Greenbelt Municipal and Industrial Water Authority, and is located on the Salt Fork of the Red River in Donley County near the city of Clarendon. Construction of Greenbelt Lake was completed in 1968, and the lake had an initial conservation capacity of 60,400 acre-feet. Greenbelt Municipal and Industrial Water Authority has a diversion right of 12,000 acre-feet per year from the lake to provide municipal, industrial, mining, and irrigation water supply. The firm yield of the reservoir in 2000 is estimated to be 7,699 acre-feet per year.

Lake Pauline

Lake Pauline is located on the upper reaches of Wanderers Creek near Quanah in Hardeman County. The dam was completed in 1928, and the reservoir had a reported conservation capacity of 4,137 acre-feet in 1968 (Bisset 1999). Lake Pauline is owned and operated by West Texas Utilities Company. Its primary use is for cooling water for the Lake Pauline power plant. The lake is permitted for 7,137 acre-feet per year, which includes 3,000 acre-feet per year of diversions from Groesbeck Creek. The power plant at Lake Pauline is used to meet peak demands during the summer and winter months. As a result, water use from the lake varies with power demands. For 1994 through 1996, the reported water use from Lake Pauline was less than 5 acre-feet per year. The use for 1998 was reported as 119 acre-feet.

TABLE 2-18

SUMMARY OF 1997 STATE WATER PLAN YIELD STUDIES

Reservoir	County	Elev. (MSL)	1997 State Water Plan			Uses	Operation Study			Critical Period		Drought of Record	Comments
			Area (acres)	Capacity (ac-ft)	Yield (af/yr)		Date	Author	Period of Record	Dates	Length (years)		
Lake Pauline	Hardeman	N/A	N/A	N/A	3,000	Industrial	N/A	N/A	N/A	N/A	N/A	N/A	TWDB estimates the yield from Lake Pauline/Groesbeck Creek to be 3,000 acre-feet/year.
Lake Kemp	Baylor	1144	15,590	268,000	116,000	Municipal	1976	F&N	1949-1974	6/42-6/45	3	6/42–5/47	1973 capacity listed; yield based on 2020 capacity.
Lake Diversion	Archer, Baylor	1051	3,419	40,000	1,100	Industrial	1976	F&N	1949-1974	Firm yield was not determined			Original capacity; operation study evaluated required make-up from Lake Kemp to maintain elevation
Santa Rosa Lake	Wilbarger	N/A	N/A	N/A	NA	Irrigation	1967	F&N	N/A	10/55-2/57	1.3	N/A	TWDB does not include lake in 1997 Water Plan. TWDB yield estimates of 3,000 acre-feet/year are based on operation studies conducted as part of Red River Master Plan (F&N 1967).
Lake Electra	Wilbarger	1110	600	8,050	600	Municipal	N/A	N/A	N/A	N/A	N/A	N/A	TWDB yield is based on water right.
North Fork Buffalo Creek Reservoir	Wichita	1048	1,500	15,400	840	Municipal	N/A	N/A	N/A	N/A	N/A	N/A	TWDB yield is based on water right.
Lake Kickapoo	Archer	1045	6,200	106,000	16,072	Municipal	1997	TWDB	1940-1989	5/58–9/80	32.3	5/58–5/82	Original area-capacity. Yield does not account for sedimentation.
Lake Arrowhead	Clay, Archer	926	16,200	262,100	29,532	Municipal	1997	TWDB	1940-1989	5/58–9/80	32.3	5/58–5/82	Original area-capacity. Yield reflects 2050 sediment conditions.
Lake Olney/ Cooper	Archer	N/A	N/A	6,650	1,260	Municipal	N/A	N/A	N/A	N/A	N/A	N/A	TWDB yield is based on water right.
Lake Nocona	Montague	827	N/A	N/A	4,500	Mun/Rec/ Ind	N/A	N/A	N/A	N/A	N/A	N/A	TWDB yield is based on original water right.
Lake Amon G. Carter	Montague	920	1,848	28,589	2,600	Municipal	1979	HDR	1941-1970	6/51–1/57	5.5	6/51–5/57	1980 area-capacity data. Yield reflects 2000 capacity.

N/A – Not Available

TABLE 2-19

UPDATED RESERVOIR YIELDS FOR REGION B

Reservoir	County	Elev. (MSL)	Year 2000			Uses	Operation Study			Critical Period		Drought of Record	Comments
			Area (acres)	Capacity (ac-ft)	Yield (af/yr)		Date	Author	Period of Record	Dates	Length (years)		
Lake Pauline	Hardeman	1490	543	3,297	1,800	Industrial	1999	F&N	1962-1982	10/69–2/71	1.3	10/69–10/71	Lake yield with Groesbeck Creek diversion
Lake Kemp	Baylor	1144	12,475	204,000	126,000	Municipal	1976	F&N	1949-1974	6/42-6/45	3	6/42–8/49	Yield reflects 2000 sediment conditions.
Lake Diversion	Archer, Baylor	1051	3,282	30,100	0	Industrial	1976	F&N	1949-1974	Firm yield was not determined			Operation study indicated Diversion required makeup from Lake Kemp to maintain elevation
Santa Rosa	Wilbarger	N/A	N/A	6,980	0	Irrigation							Yield estimate based on historical performance
Lake Electra	Wilbarger	1111	731	5,626	470	Municipal	1999	F&N	1940-1997	10/41–11/54	13.1	10/41–12/97	Area-capacity data updated in 1998. Reservoir most likely has never spilled. Separate study by Electra's consultant DGRA found similar yield.
North Fork Buffalo Creek Reservoir	Wichita	1048	1,500	14,378	2,100	Municipal	1999	F&N	1940 - 1997	7/58–2/81	22.5	7/58–6/87	Little change in yield through the planning period due to long critical period.
Lake Kickapoo	Archer	1045	6,072	96,302	15,946	Municipal	1999	F&N	1940-1989	5/58–8/80	22.3	5/58–5/82	Revised yield to account for sedimentation.
Lake Arrowhead	Clay, Archer	926	14,000	246,800	29,532	Municipal	1997	TWDB	1940-1989	5/58–9/80	22.3	5/58–5/82	Yield reflects 2050 sediment conditions. 2000 analysis was not conducted by TWDB.
Lake Olney/ Cooper	Archer	1150	465	6,165	910	Municipal	1999	F&N	1940-1997	7/58–9/84	26.2	7/58–5/90	Projected little change in yield due to long critical period.
Lake Nocona	Montague	827	1,413	21,750	1,260	Mun/Rec/ Ind	1986	F&N	1940-1984	6/51-1/57	5.5	6/51-5/57	1986 area-capacity data. Projected little change in yield over planning period.
Lake Amon G. Carter	Montague	920	1,848	27,559	2,600	Municipal	1979	HDR	1941-1970	6/51–1/57	5.5	6/51–5/57	Yield study conducted for 1980 and 2030. 2000 yield interpolated.

N/A – Not Available

Previous yield studies for Lake Pauline/Groesbeck Creek were not available. The TWDB projects the yield of Lake Pauline and Groesbeck Creek to be approximately 3,000 acre-feet per year. The sedimentation analysis predicts the capacity of the reservoir to be about 1,850 acre-feet in 2050. With such a small capacity, it is unlikely that Lake Pauline alone can support a yield of 3,000 acre-feet per year. Therefore, a yield study of Lake Pauline with Groesbeck Creek diversions was conducted for the period of record from 1962 through 1982 (which was the available period for flows in Groesbeck Creek). Since flows in Groesbeck Creek are influenced by mining activities west of Quanah, flows into Lake Pauline were developed from drainage area ratios with the North Wichita River in Foard County. Flows from Groesbeck Creek were diverted to Lake Pauline to maintain the conservation storage. Limitations to the diversions included a maximum diversion rate (56 cfs), maximum yearly diversion (3,000 acre-feet), and the total flow in the river. Minimum flows were not considered. Based on 1971 and projected 2050 area capacities of the lake, the yield of the Lake Pauline/Groesbeck Creek system was determined to be 1,983 and 1,532 acre-feet per year, respectively. The estimated firm yield for 2000 is 1,800 acre-feet per year.

Lakes Kemp and Diversion

Lake Kemp is located on the Wichita River, immediately upstream of State Highway 183 in Baylor County. The original storage in 1958 was estimated at 298,00 acre-feet and in a 1973 survey was estimated at 268,000 acre-feet. Lake Diversion was constructed approximately 20 miles downstream of Lake Kemp for secondary storage. The reservoir lies in both Archer and Baylor counties and has a capacity of 40,000 acre-feet. In 1972, West Texas Utilities estimated the storage at 28,000 acre-feet.

Lake Diversion is operated in conjunction with Lake Kemp to provide water supply for municipal, industrial, irrigation, mining, and recreational purposes. The city of Wichita Falls and WCWID #2 own both Lake Kemp and Lake Diversion. Water released from Lake Kemp travels to Lake Diversion for distribution. Irrigation water is diverted into canal systems. A Texas State fish hatchery lies below Lake Diversion and receives about 3 cfs of water from the irrigation district.

Due to high salinity loads in the tributaries that flow to Lake Kemp, use of water from Lake Kemp is limited. Most of the water from the Lake Kemp-Lake Diversion system is used for irrigation. To improve the water quality of the Wichita River, the Red River Authority sponsored construction of a chloride control project, Truscott Brine Reservoir, which diverts saline water from the South Wichita River above Lake Kemp. Recent evaluations of the effectiveness of the project found that these diversions reduce the total chloride load to Lake Kemp by approximately 25%. This results in a lower flow-weighted chloride concentration in the reservoir. However, there still is a significant chloride load to the reservoir system from the North and Middle Wichita Rivers. Future proposed diversions from these tributaries should further reduce chloride loading into Lake Kemp.

The yield of Lake Kemp was most recently evaluated in 1976 (F&N 1976). The yield reported in the 1997 State Water Plan was based on this study using year 2020 area-capacity data. Assuming the average sedimentation rate determined from the 1973 sedimentation survey (1.13 acre-feet/square mile of drainage area) continues over the planning period, the projected

yield of Lake Kemp in 2050 is 101,540 acre-feet per year at elevation 1144. The Design Memorandum for Lake Kemp proposed that the top of the conservation pool be raised throughout the life of the project up to elevation 1150.

Lake Diversion, while considered secondary storage for Lake Kemp, actually may be a demand on Lake Kemp supplies during a drought. Water is supplied from Lake Kemp to maintain the water elevation in Lake Diversion. Under its current operation, it is assumed that Lake Diversion has no firm yield and is not a water supply source for this regional plan.

Santa Rosa Lake

Santa Rosa Lake is located in Wilbarger County on Beaver Creek. It was constructed in 1929 by W. T. Waggoner Estate for irrigation and had an original capacity of 15,755 acre-feet. Current use is for livestock and irrigation. It is permitted for 3,075 acre-feet per year, but recent historical use is much lower. According to a representative of W. T. Waggoner Estate, the lake went totally dry in 1971.

Based on the sedimentation analysis, the projected capacity of Santa Rosa Lake in 2050 is reduced to about 800 acre-feet due to the lake's large drainage area. Recent reported use from the lake is less than 70 acre-feet per year. The reported use when the lake purportedly went dry was not available, but was most likely less than the permitted use. In light of these findings, Santa Rosa Lake has little to no reliable supply and is not considered a water supply source for planning purposes.

Lake Electra

Lake Electra is located on Camp Creek near the city of Electra in Wichita County. It is owned and operated by the city of Electra and has a diversion right of 600 acre-feet per year for municipal use. At normal pool elevation (1,111 feet Mean Sea Level), the storage capacity of Lake Electra is 5,626 acre-feet. However, due to the relatively small drainage area (14.5 square miles), the lake often does not operate at normal pool elevation. Previous reports indicate the lake may never have completely filled since construction was completed in 1950.

Lake Electra is currently experiencing low lake levels and may be in a critical drought. A recent study conducted by the DGRA for the city of Electra found that the firm yield of the lake is approximately 460 acre-feet per year. This analysis was based on the 1998 area-capacity survey, using inflows developed for a period of record from 1950 to 1970. To confirm these findings, a separate yield study was conducted as part of this evaluation for the period of record from 1940 to 1997. Inflows were based on a rainfall-runoff relationship developed from Lake Kirby for Lake Electra (F&N 1948). This study found the firm yield of Lake Electra to be 470 acre-feet per year. It also indicated that the lake might never have filled, and that Lake Electra is still in its critical drought. Data received from the city's consultant indicate that water levels for the lake continued to decline in 1998 and 1999. It is possible that Lake Electra is entering another critical period and further study should be conducted to confirm the lake's yield. For this plan, it is assumed that the firm yield of Lake Electra is 470 acre-feet per year.

To supplement Lake Electra, the city has a permit to divert up to 800 acre-feet per year from Beaver Creek for emergency municipal use. This right has been used on occasion, but there is no permanent diversion structure or transmission line. A review of available flows in Beaver Creek indicates that during some years there is very little flow during the hot dry months. In 1984, total flow during the dry spring and summer was less than 800 acre-feet. Also, Beaver Creek has a higher salinity level than Lake Electra. Large diversions from Beaver Creek may require additional treatment, which is currently undesirable. During a drought, diversions from Beaver Creek will be minimal because of the water quality and low flow conditions. To fully utilize this emergency right, diversions from Beaver Creek must be planned over the year. Assuming this occurs and water is diverted at the allowable rate of 1.3 cfs, it is estimated that 550 acre-feet per year of supply is available from Beaver Creek during a dry year. However, since there is no existing diversion system in place, it is assumed that this supply is currently not available to Electra.

North Fork Buffalo Creek Reservoir

The North Fork Buffalo Creek Reservoir was constructed in 1964 to provide additional water for the city of Iowa Park. The dam is located below the confluence of North Fork Buffalo Creek and Lost Creek in Wichita County. The reservoir had an original storage capacity of 15,400 acre-feet with a drainage area of 33 square miles. The current permitted water right for the reservoir is 840 acre-feet per year. North Fork Buffalo Creek Reservoir is owned and operated by the city of Iowa Park.

The yield reported in the 1997 State Water Plan for North Fork Buffalo Creek Reservoir is the water right amount. The initial yield study of the reservoir was conducted in 1961 for a larger lake with historical flows through 1959 (BMI 1961). Subsequent yield studies of North Fork Buffalo Creek Reservoir were not available. As part of this plan, a yield study was conducted for the reservoir for 1940 through 1997. Since no U.S. Geological Survey (USGS) gage was available in the North Fork Buffalo Creek watershed, historical flows were developed from the city of Archer gage (1940–1961) and the Beaver Creek gage (1962–1997) based on drainage area ratios. The yield of the reservoir was found to be 2,100 acre-feet per year throughout the planning period. There was little difference in yields between 2000 and 2050 due to the long critical period and relative small reduction in capacity from sedimentation.

Wichita System

The Wichita System consists of Lake Kickapoo and Lake Arrowhead. These lakes are owned and operated by the city of Wichita Falls for municipal and industrial supply. Water from the lakes is transported to Wichita Falls' water treatment plants for treatment and distribution. Some raw water is sold directly to wholesale customers. A brief description of each lake follows:

Lake Kickapoo. Lake Kickapoo was built by the city of Wichita Falls in 1946 for municipal water supply with an initial conservation storage capacity of 106,000 acre-feet. The reservoir is located on the North Fork of the Little Wichita River in Archer County. Diversion rights from the lake total 41,720 acre-feet per year. Recent reservoir operation analyses for Lake Kickapoo conducted by the TWDB reported the firm yield to be 16,072 acre-feet per year with

an estimated conservation storage of 105,000. The TWDB analysis did not take into account sedimentation. Therefore, the long-term yield of Lake Kickapoo was re-analyzed. The results indicated only a minimal decrease in reservoir yield over the planning period. This was attributed to the long critical period (1958-1982). The projected yields of Lake Kickapoo in 2000 and 2050 are 15,945 and 15,343 acre-feet per year, respectively. The revised yields are used in the assessment of supply.

Lake Arrowhead. Lake Arrowhead was built in 1966 by the city of Wichita Falls for municipal, industrial, and recreational use. The lake is located on the Little Wichita River in Clay County, about 12 miles southeast of Wichita Falls. Diversion rights from Lake Arrowhead are over 45,000 acre-feet per year. This reservoir was recently evaluated by the TWDB (1997) in conjunction with Lake Kickapoo. Accounting for sedimentation, the yield of Lake Arrowhead in 2050 was reported to be 29,532 acre-feet per year, with a 2050 projected conservation storage of 224,241 acre-feet.

Lakes Olney and Cooper

Lakes Olney and Cooper are a twin-lake system located on Mesquite Creek in Archer County. Lake Olney dam was constructed in 1935 to provide municipal water for the city of Olney. In 1953, the dam for Lake Cooper was built for additional storage. Collectively, the lakes have a conservation storage capacity of 6,650 acre-feet, with diversion rights of 1,260 acre-feet per year.

The yield reported for these lakes in the 1997 State Water Plan is based on the water right. Previous yield studies were not available for review. Since the lakes have a small drainage area (12.3 square miles) that may not be able to support the full diversion right, estimates of the firm yield of Lakes Olney and Cooper for 2000 and 2050 were determined. Inflows were developed from the Archer City and Beaver Creek gages, and area-capacity relationships were estimated assuming a trapezoidal shape. The firm yield of the lakes was determined to be 910 acre-feet per year. This yield remains constant through the planning period due to the long critical period (26.2 years) and small amount of sedimentation.

Lake Nocona

Lake Nocona is a 25,400-acre-foot reservoir located on Farmers Creek in Montague County, approximately 8 miles northeast of the city of Nocona. Construction was completed in 1960 to provide municipal water supply to the city of Nocona. The lake is owned and operated by the North Montague County Water Supply District. The original permit for Lake Nocona allowed diversion and use of 4,500 acre-feet per year for municipal, industrial, and mining purposes. In 1984, the final determination of water rights for the Middle Red River segment of the Red River Basin reduced the authorized diversion to 645 acre-feet per year for municipal use only. Subsequent studies reported the firm yield of the reservoir to be 1,260 acre-feet per year through 2030 (F&N 1986). The water right permit for diversions from Lake Nocona was amended in 1987 to 1,260 acre-feet per year for municipal, irrigation, and recreational uses.

The 1986 study found that sedimentation is not expected to significantly affect the firm yield of Lake Nocona over the planning period. The yield analyses conducted in 1986 assumed

1986 area-capacity conditions and accounted for reduced inflows from Soil Conservation Services (SCS) structures. It was assumed that over time, the impact of the SCS structures on runoff would decrease as the sediment pools become silted. This would result in an increase of inflows over the critical period, which would negate the reduction in yield due to future sedimentation. The study concluded that the firm yield of Lake Nocona should be approximately 1,260 acre-feet per year through 2030. For this plan, it is assumed that the firm yield remains constant through the planning period.

Lake Amon G. Carter

Lake Amon G. Carter is located on Big Sandy Creek in Montague County, about 6 miles south of the city of Bowie, Texas. The lake was originally constructed in 1956 and enlarged in 1979. It has a current storage capacity of 28,600 acre-feet and an estimated yield of 2,600 acre-feet per year. The lake is owned and operated by the city of Bowie for water supply. The existing water right permit allows for diversion of 5,000 acre-feet per year for municipal, industrial, and mining water use.

Lake Amon G. Carter's yield reported by TWDB is based on 2000 capacity. Operation studies using 2030 area-capacity data indicate a reduction in yield of just over 100 acre-feet per year (2,488 acre-feet per year). Additional sedimentation may continue to slightly reduce the firm yield of this reservoir, but it should not be significant. For this study, the 2050 firm yield of Lake Amon G. Carter was estimated at 2,413 acre-feet per year.

Miller's Creek Reservoir

Miller's Creek Reservoir is located about 7 miles southeast of Bomarton, Texas. The dam was constructed in 1977 on Miller's Creek in Baylor County, and the reservoir extends southwest into Throckmorton County. It is owned and operated by the North Central Texas Municipal Water Authority (MWA). It has a permitted diversion of 5,000 acre-feet per year for municipal, industrial, and mining uses. Since water from this reservoir is primarily used for municipal supply for cities located in Knox and Haskell counties in Region G, this reservoir will not be further considered in the Region B analyses.

Other Lakes and Reservoirs in the Region

Lake Wichita. Lake Wichita is located south of the city of Wichita Falls and lies in Archer and Wichita counties. It was constructed in 1901 on Holliday Creek for irrigation and municipal use, but little water has been used for municipal purposes since Lake Kickapoo water supply became available. This is because Lake Wichita has a very high chloride content and must be blended with higher quality water to be acceptable for municipal use. Presently, Lake Wichita is used for recreational purposes only.

Lake Iowa Park. Lake Iowa Park is located on Stevens Creek, northwest of the city of Iowa Park, and has been a source of water for the city of Iowa Park since 1949. The lake has a storage capacity of 2,565 acre-feet, and the water right permit allows diversion of 500 acre-feet per year for municipal use. It is currently used in conjunction with North Fork Buffalo Creek for

supply to the city of Iowa Park. No yield studies were conducted for this lake. For this plan, it is assumed that half the water right is available for supply.

SEDIMENTATION AND RESERVOIR YIELDS

Sediment production rates in Region B vary considerably due to land use, soil types, and topography. Wind erosion is quite active across the rolling prairies and cultivated fields. The U.S. Geological Survey and the U.S. Soil Conservation Services have compiled much of the sedimentation data available for reservoirs in Region B. Only Lake Kemp, Santa Rosa Lake, Lake Amon G. Carter, and Lake Nocona have published sedimentation surveys. Therefore, for this study, estimates of sedimentation rates were developed from several sources. For sedimentation rates developed from the Texas Board of Water Engineers Report 5912, the effects of SCS structures and development were considered. Estimates of reservoir capacities for 2000 and 2050, based on the reservoir's drainage area and sedimentation rate, are presented in Table 2-20. Since the yield of a reservoir is affected by the reservoir's area-capacity relationship, high sedimentation rates will reduce the reservoir's storage capacity and firm yield. The projected reservoir yields over the planning period are presented in Appendix A, Table 4 and are found at the website.

TABLE 2-20

ESTIMATED SEDIMENTATION RATES AND PROJECTED CAPACITIES

Reservoir	Drainage Area (sq. mi.)	Sediment Rate (af/yr/sq mi)	Year Began Filling	Year of Initial Capacity	Capacities (acre-feet)			Source (sediment rate)
					Initial	2000	2050	
Lake Pauline	42.6	0.68	1928	1971	4,137	3,297	1,849	TBWE 1959
Lake Kemp	2086	1.13	1922	1973[1]	268,000	204,356	86,500	F&N 1976
Santa Rosa Lake	334	0.37	1929	1929	15,755	6,980	802	TWC 1979
Lake Electra	14.5	0.69	1950	1998[2]	5,626	5,626	5,126	TBWE 1959
North Fork Buffalo Creek	33	0.86	1964	1964	15,400	14,378	12,959	TBWE 1959
Lake Kickapoo	275	0.68	1946	1946	106,400	96,302	86,952	TBWE 1959
Lake Arrowhead	832	0.54	1966	1966	262,100	246,800	224,240	TWDB 1997
Lakes Olney and Cooper	12.3	0.68	1935/ 1953	1935/ 1953	6,650	6,165	5,747	TBWE 1959
Lake Nocona	94	0.48	1961	1961	25,400	21,750	19,500	F&N 1986
Lake Amon G. Carter	101	0.51	1956	1980[3]	28,589	27,559	24,983	HDR 1979

[1] Revised construction was completed in 1973. At that time, the Corps of Engineers re-surveyed the lake.
[2] 1998 area-capacity data. Previous survey conducted in 1987 indicated much larger capacity. This difference is currently being investigated.
[3] Enlargement of Lake Amon G. Carter was completed in 1980 and area-capacity was determined at that time.

RESERVOIR WATER RIGHTS AND CONTRACTS

Water rights for reservoirs located in Region B are summarized on Table 2-21. Comparisons of rights to firm yields indicate that water rights for many of the reservoirs in Region B exceed firm yield. For most of the reservoirs, the existing contractual demands are typically less than reservoir yields. Only for Lake Electra are the historical use and municipal sales greater than the reservoir's firm yield. For Lake Kemp, the 2000 firm yield is approximately 65% of the permitted right. While historical use has not exceeded the reservoir yield, the city of Wichita Falls and WCWID #2 will need to develop operational policies to ensure that there are sufficient supplies for users, especially if Wichita Falls begins to use water from Lake Kemp for municipal use on a regular basis. Presently, water from Lake Kemp is used only for irrigation and industrial uses, with occasional emergency municipal use. A summary of the existing known contracts by reservoir is presented in Table 2-22. With the exception of the city of Wichita Falls, the primary water right holders are not included on Table 2-22.

STREAM SUPPLIES

Portions of three river basins are located in Region B. The Red River and its tributaries represent the largest river system, flowing across the central and northern areas of the region. The Brazos River flows through the southern portion of King and Baylor counties, and the upper tributaries of the Trinity River lie in southwest Montague County.

The Red River forms the northern boundary of Region B and flows eastward along the Texas–Oklahoma border. Tributaries within the region include the Pease River, Wichita River, and Little Wichita River. High concentrations of TDS, SO_4, and Cl are concerns for the upper reaches of these streams during low flow conditions. Naturally occurring salt springs, seeps, and gypsum outcrops are found in the area westward of Wichita County to the High Plains Caprock Escarpment in Region A. Water quality gradually improves downstream toward the eastern portion of the region. As a result, water from rivers in Cottle, Foard, King, Hardeman, and parts of Baylor and Wilbarger counties is generally not used or is restricted to irrigation use only.

Existing stream water rights for the Red River system in Region B are shown on Table 2-23 and include rights on the Red River in Clay and Montague counties, Little Wichita River, Wichita River, and Beaver Creek. Beaver Creek is a tributary to the Wichita River and flows eastward from Foard County to the Wichita River in Wichita County. Groesbeck Creek, which has a large water right associated with Lake Pauline, is addressed with this reservoir. Generally, rights associated with reservoirs, unnamed tributaries, or smaller rivers and streams are not included on Table 2-23.

To assess the availability of water from streams in Region B, historical flows for the major rivers were reviewed. Many existing water rights are not limited by minimum flows for environmental protection, but future rights will be subject to minimum flow requirements. Therefore, a comparison of historical flows, water rights, and future available supply was evaluated. The Lyons method, which is the TNRCC's default method in the absence of specific studies, was used to determine the amount of flow available when minimum flows are

TABLE 2-21

SUMMARY OF RESERVOIR WATER RIGHTS IN REGION B

Reservoir	Water Right No.	Holder	Water Right Amount (acre-feet/year)						2000 Yield (af/yr)
			Municipal	Industrial	Irrigation	Mining	Recreation	Total	
Greenbelt	5233	Greenbelt MIWA	14,530	500	250	750		16,030	7,699
Pauline/Groesbeck	5230	West Texas Utility Company		7,137	16		0	7,153	1,800
Kemp/Diversion	5123	WCWID#2 Wichita Falls	25,150	40,000	120,000	2,000	5,850	193,000	126,000
Santa Rosa	5124	W.T. Waggoner Estate			3,075			3,075	0
Electra	5128 5128	City of Electra Emergency Supply	600 800					1,400	400
Kickapoo	5144	Wichita Falls	40,000					40,000	15,945
Arrowhead	5150	Wichita Falls	45,000					45,000	29,532
Olney/Cooper	5146	City of Olney	1,260					1,260	910
North Fork Buffalo Creek	5131	City of Iowa Park	840					840	2,100
Iowa Park	5132	City of Iowa Park	500					500	250*
Nocona	4879	North Montague County WSD	1,080		100		80	1,260	1,260
Amon G. Carter	3320	City of Bowie	3,500	1,300		200		5,000	2,600

* No available yield studies. The yield was assumed to be half the water right.
Source: Texas Natural Resource Conservation Commission, Water Rights Database, 1999.

TABLE 2-22

SUMMARY OF EXISTING WATER SUPPLY CONTRACTS

Source Name	Contract Holder	Contract Amount		Comment
		mgd	af/yr	
Greenbelt	Crowell		247	No Contract Amount – 1996 Historical Use
Greenbelt	Quanah		720	No Contract Amount – 1996 Historical Use
Greenbelt	Red River Authority		237	No Contract Amount – 1996 Historical Use
Greenbelt	Georgia Pacific		328	No Contract Amount – 1996 Historical Use
Kemp/Diversion	Panda Energy International	8	9,000	New Contract*
Kemp/Diversion	West Texas Utilities Company		20,000	Contract, Water Right No.398
Kemp/Diversion	TPW Dundee Fish Hatchery		2,200	
Nocona	Nocona Hills Owners Association		246	Contract, Water Right No.240
Wichita System	Archer City	0.6	673	Contract – Lake Kickapoo, Water Right No. 384
Wichita System	Archer County MUD #1	0.15	168	Contract, No Expiration Date
Wichita System	Burkburnett	2.493	2,795	Contract
Wichita System	Dean Dale WSC	0.825	925	Contract, No Expiration Date
Wichita System	Friberg-Cooper WSC	0.25	280	
Wichita System	Holliday		264	No Contract Amount – 1996 Historical Use
Wichita System	Iowa Park	1.995	2,236	
Wichita System	Lakeside City		392	
Wichita System	Olney	1	1,120	Contract – Lake Kickapoo, Water Right No. 1471
Wichita System	Pleasant Valley		78	No Contract Amount – 1996 Historical Use
Wichita System	Red River Authority	0.75	841	
Wichita System	Scotland	0.25	280	
Wichita System	Sheppard AFB	2.167	2,429	Budgeted amount. The AFB is not restricted to a maximum or minimum water supply.
Wichita System	Wichita Falls		21,650	1996 Historical Use

TABLE 2-22 (Continued)

Source Name	Contract Holder	Contract Amount		Comment
		mgd	af/yr	
Wichita System	Wichita Valley WSC	0.25	280	
Wichita System	Windthorst WSC	0.75	841	
Wichita System	AC Spark Plug		101	No Contract Amount - Historical Use
Wichita System	Pittsburg Plate Glass		303	No Contract Amount - Historical Use
Wichita System	Stanley Tool		95	No Contract Amount - Historical Use
Wichita System	Vetrotex America		842	No Contract Amount - Historical Use
Wichita System	Flake Ind. Serv.		106	No Contract Amount - Historical Use
Wichita System	Wichita Nat. Linen		93	No Contract Amount - Historical Use
Wichita System	Howmet Turbine		115	No Contract Amount - Historical Use
Wichita System	W F Energy		349	No Contract Amount - Historical Use
Wichita System	Howmet Refurb.		31	No Contract Amount - Historical Use
Total Amount – Wichita System			37,310	

Sources: David Lehfeldt (City of Wichita). Communication with Simone Kiel (of Freese and Nichols, Inc.), Data as of May 1999, Received August 1999.
Bobby Kidd (Greenbelt Municipal and Industrial Water Authority). Communication with Simone Kiel (of Freese and Nichols, Inc.), August 1999.
Texas Natural Resource Conservation Commission, Water Rights Database, 1999.

* The contract with Panda Energy is for 8 mgd of water taken from the WCWID canal system, approximately 17 miles downstream of Lake Diversion. Accounting for losses during transport, the amount of water from the Kemp/Diversion system to Panda Energy is approximated at 14,000 acre-feet/year.

TABLE 2-23

STREAM WATER RIGHTS

Water Right	County	Amount (acre-feet/year)	Use	Owner
Red River				
4877	Montague	1,600	Mining	Peba Oil & Gas
5143	Clay	200	Irrigation	Joe J. Parker
Little Wichita River				
4268	Clay	3,600	Irrigation	A.L. Rhodes
5152	Clay	1,560	Municipal	City of Henrietta
Wichita River				
4433	Wichita	300	Irrigation	Alvin & Nana Robertson
5135	Clay	357	Irrigation	Eagle Farms, Inc.
5136	Clay	200	Irrigation	Joe L. Hale Estate
5138	Clay	55	Irrigation	M.E. McBride
5139	Clay	30	Irrigation	Bob Brown
5140	Clay	270	Industrial	Red River Feed Yard, Inc.
5152A	Wichita	2,352	Recreation	City of Wichita Falls
5530	Wichita	32	Irrigation	Joe L. Burton
Beaver Creek				
5125	Wilbarger	675	Irrigation	W.T. Waggoner Estate
5126	Wilbarger	60	Municipal	W.T. Waggoner Estate
5127	Wilbarger	85	Municipal, Mining	W.T. Waggoner Estate
5129	Wichita	404	Irrigation	Harry L. Mitchell
5393	Wichita	450	Irrigation	James Brockriede
5128*	Wilbarger	800	Municipal	City of Electra

* This water right is associated with Lake Electra. It is a right to divert water from Beaver Creek to Lake Electra for emergency municipal use.

Source: Texas Natural Resource Conservation Commission, Water Rights Database, 1999.

considered (Lyons 1979). The Lyons method recommends maintaining minimum stream flows of 40% of the median flow during October through February and 60% of the median flow during March through September. Flows above these amounts were assumed available for supply. After accounting for in-stream flow requirements, the minimum annual flow for the period of record was selected as the available supply during drought conditions. A summary of the run-of-the-river analysis is presented in Table 2-24.

TABLE 2-24

STREAM AVAILABLE SUPPLY

River	USGS Gage	Period of Record	Minimum Flow (af/yr)[1]	Available Supply (af/yr)[2]	Existing Water Rights
Red River	7308500 (near Burkburnett)	1960–1998	99,506	3,127	200
Red River	7315500 (Terral, OK)	1960–1998	449,046	112,879	1,800
Little Wichita	7314900 (above Henrietta)	1966–1998	1,463	902	5,160 (3,600)[3]
Wichita	7312500 (at Wichita Falls)	1960-1998	60,725	20,833	2,684
Wichita	7212700 (near Charlie)	1968-1998	101,014	35,049	3,596
Beaver Creek	7312200 (at Electra)	1960-1998	11,645	7,004	2,474

[1] Minimum annual flow recorded during the period of record.
[2] Minimum flow after accounting for in-stream requirements.
[3] Existing water rights, excluding city of Henrietta.

As shown in Table 2-24, flows are sufficient in the Red and Wichita rivers and Beaver Creek to support existing water rights, and there may be additional flow for potential future diversions. However, the water in these streams is high in chlorides and suspended solids, which may be unsuitable for municipal use. The analysis for the Little Wichita River found that there is little available flow for diversions. This is due in part to impoundment of upstream flows in Lake Arrowhead. Since the water right for the city of Henrietta has priority over both Lake Arrowhead and Lake Kickapoo, much of this right is supplied via Lake Arrowhead. Water is released from Lake Arrowhead and flows downstream to the city's diversion point. Currently, it does not appear that the Little Wichita River can fully support all existing water rights during a drought. Some reductions in flows for upstream water right holders may already be accounted for in the analyses. However, reported historical use for water rights greater than 1,000 acre-feet per year indicates that many of these rights are currently not being used.

GROUNDWATER SUPPLIES

General Description

Groundwater is primarily supplied in Region B by two aquifers, the Seymour and the Blaine Gypsum. The Seymour is designated a major aquifer and is found in the central and western portions of the region. It is currently used in Hardeman, Wilbarger, Wichita, Clay, Baylor, Foard, and Cottle counties. The Blaine is considered a minor aquifer, and useable groundwater is limited to the westernmost portion of the region. These aquifers provide a large percentage of available supply in these counties. In addition, the upper portion of the Trinity Aquifer occurs in Montague County in the eastern part of the region. Limited quantities of groundwater are used from the Trinity for municipal and irrigation uses. There are also unconsolidated formations within the region that are used for groundwater supply in some areas. The TWDB identifies these sources as "Undifferentiated Other Aquifer". These formations are not well defined in the literature, but still provide substantial quantities of water in Archer, Clay, Cottle, Montague, and Wichita counties. For this report, groundwater availability for "Other Aquifers" will be determined from reported historical use.

Seymour Aquifer

The Seymour Formation consists of isolated areas of alluvium that vary in saturated thickness from less than 10 feet to over 80 feet. This aquifer is relatively shallow and exists under water table conditions in most of its extent. Artesian conditions can occur where the water-bearing zone is overlain by clay. The upper portion of the Seymour consists of fine-grained and cemented sediments. The basal portion of the formation has greater permeability and produces greater volumes of water. Yields of wells typically range from 100 gallons per minute (gpm) to 1,300 gpm, depending on the saturated thickness, and average about 300 gpm.

Recharge to the Seymour is largely due to direct infiltration of precipitation over the outcrop area. Surface streams adjoining the outcrop are at elevations lower than the water levels in the Seymour Aquifer and do not contribute to recharge. Other possible sources of recharge include infiltration from irrigation or upward leakage of water from underlying Permian formations, but these amounts are insignificant.

Natural discharge from the Seymour occurs through seeps and springs, evapotranspiration, and leakage to the Permian. Harden estimates that a large part of the Seymour's total natural discharge is from evapotranspiration from plants and is considerably larger than discharges to seeps and springs (TWDB Report 337 1992).

Water quality of the Seymour is variable throughout the region, and generally ranges from fresh to slightly saline. Brine pollution from earlier oil activities and excessive pumping has caused localized concentrations of minerals in the alluvium, limiting full utilization of the water resource. In addition, high nitrate concentrations occur in the groundwater over a wide area. These nitrate concentrations are often due to agricultural practices and can be attributed to nitrogen fertilizer or leaching from areas formerly covered by nitrogen fixing vegetation, such as grasses or mesquite groves. Other sources of nitrate include organic matter from poorly functioning septic systems, infiltration of animal wastes, or naturally occurring sources.

Blaine Aquifer

The Blaine Formation extends in a narrow outcrop band from Wheeler to King counties. Groundwater occurs in numerous solution channels and caverns in beds of gypsum and anhydrite. In most places, the aquifer exists under water table conditions, but it is also artesian where overlain by Dog Creek Shale. Saturated thickness of the aquifer approaches 300 feet in its northern extent, and is generally less in the Region B area. Well yields vary considerably from one location to another due to the nature of solution channels. It is common for dry holes to be found adjacent to wells of moderate to high yield. The average well yield is 400 gpm.

The primary source of recharge to the Blaine is precipitation that falls on the High Plains Escarpment to the west and the Blaine outcrop area. The solution openings and fractures in the gypsum provide access for water to percolate downward. The Blaine may also receive some recharge from the overlying Dog Creek Shale.

Water in the Blaine generally moves eastward through the solution channels, dissolving mineral deposits along the way, and discharging to low topographic areas. The dissolved solids concentrations in the aquifer increase with depth and generally range from 1,000 to over 10,000 milligrams per liter (mg/L). Due to the high mineral content, the TWDB has limited the extent of the Blaine to areas with water less than 10,000 mg/L of dissolved solids.

Natural salt springs and seeps from the Blaine contribute to increased salinity of surface water. Due to the high mineral content, the Blaine has been used primarily for irrigation of salt tolerant crops.

Trinity Group

The Trinity Group consists of three formations, Travis Peak, Glen Rose, and Paluxy. In the northern part of its extent, the Glen Rose thins out and the Travis Peak and Paluxy coalesce into a single geologic unit known as the Antler Formation. In Region B, the Trinity Group outcrops in the eastern portion of Montague County. The thickness of the aquifer ranges from less than 10 feet to 600 feet. Water table conditions occur in outcrop area, while artesian conditions exist in the downdip formation. Well yields in the Trinity Group range from moderate to low. The effective recharge for the entire Trinity Aquifer as determined by the TDWR is 1.5% of the mean annual precipitation over the outcrop area (TDWR 1982).

Limited amounts of good quality water can be obtained from the Trinity in Montague County. Groundwater is generally used for municipal, mining, irrigation, and livestock purposes. Water level declines have been recorded in heavily pumped areas to the south and southeast of Montague County.

GROUNDWATER AVAILABILITY AND RECHARGE

The average annual groundwater availability is the amount of water that could be reasonably developed from an aquifer. It is comprised of the annual effective recharge plus the

amount of water that can be recovered annually from storage over a specified planning period without causing irreversible harm, such as subsidence or water quality deterioration. As part of the 1997 State Water Plan, the TWDB evaluated groundwater availability for the major and minor aquifers of the state. Previous publications and water well data were used to derive annual groundwater availability. Effective recharge was determined by applying a percentage of the mean annual precipitation on the aquifer's outcrop area. For the Seymour, the TWDB used a conservative estimate of 5% of the average annual precipitation for the entire Seymour Formation. This percentage was generally based on the low flow analyses used in the groundwater studies of Baylor and Jones counties (TDWR Report 238 1979). In addition, an estimated annual amount recoverable from storage was determined based on 75% of total storage for the planning period from 1974 through 2030. After 2030, it was assumed no water would be available from storage.

Reviews of previous groundwater publications found a range of reportable recharge rates and availability estimates for the Seymour Aquifer. The Baylor study (TDWR 1978) indicated an effective recharge rate of 10% of the average annual precipitation for 1969. However, groundwater availability was limited in some areas due to thin saturated thickness and high loss to evapotranspiration. The Baylor study also did not include mining of groundwater from storage due to the nature of the near surface aquifer (i.e., did not want to create abnormally low water levels). Most recently, a study by Woodward-Clyde for the city of Vernon estimated the recharge to the Seymour in the Odell-Lockett area in Wilbarger County to be approximately 15% of the average rainfall (Woodward-Clyde 1998).

This higher estimate of recharge appears to be limited to specific areas and cannot be applied over the regional aquifer. Also, it is unrealistic to expect that all aquifer recharge will be available for development. The TWDB estimate of 5 to 7% of the annual precipitation is a reasonable estimate of effective recharge for the Seymour, and is appropriate for regional water planning purposes. However, since the Seymour Aquifer is a near-surface unconfined aquifer and is sensitive to recharge and withdrawals, mining of the aquifer may adversely affect water supply. Therefore, for this plan, mining of storage is not included in the groundwater availability estimates for the Seymour.

For the Blaine Gypsum formation, comparisons of declines of water levels and pumpage were used to estimate effective recharge. In Hardeman County, Maderak (TDWR 1972) determined the effective recharge to the Blaine to be between 5 and 7% of the average annual precipitation. The TWDB used a conservative estimate of 5% for water availability planning. No recoverable storage from the Blaine was included in the availability estimates. For the Blaine, groundwater estimates include water with TDS up to 10,000 mg/L. For the other aquifers in the region, the availability estimates were limited to water containing less than 3,000 mg/L of TDS.

The TWDB methodology for groundwater availability for the Blaine Aquifer is appropriate for this planning effort. However, the Blaine Aquifer has a large amount of groundwater with moderate to high salinity. As a result, much of the water from this formation is not used in the region. The 1997 Water Plan includes water with moderate salinity in the availability numbers for irrigation, but is not appropriate for municipal use. Therefore, the

groundwater availability from the Blaine is broken down by TDS level. Based on historical water quality data, there is no water available for municipal purposes. Water with TDS levels between 1,000 and 3,000 is appropriate for irrigation, livestock, mining, and some industrial uses. Water with TDS levels greater than 3,000 may be available with treatment or irrigation of salt tolerant crops.

The effective recharge for the Trinity Aquifer within the Brazos, Trinity, and Red River basins was determined by the trough method (TDWR Report 238 1979). Using this method, it was determined that approximately 1.5% of annual precipitation over the outcrop area is available for development as effective recharge. In addition, the TWDB estimated that 1 million acre-feet of water could be withdrawn from artesian storage within the Trinity. However, much of the Trinity Group within Montague County is not artesian, and the storage values may be less.

Since much of the Trinity Aquifer is artesian and the outcrop area is used to recharge the downdip portion of the aquifer, a direct application of effective recharge over the outcrop area is not appropriate to determine groundwater availability. For this planning effort, availability estimates determined by the TWDB for the Trinity Aquifer will be used.

For the Seymour and Blaine aquifers, the recharge values used in the 1997 Water Plan were based on outcrop areas defined in 1979. Since 1979, the outcrop areas have been re-defined and there is a longer record of precipitation data available. As a result, the amount of groundwater that is available from these aquifers differs from the 1997 Water Plan. Groundwater availabilities for the Seymour and Blaine aquifers were re-calculated as 5% of the mean annual rainfall over the outcrop area, using the latest precipitation data and the most recent delineation of recharge areas. The availability estimates for the Trinity were taken directly from the 1997 Water Plan. A summary of groundwater availability by aquifer and county is presented in Table 2-25. Table 2-26 shows the availability in the Blaine Aquifer by concentration of TDS.

TABLE 2-25

GROUNDWATER AVAILABILITY – REGION B

County Name	Basin	Aquifer Name	Ground Water Availability (acre-feet/year)	Effective Recharge Rate (inches/year)
Baylor	Brazos	Seymour	8,205	1.35
Baylor	Red	Seymour	1,485	1.35
Baylor	*Total*	*Seymour*	*9,690*	*1.35*
Clay	Red	Seymour	7,870	1.39
Cottle	Red	Seymour	8,410	1.11
Cottle	Red	Blaine	27,100	1.01
Foard	Red	Seymour	12,130	1.23
Foard	Red	Blaine	15,390	1.19
Hardeman	Red	Seymour	15,390	1.18
Hardeman	Red	Blaine	23,770	0.92
King	Red	Blaine	17,590	1.10
Montague	Red	Trinity	239	0.51
Montague	Trinity	Trinity	2,443	0.51
Montague	*Total*	*Trinity*	*2,682*	*0.51*
Wichita	Red	Seymour	13,920	1.38
Wilbarger	Red	Seymour	30,500	1.28

TABLE 2-26

AVAILABILITY IN BLAINE AQUIFER BY TDS

County	Basin	Groundwater Availability (TDS [mg/L] acre-feet/year)			
		Total	1,000-3,000	3,000-10,000	>10,000
Cottle	Red	27,100	6,494	18,153	2,453
Foard	Red	15,390	10,945	4,445	0
Hardeman	Red	23,770	13,601	10,169	0
King	Red	17,590	3,706	13,884	0

As shown in Tables 2-25 and 2-26, large quantities of water are available in the Seymour and Blaine aquifers, and limited quantities are available in the Trinity Aquifer. However, the water in the Blaine is unsuitable for municipal use without additional treatment, and only a portion is readily available for other uses. Water quality issues associated with the Seymour Aquifer (nitrates and TDS) also limit the usefulness of this resource. Historical use indicates that with the exception of Wilbarger County, much of the groundwater is not fully developed or is not currently being used. A comparison of the 1997 historical use and groundwater availability estimates is shown on Table 2-27.

TABLE 2-27

GROUNDWATER HISTORICAL USE

County	Aquifer	Availability (acre-feet/year)	Historical Use 1997 (acre-feet/year)
Baylor	Seymour	9,690	1,352
Clay	Seymour	7,870	921
Cottle	Seymour	8,410	22
Cottle	Blaine	27,100	2,517
Foard	Seymour	12,130	3,688
Foard	Blaine	15,390	23
Hardeman	Seymour	15,390	123
Hardeman	Blaine	23,770	3,901
King	Blaine	17,590	213
Montague	Trinity	2,682	419
Wichita	Seymour	13,920	2,631
Wilbarger	Seymour	30,500	23,344

RELIABILITY OF LOCAL SUPPLIES

Many local cities and communities in Region B rely on groundwater for all or a portion of their municipal supply. Those communities that use groundwater exclusively include the cities of Vernon, Seymour, Paducah, Saint Jo, and Montague. The cities of Electra, Burkburnett, and Chillicothe use a combination of groundwater and surface water. Also, several water supply corporations use groundwater to supply rural areas. Based on surveys of water users in Region

B, some users are experiencing lower water table elevations, nitrate contamination, and/or salt water intrusion of their groundwater supplies. Nitrate contamination is a particular concern in the Seymour Aquifer.

Two cities, Vernon and Electra, have recently conducted independent studies of their groundwater systems. The Vernon study (Woodward-Clyde 1998) found that the city has an estimated reliable supply of 2.5 million gallons per day (mgd), which is about 2,800 acre-feet per year. In addition, approximately 0.5 mgd is available from several older city wells. This supply has higher nitrate levels and historically has been used only for peak summer demands. The city plans to utilize these wells for manufacturing needs that do not have nitrate limits. The study for the city of Electra found that the system could sustain between 0.1 and 0.15 mgd without significant water table decline. This amount (112 acre-feet per year) was assumed available for future use. However, there are water quality issues with the groundwater (nitrates and TDS) that may preclude its use for municipal needs without additional treatment.

INTERBASIN AND INTERREGION TRANSFERS

There is only one known interbasin transfer in Region B. This is from Lake Kickapoo in the Red River Basin to the city of Olney in the Brazos Basin. The city of Olney has a contract with the city of Wichita Falls to provide 1.0 mgd of water during peak demands. Most years, this additional supply is not used or is minimally used.

The only surface water supply source located outside Region B is Greenbelt Lake. Water is supplied from Greenbelt Municipal and Industrial Water Authority to selected cities and communities in Hardeman and Foard counties via a pipeline from Greenbelt Lake.

ALLOCATION OF EXISTING SUPPLIES

The TWDB has requested that existing water supply be allocated to water users by city and category. This includes a breakdown by county and river basin. Table 2-28 represents a picture of where the existing water is being used today. If available, surface water allocations are based on current water rights, contracts, and available yields, accounting for the most restraining limitation (e.g., reservoir yield or water treatment). Groundwater allocations are based on current developed well fields, accounting for aquifer limits. For categories or cities with no associated contracts or rights, historical use data provided by the TWDB were used. Where appropriate, the highest reported use over the past 10 years was used. Surface water use reported to TWDB for livestock watering was assumed supplied by farm stock ponds.

Once the allocations were made, they were checked against source yields. Adjustments were made as needed. If a source's yield was less than the water rights, adjustments were made based on historical use and projected demands. If all future demands could be met by the source, a hierarchy of water rights was not performed.

TABLE 2-28

ALLOCATION OF EXISTING SUPPLIES – REGION B

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Red	Archer	Archer City	Wichita System	673	673	673	673	673	673	Long-term contract
Brazos	Archer	County-Other	Other Aquifer	30	30	30	30	30	30	80% of Historical Max Use (adjusted for aquifer limit)
Red	Archer	County-Other	Other Aquifer	107	107	107	107	107	107	80% of Historical Max Use (adjusted for aquifer limit)
Red	Archer	County-Other	Wichita System	1,009	1,009	1,009	1,009	1,009	1,009	Contracts
Trinity	Archer	County-Other	Other Aquifer	7	7	7	7	7	7	80% of Historical Max Use (adjusted for aquifer limit)
Red	Archer	Holliday	Wichita System	230	225	215	207	199	191	No Contract Amt., Supply = Demand
Red	Archer	Irrigation (On-Farm)	Kemp	4,891	4,048	3,765	3,483	3,201	3,100	5% of Available Irrigation Releases
Red	Archer	Lakeside City	Wichita System	392	392	392	392	392	392	Contract, No Expiration Date
Brazos	Archer	Livestock	Other Aquifer	11	11	11	11	11	11	80% of Historical Max Use (adjusted for aquifer limit)
Brazos	Archer	Livestock	Local Supply	122	122	122	122	122	122	Historical Max Use, Stock Tanks
Red	Archer	Livestock	Other Aquifer	182	182	182	182	182	182	80% of Historical Max Use (adjusted for aquifer limit)
Red	Archer	Livestock	Local Supply	2,051	2,051	2,051	2,051	2,051	2,051	Historical Max Use, Stock Tanks
Trinity	Archer	Livestock	Other Aquifer	24	24	24	24	24	24	80% of Historical Max Use (adjusted for aquifer limit)
Trinity	Archer	Livestock	Local Supply	266	266	266	266	266	266	Historical Max Use, Stock Tanks
Red	Archer	Mining	Other Aquifer	1	1	1	1	1	1	Historical Max Use
Red	Archer	Scotland	Wichita System	280	280	280	280	280	280	Contract, No Expiration Date
Red	Archer	Steam-Electric Power	Kemp	14,000	14,000	14,000	14,000	14,000	14,000	New Contract for proposed plant
Brazos	Baylor	County-Other	Seymour	189	189	189	189	189	189	Historical Max Use - 10 Yrs, Baylor WSC Max Use = 220 (Red & Brazos)
Red	Baylor	County-Other	Seymour	30	30	30	30	30	30	Historical Max Use - 10 Years
Brazos	Baylor	Irrigation (On-Farm)	Seymour	1,837	1,837	1,837	1,837	1,837	1,837	Historical Max Use
Red	Baylor	Irrigation (On-Farm)	Seymour	375	375	375	375	375	375	Historical Max Use

TABLE 2-28 (Continued)

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Brazos	Baylor	Livestock	Seymour	41	41	41	41	41	41	Historical Max Use
Brazos	Baylor	Livestock	Local Supply	373	373	373	373	373	373	Historical Max Use, Stock Tanks
Red	Baylor	Livestock	Seymour	69	69	69	69	69	69	Historical Max Use
Red	Baylor	Livestock	Local Supply	621	621	621	621	621	621	Historical Max Use, Stock Tanks
Brazos	Baylor	Mining	Seymour	47	47	47	47	47	47	Historical Max Use
Brazos	Baylor	Seymour	Seymour	747	747	747	747	747	747	Historical Max Use
Red	Clay	Byers	Seymour	89	89	89	89	89	89	Historical Max Use
Red	Clay	County-Other	Wichita System	1,766	1,766	1,766	1,766	1,766	1,766	Contracts with Arrowhead Prop/RRA /Dean Dale
Red	Clay	County-Other	Seymour	55	55	55	55	55	55	Historical Max Use
Red	Clay	County-Other	Other Aquifer	300	300	300	300	300	300	Historical Max Use
Trinity	Clay	County-Other	Other Aquifer	72	72	72	72	72	72	Historical Max Use
Red	Clay	Henrietta	Wichita System	600	600	600	600	600	600	Estimated amount from Lake Arrowhead for shortfall of superior run of river right
Red	Clay	Henrietta	Local Supply Little Wichita River	960	960	960	960	960	960	Run-of-River Right – Little Wichita (difference between right amount and Arrowhead makeup)
Red	Clay	Irrigation (On-Farm)	Other Aquifer	250	250	250	250	250	250	Historical Max Use – Split Between Seymour & Other
Red	Clay	Irrigation (On-Farm)	Seymour	287	287	287	287	287	287	Historical Max Use – Split Between Seymour & Other
Red	Clay	Irrigation (On-Farm)	Kemp	4,754	3,911	3,628	3,346	3,064	2,963	5% of Available Irrigation Releases
Red	Clay	Livestock	Local Supply	1,747	1,747	1,747	1,747	1,747	1,747	Historical Max Use, Stock Tanks
Red	Clay	Livestock	Seymour	100	100	100	100	100	100	Historical Max Use
Red	Clay	Livestock	Other Aquifer	94	94	94	94	94	94	Historical Max Use
Trinity	Clay	Livestock	Local Supply	225	225	225	225	225	225	Historical Max Use, Stock Tanks
Trinity	Clay	Livestock	Other Aquifer	25	25	25	25	25	25	Historical Max Use
Red	Clay	Mining	Seymour	502	502	502	502	502	502	Historical Max Use
Trinity	Clay	Mining	Other Aquifer	6	6	6	6	6	6	Historical Max Use

TABLE 2-28 (Continued)

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Red	Clay	Petrolia	Local Supply	0	0	0	0	0	0	Petrolia City Lake (assume no long-term reliable supply)
Red	Clay	Petrolia	Seymour	70	70	70	70	70	70	Historical Use
Red	Cottle	County-Other	Other Aquifer	155	155	155	155	155	155	Historical Max Use
Red	Cottle	County-Other	Local Supply	15	15	15	15	15	15	Historical Max Use
Red	Cottle	Irrigation (On-Farm)	Blaine	4,525	4,525	4,525	4,525	4,525	4,525	Historical Max Use
Red	Cottle	Irrigation (On-Farm)	Other Aquifer	0	0	0	0	0	0	Historical Max Use
Red	Cottle	Irrigation (On-Farm)	Local Supply	46	46	46	46	46	46	Historical Max Use
Red	Cottle	Livestock	Seymour	47	47	47	47	47	47	Historical Max Use
Red	Cottle	Livestock	Local Supply	429	429	429	429	429	429	Historical Max Use, Stock Tanks
Red	Cottle	Mining	Local Supply	23	23	23	23	23	23	Historical Max Use
Red	Cottle	Paducah	Other Aquifer	442	442	442	442	442	442	Historical Max Use - 10 Years
Red	Foard	County-Other	Greenbelt	80	75	73	72	71	65	No Contract Amt., Supply = Demand
Red	Foard	County-Other	Seymour	113	113	113	113	113	113	Historical Max Use
Red	Foard	Crowell	Greenbelt	313	294	275	257	243	230	No Contract Amt., Supply = Demand
Red	Foard	Irrigation (On-Farm)	Seymour	5,200	5,200	5,200	5,200	5,200	5,200	Historical Max Use
Red	Foard	Irrigation (On-Farm)	Blaine	23	23	23	23	23	23	Historical Max Use
Red	Foard	Irrigation (On-Farm)	Seymour	32	32	32	32	32	32	Historical Max Use
Red	Foard	Livestock	Local Supply	291	291	291	291	291	291	Historical Max Use, Stock Tanks
Red	Foard	Mining	Seymour	23	23	23	23	23	23	Historical Max Use
Red	Hardeman	Chillicothe	Greenbelt	61	58	56	56	55	55	Assume Greenbelt Meets 50% of Demands
Red	Hardeman	Chillicothe	Seymour	80	80	80	80	80	80	Current GW Use
Red	Hardeman	County-Other	Greenbelt	168	168	168	168	168	168	No Contract Amt., Supply = 1996 use
Red	Hardeman	County-Other	Seymour	116	116	116	116	116	116	Historical Max Use
Red	Hardeman	Irrigation (On-Farm)	Pauline/Groesbeck	145	145	145	145	145	145	Historical Max Use, ROR Groesbeck Creek and Lake Pauline
Red	Hardeman	Irrigation (On-Farm)	Blaine	7,000	7,000	7,000	7,000	7,000	7,000	Historical Max Use
Red	Hardeman	Irrigation (On-Farm)	Seymour	150	150	150	150	150	150	Historical Max Use

TABLE 2-28 (Continued)

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Red	Hardeman	Livestock	Local Supply	298	298	298	298	298	298	Historical Max Use, Stock Tanks
Red	Hardeman	Livestock	Seymour	198	198	198	198	198	198	Historical Max Use
Red	Hardeman	Manufacturing	Greenbelt	347	374	398	424	452	480	No Contract Amt., Supply = Demand
Red	Hardeman	Mining	Local Supply	7	7	7	7	7	7	Historical Max Use
Red	Hardeman	Quanah	Greenbelt	614	572	532	514	502	492	No Contract Amt., Supply = Demand
Red	Hardeman	Steam-Electric Power	Pauline/Groesbeck	1,655	1,601	1,548	1,494	1,440	1,387	Pauline/Groesbeck Creek Yield minus Irrigation use
Brazos	King	County-Other	Other Aquifer	4	4	4	4	4	4	Historical Max Use
Red	King	County-Other	Blaine	161	161	161	161	161	161	Historical Max Use
Red	King	Guthrie	Other Aquifer	86	86	86	86	86	86	Historical Max - Supplied By RRA From Dickens Co.
Red	King	Irrigation (On-Farm)	Blaine	750	750	750	750	750	750	Historical Max Use
Brazos	King	Livestock	Local Supply	255	255	255	255	255	255	Historical Max Use, Stock Tanks
Brazos	King	Livestock	Other Aquifer	28	28	28	28	28	28	Historical Max Use
Red	King	Livestock	Blaine	49	49	49	49	49	49	Historical Max Use
Red	King	Livestock	Local Supply	439	439	439	439	439	439	Historical Max Use, Stock Tanks
Trinity	Montague	Bowie	Amon G. Carter	2,457	2,420	2,382	2,345	2,307	2,270	Yield of Reservoir- Sales
Red	Montague	County-Other	Nocona	38	38	38	38	38	38	Historical Max Use
Red	Montague	County-Other	Other Aquifer	416	416	416	416	416	416	Historical Max Use
Red	Montague	County-Other	Trinity	0	0	0	0	0	0	Historical Max Use
Trinity	Montague	County-Other	Other Aquifer	300	300	300	300	300	300	Historical Max Use
Trinity	Montague	County-Other	Amon G. Carter	143	143	143	143	143	143	Historical Max Use
Red	Montague	Irrigation (On-Farm)	Other Aquifer	19	19	19	19	19	19	Historical Max Use
Red	Montague	Irrigation (On-Farm)	Nocona	100	100	100	100	100	100	Water Right 4879
Red	Montague	Irrigation (On-Farm)	Local Supply	100	100	100	100	100	100	Run-of-River Rights
Trinity	Montague	Irrigation (On-Farm)	Trinity	179	179	179	179	179	179	Historical Max Use
Trinity	Montague	Irrigation (On-Farm)	Local Supply	133	133	133	133	133	133	Historical Max Use – surface water
Red	Montague	Livestock	Other Aquifer	106	106	106	106	106	106	Historical Max Use
Red	Montague	Livestock	Local Supply	951	951	951	951	951	951	Historical Max Use, Stock Tanks

TABLE 2-28 (Continued)

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Trinity	Montague	Livestock	Trinity	79	79	79	79	79	79	Historical Max Use
Trinity	Montague	Livestock	Local Supply	714	714	714	714	714	714	Historical Max Use, Stock Tanks
Red	Montague	Manufacturing	Nocona	10	10	12	15	19	24	Historical Max Use/Future Demand
Red	Montague	Mining	Local Supply	313	313	313	313	313	313	Run-of-River Right, Hist Max
Red	Montague	Mining	Other Aquifer	310	310	310	310	310	310	Historical Max Use
Trinity	Montague	Mining	Trinity	18	18	18	18	18	18	Historical Max Use
Red	Montague	Montague	Other Aquifer	38	38	38	38	38	38	Historical Max Use
Red	Montague	Nocona	Nocona	1,112	1,112	1,110	1,107	1,103	1,098	Remainder of water right
Red	Montague	Saint Jo	Trinity	47	47	47	47	47	47	
Trinity	Montague	Saint Jo	Trinity	139	139	139	139	139	139	Historical Max Use
Red	Wichita	Burkburnett	Seymour	916	916	916	916	916	916	Historical Max - 10 Years
Red	Wichita	Burkburnett	Wichita System	2,795	2,795	2,795	2,795	2,795	2,795	Contract
Red	Wichita	County-Other	Wichita System	1,682	1,682	1,682	1,682	1,682	1,682	WSC Contracts In Wichita Co.
Red	Wichita	County-Other	Seymour	851	851	851	851	851	851	Historical Max - 10 Years
Red	Wichita	County-Other	North Fork Buffalo Creek	340	340	340	340	340	340	Iowa Park Sales to Wichita Co. WSC
Red	Wichita	Electra	Electra City Lake	440	440	440	440	440	440	Yield Study
Red	Wichita	Electra	Seymour	112	112	112	112	112	112	1998 Study
Red	Wichita	Iowa Park	North Fork Buffalo Creek	500	500	500	500	500	500	Water Right-Minus County Sales
Red	Wichita	Iowa Park	Local Supply	250	250	250	250	250	250	Half - Lake Iowa Park Water Right
Red	Wichita	Irrigation (On-Farm)	Kemp	71,354	67,972	63,686	59,402	55,126	54,109	90% of Available Irrigation Releases
Red	Wichita	Irrigation (On-Farm)	Seymour	712	712	712	712	712	712	Historical Max Use
Red	Wichita	Irrigation (On-Farm)	Other Aquifer	179	179	179	179	179	179	Historical Max Use
Red	Wichita	Livestock	Seymour	78	78	78	78	78	78	Historical Max Use
Red	Wichita	Livestock	Local Supply	700	700	700	700	700	700	Historical Max Use, Stock Tanks
Red	Wichita	Manufacturing	Wichita System	1,836	1,997	2,095	2,185	2,297	2,384	Demands – Existing contracts
Red	Wichita	Manufacturing	Seymour	216	216	216	216	216	216	Historical Max Use
Red	Wichita	Mining	Seymour	594	594	594	594	594	594	Historical Max Use
Red	Wichita	Pleasant Valley	Wichita System	101	100	95	93	91	90	No Contract Amt; Supply = Demands

TABLE 2-28 (Continued)

Basin Name	County Name	City Name	Source Name	Existing Supply (acre-feet/year)						Comment
				2000	2010	2020	2030	2040	2050	
Red	Wichita	Steam-Electric Power	Wichita System	360	360	360	360	360	360	Historical Max - 10 Years
Red	Wichita	Wichita Falls	Wichita System	28,118	27,893	27,689	27,489	27,266	27,068	Remainder of System Yield[1]
Red	Wilbarger	County-Other	Seymour	676	676	676	676	676	676	1997 Usage, 10-Year Max = 2,324 (1988)
Red	Wilbarger	County-Other	Electra City Lake	30	30	30	30	30	30	Municipal Sales From Electra to Harrolds WSC
Red	Wilbarger	Irrigation (On-Farm)	Seymour	23,989	23,989	23,989	23,989	23,989	23,989	Historical Max Use, Adjusted for availability limit
Red	Wilbarger	Livestock	Seymour	180	180	180	180	180	180	Historical Max Use
Red	Wilbarger	Livestock	Local Supply	1,617	1,617	1,617	1,617	1,617	1,617	Historical Max Use, Stock Tanks
Red	Wilbarger	Manufacturing	Seymour	685	685	685	685	685	685	Historical Max Use
Red	Wilbarger	Mining	Seymour	10	10	10	10	10	10	Historical Use
Red	Wilbarger	Mining	Local Supply	30	30	30	30	30	30	Run of River Right - 5127
Red	Wilbarger	Steam-Electric Power	Kemp	20,000	20,000	20,000	20,000	20,000	20,000	Water Right (Assume Contract Renewed)
Red	Wilbarger	Vernon	Seymour	2,640	2,640	2,640	2,640	2,640	2,640	Long-Term Average - Municipal (recent study)
Brazos	Young	Olney	Wichita System	1,121	1,121	1,121	1,121	1,121	1,121	Water Right
Brazos	Young	Olney	Local Supply	910	910	910	910	910	910	Lakes Olney/Cooper – reservoir yield

* The Wichita System yield was reduced by 2,429 acre-feet per year to account for demands by Sheppard AFB.

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A similar approach was taken for groundwater. However, in lieu of water rights and contracts, the historical maximum use (past 10 years) and groundwater availability were considered. For the cities of Vernon and Electra, which have recently had their groundwater supplies evaluated, the findings of these studies were used for long-term supply availability.

As a special case with mixed uses, the demands and water supply for Sheppard Air Force Base (AFB) were accounted for separately. Sheppard AFB receives most of its water supply from the city of Wichita Falls. Its current contract does not specify a minimum or maximum amount, but it is expected that Sheppard AFB will use approximately 2,429 acre-feet per year of water over the planning period. This amount is accounted for in the total available supply from the Wichita system shown on Table 2-28.

COMPARISON OF WATER DEMANDS TO CURRENT SUPPLIES TEXAS STATE SENATE BILL 1, REGION B

Current Supply

The current supply in Region B consists of surface water from in-region reservoirs, groundwater, local supplies, and interregional transfers. Based on 2000 yields, total in-region reservoir water supply in Region B is estimated at 180,500 acre-feet per year. This supply is projected to decrease by 14% to 155,000 acre-feet per year in 2050. The total developed groundwater supply in the region is about 59,000 acre-feet per year, with the Seymour Aquifer accounting for 71% and the Blaine Aquifer accounting for 21%. The Trinity Aquifer provides only a small portion of the region's available supply. Since groundwater availability generally does not include mining of the aquifers, groundwater supply is not projected to decline over the planning period. Local supplies consist of on-farm stock ponds, small reservoirs, and several run-of-the-river rights. Interregional transfers account for only a small percentage of total water supply in the region and include supply from Greenbelt Lake and groundwater from Dickens County. The total current available supply for the region is approximately 252,000 acre-feet per year. The existing distribution of supply by source type is shown on Figure 2-12.

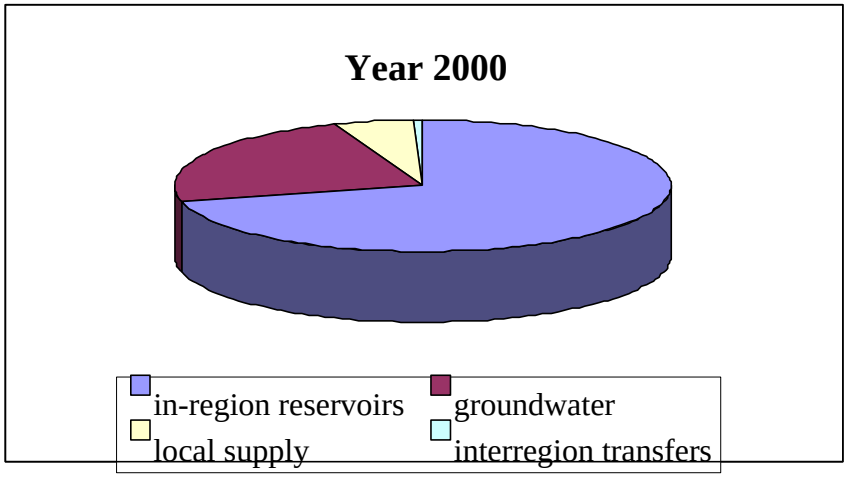

Figure 2-12. Distribution of Current Supplies.

Regional Demands

Regional demands were developed by city, county, and category. In summary, total demands for the region are projected to increase slightly from 169,600 to 183,200 acre-feet per year. The largest water demand category is irrigation, accounting for over 50% of total use. Municipal and steam-electric power are the next two largest water users in Region B. Mining is the smallest water demand category, accounting for less than 1% of total demands. Most of the demands by category are not anticipated to change much over the planning period, with the exception of steam electric power. A proposed new power plant in Archer County will significantly increase the demands for that category.

Comparison of Supply and Demand

A comparison of current supply to demand was performed using the projected demands and the allocation of existing supplies as evaluated under drought of record conditions. Allocations of existing supplies were based on the most restrictive of current water rights, contracts, and available yields for surface water and historical use and groundwater availability for groundwater. The allocation process did not directly address water quality issues, such as nitrates. Salinity was addressed to some extent by not assigning supplies with known high salinity levels for municipal use. This included Lake Kemp and most of the Blaine Aquifer. Further discussion of water quality issues and the effect on supply is presented in Section 4.4.

As a region, there is adequate supply to meet the region's needs. A comparison of the total regional supply to demand is shown on Figure 2-13. Comparisons for the three largest water use types, irrigation, municipal, and steam-electric power, are shown on Figures 2-14 through 2-16.

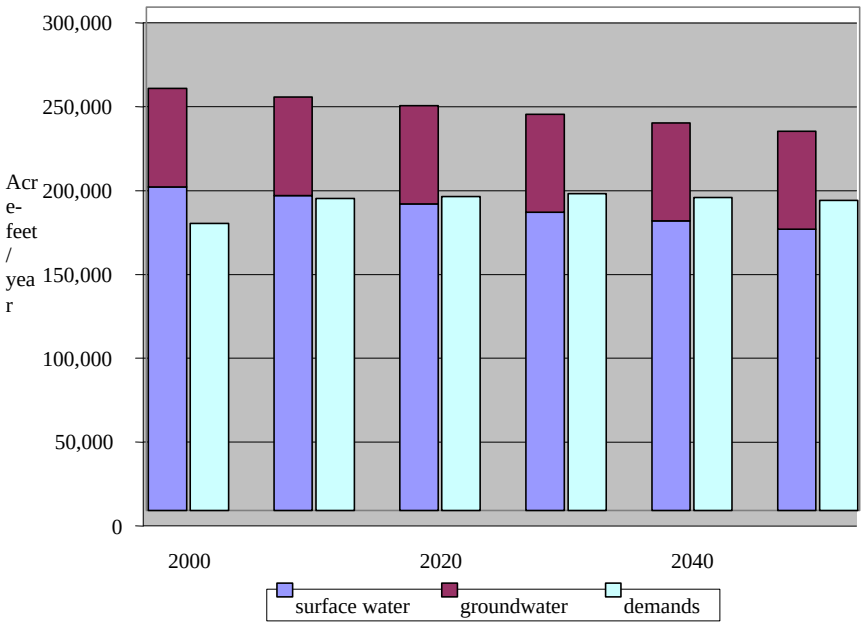

Figure 2-13. Supply and Demand for Region B.

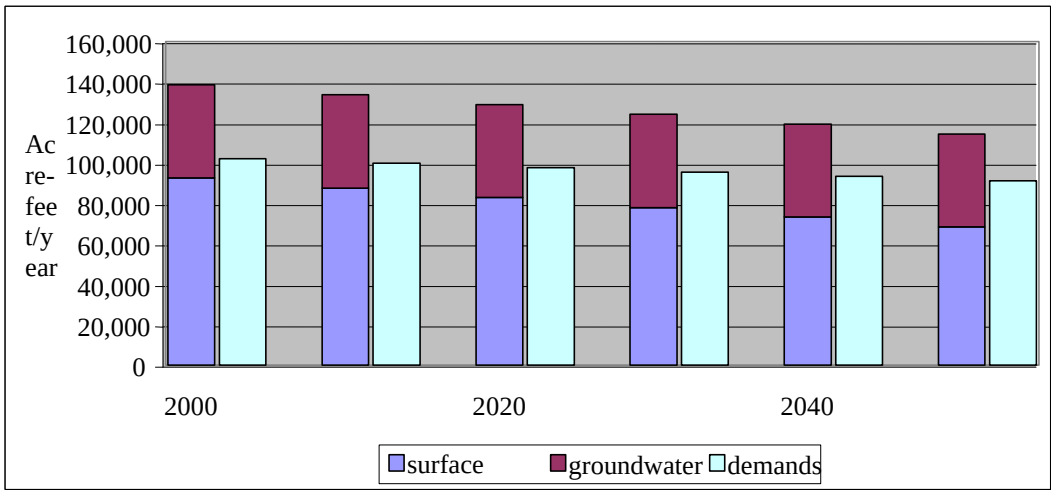

Figure 2-14. Irrigation Supply and Demand for Region B.

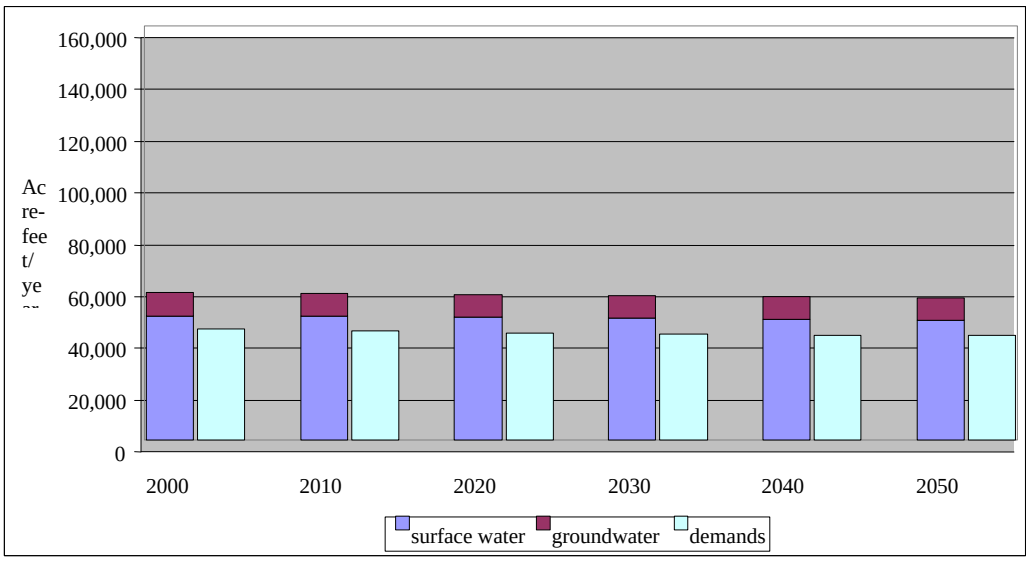

Figure 2-15. Municipal Supply and Demand for Region B.

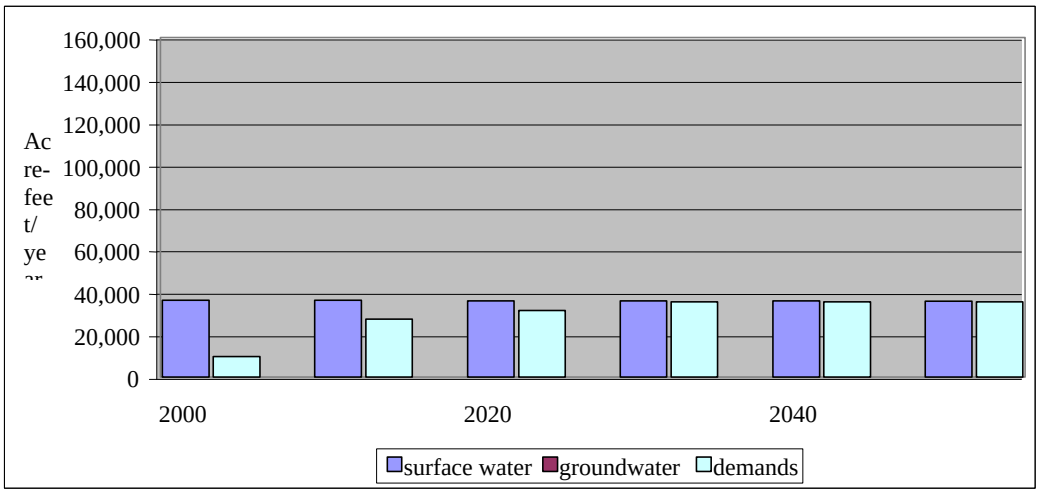

Figure 2-16. Steam-Electric Power Supply and Demand for Region B.

A summary of supply and demand by county for 2000 and 2050 is presented in Tables 2-29 and 2-30, respectively, and the comparison of supply versus demand by user group for Region B is presented on Table 2-31. There are only three identified shortages that cannot be met by existing infrastructure and supply - municipal needs of the city of Vernon; manufacturing needs in Wilbarger County, which are supplied by Vernon; and municipal needs of the city of Electra. These shortages are projected to be imminent, and both cities are currently investigating new supply sources and other alternatives. Discussion of the management strategies for these entities is presented in Chapter 5. Table 2-32 presents the identified water users with identified shortages over the planning period.

TABLE 2-29

COMPARISON OF SUPPLY VERSUS DEMAND BY COUNTY – YEAR 2000

County	Irrigation		Manufacturing		Mining		Municipal		Steam-Electric		Livestock	
	Supply	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**
Archer	4,891	3,600	0	0	1	0	2,752	1,688	14,000	0	2,711	2,711
Baylor	2,212	707	0	0	47	32	1,003	980	0	0	1,104	953
Clay	5,291	4,000	0	0	508	308	3,947	1,654	0	0	2,201	2,191
Cottle	4,584	4,434	0	0	23	25	870	796	0	0	476	387
Foard	5,255	4,978	0	0	23	23	494	393	0	0	291	289
Hardeman	7,295	4,999	347	347	7	3	1,039	936	1,655	1,000	496	480
King	750	20	0	0	0	0	365	355	0	0	771	771
Montague	531	297	10	7	641	627	4,907	2,921	0	0	1,850	1,850
Wichita	72,245	60,000	2,172	2,172	594	134	38,071	27,545	360	360	778	740
Wilbarger	23,989	19,071	**685**	**740**	40	24	**3,346**	**3,397**	20,000	8,100	1,797	1,797
Young							2,031	730				

TABLE 2-30

COMPARISON OF SUPPLY VERSUS DEMAND BY COUNTY – YEAR 2050

County	Irrigation		Manufacturing		Mining		Municipal		Steam Electric		Livestock	
	Supply	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**	**Supply**	**Demand**
Archer	3,100	3,100	0	0	1	0	2,690	1,471	14,000	14,000	2,711	2,711
Baylor	2,212	607	0	0	47	0	976	655	0	0	1,104	953
Clay	3,500	3,500	0	0	508	180	3,920	1,410	0	0	2,201	2,191
Cottle	4,584	3,808	0	0	23	30	753	520	0	0	476	387
Foard	5,255	4,275	0	0	27	27	411	295	0	0	291	289
Hardeman	7,295	4,293	480	480	7	2	911	806	1,387	1,000	496	480
King	750	20	0	0	0	0	356	303	0	0	771	771
Montague	531	297	24	24	641	490	4,689	2,321	0	0	1,850	1,850
Wichita	55,000	55,000	2,814	2,814	594	39	36,866	27,373	360	360	778	740
Wilbarger	23,989	16,377	**685**	**1,206**	40	24	3,346	3,267	20,000	20,000	1,797	1,797
Young							2,031	672				

TABLE 2-31

DIFFERENCE OF SUPPLY AND DEMAND BY USER GROUP

Water User Group	County	Basin	2000	2010	2020	2030	2040	2050
Archer City	Archer	Red	351	357	372	383	394	406
County-Other	Archer	Brazos	0	0	22	20	23	23
County-Other	Archer	Red	442	437	461	475	488	498
County-Other	Archer	Trinity	0	0	0	5	5	5
Holliday	Archer	Red	0	0	0	0	0	0
Irrigation	Archer	Red	1,291	548	365	183	1	0
Lakeside City	Archer	Red	214	211	204	202	206	208
Livestock	Archer	Brazos	0	0	0	0	0	0
Livestock	Archer	Red	0	0	0	0	0	0
Livestock	Archer	Trinity	0	0	0	0	0	0
Mining	Archer	Red	1	1	1	1	1	1
Scotland	Archer	Red	56	54	66	72	75	78
Steam-Electric Power	Archer	Red	14,000	0	0	0	0	0
County-Other	Baylor	Brazos	0	0	0	0	0	0
County-Other	Baylor	Red	8	13	15	17	17	18
Irrigation	Baylor	Brazos	1,335	1,350	1,364	1,378	1,392	1,406
Irrigation	Baylor	Red	170	177	182	188	194	199
Livestock	Baylor	Brazos	57	57	57	57	57	57
Livestock	Baylor	Red	94	94	94	94	94	94
Mining	Baylor	Brazos	15	26	37	42	47	47
Seymour	Baylor	Brazos	15	79	197	261	284	303
Byers	Clay	Red	0	4	11	15	16	15
County-Other	Clay	Red	1,420	1,483	1,556	1,598	1,659	1,610
County-Other	Clay	Trinity	11	27	39	44	50	50
Henrietta	Clay	Red	862	863	867	853	836	835
Irrigation	Clay	Red	1,291	548	365	183	1	0
Livestock	Clay	Red	0	0	0	0	0	0
Livestock	Clay	Trinity	10	10	10	10	10	10
Mining	Clay	Red	198	283	307	321	325	325
Mining	Clay	Trinity	2	3	3	3	3	3

TABLE 2-31 (Continued)

Water User Group	County	Basin	2000	2010	2020	2030	2040	2050
Petrolia	Clay	Red	0	0	0	0	0	0
County-Other	Cottle	Red	0	0	0	0	0	0
Irrigation	Cottle	Red	150	283	412	537	659	776
Livestock	Cottle	Red	89	89	89	89	89	89
Mining	Cottle	Red	0	0	0	0	0	0
Paducah	Cottle	Red	74	104	141	173	205	233
County-Other	Foard	Red	101	106	108	109	110	116
Crowell	Foard	Red	0	0	0	0	0	0
Irrigation	Foard	Red	277	426	571	712	848	980
Livestock	Foard	Red	2	2	2	2	2	2
Mining	Foard	Red	0	0	0	0	0	0
Chillicothe	Hardeman	Red	19	22	24	24	25	25
County-Other	Hardeman	Red	84	90	82	84	83	80
Irrigation	Hardeman	Red	2,296	2,446	2,591	2,732	2,869	3,002
Livestock	Hardeman	Red	16	16	16	16	16	16
Manufacturing	Hardeman	Red	0	0	0	0	0	0
Mining	Hardeman	Red	4	4	4	5	5	5
Quanah	Hardeman	Red	0	0	0	0	0	0
Steam-Electric Power	Hardeman	Red	655	601	548	494	440	387
County-Other	King	Brazos	1	1	1	3	3	3
County-Other	King	Red	0	0	0	0	0	0
Guthrie	King	Red	9	11	17	28	40	50
Irrigation	King	Red	730	730	730	730	730	730
Livestock	King	Brazos	0	0	0	0	0	0
Livestock	King	Red	0	0	0	0	0	0
Bowie	Montague	Trinity	1,367	1,404	1,411	1,392	1,361	1,327
County-Other	Montague	Red	66	96	116	142	161	157
County-Other	Montague	Trinity	91	172	195	232	265	323
Irrigation	Montague	Red	160	160	160	160	160	160
Irrigation	Montague	Trinity	74	74	74	74	74	74
Livestock	Montague	Red	0	0	0	0	0	0

TABLE 2-31 (Continued)

Water User Group	County	Basin	2000	2010	2020	2030	2040	2050
Livestock	Montague	Trinity	0	0	0	0	0	0
Manufacturing	Montague	Red	3	1	0	0	0	0
Mining	Montague	Red	14	134	156	162	156	143
Mining	Montague	Trinity	0	2	4	6	8	8
Montague	Montague	Red	0	0	0	0	0	2
Nocona	Montague	Red	415	448	479	492	500	502
Saint Jo	Montague	Red	12	16	14	14	14	15
Saint Jo	Montague	Trinity	35	44	39	40	41	42
Burkburnett	Wichita	Red	1,824	1,846	1,883	1,888	1,884	1,869
County-Other	Wichita	Red	2,214	2,164	2,157	2,165	2,164	2,181
Electra	Wichita	Red	-65	-63	-61	-51	-52	-57
Iowa Park	Wichita	Red	1,451	1,480	1,494	1,496	1,492	1,482
Irrigation	Wichita	Red	12,245	9,863	6,577	3,293	17	0
Livestock	Wichita	Red	38	38	38	38	38	38
Manufacturing	Wichita	Red	0	0	0	0	0	0
Mining	Wichita	Red	460	508	516	524	548	555
Pleasant Valley	Wichita	Red	0	0	0	0	0	0
Sheppard AFB	Wichita	Red	2,429	2,429	2,429	2,429	2,429	2,429
Steam-Electric Power	Wichita	Red	0	0	0	0	0	0
Wichita Falls	Wichita	Red	5,102	4,886	4,883	4,711	4,412	4,018
County-Other	Wilbarger	Red	221	194	189	186	187	170
Irrigation	Wilbarger	Red	4,918	5,490	6,045	6,583	7,105	7,612
Livestock	Wilbarger	Red	0	0	0	0	0	0
Manufacturing	Wilbarger	Red	-55	-164	-219	-286	-402	-521
Mining	Wilbarger	Red	16	17	16	16	16	16
Steam-Electric Power	Wilbarger	Red	11,900	8,000	4,000	0	0	0
Vernon	Wilbarger	Red	-272	-167	-137	-147	-105	-91
Olney	Young	Brazos	1,301	1,304	1,324	1,338	1,351	1,359

NOTE: Negative numbers indicate a shortage and positive numbers indicate allocated supply in excess of projected demands. Supply is based on allocations developed for Chapter 3, Appendix B, Table 5, incorporating the modifications specified on Table 4-2. Demands were developed in Chapter 2 and summarized in Appendix B, Table 2.

TABLE 2-32

IDENTIFIED SUPPLY NEEDS FOR REGION B

Water User Group	County	Basin	2000	2010	2020	2030	2040	2050
Electra	Wichita	Red	-65	-63	-61	-51	-52	-57
Manufacturing	Wilbarger	Red	-55	-164	-219	-286	-402	-521
Vernon	Wilbarger	Red	-272	-167	-137	-147	-105	-91

NOTE: Supply needs are based on firm yield analysis of surface water reservoirs and available supply from existing groundwater well fields.

EFFECT OF WATER QUALITY ON SUPPLY

Based on Table 2-31, an adequate supply of water is available for the various user groups and types of use within Region B as a whole. Many water user groups have supplies that exceed their projected needs. However, a few individual systems are projected to experience shortages of water during the planning period.

An implied assumption of the supply analysis is that the quality of existing water supplies is acceptable for the listed use. In other words, water supplies that are currently being used are assumed to continue to be available, regardless of the quality. However, SB1 also requires that water quality issues be considered when determining the availability of water during the planning period. For this report, evaluations of source water quality are generally confined to waters used for human consumption. The effect of Lake Kemp water quality on agricultural use is also reviewed.

Municipal Water Systems with Existing or Potential Quality Concerns

To determine whether the quality of specific sources of supply imposes a potential limitation on their use, the quality of the major sources of supply was compared to current and proposed drinking water standards. Pursuant to the Federal Safe Drinking Water Act, the U.S. Environmental Protection Agency (EPA) has adopted maximum contaminant levels (MCL's) for a list of organic and inorganic contaminants of drinking water. This list constitutes the primary drinking water standards, and water used for human consumption is to comply with the MCL's established by this list. The EPA is considering a number of changes to the primary drinking water standards. These potential changes include the addition of MCL's for a number of contaminants not currently on the list and the lowering of MCL's for some currently regulated contaminants. Consideration of the proposed standards when evaluating water quality is important because of the length of the planning horizon. Revised standards will be in effect long before 2050 and could potentially have a substantial impact on the availability of water supplies.

The consulting team reviewed the TNRCC records that identify systems that are not compliant with current and proposed primary drinking water standards. Compliance with secondary drinking water standards was not evaluated since secondary standards do not have the same regulatory and public health implications. Also, compliance with the bacteriological standards (total coliform and fecal coliform) was not evaluated since violations of these

standards, when they occur, are typically associated with operational techniques and not the quality of raw water supply. The water systems in Region B that have existing or potential non-compliances were identified, and the parameter of concern was also identified. Table 2-33 provides the results of the review.

TABLE 2–33

WATER SYSTEMS NOT COMPLIANT WITH PRIMARY DRINKING WATER QUALITY STANDARDS

Water System	County	Water Source	Current Standard NO_3 (MCL = 10mg/L)
Baylor WSC	Baylor	Seymour Aquifer	X
Seymour	Baylor	Seymour Aquifer	X
Byers	Clay	Seymour Aquifer	X
Charlie WSC	Clay	Seymour Aquifer	X
Thalia WSC	Foard	Seymour Aquifer	X
Burkburnett	Wichita	Seymour Aquifer and Wichita System	X
Friberg-Cooper WSC	Wichita	Seymour Aquifer	X
Electra	Wichita	Seymour Aquifer and Electra City Lake	X
Box Community Water System	Wilbarger	Seymour Aquifer	X
Lockett Water System	Wilbarger	Seymour Aquifer	X
Oklaunion WSC	Wilbarger	Seymour Aquifer	X
Hinds-Wildcat Water System	Wilbarger	Seymour Aquifer	X
Vernon	Wilbarger	Seymour Aquifer	X

The TNRCC records indicate that the only primary drinking water standard (other than bacteriological) currently exceeded by water users in Region B is the nitrate criterion. A total of 13 water users have water supplies that exceed the MCL for nitrate. There are also two systems that may not comply with the proposed arsenic drinking water standard. However, since the EPA has not published the preferred MCL for arsenic, it is premature to assess compliance with this standard.

Nitrate Concerns

The nitrate MCL is 10 mg/L. Consumption of water with nitrate levels in excess of 10 mg/L by infants can cause methemoglobinemia or "blue baby syndrome", a potentially fatal condition. Additionally, pregnant women are urged not to drink water with a high concentration of nitrates because of the potential health effects on the unborn fetus.

In Region B, moderate to high nitrate levels are found in water from the Seymour Aquifer. These concentrations are partly attributed to agricultural activities in the area. Long-standing practices associated with fertilizing crops are believed to have caused an increase in nitrates in the groundwater. Not all water produced from the Seymour Aquifer has excessive nitrates, but the water users shown in Table 2-33 have historically exhibited nitrate

concentrations that range from slightly above the MCL of 10 mg/L to over 25 mg/L, in some cases.

Removal of nitrates from water can be expensive. Reverse osmosis (RO) or a comparable advanced membrane technique is required. The city of Seymour is currently installing an RO system to improve its drinking water quality. Nitrates can also be reduced by blending the water with another water source with low nitrate levels, if such a source is available and is otherwise of acceptable quality. The TNRCC currently is urging all water systems in the region using water with high nitrate levels to reduce the nitrate concentration by treatment, by blending, or by securing an alternate source of water. Deadlines for these water users to achieve the drinking water standard for nitrate have not been set. However, it can be expected that the TNRCC will continue to work toward achieving this goal and may eventually set deadlines for compliance.

According to the demand projection, municipal water use for the 13 water users in Table 2-33 is estimated to be slightly less than 7,000 acre-feet in 2000, and usage is projected to remain relatively constant throughout the planning period. These users account for about 17% of all municipal water use in the region. For many of these users, groundwater from the Seymour Aquifer is the only supply source. For the cities of Burkburnett and Electra, groundwater is only a portion of their supply. The largest water users in Region B that exceed the nitrate MCL and the estimated current groundwater supply are as follows:

- Vernon (2,800 acre-feet)
- Burkburnett (916 acre-feet)
- Seymour (747 acre-feet)
- Baylor WSC (220 acre-feet)

The remaining water systems that exceed the nitrate MCL are projected to use approximately 700 acre-feet of water in 2000. Many of these systems have ongoing efforts to reduce the nitrate levels in their water. Several systems are working together to solve their problems. It is expected that the majority of these users will achieve substantial reductions within a few years. In some cases, the proposed program to improve the quality of the water supply includes obtaining water from another supplier or a different raw water source. These plans will be summarized in the discussion of alternative water supply plans presented in Chapter 5.

Because most affected water systems are expected to solve their nitrate problem within a few years, the estimated volume of water available from the Seymour Aquifer has not been reduced based on quality limitations. However, the Seymour Aquifer should not be considered as an available source for municipal water use beyond current usage, except in those areas where supplies do not exceed the nitrate MCL or a supply strategy is identified that provides for achieving compliance with the nitrate standard.

Arsenic Concerns

The concentration of arsenic in water supplies is regulated because arsenic is believed to be a carcinogen. Currently, the MCL for arsenic is 50 μg/L. However, adoption of a lower MCL has been under evaluation by the EPA for some time. Several alternative MCL's are currently being considered. According to the TNRCC, the EPA is considering a limit between 3 μg/L and 10 μg/L. The proposed MCL for arsenic is to be published for comments in May 2000, with the intent of adoption by September 2000.

Limited data available on the water sources in Region B suggest that Lake Arrowhead may contain arsenic levels above the lower limit of consideration. Several systems that rely entirely on water from Lake Arrowhead reported arsenic concentrations of 6 μg/L in 1999. Lake Arrowhead is a major source of water for the region and is used as supply for many water systems. While arsenic may be a potential water quality problem, further information is needed before it can be determined if any of the water in Region B is impacted because of the presence of arsenic. A decision by the EPA is needed regarding the revised MCL for arsenic. Also, additional testing of Lake Arrowhead water should be performed to determine more accurately the current arsenic levels in the lake. If the arsenic concentrations in Lake Arrowhead are found to exceed the new MCL, additional treatment or blending with another source may be required.

Salinity Concerns for Lake Kemp and Diversion Lake

Waters in the Wichita River Basin have historically exhibited high dissolved solids and chloride concentrations. Previous studies, dating back to 1957, have documented that the salt concentrations in the area significantly limit the use of these waters for municipal, industrial, and irrigation purposes.

In the 1960's, the U.S. Army Corps of Engineers (USACE) determined that an average of over 3,600 tons per day of chlorides was being discharged to the Red River system from natural and man-made sources. A project, known as the Red River Chloride Control Project, was designed to reduce the amount of salt contamination from eight of the Red River Basin's ten identified natural salt sources, three of which lie within the Wichita River Basin. To date, only one of the proposed chloride control facilities in the Wichita River Basin has been constructed and is operational at Area VIII. This low-flow dam structure on the South Wichita River (within the Lake Kemp drainage basin) retains low flows that are high in salts and diverts them via a pump station and pipeline to Truscott Brine Reservoir. Low-flow diversion dams are also planned for the Middle and North Wichita Rivers, salt source Area X, and Area VII. When constructed, high chloride water that would normally flow to Lake Kemp and Lake Diversion would be diverted to the Truscott Brine Reservoir.

Recent water quality data of the Lake Kemp/Diversion system indicate that chloride levels have decreased since completion of the first chloride control project, but they still limit water use. The primary uses impacted by the lakes' salt content are potable water supplies and irrigation. Water quality criteria established pursuant to the Safe Drinking Water Act consider high salt content aesthetically undesirable and it is regulated under secondary drinking water standards. Chloride, sulfate, and total dissolved solids concentrations are subject to the

secondary standards. The TNRCC-established criteria for these parameters are somewhat higher than EPA criteria, and water systems in Texas are subject to State criteria. Both TNRCC and EPA standards and typical Lake Kemp levels for these parameters are presented in Table 2-34.

TABLE 2-34
SECONDARY DRINKING WATER STANDARDS AND SALINITY LEVELS OF LAKE KEMP

Parameter	TNRCC Criteria	EPA Criteria	Lake Kemp/Diversion Typical Concentration
Chloride (mg/L)	300	250	800 – 1,200
Sulfate (mg/L)	300	250	550 – 800
Total Dissolved Solids (mg/L)	1,000	500	2,000 – 3,500

It is sometimes possible to use water with salt concentrations that exceed the drinking water criteria by blending it with water with lower salt content. This practice may be considered in the Wichita River Basin, but is often limited to emergency use only. At the present time, a blend containing less than 25% of the waters from Lake Kemp or Diversion Lake is typically necessary if TNRCC criteria are to be achieved. This obviously limits the extent to which waters from these reservoirs can be used for potable supply.

The salinity of irrigation water from Lake Kemp can also limit the crops to which it can be applied. Several systems for classifying the salinity of waters characterize the suitability of the water for various types of crops. One classification system developed by the U.S. Department of Agriculture (USDA) in 1954 identifies four classes of water, based on chloride concentration of the water, and describes the suitability of each class for irrigation. The classes and their corresponding description of suitability are as follows:

Class I **Low Salinity Water** Chloride < 250 mg/L	Water is considered excellent to good and suitable for most plants growing on most soils with little likelihood that soil salinity will develop.
Class II **Medium Salinity Water** Chloride > 250 mg/L, but < 750 mg/L	Water can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.
Class III **High Salinity Water** Chloride > 750 mg/L, but < 2,150 mg/L	Water cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.
Class IV **Very High Salinity** Chloride > 2,150 mg/L	Water is not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. Only very salt tolerant crops should be selected.

The water in Lake Kemp and Lake Diversion is generally Class III. Therefore, its use for irrigation is limited to plants with high salt tolerance. The USDA Plant Sciences Group has performed research on the salt tolerance of various herbaceous crops. Examples of salt tolerant crops include cotton, barley, sugar beet, Bermuda grass, and asparagus.

System Limitations

In addition to water supply and water quality issues, system limitations were identified for municipalities within the region. System limitations include water treatment plant design capacity, major water transmission pipelines, and associated pumping facilities. Distribution systems and storage facilities within a community were not addressed.

Municipal water systems are typically designed for peak flow conditions. The water supply analysis presented in Section 4.3 considered average day conditions and did not address limitations associated with peak demands. To assess peak demands for the municipalities in Region B, a peaking factor was applied to average day demands. Many larger municipalities provided this peaking factor based on historical use, and these are shown on Table 2-35. For those users without a known peaking factor, a factor of 2 was assumed.

TABLE 2-35

PEAK DAY DEMANDS

Water User Group	Average Day Demand (mgd) Year 2000	Peaking Factor*	Peak Day Demand (mgd) Year 2000
Archer City	0.29		0.57
Holliday	0.21		0.41
Lakeside City	0.16		0.32
Scotland	0.20		0.40
Seymour	0.65		1.31
Byers	0.08		0.16
Henrietta	0.62	2.0	1.25
Petrolia	0.09		0.18
Paducah	0.34		0.67
Crowell	0.28		0.56
Chillicothe	0.11		0.22
Quanah	0.55		1.10
Guthrie	0.07		0.14
Bowie	0.97	2.25	2.19
Nocona	0.62	1.66	1.03
Saint Jo	0.13		0.25
Burkburnett	1.68	1.70	2.86
Electra	0.55		1.10
Iowa Park	1.19		2.38
Pleasant Valley	0.09		0.18
Wichita Falls	20.47	2.25	46.06
Vernon	2.60		5.20
Olney	0.65	1.87	1.22

* For those cities without a given peaking factor, a factor of 2 was assumed.

Water treatment plant capacities for surface water treatment were provided from a TNRCC database and confirmed by the municipalities. Transmission pipeline capacities were estimated from pipe diameters and average flow velocities. The water users provided pumping capacities for the major transmission systems. Water treatment plant capacities were evaluated for all users who receive treated water from that system. For example, for the city of Wichita Falls, the sum of the peak demands for all treated water customers was compared to the capacity of the city's water treatment plant. For customers that receive both raw and treated water, a representative portion of the customer's peak demand for treated water was determined. In addition to the physical system limitations, a comparison of available supply to peak demands was made for those entities with a contract that specified a peak demand limit (e.g., city of Wichita Falls customers). A summary of the findings is presented on Table 2-36.

As shown on Table 2-36, only the city of Wichita Falls may experience system limitations due to the capacities of their water treatment facilities. The other municipalities within the region appear to have sufficient capacities to transport and treat peak demands. However, the city of Scotland and several water supply corporations in Archer County appear to have contractual limits that are less than the projected peak demands. Further review of their respective contracts and water use may be warranted to ensure that peak demands can be met.

System Operations and Reliability

The analysis for current surface water supplies within the region is based on the firm yield of the reservoirs. This approach is required by SB1 regulations, but is often not reflective of how reservoir yields have been determined in other planning efforts. Firm yield analyses determine the amount of water that is available on an annual basis during a repeat of historical drought of record conditions assuming that all the water in the reservoir is available for use. This means that the reservoir content will approach zero sometime during the drought period if the firm yield is used. This analysis is also based on historical rainfall and runoff for each reservoir. Experts at the University of Arizona's Climate Assessment Project for the Southwest recently indicated that Texas might be heading into a significant dry period. Since 1995, climatic patterns have shifted, bringing warmer, drier weather to the Southern United States. This phenomenon, called the Pacific Decadal Oscillation, usually lasts 20 to 30 years (San Antonio Express News 2/7/2000). If this happens, the region may be entering a new drought period that may surpass the historical drought of record, and the firm yield may overestimate the available water supply. However, it is still too early to assess the impact of this weather shift.

Based on these concerns and the uncertainties inherent with the yield analyses, the available water supply for the region may be less than estimated. For these reasons, most water supply systems will not allow their reservoir contents to drop to very low levels without utilizing alternative supplies and implementing drought contingency measures. Many cities within Region B have recently initiated drought contingency measures in response to continuing dropping reservoir levels and are actively considering alternative water sources.

TABLE 2-36

WATER USER GROUPS WITH SYSTEM LIMITATIONS

Water User Group	County	Supply Source	Basin	WTP	Transmission	Supply	Limit (mgd)	Peak Demand (mgd)					
								2000	2010	2020	2030	2040	2050
City of Wichita (treated water provider)	Wichita	Wichita System	Red	X			54.6	57.08	57.00	56.46	56.35	56.46	56.92
County - Other	Archer	Wichita System	Red			X	0.9	1.05	1.06	1.02	1.00	0.98	0.96
Scotland	Archer	Wichita System	Red			X	0.25	0.40	0.40	0.38	0.37	0.37	0.36

The limit specified for city of Wichita Falls is the existing capacity of the water treatment plant. The peak demands for the city of Wichita Falls are the sum of the peak demands of all customers with existing contracts for treated water. Customers who receive raw water are not included.

The limit for County – Other, Archer County, reflects existing contractual limits between the city of Wichita Falls and Archer County WSC's. County - Other peak day demands are based on the percentage of supply historically provided by the Wichita System.

The limit for Scotland is the contractual limit for treated water from the city of Wichita Falls. The peak demands are based on the projected demands for the city of Scotland with a peaking factor of 2.

To provide a more conservative estimate of the available surface water supply within the region, a safe yield analysis was conducted for the two largest reservoirs in Region B: Lake Kickapoo and Lake Arrowhead. Both lakes are operated by the city of Wichita Falls and provide a large portion of the municipal supply in Region B. Many users of smaller reservoirs in the region are supplemented with water from this system.

The safe yield analysis utilizes the same historical hydrology as the firm yield analysis, but assumes that a 1-year supply of water is reserved in the reservoir at all times. This analysis has been commonly used for water resource planning in this region in the past. However, the 1-year reserve amount may still be less than the preferred minimum operating content. For the city of Wichita Falls, severe drought contingency measures are initiated when the content of the Wichita System drops below 40% (137,000 acre-feet), which is much greater than a 1-year reserve. Using existing reservoir operation models, the safe yields for the Wichita System for 2000 and 2050 are estimated at 41,400 and 36,900 acre-feet per year, respectively. This represents a decrease in annual supply from the firm yield analysis of approximately 18% by 2050.

To assess the effect of this reduction in available supply on the city of Wichita Falls, a summary of supply and demand for the city is presented on Table 2-37. This analysis assumes that Wichita Falls' customers are entitled to their full contracted amounts, and any contracted supplies in excess of their needs are not available to the city of Wichita Falls. As a result, there are not sufficient supplies to meet contractual obligations and city of Wichita Falls demands. Therefore, the city of Wichita Falls may need to develop alternative supplies to maintain a minimum operation content of approximately 40,000 acre-feet in the Wichita System.

TABLE 2-37

SAFE YIELD ANALYSIS FOR THE WICHITA SYSTEM

Safe Yield Supply	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Kickapoo	12,400	12,300	12,200	12,100	12,000	11,900
Arrowhead	29,000	28,200	27,400	26,600	25,800	25,000
Wichita System	*41,400*	*40,500*	*39,600*	*38,700*	*37,800*	*36,900*
Existing Customers (Contracted Amount)	17,359	17,464	17,547	17,627	17,729	17,927
Manufacturing Increase (see Table 2-29)	270	302	330	357	389	414
Wichita Falls (remaining supply)	23,771	22,734	21,723	20,716	19,682	18,559
Demands						
Wichita Falls	22,946	22,905	22,676	22,621	22,665	22,836
Needs						
Wichita Falls	825	-171	-953	-1,905	-2,983	-4,277

Safe yield analyses were conducted using reservoir operation studies developed by TWDB (1997).

Summary of Regional Needs

In Region B, water supply needs were identified for three water users, Electra, Vernon, and manufacturing needs in Wilbarger County. This means that existing water supplies to these users will not support projected demand through the planning period. Both Vernon and Electra are aware of these needs and are currently looking for new water sources. There are existing supplies in excess of the demands in the region. These options will be explored in more detail.

In addition to water supply needs, the cities of Vernon and Electra are experiencing water quality issues with their groundwater supplies. Nitrates in excess of the current drinking water standard were identified for several Seymour Aquifer users in Baylor, Clay, Foard, Wichita, and Wilbarger counties. Approximately 5,400 acre-feet of allocated municipal supply do not meet the nitrate standard. These concerns are also currently being addressed by local entities and will be discussed further.

Salinity levels in area lakes and aquifers are a continuing water quality concern within the region. Existing chloride control projects, such as the Truscott Brine Reservoir, are reducing chloride concentrations in Lake Kemp and Lake Diversion, but the full impact has not been realized. Completion of the additional chloride control structures should further reduce the salinity levels in this water source. This will result in more water available for municipal use (by decreasing the required blending amount) and will enable irrigators to grow a wider diversity of crops.

The municipalities in Region B generally have sufficient system capacities to treat and transport available supplies, considering projected peak demand conditions. The city of Wichita Falls was the only identified city that may not be able to treat sufficient water to meet peak demands for all its treated water customers at the same time. This scenario may not happen; however, the water treatment plant capacity may limit the city in providing treated water to new customers or increase supply to existing customers.

Based on a safe yield analysis of the Wichita System, the city of Wichita Falls may need to utilize alternative supplies to maintain a 1-year reserve in the Wichita System. The city has municipal rights in Lake Kemp and Lake Diversion that could be used, but water quality issues limit this source. The city is currently exploring other alternatives to increase the reliability of their supplies.

Entities with Supplies in Excess of Needs

As shown on Table 2-38, there appears to be excess supply for the cities of Bowie (from Lake Amon G. Carter), Burkburnett, Iowa Park, and Olney. With the exception of Bowie, all these cities receive water from the Wichita System. For these cities, allocated supplies from the Wichita System are based on contract amounts that are determined from peak flow requirements. These contracts are used for supplemental supply needed to meet peak summer demands. Most likely, these cities do not receive the fully allocated annual amount, and therefore do not have a large surplus supply. This indicates that there may be additional supply for the city of Wichita Falls, but there is limited peak treatment capacity.

TABLE 2-38

WATER USER GROUPS WITH SUPPLY IN EXCESS OF NEEDS OF 1,000 ACRE-FEET/YEAR

Key	Water User Group	County	Basin	Source	2000	2010	2020	2030	2040	2050
**	Irrigation	Baylor	Brazos	Seymour	1,335	1,350	1,364	1,378	1,392	1,406
*	County-Other	Clay	Red	Wichita System	1,420	1,483	1,556	1,598	1,659	1,610
**	Irrigation	Hardeman	Red	Blaine	2,296	2,446	2,591	2,732	2,869	3,002
	Bowie	Montague	Trinity	Amon G. Carter	1,367	1,404	1,411	1,392	1,361	1,327
*	Burkburnett	Wichita	Red	Wichita System	1,824	1,846	1,883	1,888	1,884	1,869
*	County-Other	Wichita	Red	Wichita System	2,214	2,164	2,157	2,165	2,164	2,181
*	Iowa Park	Wichita	Red	Wichita System	1,451	1,480	1,494	1,960	1,492	1,482
	Irrigation	Wichita	Red	Kemp	12,245	9,863	6,577	3,293	17	0
**	Irrigation	Wilbarger	Red	Seymour	4,918	5,490	6,045	6,583	7,105	7,612
	Steam-Electric Power	Wilbarger	Red	Kemp	11,900	8,000	4,000	0	0	0
*	Olney	Young	Brazos	Wichita System	1,301	1,304	1,324	1,338	1,351	1,359

Key: * Receives all or portion of supply from the Wichita System.
** Receives all or most of supply from groundwater.

Note: Supplies in excess of needs are based on firm yield analysis. The city of Wichita Falls also shows an excess of needs for firm yield analysis, but indicates a shortage for safe yield analysis. Therefore, the city of Wichita Falls is not included on this table.

For irrigation uses in Baylor, Hardeman, and Wilbarger counties, water is supplied primarily from groundwater. Groundwater for irrigation is typically used on a local basis, and existing well fields may not be appropriate for other identified regional needs. However, the apparent reduction in irrigation use in these counties should reduce stress on the respective aquifers, allowing continued use from these sources for other needs. Other users with supplies in excess of 1,000 acre-feet per year include irrigation supply in Wichita County. This supply is allocated from Lake Kemp and may not be suitable for municipal needs due to its salinity levels.

As a major water provider, the city of Wichita Falls has supplies in excess of their customers' projected needs (Table 2-39). However, most of these supplies are committed by contracts. As discussed above, these contracts specify a daily maximum rate. If an annual amount as well as the daily rate is specified on future contracts, additional raw water may become available for other uses.

TABLE 2-39

COMPARISON OF WATER DEMANDS WITH CURRENT SUPPLIES BY MAJOR WATER PROVIDER

Major Water Provider Name	Major Water Provider Number	County Number	Basin Number	2000	2010	2020	2030	2040
Wichita Falls	944456	5	2	427	433	448	458	468
Wichita Falls	944456	5	2	402	398	419	432	444
Wichita Falls	944456	5	2	0	0	0	0	0
Wichita Falls	944456	5	2	214	211	204	202	206
Wichita Falls	944456	5	2	56	54	66	72	75
Wichita Falls	944456	39	2	1,425	1,427	1,435	1,439	1,442
Wichita Falls	944456	39	2	331	332	333	328	321
Wichita Falls	944456	243	2	1,877	1,895	1,935	1,945	1,955
Wichita Falls	944456	243	2	1,131	1,096	1,091	1,096	1,102
Wichita Falls	944456	243	2	2,149	2,156	2,161	2,166	2,171
Wichita Falls	944456	243	2	0	0	0	0	0
Wichita Falls	944456	243	2	0	0	0	0	0
Wichita Falls	944456	243	2	0	0	0	0	0
Wichita Falls	944456	243	2	4,902	4,686	4,683	4,511	4,212
Wichita Falls	944456	252	12	1,051	1,053	1,056	1,061	1,061
Wichita Falls	944456	Blank	Blank	11,000	11,000	11,000	11,000	11,000
Greenbelt MWA	20	99	2	0	0	0	0	0
Greenbelt MWA	20	38	2	0	0	0	0	0
Greenbelt MWA	20	65	2	0	0	0	0	0
Greenbelt MWA	20	78	2	0	0	0	0	0
Greenbelt MWA	20	65	2	0	0	0	0	0
Greenbelt MWA	20	96	2	0	0	0	0	0
Greenbelt MWA	20	99	2	0	0	0	0	0
Greenbelt MWA	20	Blank	Blank	0	0	0	0	0
Greenbelt MWA	20	Blank	Blank	3,707	3,611	3,548	3,435	3,297

Regional surface water reservoirs and groundwater supplies in excess of the allocated amounts are shown on Table 2-40. Most of these supplies are groundwater sources that are not currently developed, but may be utilized to meet projected needs. The North Fork Buffalo Creek Reservoir, the only reservoir not fully allocated, has an estimated reservoir yield slightly greater than the water right; however, the yield analysis was not based on direct reservoir measurements and may not accurately reflect true yield. If this source is considered for additional supply, a more detailed yield study will be needed.

TABLE 2-40

REGIONAL SUPPLIES NOT ALLOCATED TO A USER GROUP
(Greater than 1,000 acre-feet/year)

Source	County	2000	2010	2020	2030	2040	2050
Water Supply Source							
No. Fork Buffalo Creek Res.	Wichita	1,260	1,260	1,260	1,260	1,260	1,260
Groundwater Sources							
Seymour	Baylor	8,696	8,696	8,696	8,696	8,696	8,696
Seymour	Clay	7,114	7,114	7,114	7,114	7,114	7,114
Blaine	Cottle	22,575	22,575	22,575	22,575	22,575	22,575
Seymour	Cottle	8,473	8,473	8,473	8,473	8,473	8,473
Blaine	Foard	15,367	15,367	15,367	15,367	15,367	15,367
Seymour	Foard	7,105	7,105	7,105	7,105	7,105	7,105
Blaine	Hardeman	16,770	16,770	16,770	16,770	16,770	16,770
Seymour	Hardeman	17,815	17,815	17,815	17,815	17,815	17,815
Blaine	King	16,630	16,630	16,630	16,630	16,630	16,630
Trinity	Montague	2,020	2,020	2,020	1,570	1,570	1,168
Seymour	Wichita	10,896	10,896	10,896	10,896	10,896	10,896
Seymour	Wilbarger	6,973	6,973	6,973	6,973	6,973	6,973

Note: Surface water supplies are based on firm yield analyses.

IDENTIFICATION, EVALUATION, AND SELECTION OF WATER MANAGEMENT STRATEGIES, TEXAS STATE SENATE BILL 1, REGION B

Identified Regional Needs and Evaluation Procedures

Regional Needs. In Region B (Figure 2-17), water supply needs were identified for three categories: quantity, quality, and water supply system limitations. A total of 12 water user groups were identified with one or more of these need categories and are shown in Table 2-41. Only three water user groups, Electra, Vernon, and Wilbarger manufacturing, were identified with quantity needs. Several municipal suppliers have water quality issues, and the city of Wichita Falls may have system limitations. Since this initial evaluation of water supply was performed, many entities are addressing their needs. Several municipalities have constructed or are in the process of constructing water treatment systems to solve water quality concerns. The city of Wichita Falls has begun to expand their water treatment capacity, and Electra is pursuing

Regional Water Planning Area B
Vicinity Map

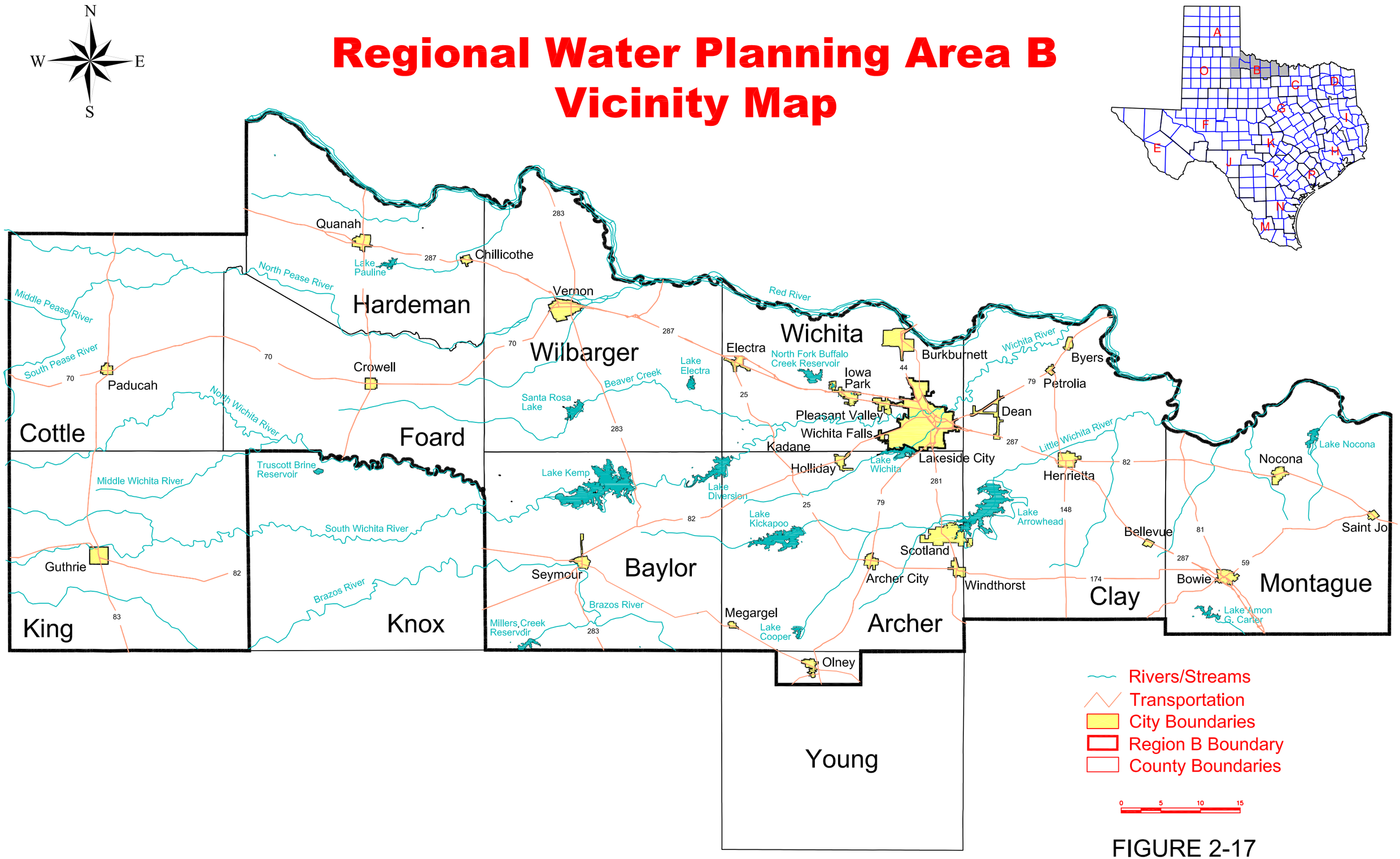

FIGURE 2-17

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additional groundwater supplies to meet its short-term needs. This section will address identified needs and the most recent developments by the water user groups when possible, and will evaluate strategies only for needs that have not been resolved. This section will also address regional strategies to improve reliability and quality of the region's water supply.

TABLE 2-41

WATER USERS WITH IDENTIFIED NEEDS

User	County	Water Supply Needs		
		Quantity	Quality	System
County Other	Baylor		X	
Seymour	Baylor		X	
Byers	Clay		X	
County Other	Clay		X	
County Other	Foard		X	
Burkburnett	Wichita		X	
County Other	Wichita		X	
Electra	Wichita	X	X	
Wichita Falls	Wichita			X
County Other	Wilbarger		X	
Manufacturing	Wilbarger	X	X	
Vernon	Wilbarger	X	X	

Note:
Baylor - County Other includes Baylor Water Supply Corporation
Clay - County Other includes Charlie Water Supply Corporation
Foard - County Other includes Thalia Water Supply Corporation
Wichita - County Other includes Friberg-Cooper Water Supply Corporation
Wilbarger - County Other includes Box Community Water System, Lockett, Oklaunion Water System, and Hinds-Wildcat

Evaluation Procedures. For each identified need, water supply strategies were developed based on discussions with the water user group and the Regional Water Planning Group (RWPG) Technical Advisory Committee. In accordance with SB1 guidance, the potentially feasible strategies were then evaluated with respect to:

- Quantity, reliability, and cost;
- Environmental factors;
- Impacts on water resources and other water management strategies;
- Impacts on agriculture and natural resources; and
- Other relevant factors.

The other considerations listed in TAC 357.7(a), such as interbasin transfers and third party impacts due to re-distribution of water rights, were not specifically reviewed because they were not applicable to strategies identified for Region B needs.

The definition of quantity is the amount of water the strategy would provide to the respective user group in acre-feet per year. This amount is considered with respect to the user's short-term and long-term needs. Reliability is an assessment of the availability of the specified water quantity to the user over time. If the quantity of water is available to the user all the time, the strategy has a high reliability. If the quantity of water is contingent on other factors, reliability will be lower. The assessment of cost for each strategy is expressed in dollars for water delivered and treated for end user requirements in acre-feet per year. Calculations of these costs follow SB1 guidelines for cost considerations and identify capital and annual costs by decade. Project capital costs are based on 1999 price levels and include construction costs, engineering, land acquisition, mitigation, right-of-way, contingencies, and other project costs. Annual costs include power costs associated with transmission, water treatment costs, water purchase (if applicable), operation and maintenance, and other project-specific costs. For Region B projects, all debt service was calculated over 30 years at a 6% interest rate, except for Lake Ringgold, which was calculated over 40 years.

Potential impacts to sensitive environmental factors were considered for each strategy. Such sensitive environmental factors included wetlands, threatened and endangered species, unique wildlife habitats, effects on environmental water needs, and cultural resources. In an attempt to quantify the impact of each strategy, existing environmental reports were reviewed in addition to cursory environmental surveys in the area of the proposed project. Based on the above stated environmental factors, each strategy was evaluated and a judgement made as to whether it would be considered low impact, moderate impact, or high impact. If a strategy is selected, a more detailed environmental evaluation may be required.

The impact on water resources considers the effects of the strategy on water quantity, quality, and use of the water resource. A water management strategy may have a positive or negative effect on a water resource. This review also evaluated whether the strategy would impact the water quantity and quality of other water management strategies identified.

A water management strategy could potentially impact agricultural production or local natural resources. Impacts to agriculture may include reduction in agricultural acreage, reduced water supply for irrigation, or impacts on water quality as it affects crop production. Some strategies may actually improve water quality, while others may have a negative impact. The impacts to natural resources may consider inundation of parklands, impacts to exploitable natural resources (such as mining), recreational use of a natural resource, and other strategy-specific factors.

Other relevant factors include regulatory requirements, political and local issues, public support, and time requirements to implement the strategy, recreational impacts of the strategy, and other socioeconomic benefits or impacts.

Strategies for Region B were developed to provide water of sufficient quantity and quality that is acceptable for its end use. As shown on Table 2-41, water quality is a primary concern for many users in Region B. Water quality issues affect water use options and treatment requirements. In evaluating the strategies, it was assumed that the final water product would meet existing State water quality requirements for the specified use. For example, a strategy that

provides water for municipal supply would meet existing drinking water standards, while water used for mining may have a lower quality. Strategies that improve water quality of other existing supplies, such as chloride control projects, were also considered.

A summary of all feasible strategies identified to meet needs in Region B is presented in the Strategies Matrix at the end of this chapter. The associated costs for each strategy are also summarized at the end of this chapter.

CITY OF WICHITA FALLS

Background

The city of Wichita Falls, located in Wichita County, has a population of approximately 104,000. It is the largest city in a radius of about 100 miles and shares economic and cultural ties with nearby communities and towns.

Water resources are an important element in the quality of life and economic well being of the city and its citizens. Surface water reservoirs serve all the municipal, industrial, agricultural, and recreational needs of the city, in addition to serving numerous neighboring cities and water supply corporations.

The service area of Wichita Falls is approximately 65% of the entire Region B population, and the municipal water demand on the Wichita Falls system accounts for approximately 65% of the total Region B municipal demand. With the majority of the municipal demand being dependent on the city of Wichita Falls for the next 50 years, it is imperative that management strategies be identified and evaluated to increase system reliability.

As required by SB1 regulations, the analysis for current water supplies within the region, including Lake Kickapoo and Lake Arrowhead, was based on the firm yield of the reservoirs. Firm yield analyses determine the amount of water that is available on an annual basis during a repeat of the historical drought of record condition assuming that all the water in the reservoir is available for use. Therefore, under the firm yield analyses, the reservoir is expected to approach zero sometime during the drought period. Also, the analysis is based on historical rainfall and runoff for each reservoir.

As discussed in the Region B Water Plan, experts at the University of Arizona's Climatic Assessment Project for the Southwest recently indicated that Texas could be heading into a significant dry period, which could potentially last for 20 to 30 years. If this occurs, the region may be entering a new drought period that surpasses the historical drought of record, and the available water supply from Lake Kickapoo and Lake Arrowhead may be less than estimated in the Region B Water Plan.

To provide a more conservative estimate of available surface water supply in Region B, a safe yield analysis was conducted for the two Wichita Falls reservoirs. This analysis utilizes the same historical hydrology as firm yield, but assumes that a 1-year supply of water is reserved in the reservoir at all times. The results of the safe yield analysis for the Wichita System for 2000

to 2050 were estimated at 41,400 and 36,900 acre-feet per year, respectively. This represents a decrease in annual supply from the firm yield analysis of approximately 18% by 2050 and will require the city to develop alternative supplies to meet their own water demands in addition to meeting all customer contractual obligations.

Though the safe yield analysis was performed assuming a 1-year supply of water remaining in the reservoirs, the city of Wichita Falls initiates emergency drought contingency measures when the reservoir levels drop to 30%, or 102,750 acre-feet capacity. At this stage, the remaining reserve is estimated to be 3 years.

Therefore, to maintain a minimum operational content in their reservoirs of from 1 to 3 years' reserve, the city of Wichita Falls will need to consider developing alternative water supply strategies.

Finally, as Wichita Falls increases their water supply and system reliability, the city's customers who have water quality needs, including the city of Burkburnett, the city of Byers, Charlie WSC, and Friberg WSC, will be able to purchase additional water from the Wichita System to blend with their groundwater supply to reduce the nitrates in compliance with State regulatory requirements.

Water Demands

Based on the safe yield analysis shown in Table 2-37, the comparison of supply and demand indicated a short-term need (through 2030) for the Wichita System of 1,905 acre-feet per year and a long-term need (through 2050) of 4,277 acre-feet per year. This analysis assumes that a 1-year supply remains in the reservoir at all times.

Should the city desire to maintain greater than a 1-year reservoir system reserve and keep reservoir operating levels above the emergency drought condition trigger level of 30% capacity (102,750 acre-feet), the city will need an additional water supply of 15,000 to 20,000 acre-feet per year through 2050.

Current Water Resources

The city of Wichita Falls currently utilizes two surface water reservoirs for their water supply, Lake Kickapoo and Lake Arrowhead.

Lake Kickapoo was constructed in 1946 for municipal water supply with an initial conservation capacity of 106,400 acre-feet. The reservoir is located approximately 18 miles southwest of Wichita Falls on the North Fork of the Little Wichita River in Archer County. The diversion rights from the reservoir total 40,000 acre-feet per year.

The projected firm yield of Lake Kickapoo in 2000 and 2050 are 15,945 and 15,343 acre-feet per year, respectively, and the projected safe yield of the lake in 2000 and 2050 is 12,400 and 11,900 acre-feet per year, respectively.

Raw water is conveyed from Lake Kickapoo to the secondary reservoir located in Wichita Falls through 18 miles of 39-inch transmission line. The main pump station is located at the dam with three intermediate booster stations along the route of the transmission line. The estimated maximum pumping capacity of the system is 27,500 acre-feet per year (25 mgd).

Lake Arrowhead was constructed in 1966 for municipal, industrial, and recreational use with an initial conservation capacity of 262,100 acre-feet. The reservoir is located approximately 10 miles southeast of Wichita Falls on the Little Wichita River in Clay County. The diversion rights from the reservoir total 45,000 acre-feet per year.

The projected firm yield of Lake Arrowhead through 2050 is 29,532 acre-feet, and the projected safe yield of the lake for 2000 and 2050 is 29,000 and 25,000 acre-feet per year, respectively.

Raw water is conveyed from Lake Arrowhead to the secondary reservoir in Wichita Falls through 10 miles of 54-inch transmission line. The main pump is located at the dam with an estimated maximum pumping capacity of 50 mgd.

Therefore, the combination of Lake Kickapoo and Lake Arrowhead (Wichita System) has a safe yield for 2000 and 2050 of 41,400 and 36,900 acre-feet per year, respectively. The maximum combined pumping capacity from the two lakes is estimated at 82,500 acre-feet per year (75 mgd).

Review of Alternative Water Supply Strategies

In consultation with the RWPG Technical Advisory Committee, four sources of additional water supply for the city of Wichita Falls were considered and are listed below:

- Wastewater Reuse - Approximately 11,000 acre-feet per year (10 mgd) of processed and treated effluent could be used for irrigation and industrial purposes or mixed with existing raw water supply at the secondary reservoir.
- Lake Kemp/Diversion - Approximately 25,150 acre-feet per year (23 mgd) of Kemp/Diversion water could be treated at the existing Cypress Water Treatment Plant (WTP) for municipal use.
- Lake Ringgold - Approximately 27,000 acre-feet per year (24.5 mgd) could be made available for municipal use by constructing a new lake near Ringgold.
- Regional Lake Kemp/Diversion Desalination Plant - 25,150 acre-feet per year (23 mgd) of Kemp/Diversion water could be treated at a new facility located near Lake Diversion for regional distribution.

Description of Potentially Feasible Alternatives

Each potentially feasible alternative is described below and shown in Figure 2-18.

City of Wichita Falls
Planning Alternatives

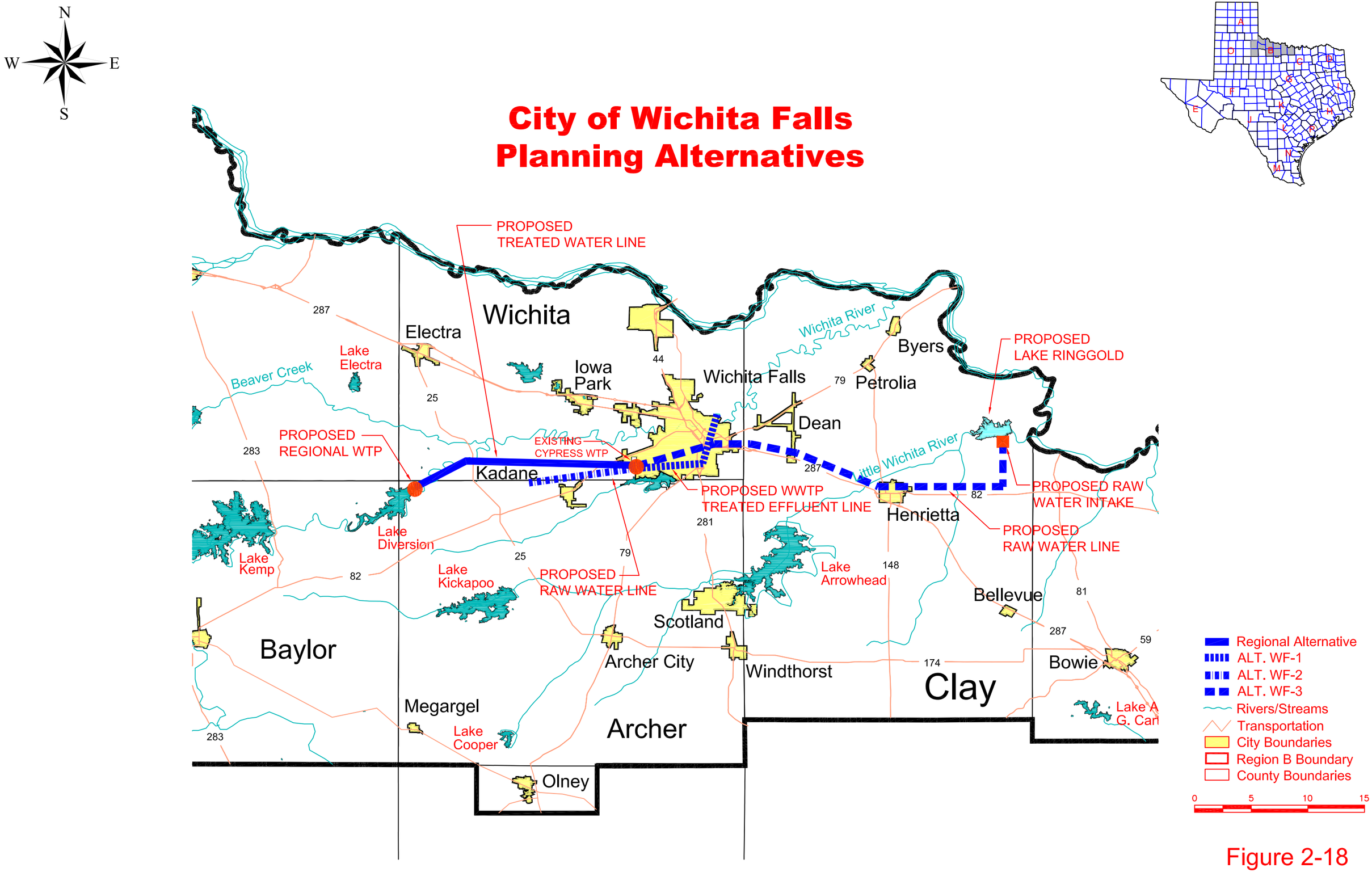

Figure 2-18

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Alternative WF-1: Wastewater Reuse.

Quantity, Reliability, and Cost. The city of Wichita Falls currently operates and maintains a wastewater treatment plant that discharges approximately 14,300 acre-feet per year (13 mgd) of very high quality treated effluent into the Wichita River for use downstream by other entities. This water would be a very reliable source for the city and could be utilized to decrease irrigation and industrial demands on the system and/or to increase municipal water supply by 11,000 acre-feet per year (10 mgd). To produce 10 mgd of reusable water, this alternative would require advanced treatment at the River Road Wastewater Treatment Plant (RRWWTP), including denitrification, microfiltration, and ultraviolet (UV) disinfection. In addition, a 30-inch pipeline and a 10-mgd pump station would be required to convey the water to the secondary reservoir prior to the final water treatment process and storage in an additional reservoir at the Jasper WTP. A summary of the capital and annual costs are presented below.

Construction Costs	
RRWWTP Denitrification Improvements	$6,000,000
Microfiltration Treatment	7,000,000
UV Disinfection	2,000,000
RRWWTP Pump Station	1,500,000
30-inch Pipeline to Secondary Reservoir (12 miles)	7,000,000
Storage Reservoir at Jasper WTP	1,500,000
10-mgd Pump Station and Water Treatment	9,000,000
Subtotal Construction Costs	$34,000,000
Other Project Costs	
Engineering, Legal, Financial, and Contingencies	$11,550,000
Land and Easements	100,000
Environmental Studies, Mitigation, and Permitting	400,000
Interest During Construction (18 Months)	2,650,000
Subtotal Other Costs	$14,700,000
Total Capital Project Costs	**$48,700,000**
Annual Costs	
Debt Service (30 years @ 6%)	$3,540,000
Operation and Maintenance	158,000
Power Costs (Pumping Facilities)	125,000
Water Treatment Costs ($0.50/1,000 Gallons)	$1,792,000
Total Annual Cost	**$5,615,000**
Available Water Yield (Acre-Feet Per Year)	11,000
Available Water Yield (mgd)	10
Cost of Water Delivered ($ Per Acre-Feet)	**$510**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$1.57**

Environmental Factors. This alternative would have low to moderate impacts on the environment since the pipeline route could be routed along the Holliday Creek Flood Control Project. In addition, the pump station would be located at the existing wastewater plant in an area of minimal impact.

Impact on Water Resources and Other Management Strategies. This alternative would have a low to moderate impact on the Wichita River in that the wastewater effluent would no longer be discharging into the river. During drought conditions, this could cause a noticeable affect on the quantity and perhaps the quality of water in the Wichita River immediately downstream from the wastewater plant. In addition, this alternative would reduce the quantity of water required from Lake Arrowhead and Lake Kickapoo reservoirs and could significantly delay the need to construct Lake Ringgold.

Impact on Agriculture and Natural Resources. This alternative would have minimal to no impact on agriculture and natural resources in that the route for the transmission pipeline is along a flood control creek. Also, although the flow from the treatment plant into the river would be significantly reduced, the effect would be minimal compared to the total flow of the river.

Other Relevant Factors. Public acceptance of this alternative may become an issue if perception prevails that properly treated wastewater effluent is a questionable source of raw water supply for the city due to unfounded health concerns or other misconceptions. In addition, this alternative will require a modification to the wastewater discharge permit, which could take 1 to 2 years.

Alternative WF-2: Water from Lake Kemp/Diversion Reservoirs.

Quantity, Reliability, and Cost. The city of Wichita Falls currently has water rights to 25,150 acre-feet of Kemp/Diversion water for municipal use. However, due to the high salinity content of the water, the city has not utilized it as a municipal water supply. Aside from water quality, this reservoir system would be a very reliable source of water supply in that it is in a different drainage basin than Lake Arrowhead and Lake Kickapoo.

To utilize 11,000 acre-feet per year (10 mgd) of Kemp/Diversion water, a pump station and approximately 13 miles of 42-inch transmission line would be required to convey the water from the reservoir system to the Cypress WTP located on the southwest side of Wichita Falls. In addition, Cypress WTP improvements will be required to include microfiltration and reverse osmosis (RO) for enhanced treatment of the high salinity water. Facilities will also need to be constructed to reject brine disposal into the Wichita River. A summary of the capital and annual costs is presented below.

Construction Costs	
12-mgd Pump Station Near Diversion	$2,000,000
42-inch Raw Water Line to Cypress Plant (13 miles)	15,500,000
10-mgd Microfiltration/Reverse Osmosis Treatment	22,500,000
Treatment Brine Reject Disposal	2,500,000
Subtotal Construction Costs	$42,500,000
Other Project Costs	
Engineering, Legal, Financial and Contingencies	$14,100,000
Land and Easements	160,000
Environmental Studies, Mitigation, and Permitting	500,000
Interest During Construction (18 months)	3,300,000
Subtotal Other Costs	$18,060,000
Total Capital Project Costs	**$60,560,000**
Annual Costs	
Debt Service (30 years @ 6%)	$4,403,000
Operation and Maintenance	205,000
Power Costs (Pumping Facilities)	50,000
Water Treatment Costs ($0.75/1,000 Gallons)	$2,688,000
Total Annual Cost	**$7,346,000**
Available Water Yield (Acre-Feet Per Year)	11,000
Available Water Yield (mgd)	10
Cost of Water Delivered ($ Per Acre-Feet)	**$668**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.05**

Environmental Factors. This alternative would have low to moderate impacts on the environment assuming the pipeline routes could be routed along highways or county roads. In addition, the pump station can be located in an area of minimal environmental impact. It is anticipated that brine discharge will be into the Wichita River.

Impact on Water Resources and Other Management Strategies. This alternative would have a low to moderate impact on the Lake Kemp/Diversion system in that the water levels in the lakes may have greater fluctuations as more water is utilized from this system. Also, with brine discharge into the Wichita River, the chloride content of the river may be impacted.

The quantity of water required from Lake Arrowhead and Lake Kickapoo reservoirs would be reduced using this alternative and could significantly delay the need to construct Lake Ringgold.

Impact on Agriculture and Natural Resources. This alternative would have a low to moderate impact on agriculture and natural resources, depending on the pipeline route selected.

Other Relevant Factors. This alternative would require the mixing of conventional treated water and water treated through a desalination process. Proper mixing and compatibility of the waters should be a consideration.

Alternative WF-3: Construct Lake Ringgold Reservoir.

Quantity, Reliability, and Cost. In the early 1980's, the city of Wichita Falls identified a potential reservoir site approximately 40 miles northeast of Wichita Falls, near the town of Ringgold. The site would be on the Little Wichita River, and studies have concluded that if constructed approximately 27,000 acre-feet per year (24.5 mgd) of water could be made available for municipal use.

This reservoir would be in the same drainage basin as Lake Arrowhead and Lake Kickapoo so it is anticipated that the water quality would be very similar to the existing reservoirs. The reliability of this water supply would be good; however, with the location of the Ringgold site being downstream and in the same drainage basin as the two existing lakes, the Ringgold Reservoir could be adversely affected during periods of extended drought. Also, in-stream flow requirements for new reservoirs will most likely reduce the estimated firm yield.

Of the 17,000 acres of land needed for the reservoir site, the city currently owns approximately 5,000 acres. Along with purchasing the remaining land for the site, additional facilities, including a lake intake structure, pump station facilities, and 40 miles of 54-inch transmission line, would be required to convey 27,000 acre-feet per year (24.5 mgd) of raw water into existing treatment facilities in Wichita Falls. A summary of the capital and annual costs are presented below.

Construction Costs	
Ringgold Reservoir (275,000-Acre-Feet Capacity)	$58,860,000
Pumping Facilities (Two 24.5 mgd)	6,000,000
54-inch Raw Water Line to Storage Reservoir (40 miles)	73,500,000
24.5-mgd Pumping Facility @ Storage Reservoir	3,000,000
24.5-mgd Water Treatment Facility	18,375,000
Subtotal Construction Cost	$159,735,000
Other Project Costs	
Engineering, Legal, Financial, and Contingencies	$52,232,000
Land and Easements	13,000,000
Environmental Studies, Mitigation, and Permitting	15,000,000
Interest During Construction (5 years)	47,487,000
Subtotal Other Cost	$127,719,000
Total Capital Project Cost	**$287,454,000**

Annual Costs	
Debt Service (Reservoir 40 years @ 6%)	$9,558,000
Debt Service (Pipeline/Pump Sta. 30 years @ 6%)	10,449,000
Operation & Maintenance	1,818,000
Power Cost (Pumping Facilities)	600,000
Water Treatment Costs ($0.25/1,000 Gallons)	$2,199,000
Total Annual Cost	**$24,624,000**
Available Water Yield (Acre-Feet Per Year)	27,000
Available Water Yield (mgd)	24.5
Cost of Water Delivered ($ Per Acre-Feet)	**$912**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.80**

Environmental Factors. This alternative would have a moderate impact on the environment with the inundation of over 9,000 acres of existing pastureland. In addition, pump stations and the pipeline into the city should be located in areas of low to moderate impact.

Impact on Water Resources and Other Management Strategies. This alternative would have a high impact on the water resources of the city in that an additional 275,000 acre-feet of reservoir storage would be created while increasing the water supply to Wichita Falls by 27,000 acre-feet per year. Although this alternative is the most expensive strategy, it would likely delay the need for the wastewater reuse project and/or the Lake Kemp/Diversion project beyond 2050.

Impact on Agriculture and Natural Resources. This alternative would have a moderate to high impact on agriculture in that well over 9,000 acres of pastureland or potential farmland would be inundated by the reservoir. Also, it is anticipated that the average daily flow in the Red River downstream of the Little Wichita River would be diminished significantly.

Other Relevant Factors. This alternative would require the city to obtain a permit from the TNRCC to impound water from the Little Wichita River. Since the city of Wichita Falls already has approximately 25,000 acre-feet of water rights in Lake Kemp/Diversion that are not currently being utilized, the burden of proof will be on the city to justify the need for this permit.

Depending on the availability of the land, permitting issues, and environmental issues, this project could take 8 to 10 years to complete.

Regional Water Treatment (Desalination) Plant Alternative (Lake Kemp/Diversion Reservoirs). This alternative is based on the city of Wichita Falls, the city of Vernon, and the city of Electra participating in a regional plan to utilize Lake Kemp/Diversion and construct a desalination plant at the reservoir site. The regional plan has the following costs allocated to the city of Wichita Falls as summarized below.

Total Regional Capital Project Cost	**$129,336,000**
City of Wichita Falls Portion (74%)	**$95,709,000**
Annual Cost	
Debt Service (30 years @ 6%)	$6,958,000
Operation and Maintenance	325,000
Power Cost (Pumping Facilities)	75,000
Water Treatment Costs ($0.75/1,000 Gallons)	$3,494,000
Total Annual Cost	**$10,852,000**
Available Water Yield (Acre-Feet Per Year)	14,300
Available Water Yield (mgd)	13
Cost of Water Delivered ($ Per Acre-Feet)	**$759**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.33**

CITY OF VERNON

Background

The city of Vernon is located in Wilbarger County in north Texas near the Texas-Oklahoma border. It is the largest city in the county with a population of about 12,500, which accounts for 80% of the total county population. As a result, the city of Vernon provides a large portion of the county's municipal water needs and nearly all the county's industrial water needs. Vernon currently obtains all of its water supply from wells in the Seymour Aquifer, mostly located north of the city. The supply and demand comparisons presented previously indicate that the long-term reliable supply from the city's existing well fields may not meet increasing demands. Also, water from the city's wells in the Seymour Aquifer has elevated nitrate levels, which are often slightly in excess of the U.S. EPA primary drinking water standard of 10 mg/L of nitrate as nitrogen.

Vernon provides water to local water supply corporations, including Box Community Water System, Hinds-Wildcat, Northside, Oklaunion WSC, and a small amount of water to the Lockett Water System. Each of these entities, with the exception of Northside, also has reported nitrate levels above the primary drinking water standard. In response to the nitrate levels in their water supply, the city of Vernon has begun design and construction of a nitrate removal system. An ion-exchange system should be completed and in operation by 2002. This system is capable of providing up to 5 mgd of treated blended water for Vernon and its customers. Box Community and Oklaunion water systems will then purchase the treated water blend from Vernon, solving their water quality issues. However, the infrastructure for the Hinds-Wildcat system is not currently designed to supply treated water from the proposed plant location, and Hinds-Wildcat will continue to receive water directly from the well field. Also, the city of Vernon provides only a portion of Lockett's water needs. Continued purchase of a small amount of treated water will not significantly reduce the nitrate levels in Lockett's water supply. It is

anticipated that Lockett will purchase low-nitrate treated water from Vernon by 2010 to blend with their existing supply.

Vernon is currently addressing the nitrate issues in its supply and the supply for some of its customers. Therefore, no additional water quality strategies will be identified for the city of Vernon, the Box Community Water System, and the Oklaunion Water System. However, water quality strategies will be identified for Hinds-Wildcat and Lockett since existing infrastructure does not readily support the purchase of treated water from the city of Vernon. The strategies identified for Vernon will focus on providing water supply for the city and manufacturing needs in Wilbarger County.

Water Demands

The comparison of supply and demand indicated short-term and long-term supply needs for the city of Vernon and manufacturing in Wilbarger County. Since the city of Vernon provides nearly all the water for county manufacturing, the water needs for both user groups will be examined together. The total short-term need (through 2030) for Vernon and manufacturing is estimated at 433 acre-feet per year, and the long-term need (by 2050) is 612 acre-feet per year. The analysis shows an immediate need in 2000, which can be temporarily met by over-drafting the city's existing groundwater sources and implementing conservation. However, additional water supplies will most likely be needed within the next decade.

Current Water Resources

The city of Vernon currently uses groundwater from two principal well fields, the Odell well field and the Winston well field. The Odell water supply wells are located approximately 12 miles north of the city, and the Winston wells are located 2 miles north of the Odell field. Water from these wells is pumped to a central storage tank at the Odell field, and then flows by gravity to the city for distribution. Since these well fields are operated as a single supply source, they are referred to collectively as the Odell-Winston well field. The reliable long-term yield of this system is approximately 2,800 acre-feet per year. Additional water supply wells are located within the city limits. These city wells have been used as needed to meet peak demands in the summer. The yield of the in-city wells is estimated at 560 acre-feet per year.

To reduce its demand on the Odell-Winston well field, Vernon has begun to use local wells for irrigation of parks and golf courses. Vernon is also proposing to directly connect Rhodia Industries to the city’s existing in-city well field. The in-city wells have high nitrate levels, which are undesirable for municipal use but do not affect the manufacturing use for Rhodia. These modifications will reduce the amount of water required for treatment.

Review of Alternative Water Supply Strategies

In consultation with the RWPG Technical Advisory Committee and city staff, ten sources of additional water supply for the city of Vernon were considered:

Treated surface water from

- Altus, Oklahoma
- Wichita Falls

Raw surface water from

- Altus, Oklahoma
- Wichita Falls
- A new dam on Wildcat Creek
- A new dam on Beaver Creek
- Lake Diversion (with desalination)

Additional groundwater from

- Round Timber Ranch Well Field (Altus, Oklahoma) or develop a new well field
- Enhanced recharge for existing well fields
- Industrial reuse

Treated and raw surface water from the city of Altus was eliminated because Altus does not want to sell any of its surface water from Tom Steed Reservoir. The comparative cost of these options is high because of the purchase costs and the fact that the water would have to be transported 35 miles across the Red River.

Two potential reservoir sites were reviewed as possible new sources of water. The dam on Beaver Creek would provide approximately 2,500 acre-feet per year of fair quality water. The Wildcat Creek site would provide about 1,700 acre-feet per year of fair to poor quality water. Both alternatives were eliminated because building such impoundments would be very expensive, and the supply may not be reliable. Permitting complexities would be high for a new reservoir, as would the institutional difficulties.

Industrial reuse would add an uncertain amount of fair to poor quality water to the city's existing water supply. Permitting complexities are expected to be moderate, but the institutional difficulties would be high. This option was eliminated because existing industries have indicated that they are not interested in industrial reuse.

Recharge rates of the Seymour Aquifer near Vernon's existing well fields may be increased by building small dams and infiltration wells in surface water drainage areas. An enhanced recharge program would add an uncertain amount of water to the city's existing supply. However, during a drought, the reliability is low and the quantity is small. Therefore, this strategy was not retained for detailed evaluation for additional water supply. The city of Vernon may still choose to develop an enhanced recharge program to increase the reliability of its existing supply, but this option alone would not provide sufficient supply to meet the projected needs.

Alternative strategies retained for detailed analysis are shown in Figure 2-19 and include:

- Purchase treated surface water from the city of Wichita Falls
- Purchase raw surface water from Lake Kickapoo
- Purchase groundwater from the city of Altus (Round Timber Ranch) or develop a new groundwater well field
- Purchase water from Lake Kemp/Diversion with desalination (regional option)

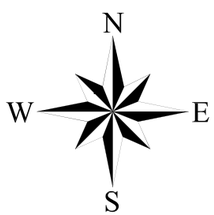
Description of Potentially Feasible Alternatives

Alternative V-1: Treated Surface Water from Wichita Falls. The city of Vernon would purchase up to 2 mgd of treated water from the city of Wichita Falls. The estimated purchase cost would be about $0.95 per thousand gallons. Water would be pumped approximately 42 miles to the city's existing 1.5-mg central storage tanks via an 18-inch pipeline from the existing Iowa Park pump station located east of the city of Iowa Park. The transmission pipeline would generally follow the right-of-way for Highway 287, crossing approximately seven major roads/highways. A new pump station with a metering vault would be located at the Iowa Park station. A booster station and 0.5-mg storage tank would be located along the route (approximately 30 miles west of Wichita Falls). This water would not require additional treatment.

Alternative V-2: Raw Surface Water from Lake Kickapoo. The city of Vernon would purchase up to 2 mgd of raw surface water from the city of Wichita Falls. The estimated purchase cost would be about $0.21 per thousand gallons. Water would be pumped approximately 45 miles via an 18-inch pipeline from Lake Kickapoo to a new surface water treatment plant. The transmission pipeline would generally follow a rural route, crossing approximately six roads/highways and one railroad. This alternative would require the construction of an intake structure and a new pump station with metering vault at Lake Kickapoo, and a booster station with a 0.5-mg storage tank. It also would require constructing a new 2-mgd surface water treatment plant.

Alternative V-3: Groundwater from Round Timber Ranch Well Field. The city of Altus is considering leasing their right to pump water from Round Timber Ranch to the city of Vernon. The Round Timber Ranch is located in Wilbarger County, Texas, near the Texas-Oklahoma border. This option would include re-development of 13 existing water wells, new well controls and pumps, and a new pumping station. The water would be pumped from the well field to a new 0.5-mg storage tank. From the tank, the water would be pumped approximately 11.5 miles through a new 14-inch transmission line to the Odell-Winston storage tank. The groundwater would then be transported to the city's treatment plant via an existing 21-inch pipeline. Previous water quality data indicate that Round Timber groundwater has nitrate levels at or just below the 10-mg/L limit. It is assumed that water from the Round Timber well field would be combined with existing Odell-Winston water and treated for nitrates at a similar treat/blend ratio. No additional treatment system will be required.

City of Vernon
Planning Alternatives



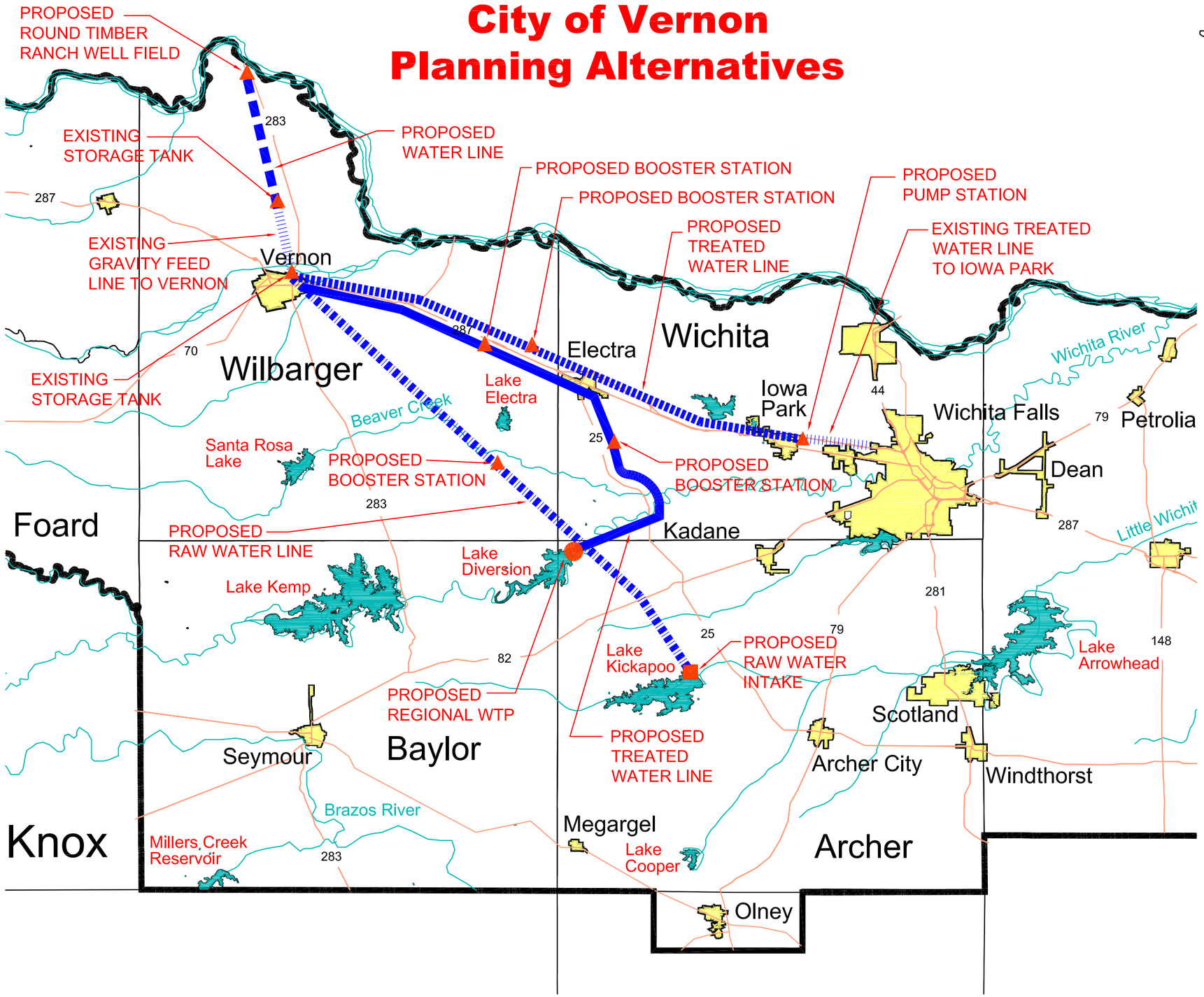


Figure 2-19

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Regional Water Treatment Plant Alternative (Lake Kemp/Diversion Reservoirs). A regional water supply project using Lake Kemp/Diversion water with desalination could provide the city of Vernon with 2 mgd of treated water. At Lake Diversion, the water would be treated by RO, and then pumped to the city of Vernon via a regional pipeline system to an existing 1.5-mg storage tank in Vernon. Further description of this alternative is presented in Section 5.6.

Analysis of Viable Strategies

Alternate V-1: Treated Surface Water from Wichita Falls.

Quantity, Reliability, and Cost. The quantity of water (2,200 acre-feet per year) would be sufficient to meet the city of Vernon's needs and projected needs for manufacturing in Wilbarger County. The city of Wichita Falls has sufficient water to provide to Vernon, but they have limited treatment capacity. Wichita Falls is currently expanding their water treatment plant by 20 mgd, which would be sufficient to provide treated water to Vernon. The reliability would be moderate since the supply is contingent on Wichita Falls' water supply, and Wichita Falls may limit their customers' supply during drought. The water cost for this alternative is estimated at $2.83 per 1,000 gallons. These costs are moderately high due to the long pipeline needed to transport the water from the Iowa Park pump station to Vernon. A summary of the capital and annual costs is presented below.

Construction Costs	
18-inch Pipeline	$9,536,000
ROW Costs	504,000
Pump Station (includes booster station and 0.5 mg storage tank)	630,000
Highway Crossings	126,000
Metering Vaults	16,000
Subtotal Construction Costs	$10,812,000
Other Project Costs	
Mitigation & Permitting	$324,000
Engineering/Contingencies	3,244,000
Interest during construction (24-month construction period)	1,124,000
Subtotal Other Costs	$4,692,000
Total Capital Project Costs	**$15,504,000**
Annual Costs	
Debt Service (30 years @ 6%)	$1,126,000
Operation and Maintenance	111,000
Pumping Costs	101,000
Treatment Costs	$0
Water Purchase Costs	$694,000
Total Annual Costs	**$2,032,000**

Available Water Yield (Acre-Feet Per Year)	2,200
Available Water Yield (mgd)	2
Cost of Water Delivered ($ Per Acre-Feet)	**$923**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.83**

Environmental Factors. Potential environmental impacts should be low since the route of the pipeline will generally follow Highway 287. The booster station required along the route can be located in an area of minimal environmental impact.

Impacts on Water Resources and Other Water Management Strategies. Water resources impacts should be low since the Wichita System has adequate yield; however, water levels in the lakes may have greater fluctuations as more of the system's yield is used. This may affect local lake owners and/or businesses on the lake. Other strategies that may be affected include sale of water from Wichita Falls to Electra via an existing pipeline to Iowa Park. This pipeline has sufficient capacity for the existing supply to Iowa Park and the city of Vernon, but it most likely cannot supply Electra, Vernon, and Iowa Park. Also, if Iowa Park utilizes its full contract amount from Wichita Falls, an additional transmission line may be needed to supply Vernon.

Impacts on Agriculture and Natural Resources. This strategy has minimal impacts on agriculture and natural resources. Since the pipeline follows an existing highway, there should be no impacts to agricultural lands, and there are no identified natural resources along the route. The water sold to Vernon from Wichita Falls is designated for municipal use and should not affect irrigation supply.

Other Relevant Factors. This strategy could be implemented between 2 and 5 years to meet Vernon's short-term and long-term needs. Permitting and regulatory requirements are expected to be few. At a minimum, a nationwide 404 permit and an NPDES storm water permit during construction would be required for the pipeline. As the pipeline route is finalized, additional coordination with State and local agencies regarding sensitive environmental factors may be needed. Also, if the pipeline affects State-owned lands, additional permits and/or a Grant of Easement may be required. This strategy would increase Wichita Falls' prominence as a regional water provider and may provide means for additional supply for growth after 2050. However, the city of Wichita Falls is currently rationing water in compliance with their drought contingency plan. The city may not be receptive to providing water to Vernon until additional water supply alternatives are developed.

Alternate V-2: Raw Surface Water from Wichita Falls.

Quantity, Reliability, and Cost. As with Alternate V-1, the quantity of water would be sufficient to meet the city of Vernon's needs and projected needs for manufacturing in Wilbarger County. The reliability is moderate since it is contingent on the firm yield of the Wichita System and may be subject to rationing during drought conditions. The costs for this alternative are estimated at $2.92 per 1,000 gallons. This is moderately high due to the long pipeline needed to

transport the water from Lake Kickapoo to Vernon and the construction of a surface water treatment plant. Operation of the water treatment plant would require additional city staff. Also, since the city of Vernon has made a commitment to the nitrate removal system, the city would need to maintain two different treatment systems.

Construction Costs	
18-inch Pipeline	$10,217,000
ROW Costs	540,000
Pump Station (includes booster station and 0.5 mg storage tank)	600,000
Crossings	136,000
Treatment Plant (2 mgd)	4,500,000
Kickapoo Intake structure/metering vaults	1,016,000
Subtotal Construction Costs	$17,009,000
Other Project Costs	
Mitigation & Permitting	$510,000
Engineering/Contingencies	1,700,000
Interest during construction (24 month construction period)	1,502,000
Subtotal Other Costs	$3,712,000
Total Capital Project Costs	**$20,721,000**
Annual Costs	
Debit Service (30 years @ 6%)	$1,506,000
Operation and Maintenance	117,000
Pumping Costs	74,000
Treatment Costs	251,000
Water Purchase Costs	$147,000
Total Annual Costs	**$2,095,000**
Available Water Yield (Acre-Feet Per Year)	2,200
Available Water Yield (mgd)	2
Cost of Water Delivered ($ Per Acre-Feet)	**$952**
Cost of Water Delivered ($ per 1,000 Gallons)	**$2.92**

Environmental Factors. The environmental impacts should be low to moderate depending on the route of the pipeline. It is assumed that the pipeline will travel in a direct route from Lake Kickapoo to Vernon. The booster station required along the route can be located in an area of minimal environmental impact.

Impacts on Water Resources and Other Water Management Strategies. There should be no water resources impacts since the Wichita System has adequate yield. However, water levels in the lakes may have greater fluctuations as more of the system's yield is used. This may affect local lake owners and/or businesses on the lake. This strategy should not affect identified

strategies for other users. The Wichita System has sufficient yield to supply both Vernon and Electra, and the city of Wichita Falls is reviewing strategies to further increase the reliability of this system.

Impacts on Agriculture and Natural Resource. The impacts to agriculture should be low since the water from Lake Kickapoo is designated for municipal use. There may be some minimal impacts to agricultural lands to allow for the right-of-way easement since the pipeline may not follow highways. Potential impacts to natural resources should be low. The pipeline could be routed to minimize impacts to natural resources.

Other Relevant Factors. This strategy could be implemented between 3 and 5 years to meet Vernon's needs. The permitting and regulatory requirements would be low to moderate. A Corps of Engineers 404 permit would be required for the raw water intake structure at Lake Kickapoo and the 45-mile transmission pipeline. With the present transmission route, the pipeline crosses several streams, including the Wichita River and Beaver Creek. As the pipeline route is finalized, additional coordination with State and local agencies regarding sensitive environmental factors may be needed. If the pipeline affects State-owned lands, additional permits and/or a Grant of Easement may be required. Also, the surface water plant design will require TNRCC approval. During construction, a storm water NPDES permit will be required. As with Alternative V-1, this strategy may provide means for additional supply for growth after 2050, but may be contingent on Wichita Falls developing additional supply.

Alternate V-3: Groundwater from Round Timber Ranch Well Field.

Quantity, Reliability, and Cost. A preliminary assessment of the groundwater supply at the Round Timber Ranch well field indicates that the well field could sustain an average water supply rate of 1.2 mgd, assuming average recharge conditions. During a drought, it is estimated that the well field could supply 1,100 acre-feet per year. This supply would be adequate to meet Vernon's projected needs through 2050, but may be able to provide for growth beyond 2050. The reliability is moderate to high, depending on local recharge and other groundwater use. The cost for this alternative is $1.16 per 1,000 gallons, depending on the purchase price from the city of Altus. This is relatively low because a pipeline would be needed only to the existing Odell-Winston well field, and the well field is already developed. A summary of the cost estimate follows.

Construction Costs	
Study of Well Field	$150,000
14-inch Pipeline	2,125,000
ROW Costs	138,000
Pump Station with 0.5 mg storage tank	410,000
Crossings, metering vaults, and well field tie-in	113,000
Re-development of wells/testing/pumps/well controls	300,000
Subtotal Construction Costs	$3,236,000

Other Project Costs	
Mitigation & Permitting	$93,000
Engineering/Contingencies	309,000
Interest during construction (12-month construction period)	145,000
Subtotal Other Costs	$547,000
Total Capital Project Costs	**$3,783,000**
Annual Costs	
Debit Service (30 years @ 6%)	$275,000
Operation and Maintenance	27,000
Pumping Costs	19,000
Treatment Costs	53,000
Water Purchase Costs	$55,000
Total Annual Costs	**$429,000**
Available Water Yield (Acre-Feet Per Year)	1100
Available Water Yield (mgd)	1
Cost of Water Delivered ($ Per Acre-Feet)	**$390**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$1.19**

Environmental Factors. The environmental impacts would be low because the pipeline route would follow existing roadways, and the well field is already in place. The waste stream from the nitrate removal system would be treated at the city's wastewater treatment plant.

Impacts on Water Resources and Other Water Management Strategies. There should be few impacts on water resources. The availability of water from the Seymour Aquifer is adequate to meet this additional demand. There are no other strategies that would be affected.

Impacts on Agriculture and Natural Resources. Threats to agriculture would be low since the well field has historically been used for municipal water supply, not farming. Also, the projected demands for irrigation in Wilbarger County are expected to decrease over the planning period.

Other Relevant Factors. This strategy could be implemented between 2 and 3 years. The permitting and regulatory requirements are expected to be few. A nationwide 404 permit would be required for the transmission pipeline from the Round Timber Ranch to the Odell well field. A storm water NPDES permit will be required during construction. Since the pipeline route generally follows existing roads, it is unlikely that additional permitting would be required. However, when the pipeline route is finalized, additional coordination with State and local agencies regarding other permitting or review requirements should be conducted. Since the quality of the groundwater is moderate, it is assumed that the water will require treatment for nitrates. Vernon is constructing a nitrate removal system for its existing supply, and the plant is

designed for expansion as needed. Also, the city of Vernon is already using groundwater and additional groundwater supply would complement its existing system.

Regional Water Treatment (Desalination) Plant Alternative (Lake Kemp/Diversion Reservoirs). This strategy is based on the city of Wichita Falls, the city of Vernon, and the city of Electra participating in a regional plan to utilize Lake Kemp/Diversion and construct a desalination plant at the reservoir site. The regional plan has the following costs allocated to the city of Vernon as summarized below.

Total Regional Capital Project Cost	**$129,336,000**
City of Vernon Portion (19%)	**24,574,000**
Annual Cost	
Debt Service (30 years @ 6%)	$1,787,000
Operation and Maintenance	166,000
Power Cost (Pumping Facilities)	36,000
Water Treatment Costs ($0.75/1,000 Gallons)	538,000
Water Purchase (From W.F. @ $0.21/1,000 Gallons)	$151,000
Total Annual Cost	**$2,678,000**
Available Water Yield (Acre-Feet Per Year)	2,200
Available Water Yield (mgd)	2
Cost of Water Delivered ($ Per Acre-Feet)	**$1,217**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$3.74**

HINDS-WILDCAT AND LOCKETT WATER SUPPLY SYSTEMS

As discussed, Vernon provides water to five local water supply systems. Due to the levels of nitrates in Vernon's current supply and the local Seymour Aquifer, several suppliers were identified with water quality needs. Most of these needs will be resolved with no additional capital improvements when Vernon's nitrate removal system is completed. Two systems, Hinds-Wildcat and Lockett, cannot receive treated water from Vernon without construction of a pipeline from Vernon's water treatment plant to the respective entity. Other options for these systems are limited due to their size and available resources. The primary source of water for this area is the Seymour Aquifer. Both systems currently employ a bottled water program for customers needing low nitrate water (pregnant women and babies under 1 year old). It is the intent of the Red River Authority of Texas, who owns and manages these water supply systems, to continue the bottled water program until such time that the required capital improvements can be completed.

Hinds-Wildcat Water Supply System

For the Hinds-Wildcat system, it would be cost prohibitive to install an individual nitrate removal system. The smallest size system is approximately 100 gpm, which is more than twice

the capacity needed. The only other alternative is a 2.5-mile, 6-inch pipeline from Vernon's treatment plant to the Hinds pump station located north of County Road 925. Vernon would then provide Hinds-Wildcat the same quantity of treated water blend (40 acre-feet per year), rather than raw water.

Quantity, Reliability, and Cost. The quantity of supply to Hinds-Wildcat is adequate for their needs, and the reliability will be high after Vernon develops one of the water supply strategies. The cost of the Hinds transmission system is moderately high because the pipeline must cross the Pease River and the quantity of water is small. A summary of the costs is presented below.

Construction Costs	
6-inch Pipeline	$238,000
ROW Costs	24,000
Pump Stations	250,000
Road Crossings	9,000
Railroad Crossings	18,000
River Crossings	18,000
Metering Vaults	16,000
Subtotal Construction Costs	$573,000
Other Project Costs	
Mitigation & Permitting	$13,000
Engineering/Contingencies	50,000
Interest during construction (6-month construction period)	12,000
Subtotal Other Costs	$75,000
Total Capital Project Costs	**$648,000**
Annual Costs	
Debt Service (30 years @ 6%)	$47,000
Operation and Maintenance	4,000
Pumping Costs	1,000
Treatment Costs	0
Water Purchase Costs	$0
Total Annual Costs	**$52,000**
Available Water Yield (Acre-Feet Per Year)	40
Available Water Yield (mgd)	0.036
Cost of Water Delivered ($ Per Acre-Feet)	**$1,300**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$4.00**

Environmental Factors. The environmental impacts would be low because the pipeline route would generally follow existing roadways. The pipeline would have to cross the Pease River, and there may be temporary environmental impacts during construction.

Impacts on Water Resources and Other Water Management Strategies. There should be no water resource impacts since no additional water is used from the Seymour Aquifer.

Impacts on Agriculture and Natural Resource. There should be no impacts on agriculture since no additional water is used from the Seymour Aquifer.

Other Relevant Factors. This strategy could be implemented between 2 and 5 years. The permitting and regulatory requirements are expected to be low. A 404 permit would be required for the transmission pipeline from Vernon to Hinds since it crosses the Pease River. As the pipeline routes are finalized, additional coordination with State and local agencies regarding sensitive environmental factors may be needed. An NPDES storm water permit will be required during construction. If a pipeline affects State-owned lands, additional permits and/or a Grant of Easement may be required.

Lockett Water Supply System

Alternative L-1 Pipeline from Vernon to Lockett. Vernon currently provides Lockett approximately 2 to 10 acre-feet per year of water via a 3- or 4-inch pipeline. The remainder of Lockett's supply (approximately 100 acre-feet per year) is from local wells in the Seymour Aquifer. To provide Lockett with low-nitrate treated water to blend with Lockett's existing supply, a new 6-inch pipeline would need to be constructed from Vernon's treatment plant to Lockett's ground storage tank. Vernon would then provide an additional 60 acre-feet per year of water to Lockett. This supply will be available when Vernon develops one of the potential water supply strategies.

Quantity, Reliability, and Cost. The cost for low nitrate water to Lockett is high due to the relatively long pipeline and small amount of water. Also, the purchase price for low nitrate water is higher than the blended supply provided to other customers. The cost per acre-foot presented below is based on the final blended supply for Lockett, not the purchase supply from Vernon. Costs to produce 40 acre-feet per year of supply from Lockett's existing well field are not included. According to the Red River Authority of Texas, these costs are relatively small, ranging from $ 0.35 to $ 0.75 per 1,000 gallons.

Construction Costs	
6-inch Pipeline	$827,000
ROW Costs	84,000
Pump Station	100,000
Highway Crossings	54,000
Metering Vaults	16,000
Subtotal Construction Costs	$1,081,000

Other Project Costs	
Mitigation & Permitting	$32,000
Engineering/Contingencies	108,000
Interest During Construction (12-month construction period)	51,000
Subtotal Other Costs	$191,000
Total Capital Project Costs	**$1,272,000**
Annual Costs	
Debt Service (30 years @ 6%)	$92,000
Operation and Maintenance	13,000
Pumping Costs	700
Treatment Costs	0
Water Purchase Costs	$48,000
Total Annual Costs	**$153,700**
Available Water Yield (Acre-Feet Per Year)	109
Available Water Yield (mgd)	0.10
Cost of Water Delivered ($ Per Acre-Feet)	**$1,405**
Cost of Water Delivered ($ Per 1,000 Gallons	**$4.31**

Environmental Factors. The environmental impacts would be low because the pipeline route would generally follow existing roadways.

Impacts on Water Resources and Other Water Management Strategies. There should be no water resource impacts since no additional water from the Seymour Aquifer is used.

Impacts on Agriculture and Natural Resources. Impacts to agriculture should be minimal. For the Lockett system, purchasing additional water from Vernon may increase available supply for agriculture in the vicinity of the Lockett well field.

Other Relevant Factors. This strategy could be implemented between 2 and 5 years. The permitting and regulatory requirements are expected to be low. The Lockett pipeline project may only require a nationwide 404 permit if it does not affect State-owned waters. As the pipeline route is finalized, additional coordination with State and local agencies regarding sensitive environmental factors may be needed. An NPDES storm water permit will be required during construction. If the pipeline affects State-owned lands, additional permits and/or a Grant of Easement may be required.

Alternative L-2 Nitrate Removal System. Alternatively, Lockett could install a small nitrate removal system to treat high nitrate water pumped from its existing well system. Lockett would continue to purchase a small amount of the treated blended water from Vernon to supplement its peak demands in the summer. It is assumed that a 100-gpm ion exchange treatment plant would be sufficient to treat Lockett's current supply and meet peak flows. The

plant would be installed near Lockett's well field and storage tank. The waste stream from the treatment plant would be small, approximately 0.5 gpm. There are no known wastewater treatment plants near the Lockett well field. Therefore, the waste stream would discharge to a 0.25-acre evaporation pond, located near the treatment plant. Based on existing water quality data, a 60% treated to 40% untreated blend would result in nitrate concentrations below the drinking water standard.

Quantity, Reliability, and Cost. The quantity of water would be sufficient to meet Lockett's needs, provided Lockett continues to supplement their peak summer demands with purchased water from Vernon. The reliability is high and the cost for a nitrate removal system is relatively low. The cost per acre-foot is based on the final blended supply for Lockett. For comparison purposes to Alternative L-1, the costs to produce supply from Lockett's existing well field are not included. According to the Red River Authority of Texas, these costs are relatively small, ranging from $ 0.35 to $ 0.75 per 1,000 gallons, which would be added directly to the cost per 1,000 gallons shown below.

Construction Costs	
Ion-Exchange Equipment (100 gpm)	$175,000
Building/Electrical	150,000
Evaporation Pond (.25 acres)	30,000
Land Purchase	10,000
Subtotal Construction Costs	$365,000
Other Project Costs	
Permitting	$15,000
Engineering/Contingencies	110,000
Interest During Construction (12-month construction period)	20,000
Subtotal Other Costs	$145,000
Total Capital Project Costs	**$510,000**
Annual Costs	
Debt Service (30 years @ 6%)	$37,000
Operation and Maintenance	5,000
Pumping Costs	0
Treatment Costs	5,000
Total Annual Costs	**$47,000**
Available Water Yield (Acre-Feet Per Yield)	109
Available Water Yield (mgd)	0.10
Cost of Water Delivered ($ Per Acre-Feet)	**$431**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$1.32**

Environmental Factors. The environmental impacts would be low because there will be no discharge of the brine wastewater stream. Also, the salt concentration of the waste stream should not be very high.

Impacts on Water Resources and Other Water Management Strategies. There should be no water resource impacts since no additional water is used from the Seymour Aquifer. The nitrate removal system improves the water quality of the supply from the Seymour Aquifer.

Impacts on Agriculture and Natural Resources. Impacts to agriculture should be low. A minimum of 1 acre of existing agricultural land would need to be purchased for the treatment plant and evaporation pond. No additional water would be pumped from the Seymour Aquifer. Therefore, there should be no additional impacts to agricultural supply.

Other Relevant Factors. This strategy could be implemented between 2 and 5 years. The permitting and regulatory requirements are expected to be moderate. The water treatment plant would require approval from TNRCC and the system would require a no discharge wastewater permit. An NPDES storm water permit will be required during construction. This alternative may require additional staff to maintain and operate the system. Also, the evaporation ponds may require periodic disposal of accumulated salt deposits.

CITY OF ELECTRA

Background

The city of Electra is located in Wichita County between Wichita Falls and Vernon on Highway 287. Electra has a population of 3,100. Approximately 60% of the city's drinking water is currently derived from surface water (Lake Electra). Groundwater from the Seymour Aquifer provides the remainder of the city's water supply.

With recent droughts, the city of Electra has frequently experienced a shortage of water. As of March 2000, curtailment of water usage on the city's part had been ongoing for at least 36 months, and the city had implemented Stage 5 of its drought contingency plan.

In an application to the Texas Water Development Board Drinking Water State Revolving Fund, filed on behalf of the city in February 2000, it was estimated that only a 6-month supply of water was left in Lake Electra, the city's main water supply source. In March, the news media placed Lake Electra at only 20% of capacity.

Because of Electra's recent water shortage, it has already begun taking measures to acquire water to meet its immediate and short-term needs. The long-term needs of Electra will be addressed in the following sections.

Water Demands

Electra provides service to approximately 1,650 connections including the Harrold Water Supply Corporation. Current normal usage (no drought restrictions enforced) averages about 0.54 mgd (605 acre-feet per year) with peaks of 0.9 mgd according to the city's consulting engineer, Donald G. Rauschuber and Associates, Inc. (DGR).

Water use projections established by the TWDB show Electra's 2000 demand to be 0.55 mgd (617 acre-feet per year). Assuming a peaking factor of two, the projected peak demand would be 1.10 mgd. The TWDB demand projections decline gradually to 609 acre-feet per year by 2050.

In addition to TWDB demands, water demand projections have been performed for the city by DGR. DGR projections extend to 2020. The DGR demands projections anticipate much more industrial and population growth for Electra than the TWDB projections. DGR projects Electra's water demand in 2020 at about 1,100 acre-feet per year.

For SB1 planning purposes, 617 acre-feet per year demand will be evaluated by the alternatives in this report. The DGR demands are given here for informational purposes. The DGR demand projections are important because the system improvements currently being undertaken by Electra will use the higher projected demand predictions in the sizing of facilities and appurtenances.

Current Water Resources

Lake Electra. Lake Electra is a small-to-medium-sized reservoir located approximately 7 miles southwest of the city. The lake is located on land owned by the W. T. Waggoner Estate. An agreement between W. T. Waggoner Estate and the city grants rights to the water in the reservoir to the city, but the W. T. Waggoner Estate retains ownership of the land and dam that forms the lake. W. T. Waggoner Estate also pumps some water from the lake for its own use, including watering livestock and irrigating crops. Additional facilities related to this water source and owned by the city include a raw water pump station, a raw water transmission line to town, and a water treatment plant, known as the "Central Plant," located in town.

Approximately 60% of Electra's water is currently produced from Lake Electra. Due to its small drainage area, Lake Electra has historically been unreliable in drought conditions. Additional water sources are needed to supplement available water and improve reliability.

River Well Field. The remaining water supply for Electra is a shallow water well field located approximately 8 miles north of town near the Red River. While the well field is generally an abundant source of supply, its water quality has been a problem. Over time, salinity and nitrate levels in the wells have risen. As a result, the city has been forced to shut down and cap some of the wells. Capacity of the remaining wells currently averages 220,000 gallons per day (gpd).

The city also operates a sand filter treatment plant at the well field, known as the "River Plant," and a transmission pipeline to town. The treatment plant is in place because the water pumped from the wells is considered by the TNRCC to be "groundwater under the influence of surface water" and, by regulation, must be treated. The transmission pipeline consists of two parallel 8-inch lines extending from the treatment plant to a booster pump station located midway to town. From the booster station to town, the line is a single 10-inch line.

In addition, the city maintains a water pumping lease on land near the River Plant. The lease was established to allow the city to drill wells and pump water. However, well development has not yet taken place on the lease property.

Review of Alternative Water Supply Strategies

Alternative water supply strategies were identified through consultation with Electra's engineer and the RWPG Technical Advisory Committee. Initially, 11 potential water supply options were investigated. The preliminary investigation reviewed alternatives related to development of new groundwater supply, development of new surface water supply, and purchase of treated water. Most alternatives were eliminated in the preliminary investigation by one or more fatal flaws. Only four alternatives were found to be potentially feasible. These alternatives are discussed here in more detail. Detailed analysis of these alternatives was performed using procedures required by the TWDB.

The potentially feasible options selected for detailed analysis are shown in Figure 2-20 and include:

1. Redevelop existing capped wells and construct a RO plant at the River Well Field;
2. Construct a new raw water pipeline from Lake Diversion and construct a RO plant at the Central Plant;
3. Buy treated water from Wichita Falls; and
4. Participate in a regional water treatment plant using Lake Kemp/Lake Diversion water.

A detailed description and analysis of each potentially feasible alternative follows.

Alternative E-1: River Well Field. Electra has made a commitment to meet its existing and short-term demands with a plan to redevelop the capped wells at the existing well field located north of town. The plan would increase its yield of the groundwater resource and reduce its dependence on Lake Electra. A design-build contract for this plan has been awarded, and the well field and treatment plant improvements are scheduled to go on-line in October 2000.

In addition to the existing well field to be redeveloped, the well plan includes three potential well fields - Lalk, Sefcik, and Elliot. The fields range from 2 to 6 miles away from the existing treatment plant. As demand requires, new wells would be drilled at the other well field sites and water would be piped to the existing treatment plant.

City of Electra
Planning Alternatives

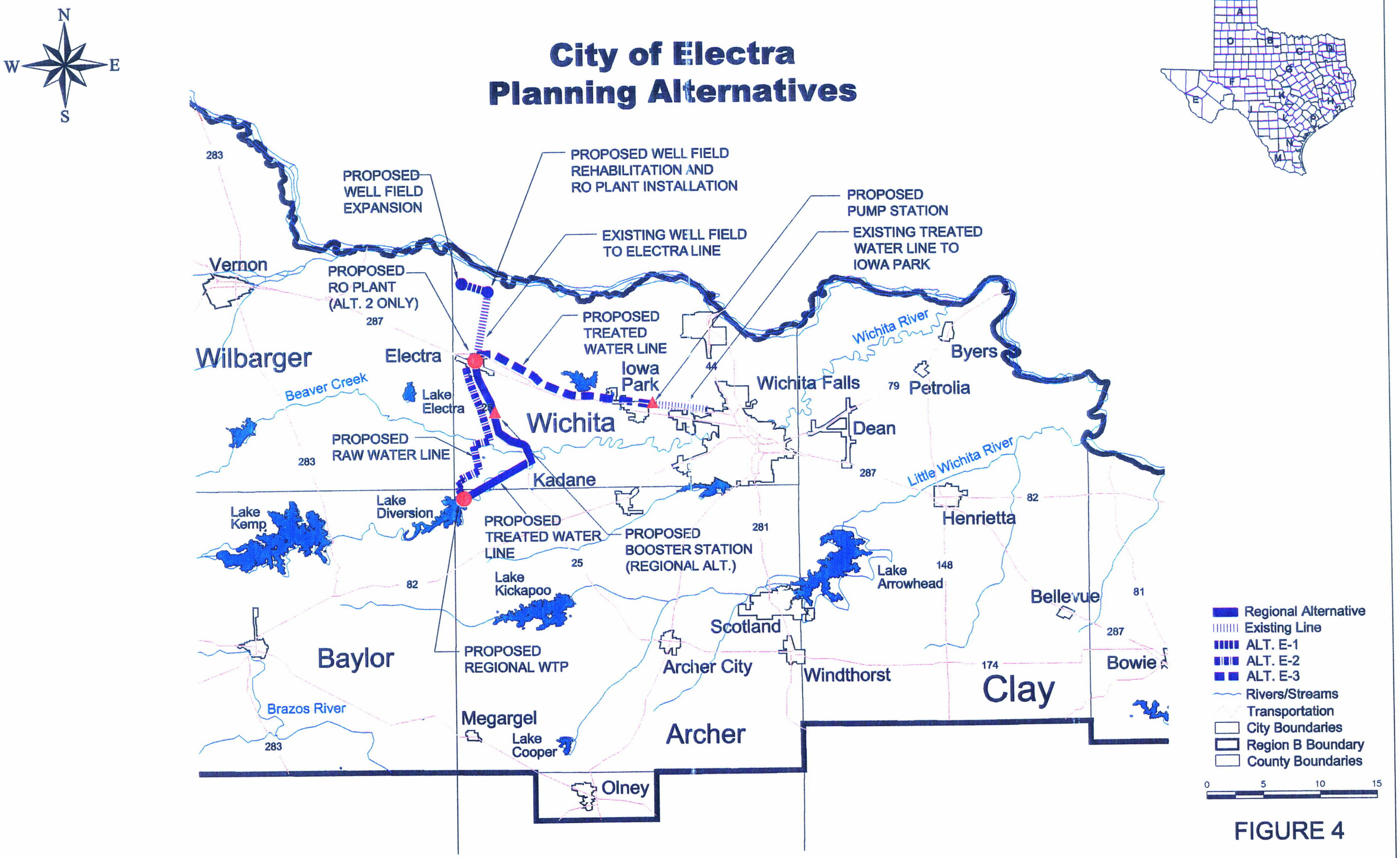

FIGURE 4

The plan initially includes reopening and reworking the capped wells at the existing well field and installing an RO treatment unit at the River Plant. A portion of the high salinity/high nitrate water will be treated with RO and the remaining portion will be treated with the current method, sand filtration. Before entering the transmission line, the two treated streams will be blended and transmitted to town via the existing pipeline. The result will be water that is low enough in salts and nitrates to be considered safe for drinking.

The capacity of this RO blend system will be 0.5 mgd (finished water), sufficient to meet 90% of Electra's average daily requirement. For the remaining demand and for peak demand, Electra will use water from Lake Electra. In the future, the well fields will be the primary supply source.

This plan requires a significant financial obligation for the city of Electra. Therefore, this "short-term" commitment is in actuality likely to be a medium-to-long-range commitment for Electra. It is expected that stages of this plan will be phased in over time as necessary to meet Electra's water needs for the next 20 years.

The phases of the current plan are as follows:

- Build RO plant at existing treatment facilities;
- Rework existing capped wells;
- Develop new well fields;
- Build pipelines from new well fields to existing plant; and
- Increase capacity of RO treatment as necessary.

It is expected that development of at least some new wells will be required. Initial pumping tests indicate the uncapped wells can produce enough quantity of water to meet Electra's needs, but the quality could degrade once pumping begins. The wells were originally capped because the quality had degraded after some period of pumping. As the water quality degrades, additional wells will be brought on-line to improve the quality of the feed/blend water.

Other phases of the well field alternative could potentially take the capacity to 1.0 mgd. Other alternatives are not evaluated here because it is assumed that the projected 617 acre-feet per year demand can be satisfied using the well field and Lake Electra as described above.

Alternative E-2: Construct New Raw Water Pipeline and RO Plant. The city of Electra would purchase raw water from the city of Wichita Falls and/or WCWID #2 out of Lake Diversion. This alternative would involve construction of 18 miles of new 12-inch line from Lake Diversion to Electra. Water would be pumped to Electra and treated at a new RO plant to be constructed at the Central Plant location.

There is an existing pump platform on Lake Diversion that is owned by West Texas Utilities (WTU). It is understood that there is enough room on the existing pump platform to accommodate additional pumps, and that the WTU is willing to allow Electra to purchase access to the pump platform.

Lake Diversion water is high in dissolved solids. Advanced membrane treatment, such as RO, would be required to produce drinkable water.

Alternative E-3: Buy Treated Water from Wichita Falls. This alternative consists of purchasing treated water from Wichita Falls. Wichita Falls has an existing contract to sell water to the city of Iowa Park, which is located between Electra and Wichita Falls. Electra would tap into the Wichita Falls to Iowa Park line at the Iowa Park terminus. Electra would also construct a new ground storage tank and booster station at the terminus of the existing line. In addition, 16 miles of 10-inch line would be constructed between the booster station and Electra. The pipeline route would generally follow U.S. Highway 287.

Regional Water Treatment Plant Alternative. A regional water supply project using Lake Kemp/Diversion water with desalination could provide the city of Electra with 1.0 mgd of treated water. At Lake Diversion, the water would be treated by RO, and then pumped to the city of Electra through a regional pipeline system. Further description of this alternative is presented in Section 5.6.

Analysis of Viable Strategies

The analysis of viable strategies was performed following the evaluation procedures identified in Section 5.1.2. The results of this evaluation follow:

Alternative E-1: River Well Field.

Quantity, Reliability, and Cost. Currently, Electra produces an average of 0.22 mgd from the river well field. After the planned uncapping of old wells and installation of an RO plant, the capacity of the well field will be increased to 0.5 mgd (approximately 90% of TWDB demands). Lake Electra will make up the remainder of the daily demand.

The shallow aquifer used by the city is capable of producing the required quantity of water, although the reliability of shallow aquifer yields during extreme drought conditions may be uncertain. The decreased normal use of Lake Electra should enable greater dependence on this surface water resource in dry periods.

The limiting factor for the groundwater will likely be quality. Quality is expected to degrade over time through pumping induced migration of salts increasing the required blend ratio of RO-treated to filter-treated water. This could require increasing the RO plant capacity.

Another issue affecting the reliability of the well fields is their proximity to the Red River. The wells are actually located in the 100-year floodplain of the Red River. As such, there is some inherent danger that the wells may be temporarily unusable because of flooding. Flooding can cause damage to pumping and transmission equipment as well as potential contamination of the wells. The existing wells have an average depth of 40 feet and are hydraulically connected to surface water. Therefore, there is a potential danger that the aquifer might become contaminated through an unexpected release of pollutants.

For costing purposes, the proposed well field rehabilitation was broken into phases. Because it is expected that the uncapped wells will rapidly degrade in the first 5 years, development of one of the three future well fields was included in Phase 1. The first phase involves reworking the existing capped wells, drilling new wells at the Lalk well field, constructing a pipeline from the new well field to the River Plant, and constructing an RO plant. A summary of the capital and annual costs is presented below.

This alternative includes 560 acre-feet per year from groundwater, which is less than the 617 acre-feet per year projected as demand. The additional 57 acre-feet per year will be made up by Lake Electra water, for which the city already has infrastructure in place. To account for this, an annual operations and maintenance cost to keep the Central Plant operating was included in the cost opinion. Costs for treating the additional Lake Electra water are therefore reflected in the unit cost of water for this option.

Construction Costs	
Water Wells	$168,000
Ground Storage/Pump Station	100,000
8-inch Water Line from Wells to River Plant	344,000
RO Treatment Plant	726,000
Brine Disposal	213,000
Subtotal Construction Costs	$1,551,000
Other Project Costs	
Engineering, Contingencies, and Legal Services	$542,000
Easement Costs	121,000
Environmental and Archeological Studies, Mitigation, and Permitting	15,000
Interest During Construction (18 Months)	128,000
Subtotal Other Costs	$806,000
Total Capital Project Costs	**$2,357,000**
Annual Costs	
Debt Service (30 years @ 6%))	$171,000
Operation and Maintenance	164,000
Power Costs	12,000
Lake Electra Plant O&M	$25,000
Total Annual Costs	**$372,000**
Available Water Yield (Acre-Feet Per Year)	617
Available Water Yield (mgd)	0.56
Annual Cost of Water Delivered ($ Per Acre-Feet)	**$604**
Annual Cost of Water Delivered ($ Per 1,000 Gallons)	**$1.85**

Environmental Impacts. Environmental impacts of the proposed well field rehabilitation center mainly on disposal of the residual salt brine from the RO treatment process. The method of disposal has not yet been decided, although the city is currently negotiating with the TNRCC for a surface water discharge permit to the Red River. Other options for disposal investigated include evaporative ponds, deep well injection, and surface application.

Discharge to the Red River is the city's preferred disposal alternative. A discharge of this sort will likely require acceptance by both the TNRCC and the Oklahoma Department of Environmental Quality (ODEQ) since the south bank of the Red River is the State boundary.

Impacts on Water Resources and Water Management Strategies. The major potential water resources impacts would come through disposal of the salt brine. As mentioned in the Environmental Impacts section, the disposal options available are direct discharge to the Red River, deep well injection, evaporative ponds, or land application.

Other impacts that might be associated with the well field are a lower aquifer level and quality degradation in the vicinity of the well fields. Also, since the aquifer is hydraulically connected to the Red River, subsurface flow to the Red River may be decreased near the wells.

Electra's acute short-term need for additional water has forced implementation of the initial stages of this alternative. As such, it is likely that this alternative will become the preferred alternative to the city, simply due to the significant investment required. Other potentially feasible alternatives, including participation in any regional alternative, will likely become less attractive to the city.

Impacts on Agriculture and Natural Resources. Agricultural impacts should be minimal. A declining aquifer level and degradation of the aquifer in the vicinity of the well field could potentially impact local irrigation, if such irrigation is practiced. This alternative should not impact natural resources of Texas.

Other Relevant Factors. The long-term viability of this alternative may depend on the success of development of new shallow well fields. Since tests in all other potential well fields have not been completed, the ultimate capacity and water quality of these future fields are not known. In addition, the city's projections for future water use exceed those of the TWDB. Should this become a reality, the city may eventually desire to implement other potentially feasible alternatives.

Alternative E-2: New Pipeline from Lake Diversion/Advanced Treatment at Central Plant.

Quantity, Reliability, and Cost. Assuming Wichita Falls and/or WCWID #2 will sell the water, Lake Diversion can provide 100% of Electra's demand to 2050. Lake Diversion could be considered a reliable source of water because it is located downstream of the larger Lake Kemp, which is also owned and controlled by the city of Wichita Falls and WCWID #2. Lake Kemp has the largest yield of any lake in the region and would be needed to support Lake Diversion. A summary of the estimated cost of this alternative follows:

Construction Costs	
0.5 mgd Pumps at Lake Diversion	$71,000
12-inch Raw Water Line (Lake Diversion to Electra)	2,821,000
RO Treatment Plant	766,000
Brine Disposal	184,000
Subtotal Construction Costs	$3,842,000
Other Project Costs	
Engineering, Contingencies, and Legal Services	$1,344,000
Easement Costs	371,000
Environmental and Archaeological Studies, Mitigation, and Permitting	15,000
Interest During Construction (24 Months)	436,000
Subtotal Other Costs	$2,166,000
Total Capital Project Costs	**$6,008,000**
Annual Costs	
Debt Service (30 years @ 6%)	$436,000
Operation and Maintenance (Including Pipeline, Pump Station, and Treatment Plant)	146,000
Power Costs	16,000
Purchased Water Cost	$66,000
Total Annual Costs	**$664,000**
Available Water Yield (Acre-Feet Per Year)	617
Available Water Yield (mgd)	0.56
Cost of Water Delivered ($ Per Acre-Feet)	**$1,076**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$3.97**

Environmental Impacts. Environmental impacts from the pipeline would be minimal. The preferred route would be primarily along the Highway 25 right-of-way and would likely involve only one major creek crossing. The most critical potential environmental impact is the disposal of the RO brine from the treatment process. The city's consultant had evaluated this alternative on the assumption of using evaporation ponds for brine disposal. While this is technically feasible, disposal of liquids in this manner would require careful monitoring of the operation to prevent accidental releases of highly saline wastewater.

Impacts on Water Resources and Water Management Strategies. Water resource impacts should be minimal. A pump platform/intake structure is already in place at Lake Diversion, minimizing additional impacts from construction within the body of the lake. Should Electra pursue this alternative, its participation in any regional strategy would be unlikely.

Impacts on Agriculture and Natural Resources. Agricultural impacts should be very minimal. As mentioned previously, the preferred pipeline route would be along existing road right-of-way. Lake Diversion is an existing reservoir, so the amount of agricultural land disturbed would be minimal.

Other Relevant Factors. No other relevant factors regarding this alternative have been identified at this time.

Alternative E-3: Buy Treated Water from Wichita Falls.

Quantity, Reliability, and Cost. This alternative would likely provide all of Electra's water demand, provided Wichita Falls has the water to sell. For comparison purposes, it was assumed that Wichita Falls will have a sufficient supply of water to enter into a contractual agreement with Electra to provide the necessary treated water. It was also assumed that the treated water would be provided to Electra at $0.95 per 1,000 gallons.

Reliability of this alternative system should be good. Because the water would be sold by contract, Wichita Falls would be obligated to provide the water to Electra. The only maintenance requirement would be on the booster pump station and the Iowa Park to Electra line. A summary of the cost of this alternative follows:

Construction Costs	
Ground Storage/Booster Pump Station	$105,000
12-inch Treated Water Line from Iowa Park to Electra	2,575,000
Subtotal Construction Costs	$2,680,000
Other Project Costs	
Engineering, Contingencies, and Legal Services	$938,000
Easement Costs	280,000
Environmental and Archaeological Studies, Mitigation, and Permitting	15,000
Interest During Construction (12 Months)	163,000
Subtotal Other Costs	$1,396,000
Total Capital Project Costs	**$4,076,000**
Annual Costs	
Debt Service (30 years @ 6%)	$296,000
Operation and Maintenance	50,000
Power Costs	13,000
Purchased Water Cost	$173,000
Total Annual Costs	**$532,000**
Available Water Yield (Acre-Feet Per Year)	617
Available Water Yield (mgd)	0.56
Cost of Water Delivered ($ Per Acre-Feet)	**$863**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.65**

Environmental Impacts. Environmental impacts should be minimal since the pipeline route would generally follow Highway 287. There will likely be some creek crossings along the pipeline route, but there are no major issues that are readily apparent at this level of study.

Impacts on Water Resources and Water Management Strategies. The impacts to other resources and strategies involved with this option would be indirect. In order for Wichita Falls to provide water to Electra, it must first have the water to sell. That means Wichita Falls will potentially have to develop new sources of water prior to entering into a contract with Electra. Therefore, the timing of such a project would likely be dependent on development of Wichita Falls' own alternatives.

Impacts on Agriculture and Natural Resources. Because the pipeline route would follow the highway alignment, it is not expected that agriculture or natural resources would be significantly impacted.

Other Relevant Factors. No other relevant factors regarding this alternative have been identified at this time.

Regional Water Treatment Plant Alternative. This alternative is based on the city of Wichita Falls, the city of Vernon, and the city of Electra participating in a regional plan to utilize Lake Kemp/Diversion and construct a desalination plant at the reservoir site.

Annual Cost - City of Electra	
Debt Service (30 years @ 6%)	$658,000
Operation and Maintenance	41,000
Power Costs (Pumping Facilities)	15,000
Water Treatment Costs ($0.75/1,000 gallons)	269,000
Raw Water Purchase (From Wichita Falls @ 0.21/1,000 gallons)	$75,000
Total Annual Cost	**$1,058,000**
Available Water Yield (Acre-Feet Per Year)	1100
Available Water Yield (mgd)	1
Cost of Water Delivered ($ Per Acre-Feet)	**$962**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.95**

THALIA WATER SUPPLY CORPORATION (WSC)

In Chapter 4, Thalia WSC was listed as deficient in water supply due to water quality. The specific parameter of concern was the concentration of nitrate in the water source. Thalia WSC has historically utilized the Seymour Aquifer to supply 100% of its water.

In 1997, the Thalia WSC applied to the TWDB Drinking Water State Revolving Fund for assistance with a project to reduce nitrate concentrations in their drinking water to acceptable levels. The project was planned to construct a water line from the city of Crowell to Thalia WSC

to enable the purchase of water for blending purposes. According to the city of Crowell, a water line has been constructed and the city is selling water to Thalia WSC at this time. Sufficient water exists from Crowell's supplier, Greenbelt Municipal and Industrial Water Authority, to provide Thalia WSC with all its water demand, if desired.

Recent water quality data from Thalia WSC suggest that nitrate levels in the distribution system have dropped substantially. It is presumed that this is a result of the purchase of sufficient water from Crowell to accomplish an adequate blend. At this time, Thalia WSC is still officially on the TNRCC list of MCL violators for nitrate. However, as recent data indicate, Thalia WSC now has the capability to eliminate this problem. Therefore, an analysis of water management alternatives for Thalia WSC is not necessary.

REGIONAL WATER TREATMENT PLANT ALTERNATIVE (LAKE KEMP/ DIVERSION RESERVOIRS)

Background

As indicated in the previous discussions of alternatives, the feasibility of meeting demand through participation in a regional water treatment plant has been investigated. The feasibility of such an alternative is dependent on having wide participation by the region's water suppliers. For this analysis, the participation of those water suppliers with identified needs -- Wichita Falls, Vernon, and Electra -- has been assumed.

Water Demands

For the regional plan, it was assumed that the maximum yield from the Lake Kemp/Lake Diversion system would be used for sizing the plant. The maximum raw water allocation of the Kemp/Diversion reservoirs for municipal use is 25,150 acre-feet per year. Substantial water rights allocations also exist for agriculture, mining, and industrial purposes.

Lake Kemp/Diversion waters are naturally high in chloride, sulfates, and total dissolved solids. Reducing these constituents to acceptable levels will require advanced membrane technology, specifically RO. Prior to RO treatment, microfiltration (MF) will be used. Assuming a 70% recovery rate for MF/RO treatment, the total finished water available would be 17,600 acre-feet per year.

Allocation of treated water for the three participating water suppliers was assumed as follows:

City of Electra	1,100 acre-feet per year
City of Vernon	2,200 acre-feet per year
City of Wichita Falls	14,300 acre-feet per year

Facilities Description

The regional water system is depicted in Figure 2-21. The facilities consist of a raw water intake structure and pump station located at Lake Diversion. Raw water would be pumped to the 16-mgd treatment plant. Treated water from the MF/RO plant would be stored in the clearwell and then pumped via a 42-inch line constructed to Kadane Corner, east of Lake Diversion. At Kadane Corner, the 42-inch transmission line proceeds eastward to Wichita Falls' existing Cypress Water Treatment Plant. A 24-inch-diameter line would also take a portion of the water at Kadane Corner north to Electra, carrying treated water for both Vernon and Electra. At Electra, the line will be reduced to an 18-inch line, which will turn northwestward along Highway 287 to Vernon. The city of Electra will receive treated water at its Central Plant from the 24-inch water line. Two booster stations are needed for the Vernon/Electra line. One will be located approximately halfway between Kadane Corner and Electra on the 24-inch line. The other will be located about halfway between Electra and Vernon.

Cost allocations will be established by each participant's allocation of water as well as by amount and size of pipeline required for each. The resulting cost allocation for capital costs is as follows:

City of Wichita Falls	74%
City of Vernon	19%
City of Electra	07%

Each entity would be responsible for the cost of delivery of its share of the treated water to its customers.

Quantity, Reliability, and Cost. The quantity of water provided by the regional treatment plant would be greater than the TWDB demand for each city. Electra would receive 1,100 acre-feet per year, Vernon 2,200 acre-feet per year, and Wichita Falls 14,300 acre-feet per year.

Current reliability of the Kemp/Diversion system is moderate to high. Lake Kemp has the highest yield of any reservoir in the region, so meeting water demands with Kemp/Diversion water should not be an issue. However, as the reservoir ages, sedimentation will likely reduce the yield and may pose reliability problems in the future. Future reliability of Lake Kemp, beyond 2050, could be classified as moderate to low.

Regional Planning Alternatives

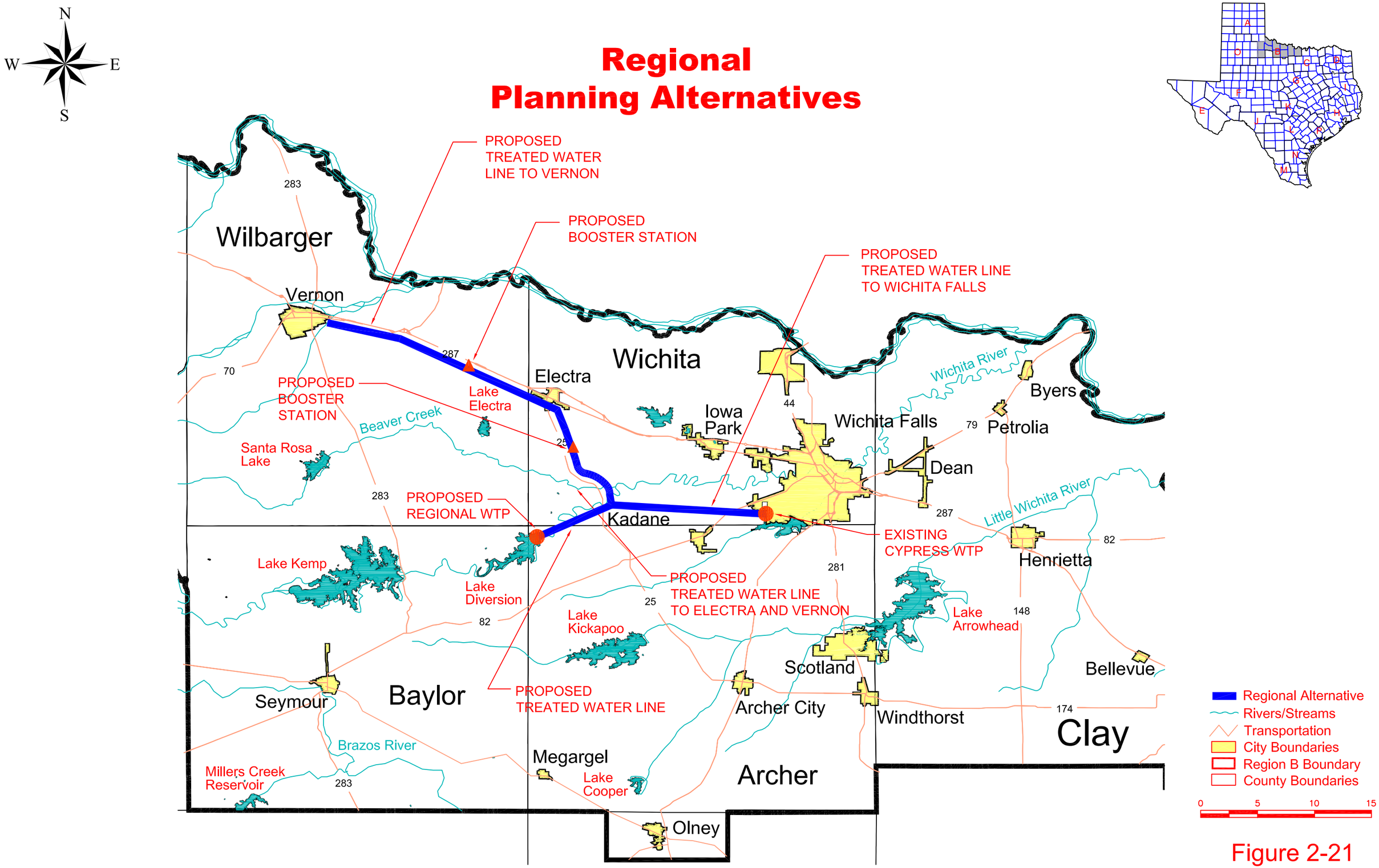

Figure 2-21

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The cost breakdown of the proposed regional treatment plant is as follows:

Construction Costs	
16-mgd Pump Station Near Diversion	$2,500,000
3-mgd Pump Station Near Electra	900,000
2-mgd Pump Station Near Vernon	750,000
Lake Intake Structure	3,500,000
16-mgd Microfiltration/Reverse Osmosis Treatment	36,000,000
Treatment Brine Reject Disposal	3,000,000
42-inch Treated Water Line (To Kadane) (7 Miles)	8,100,000
42-inch Treated Water Line (Kadane To W.F.) (17.5 Miles)	20,925,000
24-inch Treated Water Line (Kadane to Electra) (16 Miles)	7,183,000
18-inch Treated Water Line (Electra to Vernon) (21 Miles)	6,660,000
Subtotal Construction Costs	$89,518,000
Engineering, Legal, Financial, & Contingencies	$29,188,000
Land and Easements	750,000
Environmental Studies, Mitigation, and Permitting	500,000
Interest During Construction (24 months)	9,380,000
Subtotal Other Costs	$39,818,000
Total Capital Project Costs	**$129,336,000**
Allocate Project Cost of Regional System Based On Pro-Rata Design For Each Entity As Follows:	
City of Wichita Falls	74% of Cost
City of Vernon	19% of Cost
City of Electra	7% of Cost
Allocated Total Capital Project Costs:	
City of Wichita Falls	$95,709,000
City of Vernon	24,574,000
City of Electra	$9,053,000
Annual Costs - City of Wichita Falls:	
Debt Service (30 years @ 6%)	$6,958,000
Operation and Maintenance	325,000
Power Costs (Pumping Facilities)	75,000
Water Treatment Costs ($0.75/1,000 gallons)	$3,494,000
Total Annual Cost – City of Wichita Falls	**$10,852,000**
Available Water Yield (Acre-Feet Per Year)	14,300
Available Water Yield (mgd)	13
Cost of Water Delivered ($ Per Acre-Feet)	**$759**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.33**

Annual Costs - City of Vernon	
Debt Service (30 years @ 6%)	$1,787,000
Operations and Maintenance	166,000
Power Costs (Pumping Facilities)	36,000
Water Treatment Costs ($0.75/1,000 gallonss)	538,000
Raw Water Purchase (From Wichita Falls @ 0.21/1,000 gallons)	$151,000
Total Annual Cost – City of Vernon	**$2,678,000**
Available Water Yield (Acre-Feet Per Year)	2,200
Available Water Yield (mgd)	2
Cost of Water Delivered ($ Per Acre-Feet)	**$1,217**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$3.74**
Annual Cost - City of Electra	
Debt Service (30 years @ 6%)	$658,000
Operation and Maintenance	41,000
Power Costs (Pumping Facilities)	15,000
Water Treatment Costs ($0.75/1,000 gallons)	269,000
Raw Water Purchase (From Wichita Falls @ $0.21/1,000 gallons)	$75,000
Total Annual Cost – City of Electra	**$1,058,000**
Available Water Yield (Acre-Feet Per Year)	1,100
Available Water Yield (mgd)	1
Cost of Water Delivered ($ Per Acre-Feet)	**$962**
Cost of Water Delivered ($ Per 1,000 Gallons)	**$2.95**

Environmental Impacts. The environmental impacts due to pipeline construction should be low to moderate depending on the final route of the pipelines. The ground storage facility and booster stations required along the routes can be located in areas of minimal environmental impact.

Disposal of brine reject from the RO treatment plant will likely be the most significant environmental factor. The preferred disposal option would be to discharge brine reject water into the Wichita River below the water treatment plant. Other options include evaporation ponds and injection wells.

Impacts on Water Resources and Other Water Management Strategies. There may be low to moderate water resources impacts as more of the Lake Kemp/Diversion system's yield is used. Water levels in the lakes may have greater fluctuations and this may affect recreational users, local property owners, and/or businesses on the lake. This alternative is a regional strategy that is feasible only if several users support its development. If one of the cities chooses another strategy for water supply, it is unlikely that this alternative will be cost effective. Also, if Wichita Falls proceeds with developing an RO treatment system at the existing Cypress Water

Treatment Plant to treat Lake Kemp water (see alternative WF-2), there would not be sufficient additional municipal supply at Lake Kemp.

Impacts on Agriculture and Natural Resources. The impact on agricultural lands should be low. The amount of water available for irrigation may be reduced as water from Lake Kemp is used for municipal supply. Lakes Kemp and Diversion are existing and therefore will not require impoundment of additional acreage.

Other Relevant Factors. Interbasin transfer could be possible if additional entities other than Electra, Vernon, and Wichita Falls are allowed to and elect to participate. With the scenario given here, however, with only the three mentioned entities participating, no interbasin transfer will result. All source waters, users, and waste discharges are located within the Red River Basin.

This strategy could be implemented between 5 and 10 years. The permitting and regulatory requirements are expected to be low to moderate. A 404 permit would be required for the transmission pipelines. As the pipeline routes are finalized, additional coordination with State and local agencies regarding sensitive environmental factors may be needed. If the pipeline affects State-owned lands, additional permits and/or a Grant of Easement may be required.

Impacts on Water Resources and Other Water Management Strategies. Some of the other alternative strategies would provide Lake Kemp/Diversion water to the communities of Wichita Falls, Electra, and/or Vernon. In the absence of the Chloride Control Project, these alternatives require treatment of Lake Kemp/Diversion water using membrane technology. Successful implementation of the Chloride Control Project will ultimately reduce treatment costs for any alternative that utilizes Lake Kemp/Diversion as a water source by: 1) reducing the amount of treatment needed to produce high quality drinking water; and 2) increasing the ratio of produced water to raw water. This could significantly affect the feasibility of some alternatives in a more positive manner.

RECOMMENDED WATER MANAGEMENT STRATEGIES

Based on a comparison of total regional water supply to demand, it was determined that there is adequate water supply to meet the needs of Region B as a whole through 2050.

However, water supply needs were identified for the city of Wichita Falls, the city of Vernon, Hinds-Wildcat and Lockett Water Supply Systems, and the city of Electra. For each of these water user groups, various alternatives were analyzed and evaluated as documented in this chapter. Though all the strategies may be viable options and should be considered by each entity, the following described alternatives are recommended as the preferred water management strategy for each entity listed below, and are shown in Figure 2-22.

Preferred Water Management Strategies

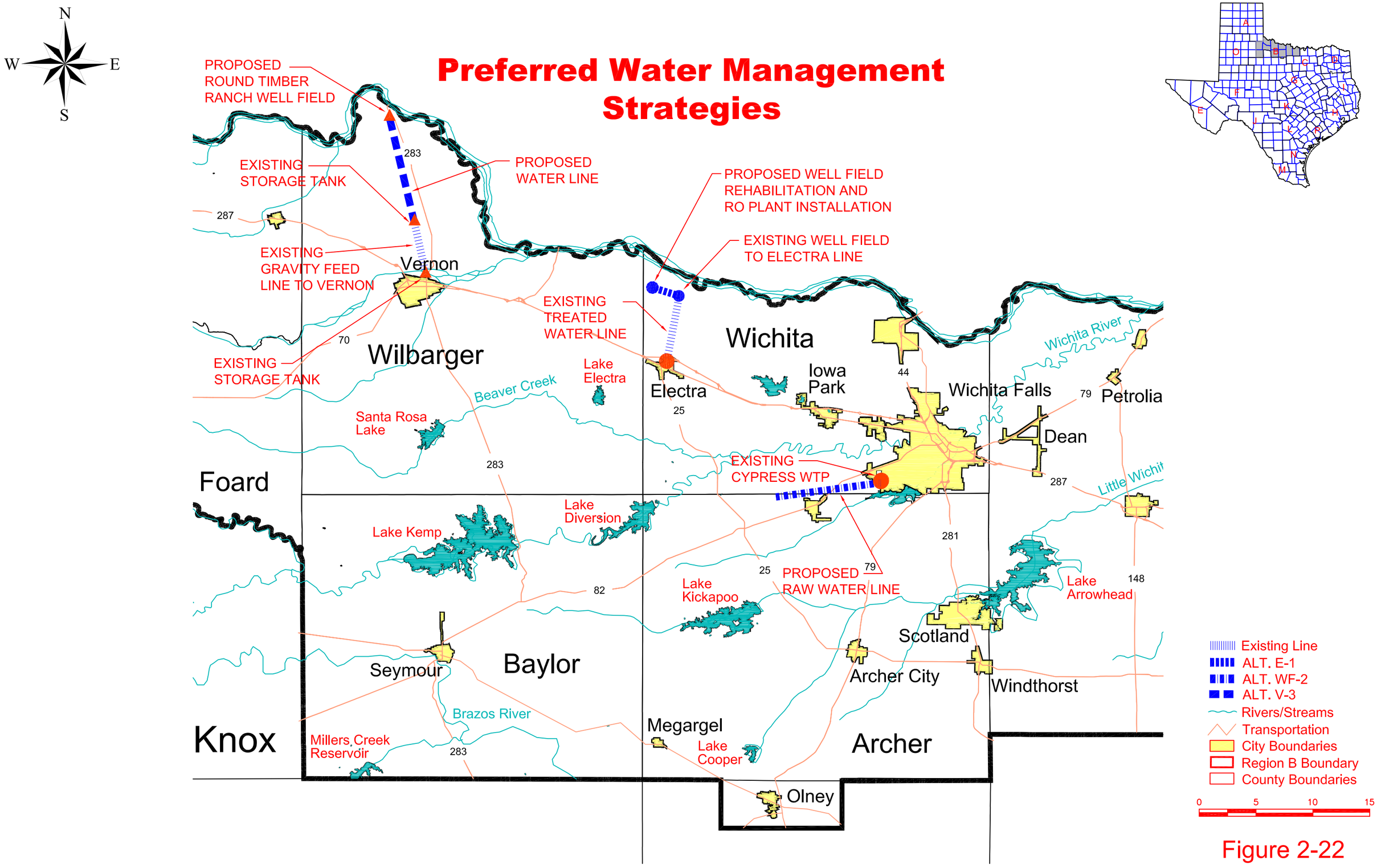

Figure 2-22

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City of Wichita Falls

The city of Wichita Falls has four viable water supply strategies. Two strategies involve utilizing existing water rights on Lake Kemp/Diversion, a third involves wastewater reuse, and the fourth requires construction of a new reservoir site. Having evaluated each strategy and in coordination with the city of Wichita Falls, the recommended preferred strategy is Alternative WF-2: Water from Lake Kemp/Diversion Reservoirs, in tandem with Alternative WF-1: Wastewater Reuse. The combination of these two strategies will provide the additional water supply necessary to maintain existing reservoir levels above the emergency drought trigger condition.

City of Vernon

The city of Vernon has four viable water supply strategies. Three strategies involve purchasing water from Wichita Falls' existing water supply sources, and one expands the use of groundwater from the Seymour Aquifer. Having evaluated each strategy and in coordination with the city of Vernon, the recommended preferred strategy is Alternative V-3: Round Timber Well Field or equivalent new well field. This alternative provides sufficient supply to meet the city's growing needs, and the water source complements Vernon's existing system.

Hinds-Wildcat System

The only strategy evaluated for the Hinds-Wildcat System, and therefore the recommended strategy, is to install a pipeline from Vernon to the existing Hinds pump station. This alternative would provide sufficient water; however, the cost will be significantly higher than the current supply.

Lockett System

Two viable strategies were evaluated for the Lockett System. One involved constructing a pipeline from the city of Vernon and the other involved constructing a small ion exchange water treatment system to treat Lockett's existing supply. Having evaluated each alternative, the recommended preferred strategy is Alternative L-2: Nitrate Removal System. This alternative has several permitting and staffing issues, but has the potential for a long-term solution to Lockett's water quality problems.

City of Electra

The city of Electra has four viable water supply strategies. Three strategies involve purchasing water from Wichita Falls' existing water supply sources, and one involves redeveloping existing capped wells and constructing an enhanced treatment facility. Having evaluated each alternative and in coordination with the city of Electra, the recommended preferred strategy is Alternative E-1: River Well Fields. This alternative, in combination with water supply from the city's existing lake, will meet Electra's projected water supply needs.

Chloride Control Project

The concentration of dissolved salts, particularly chloride, in the Lake Kemp/Diversion reservoir system, limits the use of this water for municipal, industrial, and agricultural purposes. Having evaluated the potential benefits of the Chloride Control Project, and based on the need to reclaim the Lake Kemp/Diversion reservoirs as a municipal water supply for Region B use, the Chloride Control Project is recommended as a regional water supply management strategy. In the long-term, it is anticipated that the Chloride Control Project will reduce the cost of water treatment for those entities that are utilizing Lake Kemp/Diversion water for municipal purposes, in addition to making more water available for a broader range of agricultural activities.

SUMMARY OF DROUGHT CONTINGENCY PLANS

Drought Contingency Plans are required of all wholesale and retail public water suppliers and irrigation districts by the Texas Water Code (Sections 11.1271 and 1272) and by the TNRCC Rules (30 TAC Chapter 288). These plans must meet specific requirements provided in Chapter 288. In general, drought contingency plans must include, at a minimum, the following elements:

- Provisions for public input in development of the plan
- Provisions for public education regarding the drought contingency plan
- Coordination with the RWPG
- Criteria for initiation and termination of drought response stages
- Identification of drought response stages
- Assessment of water management strategies for specific drought conditions
- Procedures for notification of the public
- Methods for determining the allocation of supplies to individual users (irrigation plans)
- Monitoring procedures to initiate or terminate a drought response stage
- Procedures for accounting for use during implementation of water allocation (irrigation plans)
- Procedures for transfer of water allocations among users (irrigation plans)
- Supply or demand measures to be implemented during stages of the plan
- Procedures for granting variances
- Procedures for enforcement of water use restrictions

Senate Bill 1 (30 TAC Chapter 357) requires the regional plan to incorporate drought contingency planning into near-term and long-term strategies to address water supply needs. Chapter 357 also requires existing drought contingency plans to be considered in development of the regional water plan. In response to these SB1 requirements, the RWPG for Region B invited representatives from retail water systems, wholesale water providers, and irrigation districts within the region to a series of workshops on drought contingency planning. The intent of the workshops was to aid water providers in the development of drought contingency plans for each of their organizations. Most of the region's water systems responded to this process and worked closely with the RWPG to develop appropriate drought responses. Each participant worked with the regional water planning staff and consultants to prepare an appropriate draft drought

contingency plan for their water system. Once the governing bodies of the water providers had approved the drought contingency plans, they were submitted to the RWPG, as required by Chapter 288.

A summary of the drought contingency plans currently in effect in Region B is contained in Table 5-2 in the Region B water plan; however, these plans are not displayed in this report These plans satisfy drought contingency plan requirements of 30 TAC Chapter 288. Drought contingency triggers for each plan are based on sources, where sufficient source information is available, or on water system constraints. The applicable trigger criteria and response actions are included in the table.

RECOMMENDATIONS INCLUDING UNIQUE ECOLOGICAL STREAM SEGMENTS, RESERVOIR SITES, LEGISLATIVE & REGIONAL POLICY ISSUES, TEXAS STATE SENATE BILL 1, REGION B

Introduction

With the passage of SB1, the 75th Legislature established a regional process to plan for the water needs of Texas through 2050. As a part of this planning process, the TWDB created 16 RWPG's and implemented rules and regulations to govern the process on a regional basis.

Region B, as designated by SB1, is comprised of ten counties and a portion of another in north-central Texas.

As a part of the plan, this report identifies and makes recommendations that the RWPG deems vital to management and conservation of the water resources in Region B.

Discussion of Regional Issues

In addition to the specific water management strategies recommended for Region B in Chapter 5 of the plan, the RWPG deemed several other issues to be significant water management concepts to be given further consideration as part of the Region B Plan. The Chloride Control Project on the Wichita and Pease Rivers is a water management strategy with high regional support. Other strategies that enhance and/or increase existing supplies in the region, such as brush control, groundwater recharge enhancement, weather modification, and increased conservation storage for Lake Kemp, are each potentially feasible management strategies throughout and perhaps beyond the 50-year planning horizon.

Senate Bill 1 requires future projects to be consistent with the approved regional water plan to be eligible for TWDB funding and TNRCC permitting. However, it is the intention of the RWPG that surface water uses that will not have a significant impact on the region's water supply and water supply projects that do not involve development of or connection to a new water source are deemed consistent with the regional water plan even though not specifically recommended in the plan.

Chloride Control Project. Natural mineral pollutants, primarily chloride and sulfates in the upper reaches of the Red River Basin in Region B, render downstream waters unusable for most beneficial purposes. From a study initiated by the U.S. Public Health Service in 1957, it was determined that ten natural salt source areas located in the Red River Basin contribute a daily average of about 3,300 tons of chlorides to the Red River. Subsequent to that study, in 1959 the U.S. Army Corps of Engineers proposed measures to control the natural chloride pollution by recommending control/structural facilities for eight of the ten salt source areas.

These recommended chloride control structures are proposed to improve the water quality conditions of the Red River and its tributaries to the extent that the water may be utilized for municipal, industrial, and agricultural uses on a regular basis.

It is anticipated that the Wichita River Basin Chloride Control Project will effectively remove 362 tons per day of the 429 tons per day of chloride entering the Wichita River System. This improved water quality will allow for full utilization of Lakes Kemp and Diversion.

This additional source would not only increase the reliability of the city of Wichita Falls system, but would also provide for more diverse and expanded agricultural use and more efficient industrial use.

Also, in the long term, as chloride control facilities are constructed on the Pease River in conjunction with the Crowell Brine Reservoir, the potential exists for another freshwater supply reservoir on the Pease River near Crowell in Foard County, with an estimated yield of 138,000 acre-feet per year.

Brush Control Program. The U.S. Natural Resource Conservation Service (NRCS) estimates that brush in Texas uses about 10 million acre-feet of water annually versus the 15 million acre-feet per year for current human use. Possible advantages of brush control, groundwater enhancement, and weather modification could be additions to water supplies, recharge of shallow groundwater aquifers, and spring flow enhancement.

Though water yield following brush control has been investigated in several areas of Texas, the economic benefits and overall productivity of a brush control program may vary significantly depending on geology, nature of water yield, presence of brush, type of brush, and impact on threatened or endangered species.

Recently, the Texas Legislature approved a brush and water study to be conducted through the Texas State Soil and Water Conservation Board, upstream of Lake Kemp on a portion of the Region B Wichita River watershed. The stated goal of this study is to increase stream flow and water availability for industrial, municipal, and other uses through brush control and management.

It is anticipated that this study will provide the Region B RWPG with an estimate of potential stream flow changes in the Wichita River if a large-scale brush management program is conducted, in addition to identifying and prioritizing areas within the Wichita River watershed that contribute the most to stream flow. The planning group should utilize results of this study to

gauge the potential effect of brush control on water flow and ecosystem components such as wildlife, livestock production, aesthetics, and land values.

Recharge Enhancement. Recharge enhancement is the process in which surface water is purposefully directed to areas where permeable soils or fractured rock allow rapid infiltration of the surface water into the subsurface to increase localized groundwater recharge. This would include any man-made structure that would slow down or hold surface water to increase the probability of groundwater recharge.

In Region B, groundwater is a major source of water for much of the western portion of the region. The Seymour Aquifer, which is generally unconfined, is fairly responsive to local recharge and may benefit from enhanced recharge programs. Further study is needed to determine the applicability of such programs in Region B, the quantity of increased groundwater supplies from enhanced recharge structures, and the potential impacts to surface water rights.

Weather Modification. Weather modification is an attempt to increase the efficiency of a cloud to produce precipitation. Efforts to enhance rainfall in Texas began in 1880 and have continued to the present day. Several weather modification programs are in place in areas to the west of Region B. While research has suggested increases of 15% or more of rainfall in areas participating in weather modification, some areas in west Texas have shown greater increases in rainfall. Weather modification programs in Region B could potentially increase surface runoff to reservoirs, reduce irrigation demands, and increase recharge to groundwater sources. Based on existing programs, the cost of operating a weather modification program is approximately 10 cents per acre.

Increase Conservation Storage for Lake Kemp. The U.S. Army Corps of Engineers (USACE) constructed Lake Kemp for flood control and water supply. It is located in an area with high sedimentation rates, and as a result, the firm yield of the reservoir is expected to decrease significantly over the planning period. A new sedimentation survey of Lake Kemp was initiated in 1999, but due to low lake levels, the survey has not been completed. With completion of the chloride control project, water quality in the Wichita Basin is expected to improve such that water from Lake Kemp will become more desirable for existing and future users. This could result in increased demands that may exceed the available supply of the lake.

The USACE has provisions to transfer a portion of the flood storage to conservation storage to compensate for siltation, if there is a need for water supply. Since there is regional concern over the long-term quantity of supply from Lake Kemp, it is recommended that following completion of the sedimentation study, the feasibility of transferring flood storage to conservation storage be evaluated during the next planning cycle.

Designation of Unique Stream Segments and Reservoir Sites. In accordance with TAC Section 357.8, the RWPG is not required to, but may include in the adopted regional water plan recommendations for river and stream segments of unique ecological value, in addition to unique sites for reservoir construction. Such designation would provide for protection of these specific sites to the extent that a State agency or political subdivision may not obtain a fee title or

an easement that would destroy the unique ecological value of the designated stream segment or significantly prevent the construction of a reservoir on a designated site.

Unique Stream Segments. Within Region B, the TPWD has suggested that certain stream segments of the Middle Pease River in Cottle County, the Pease River in Foard County, and the Red River from the Wichita/Clay County line upstream through Hardeman County be considered for recommendation as stream and/or river segments of unique value. The TPWD believes that each of these segments satisfy at least one of the designation criteria defined in SB1.

The Region B RWPG is committed to the protection and conservation of unique and sensitive areas within the region. To that end, the consensus of the planning group is that a more comprehensive study with supporting data is necessary to accurately characterize and evaluate the listed stream/river segments to determine if it is appropriate to recommend them for designation.

In addition, the significance and impact of the designation are not clearly delineated in the legislation or implementing rules. It is not clear what governmental or private activities, other than reservoir construction, might be subject to additional constraints or limitations as a result of designation. It is also not clear what geographic extent might be impacted by the designation. For example, is the entire watershed of the designated stream subject to additional limitations, and how far upstream of the designated stream would limitations apply? The Region B RWPG suggests that the legislature may wish to clarify their intent with regard to these results of designation.

Reservoir Sites. It is generally recognized that studies over the last 40 years have identified perhaps the last remaining reservoir site within Region B in which the chemical concentrations are low enough for municipal use.

This site, known as the Ringgold Reservoir site, is located on the Little Wichita River in Clay County, approximately one-half mile upstream from the confluence with the Red River.

With the potential for an estimated increase in water supply yield for Region B of approximately 27,000 acre-feet per year, it is the consensus of the RWPG that this identified site could reasonably be needed to meet regional water needs beyond the 50-year planning period.

Discussion of Regulatory and Legislative Actions

To facilitate the orderly development, management, and conservation of water resources within the region, and to assist the region in preparing for and responding to drought conditions, the Region B RWPG believes that the regulatory agencies and legislature should consider certain actions relating to water quality and funding issues that affect Region B.

Regulatory Review of Nitrate MCL. In Region B, a number of small user groups utilize water with nitrate levels in excess of 10 mg/l. For the most part, this supply is their only source of water, and advanced treatment for the removal of nitrates is very costly. Presently,

these systems employ bottled water programs for customers that may be sensitive to nitrate concentrations (pregnant women and infants). This program is considered an interim measure by the TNRCC until the system can comply with the nitrate standards.

It is the consensus of the Region B RWPG that the regulatory agency review its MCL standards for smaller systems which have no cost effective means to comply with the current nitrate MCL of 10 mg/l, and consider funding new studies to determine the health effects of nitrates in drinking water.

In addition, the planning group requests that the regulatory agencies consider bottled water programs as a long-term strategy to meet the nitrate water quality standards, or alternatively simply provide for a waiver process.

Funding for Comprehensive Studies. In preparing the Region B Water Plan, there are several regional water planning, management, and conservation related issues that will require additional funding for data collection and administrative activities to adequately assess their viability or feasibility as a cost effective management strategy for Region B. For example, additional funds are needed to identify and evaluate brush control programs in an effort to increase water yields, to complete the Groundwater Availability Models (GAM), to identify and designate unique stream segments and/or reservoir sites for protection of these areas, and to implement other chloride control measures and wastewater reuse programs throughout Region B.

SUMMARY OF REGIONAL RECOMMENDATIONS

In accordance with 31 TAC 357.7 (a)(9), 31 TAC 357.8, and 31 TAC 357.9, the following recommendations are proposed to facilitate orderly development, management, and conservation of the water resources available within Region B:

- It is recommended that the Chloride Control Project on the Wichita River be made a regional priority to enhance the water quality of Lake Kemp and Lake Diversion and to reclaim those lakes as a viable, cost effective, short-term and long-term regional water supply source.

- It is recommended that Region B participate in the State study on brush management and water yields to be conducted on the Wichita River watershed upstream of Lake Kemp. Pending the results of that study, it may be beneficial for the region to adopt selected brush control programs as a water management strategy. In addition, should brush management programs be implemented in the future, it is recommended that the State provide for adequate funding of the programs.

- It is recommended that no segments be designated as "Unique Stream/River Segments" or "Unique Reservoir Sites" at this time. Pending the results of comprehensive studies and clarification by the legislature of the significance and

impacts of designation, the RWPG may consider designations within the region in the future.

- It is recommended that Region B encourage the regulatory agencies to consider allowing continued long-term use of bottled water programs and/or providing a waiver for small user groups that can demonstrate they have no reasonable cost-effective means to comply with the current MCL of 10 mg/l.

- It is recommended that Region B support and seek adequate State funding to develop, implement, and evaluate the necessary management strategies adopted as part of this regional plan. This includes strategies identified to meet a specific need as well as general strategies to increase water supply in the region.

- It is recommended that Region B support the grass-roots regional water planning process enacted by SB1 and strongly encourages that the process be continued with adequate State funding for all planning efforts including administrative activities, data collection, and Groundwater Availability Modeling (GAM).

- It recommended that Region B support State funding for agricultural water use data collection and agricultural water use management/conservation projects.

- Senate Bill 1 requires future projects to be consistent with the approved regional water plan to be eligible for TWDB funding and TNRCC permitting. It is recommended that surface water uses that will not have a significant impact on the region's water supply and water supply projects that do not involve development of or connection to a new water source should be deemed consistent with the regional water plan even though not specifically recommended in the plan.

KNOX COUNTY WATER SUPPLY PLAN

Table 2-42 lists each water user group in Knox County and their corresponding surplus or shortage in 2030 and 2050. For each water user group with a projected shortage, a water supply plan has been developed and is presented in the following subsections. Water supply plans are also presented for some entities that need pumping/conveyance facilities to utilize their existing water resources, or to become a regional provider. In addition, long-term considerations are provided for some entities with projected surpluses. Knox County, through its County Commissioner’s Court, has submitted a series of resolutions supporting a variety of regional water supply planning and development initiatives. The recommended plans described below either include specific proposed projects mentioned in the resolutions, or are generally consistent with them.

TABLE 2-42

KNOX COUNTY SURPLUS/(SHORTAGE)

Water User Group	Surplus/(Shortage)* 2030 (acre-feet/year)	Surplus/(Shortage)* 2050 (acre-feet/year)	Comment
City of Benjamin	31	28	Projected surplus
Knox City	(235)	(235)	Projected shortage – see plan below
City of Munday	(294)	(295)	Projected shortage – see plan below
County-Other	5	5	Projected surplus
Manufacturing	0	0	No demand or supply
Steam-Electric	0	0	No demand or supply
Mining	8	9	Projected surplus
Irrigation	(2,199)	(799)	Projected shortage – see plan below
Livestock	0	0	Supply equals demand

* From Tables 2-29 and 2-30, Comparison of Supply Versus Demand by County – 2000 and 2050, respectively.

City of Benjamin

Small surface water supplies are obtained from Miller's Creek Reservoir and local sources, but primary groundwater sources are the Seymour and Blaine aquifers. The groundwater supply is limited by well capacity. No current or future shortages are projected, and no changes in water supply are recommended.

Knox City

Description of Supply. Knox City obtains surface water via a contract with North Central Texas MWD. This contract expires in 2010; however, the supply is limited. Knox City has a projected shortage of 235 acre-feet in 2030, representing 100% of demand.

Options Considered. Table 2-43 lists the water management strategies, report section references discussing strategy, total project cost, and unit costs that were considered for meeting Knox City's shortages.

TABLE 2-43

WATER MANAGEMENT STRATEGIES CONSIDERED FOR KNOX CITY

Option	Yield (acre-feet/year)	Approximate Cost Total	Approximate Cost Unit ($/acre-feet)
Extend existing contract with North Central Texas MWD	235	$152,750/year	$650[1]
No Action	-	$9,974,000*	$42,443[2]

[1] Estimated wholesale rate for treated water.

[2] Economic impact of not meeting shortage (i.e., "no action" alternative) in 2030 as estimated by the TWDB.

Water Supply Plan. Working within the planning criteria established by the Brazos G RWPG and the TWDB, the following water supply plan is recommended to meet the projected 2030 shortage of Knox City: Extend and amend existing contract to supply an additional 235 acre-feet/year.

Costs. Costs of the Recommended Plan for Knox City: Extension of existing contract:

- Cost Source: Estimated wholesale of $650/acre-feet for treated water
- Date to be Implemented: 2010
- Total Annual Cost: $152,750

City of Munday

Description of Supply. The city of Munday obtains surface water via a contract with North Central Texas MWD. This contract expires in 2010; however, the supply is limited. The city of Munday has a projected shortage of 291 acre-feet in 2030. This represents 100% of demand.

Options Considered. Table 2-44 lists the water management strategies, report section references discussing strategy, total project cost, and unit costs that were considered for meeting the city of Munday's shortages.

TABLE 2-44
WATER MANAGEMENT STRATEGIES CONSIDERED FOR THE CITY OF MUNDAY

Option	Yield (acre-feet/year)	Approximate Cost	
		Total	Unit ($/acre-feet)
Extend existing contract with North Central Texas MWD	294	$191,100/year	$650[1]
No Action	-	$12,478,000*	$42,443[2]

[1] Estimated wholesale rate for treated water.
[2] Economic impact of not meeting shortage (i.e., "no action" alternative) in 2030 as estimated by the TWDB.

Water Supply Plan. Working within the planning criteria established by the Brazos G RWPG and the TWDB, the following water supply plan is recommended to meet the projected 2030 shortage of Munday: Extend and amend existing contract to supply an additional 294 acre-feet/year.

Costs. Costs of the Recommended Plan for Munday: Extension of existing contract:

- Cost Source: Estimated wholesale value of $650/acre-feet for treated water
- Date to be Implemented: 2010
- Total Annual Cost: $191,100

County-Other Category

The water supply entities for County-Other show a projected surplus, and no changes in water supply are recommended.

Manufacturing

No manufacturing demand exists or is projected for the county.

Steam-Electric

There is no steam-electric demand or supply in Knox County.

Mining

The water supply entities for mining show a projected surplus, and no changes in water supply are recommended.

Irrigation

Description of Supply. Surface water supplies for irrigation in Knox County are obtained from Wild Horse Creek, Lake Catherine, and Lake Davis. The estimated annual reliable surface water supply for irrigation is 2,064 acre-feet until 2050. The primary groundwater source in Knox County is the Seymour Aquifer. Estimated reliable supply of groundwater is 25,000 acre-feet until 2050. As demonstrated in Table 2-46, there is a current and long-term shortage in irrigation water supplies through 2050.

Options Considered. Table 2-45 lists the water management strategies that were considered for Knox County irrigation shortages, total project cost, and unit costs for meeting the shortage.

TABLE 2-45

WATER MANAGEMENT STRATEGIES CONSIDERED FOR KNOX COUNTY IRRIGATION

Option	Yield (acre-feet/year)	Approximate Cost	
		Total	Unit ($/acre-feet)
Irrigation System Conversion [1]	2,200	$96,800/year	$44
Brush Control	([2])	([2])	([2])
Weather Modification [3]	([2])	$500,000 to $850,000/year	([2])
No Action	-	$318,000[4]	$144[4]

[1] Source of Cost Estimate: Texas Agriculture Experiment Station.
[2] Definitive yield and/or cost cannot be determined.
[3] Source of Cost Estimate: Section 5B.10.
[4] Economic impact of not meeting shortage (i.e., “no action”) in 2030 as estimated by the TWDB.

Water Supply Plan. Working within the planning criteria established by the Brazos G RWPG and the TWDB, the following water supply plan is recommended to meet the projected 2030 shortage of the irrigation category.

Knox County has a projected irrigation shortage of 2,199 acre-feet in 2030 and 779 acre-feet in 2050. No new water supplies are economically feasible to meet this projected shortage. Water conservation strategies in the form of conversion to irrigation systems with increased efficiency could supply some of the unmet demands. The options are to upgrade the gated pipe systems to center pivot systems and upgrade older center pivots. Conversion of 2,000 acres of the 19,500 acres of irrigated cotton in Knox County from gated pipe to center pivot could meet the projected shortage in 2030.

As shown in Table 2-46, conservation practices can meet about 2,200 acre-feet/year of the projected shortages. This will meet the projected shortages by 2030. Prior to that, it is not economically feasible to meet projected irrigation shortages in Knox County.

Costs. Costs of the recommended plan for Knox County irrigation supply are outlined in Table 2-46. Costs for some options, such as brush control and weather modification, cannot be directly quantified due to lack of specific data. Costs for these options have been estimated based on generally available data. Conversion of 2,000 acres of the 19,500 acres of irrigated cotton in Knox County from gated pipe to center pivot could meet the projected shortage in 2030. This would conserve 1.11 acre-feet water per acre at an average annual cost of $44.11/acre-feet and would provide 2,200 acre-feet/year.

Livestock

No future shortages are projected in the livestock category, and no changes in water supply are recommended.

TABLE 2-46

RECOMMENDED PLAN COSTS BY DECADE FOR KNOX COUNTY IRRIGATION[1]

Plan Element	2000	2010	2020	2030	2040	2050
Irrigation System Conversion[2]						
Projected Shortage (acre-feet/year)[3]	(4,465)	(3,691)	(2,936)	(2,199)	(1,480)	(779)
Supply from Plan Element (acre-feet/year)	2,200	2,200	2,200	2,200	2,200	2,200
Annual Cost ($/year)	$96,800	$96,800	$96,800	$96,800	$96,800	$96,800
Unit Cost ($/acre-feet)	$44	$44	$44	$44	$44	$44
Weather Modification[4]						
Supply from Plan Element (acre-feet/year)	(*)	(*)	(*)	(*)	(*)	(*)
Annual Cost ($/year)	$500,000-$850,000	$500,000-$850,000	$500,000-$850,000	$500,000-$850,000	$500,000-$850,000	$500,000-$850,000
Unit Cost ($/acre-feet)	(*)	(*)	(*)	(*)	(*)	(*)
Brush Control[4]						
Supply from Plan Element (acre-feet/year)	(*)	(*)	(*)	(*)	(*)	(*)
Annual Cost ($/year)	(*)	(*)	(*)	(*)	(*)	(*)
Unit Cost ($/acre-feet)	(*)	(*)	(*)	(*)	(*)	(*)
Sum of Supply from Plan Elements (acre-feet/year)	2,200	2,200	2,200	2,200	2,200	2,200
Unmet Demand[5]	(2,265)	(1,491)	(736)	0	0	0

[1] Unless otherwise noted, costs are Total Project Cost and Unit Cost ($/acre-feet per year) for water conserved through management practices. Unit cost is for full utilization of project capacity.
[2] Source of Cost Estimate: Texas Agriculture Experiment Station.
[3] Total projected irrigation shortages are presented.
[4] Source of Cost Estimate: Section 5B.10.
[5] Apart from the conservation options presented, it is not economically feasible to meet projected irrigation shortages listed as unmet demand in Knox County.
* Definitive yield and/or cost cannot be determined.

PART IIB - WATER SUPPLY AND DEMAND - REGION C – DALLAS/FORT WORTH AND LOUISIANA

OVERVIEW

The format of the Region C water plan is similar to that of Region B; however, due to the voluminous material prepared for this region (four volumes), the material presented in this section incorporates the executive summary of the regional plan. The entirety of this region's water plan can be found on the Texas Water Development Board's website at http://www.twdb.state.tx.us/assistgance/rwpg. The focus of this effort is on current use of Lake Texoma and planned utilization of Lake Texoma for future water needs as described in the water plan. The purpose is to describe the need for water in this region and to outline the planned water management strategy for the region. Evaluation of the potential benefits for use of Lake Texoma without and with the chloride control project is discussed in the next section. Therefore, the executive summary of the "Initially Prepared Region C Water Plan," August 2000, Volumes I-IV by Freese and Nichols, Inc., and others, is used to provide the data and information for Region C. Information and data used in this section are also found in an updated January 2001 version at the TWDB website link http://www.twdb.state.us/. Region C covers all or part of 16 counties in north-central Texas, mainly in the Trinity River Basin as shown in Figure 2-23. Six of the sixteen counties, Jack, Parker, and Wise, west of Fort Worth; and Freestone, Navarro, and Henderson, southeast of Dallas, are not included in the Wichita Basin Chloride Control study area, since they are least likely to use Lake Texoma water.

The Region C water plan was developed under the direction of the 19-member Region C RWPG. The planning process included the following steps, which are presented in this summary and described in greater detail in the main report and the appendices:

- Description of Region C
- Population and Water Demand Projections
- Analysis of Water Supply Currently Available to Region C
- Comparison of Water Supply and Projected Water Demand
- Evaluation and Selection of Water Management Strategies
- Regulatory, Administrative, Legislative, and Other Recommendations
- Plan Approval Process and Public Participation

DESCRIPTION OF REGION C

The 16 counties in Region C comprise most of the upper Trinity River Basin and portions of the Red River Basin around Lake Texoma. As of 1998, the estimated population of Region C was 4,779,210 - 24.4% of Texas' total population. The two most populous counties in Region C, Dallas and Tarrant, have 70.6% of the region's population. There are 38 cities in Region C with an estimated 1998 population of more than 20,000. These cities include 80.5% of the 1998 population of the region. Appendix 1 of the Water Plan describes Region C in detail.

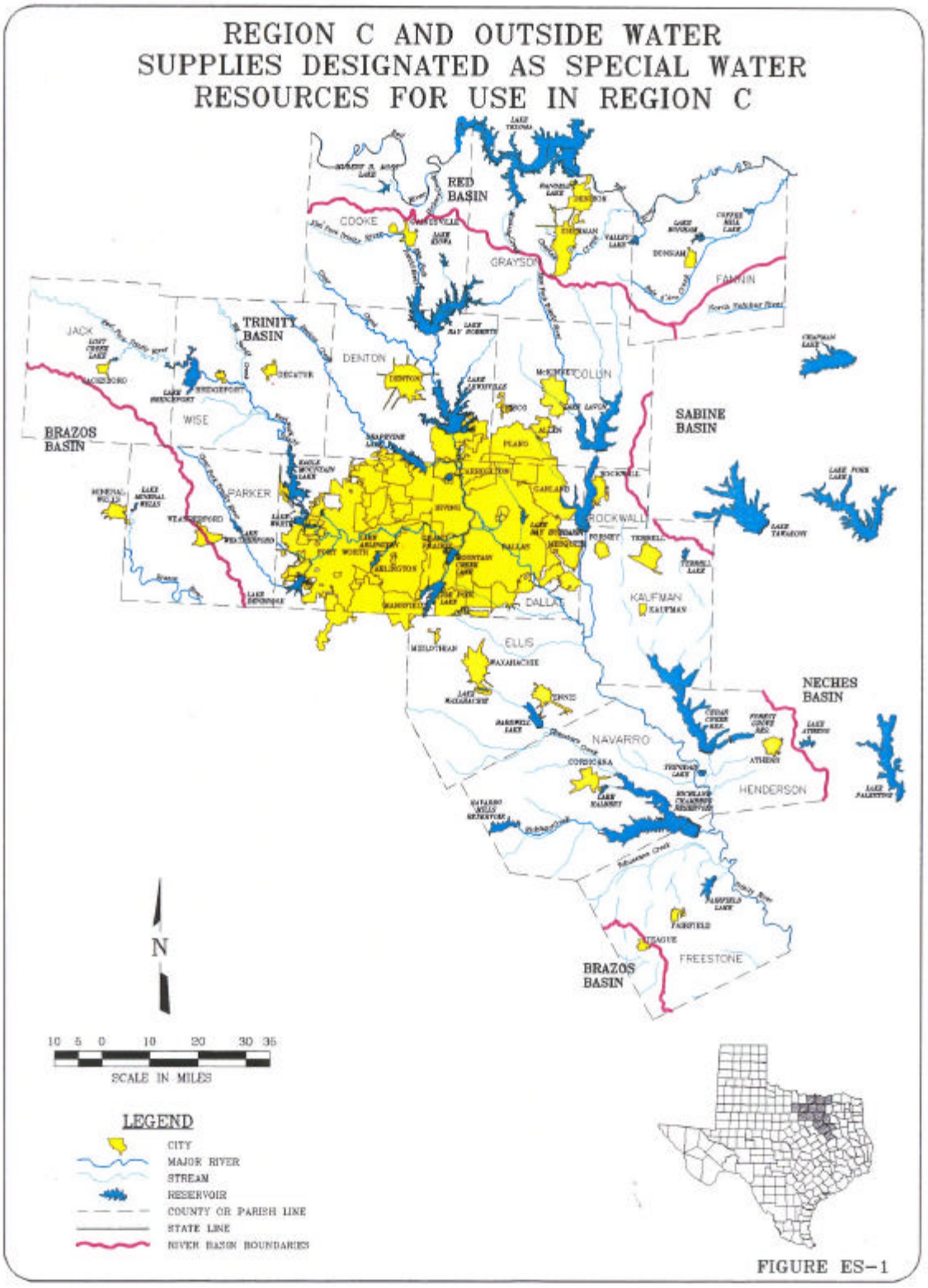


Figure 2-23. Region C.

ECONOMIC ACTIVITY IN REGION C

Region C includes most of the Dallas and Fort Worth-Arlington metropolitan statistical areas, which have experienced strong economic growth in the 1990's. Payroll and employment in Region C are concentrated in the central urban counties of Dallas and Tarrant. The largest business sectors in Region C in terms of payroll are services and manufacturing.

WATER-RELATED PHYSICAL FEATURES IN REGION C

Most of Region C is in the upper portion of the Trinity Basin, with smaller parts in the Red, Brazos, Sulphur, and Sabine basins. Figure 2-23 shows the major streams in Region C. Precipitation increases west to east in Region C, from slightly more than 30 inches per year in western Jack County to more than 44 inches per year in the northeast corner of Fannin County. The average annual runoff in the region also increases from the west to the east. Evaporation is higher in the western part of Region C. The patterns of rainfall, runoff, and evaporation result in more abundant water supplies in the eastern part of Region C than in the west.

There are 34 reservoirs in Region C with conservation storage over 5,000 acre-feet. All are shown in Figure 2-23. These reservoirs and others outside Region C provide most of the region's water supply. Reservoirs are necessary to provide a reliable surface water supply in this part of the state because of the wide variations in natural stream flow. Reservoir storage serves to capture high flows when they are available and save them for use during normal or low flow.

The Trinity aquifer supplies most of the groundwater used in Region C. Other aquifers in the region include the Carrizo-Wilcox, the Woodbine, the Nacatoch, and the Queen City.

CURRENT WATER USES AND DEMAND CENTERS IN REGION C

Water use in Region C has increased significantly since 1980, primarily in response to increasing population and municipal demand. The historical record shows years of high use, including 1988, 1996, and 1998. High use years are associated with dry weather, which causes higher municipal demands due to increased outdoor water use. It is interesting to note that Region C, with 24.4% of Texas' population, had only 7.2% of the state's water use in 1997. This is primarily because Region C has very limited water use for irrigation. About 85% of the current water use in Region C is for municipal supply, followed by manufacturing use, then by steam-electric power generation. Irrigation, mining, and livestock are relatively minor uses of water in Region C.

CURRENT SOURCES OF WATER SUPPLY

Total water use in Region C has increased significantly since 1980, but groundwater use has actually decreased in that period. Since 1990, over 90% of the water use in Region C has been supplied by surface water, but groundwater is still an important source of supply, especially

in some rural areas. Most of the surface water supply in Region C comes from major reservoirs. Another significant water source for Region C is surface water imported from other regions. The Trinity aquifer is by far the largest source of groundwater in Region C, with the Woodbine, Carrizo-Wilcox, and other minor aquifers also used. Current use of groundwater exceeds the reliable long-term supply available in many parts of Region C.

Over half the water used for municipal supply in Region C is discharged as treated effluent from wastewater treatment plants, making wastewater reclamation and reuse a potentially significant source of additional water supply for the region. At present, only a fraction of the region's treated wastewater is actually reclaimed and reused in the region. Many of the region's water suppliers are considering reuse projects, and it is clear that reuse of treated wastewater will be a significant part of future water planning for Region C.

WATER PROVIDERS IN REGION C

Water providers in Region C include regional wholesale suppliers (river authorities and water districts) and retail suppliers (cities and towns, water supply corporations, special utility districts, and private water companies). Cities and towns provide most of the retail water service in Region C. Table 2-47 shows some basic data on sales to others by the five major water providers in Region C, which are the only water suppliers in the region with over 20,000 acre-feet per year in wholesale sales.

TABLE 2-47
MAJOR WATER PROVIDERS IN REGION C

	1997 Wholesale Sales (acre-feet)			Number of Wholesale Customers		
Major Water Provider	**Raw**	**Treated**	**Total**	**Cities**	**Water Suppliers**	**Others**
Tarrant Regional Water District	258,448	0	258,448	12	11	16
North Texas Municipal Water District	0	168,247	168,247	23	14	1
Dallas	13,324	148,281	161,605	17	4	2
Fort Worth	427	39,521	39,948	28	2	4
Trinity River Authority	15,220	22,217	37,437	8	2	1

AGRICULTURAL AND NATURAL RESOURCES IN REGION C

Agricultural and natural resources in Region C are dependent on the region's water resources. Wetlands often rely on water from streams and reservoirs. They provide food and habitat for fish and wildlife, water quality improvement, flood protection, shoreline erosion control, and groundwater exchange, in addition to opportunities for human recreation, education, and research. Threatened or endangered species can depend on habitat associated with rivers and streams. The Texas Parks and Wildlife Department has identified several Region C stream

segments as having significant natural resources based on their high water quality, exceptional aquatic life, high aesthetic value, fisheries, spawning areas, unique state holdings, endangered or threatened species, priority bottomland hardwood habitat, wetlands, springs, and pristine areas.

Region C includes almost 6,000,000 acres in farms and over 2,500,000 acres of cropland. Less than 1% of the cropland in Region C is irrigated, but there are localized areas of irrigation. The market value of agriculture products is significant in all Region C counties, with a total value for 1997 of almost $500 million. For the region as a whole, the market value of livestock is almost twice that of crops. There are large areas in Cooke, Denton, Collin, Tarrant, Dallas, and Ellis counties classified as prime farmland by the Natural Resources Conservation Service.

Oil and natural gas fields are significant natural resources in portions of Region C. There is a high density of oil wells in Jack, Wise, Cooke, and Grayson counties, with a lesser density in Denton, Parker, Navarro, Henderson, and Kaufman counties. There is a high density of producing natural gas wells in Freestone, Parker, Jack, and Wise counties, with a lesser density in Navarro, Henderson, Denton, Cooke, and Grayson counties.

There are some lignite coal resources in Region C. The most significant current lignite production in Region C is in Freestone County to supply TXU Electric's Big Brown Steam Electric Station on Lake Fairfield.

SUMMARY OF THREATS AND CONSTRAINTS TO WATER SUPPLY IN REGION C

The most significant potential threats to existing water supplies in Region C are surface water quality concerns, groundwater drawdown, and groundwater quality. Constraints on the development of new supplies include the availability of sites and unappropriated water for new water supply reservoirs and the challenges imposed by environmental concerns and permitting.

Most of the water suppliers in Region C will have to develop additional supplies before 2050. The major water suppliers have supplies well in excess of current needs, but they will require additional water to meet projected growth. Some smaller water suppliers face a more urgent need for water.

Surface water quality concerns that might affect Region C water supplies include the following:

- Detection of atrazine at low levels in some water supply reservoirs
- Nutrient levels in water supply reservoirs
- Total organic carbon (TOC) levels in source waters
- Elevated levels of dissolved solids in some reservoirs and stream reaches
- Trace levels of arsenic in some waters

In general, these concerns can be addressed by standard water treatment methods and do not pose a significant threat to water supplies in the region.

Drawdown of aquifers poses a threat to small water suppliers and to household water use in rural areas. As water levels decline, the cost of pumping water grows and water quality generally suffers. Water level declines have been reported in localized areas in each of the aquifers in Region C. In particular, region-wide pumping from the Trinity and Nacatoch aquifers is estimated to be greater than the recharge. Concern about groundwater drawdown is likely to prevent any substantial increase in groundwater use in Region C and may require conversion to surface water in some areas.

Groundwater quality in Region C aquifers is generally acceptable for most municipal and industrial purposes. However, natural concentrations of arsenic, fluoride, nitrate, chloride, iron, manganese, sulfate, and total dissolved solids in excess of either primary or secondary drinking water standards occur in some areas.

WATER-RELATED THREATS TO AGRICULTURAL AND NATURAL RESOURCES IN REGION C

Water-related threats to agricultural and natural resources in Region C include changes to natural flow conditions, water quality concerns, and inundation of land due to reservoir development. In general, there are few significant water-related threats to agricultural resources in Region C due to the limited use of water for agricultural purposes. Water-related threats to natural resources are more significant.

Population and Water Demand Projections

Methodology for Projections of Population and Water Demand. The Texas Water Development Board's SB1 planning guidelines require the use of TWDB's population and water demand projections from the 1997 Texas Water Plan unless revisions are approved by TWDB based on changed conditions or new information. The TWDB projects water demand separately for municipal, manufacturing, steam-electric power generation, mining, irrigation, and livestock uses. Municipal demand is developed for each community with a population over 500 and includes commercial, institutional, and residential water uses but does not include manufacturing use. A "county other" group for each county covers municipal use in rural areas and communities with less than 500 people. All demand categories except municipal are developed on a county-wide basis.

To develop population and water demand projections for Region C, the Region C RWPG went through the following steps:

- Assembled historical data and previous TWDB projections and developed tables and figures that could be reviewed by counties, cities, water suppliers, industries, and other interested entities.
- Sent the TWDB data and a questionnaire to all Region C counties, cities with a population over 1,000, regional water suppliers, retail water suppliers (supplying over 0.2 mgd), and large industries.

- Gathered population data from the Texas State Data Center and the North Central Texas Council of Governments.
- Reviewed previous TWDB population projections for each county and recommended changes to projections where current populations deviate significantly from previous projections.
- Adjusted city population projections based on historical trends and knowledge of expected future development using the county population projections as controls.
- Compared TWDB's projections of per capita municipal water demand from the 1997 Texas Water Plan with actual per capita water demand in the 1990's from TWDB data.
- Developed data on 1998 per capita water use for Region C water providers.
- Adjusted previous TWDB projections in per capita water demand to reflect actual use in the 1990's, trends in water use, water conservation, reasonable minimum demands for water, knowledge of future development that might affect per capita needs, and other factors.
- Developed tables and graphs for each city in the region to assist in review of the recommended projections.
- Revised projections of water demand for steam-electric power generation based on input from Texas Utilities (TXU) Electric.
- Checked previous TWDB projections for manufacturing, mining, irrigation, and livestock use and left them unchanged after comparison with recent historical data.
- Formed a Technical Review Committee consisting of experienced water resource planners to review the recommendations of the consultants on population and water use and report to the planning group.
- Held a public meeting to receive input on water demand projections.
- Made a number of additional changes as a result of TWDB review and input.
- Submitted the revised projections to the TWDB, which approved the revised projections in December 1999.

Appendix 2 of the region's water plan discusses in detail the population and water demand projections.

Population Projections. Table 2-48 presents the adopted population projections by county for Region C. Figure 2-24 shows the historical and projected population for the region. All counties are projected to increase in population between now and 2050. The projected 2050 population for Region C is 9,481,157. Once the county population projections were completed, city population projections were adjusted based on historical trends and knowledge of expected future development. The county populations served as controls in this process, and all population not assigned to a particular city was included as county other.

Water Demand Projections. Table 2-49 shows the adopted water demand projections for Region C by county. Table 2-50 and Figure 2-25 show the projected water demand for the region by type of use. The projected 2050 water demand for Region C is 2,536,902 acre-feet per year, which is more than double the 1996 use in the region. Most of the change from previous TWDB projections is in municipal demands, with a smaller change in steam-electric power

TABLE 2-48

ADOPTED COUNTY POPULATION PROJECTIONS FOR REGION C

County	Historical 1996	2000	2010	2020	2030	2040	2050	Actual 2000 vs Water Plan
Collin	373,095	443,000	635,455	923,309	1,150,001	1,351,000	1,501,395	
Cooke	33,196	34,209	36,967	38,816	40,000	41,250	42,500	
Dallas	1,999,926	2,104,858	2,326,828	2,556,793	2,784,704	3,045,931	3,259,995	
Denton	349,566	423,327	591,350	802,461	1,033,731	1,200,000	1,349,999	
Ellis	94,097	103,070	123,854	144,054	162,273	175,403	185,364	
Fannin	27,435	30,000	33,601	37,000	39,501	40,499	41,001	
Freestone	17,757	18,167	18,800	19,300	19,600	20,000	20,300	
Grayson	100,611	106,119	110,226	114,702	117,865	120,981	122,000	
Henderson (Partial)	45,761	46,562	51,261	55,515	57,704	58,690	60,476	
Jack	7,435	7,819	8,139	8,591	8,934	9,175	9,353	
Kaufman	61,646	68,368	87,106	108,291	129,359	147,108	162,417	
Navarro	42,875	45,191	49,207	53,031	57,015	59,200	61,000	
Parker	73,897	80,436	99,095	118,287	139,094	156,023	171,216	
Rockwall	34,287	41,175	61,392	88,136	122,000	160,588	203,529	
Tarrant	1,306,457	1,415,759	1,594,218	1,798,894	1,915,375	2,111,193	2,205,610	
Wise	41,019	44,800	54,674	64,363	73,641	81,000	85,002	
Region C Total	4,609,060	5,012,860	5,882,173	6,931,543	7,850,797	8,778,041	9,481,157	

NOTE: ADD ACTUAL 2000 POPULATION CENSUS

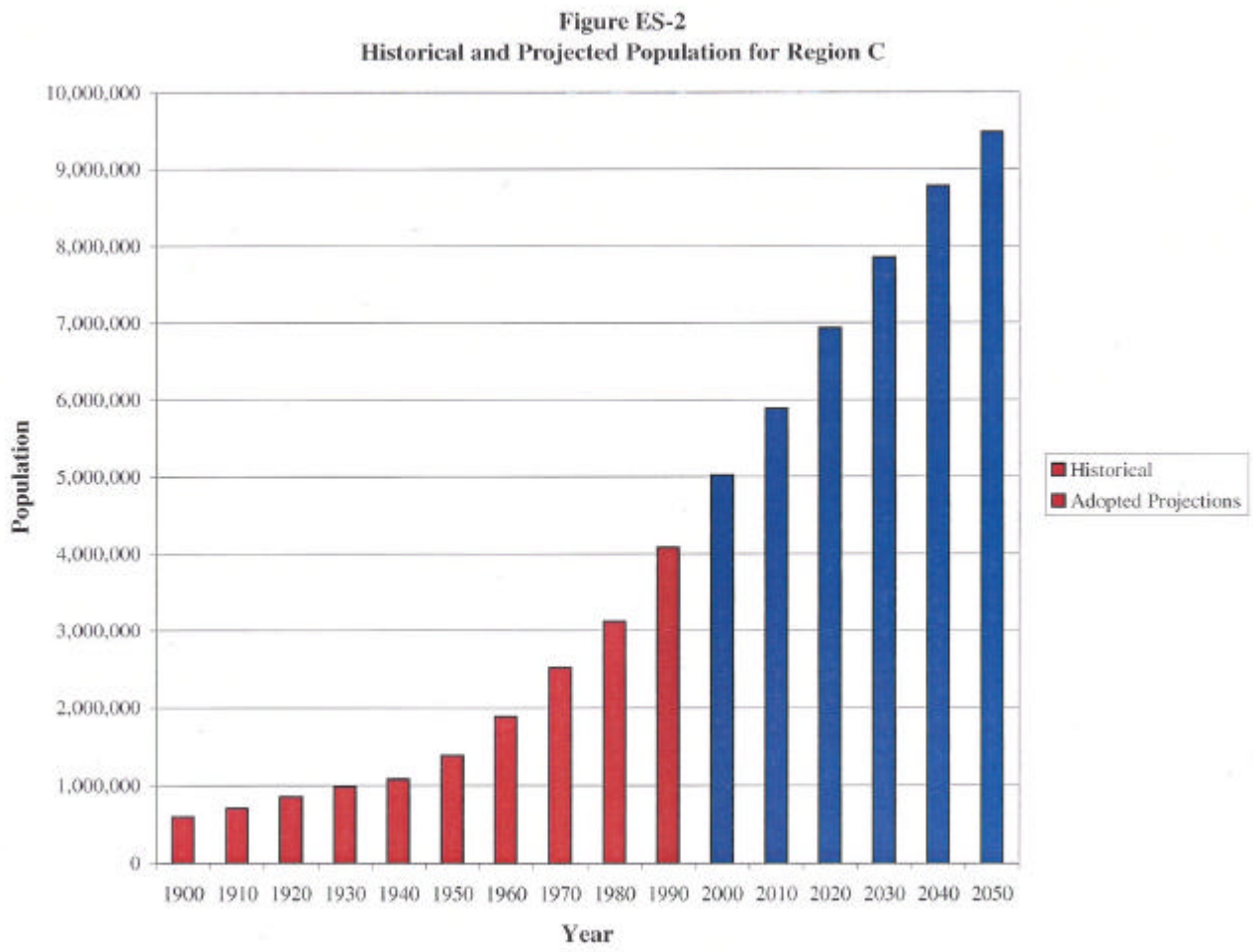


Figure 2-24. Historical and Projected Population for Region C.

TABLE 2-49
ADOPTED COUNTY WATER DEMAND PROJECTIONS FOR REGION C
(Values in Acre-Feet per Year)

County	Historical 1996	2000	2010	2020	2030	2040	2050
Collin	89,230	129,015	199,964	262,520	312,307	363,821	401,007
Cooke	8,429	9,054	9,133	9,238	9,304	9,581	9,879
Dallas	505,423	594,937	683,097	751,767	810,356	883,850	940,289
Denton	65,075	90,209	135,740	185,725	230,286	257,410	281,989
Ellis	19,721	24,372	43,204	46,030	49,309	53,991	55,575
Fannin	17,515	12,100	13,330	14,500	15,597	16,572	17,515
Freestone	20,608	20,074	31,058	33,000	33,036	37,260	37,290
Grayson	29,152	29,060	29,760	30,242	31,347	32,508	33,688
Henderson (Partial)	10,785	12,697	13,169	13,478	13,697	13,737	13,908
Jack	3,337	2,644	2,589	2,574	2,591	2,615	2,652
Kaufman	10,653	21,219	24,401	27,392	32,361	34,832	42,017
Navarro	10,558	10,301	10,845	11,210	11,850	12,303	12,735
Parker	12,372	14,120	24,528	28,455	37,697	42,853	45,725
Rockwall	6,566	9,160	19,805	26,027	33,061	41,320	50,249
Tarrant	291,406	379,205	423,578	468,728	490,960	527,716	553,302
Wise	25,688	18,206	31,460	34,007	36,067	37,819	39,082
Region C Total	1,126,518	1,376,373	1,695,661	1,944,893	2,149,826	2,368,188	2,536,902

TABLE 2-50
ADOPTED WATER DEMAND PROJECTIONS FOR REGION C BY TYPE OF USE
(Values in Acre-Feet per Year)

County	Historical 1996	2000	2010	2020	2030	2040	2050
Municipal	946,454	1,162,093	1,401,197	1,625,412	1,808,337	1,988,513	2,125,330
Manufacturing	71,366	117,577	135,114	148,798	162,714	183,188	207,637
Steam-Electric Power	52,103	59,800	122,300	132,700	139,700	156,192	162,192
Mining	22,576	13,046	13,231	14,190	15,294	16,515	17,950
Irrigation	9,689	5,382	5,344	5,318	5,306	5,305	5,318
Livestock	24,330	18,475	18,475	18,475	18,475	18,475	18,475
Total	1,126,518	1,376,373	1,695,661	1,944,893	2,149,826	2,368,188	2,536,902

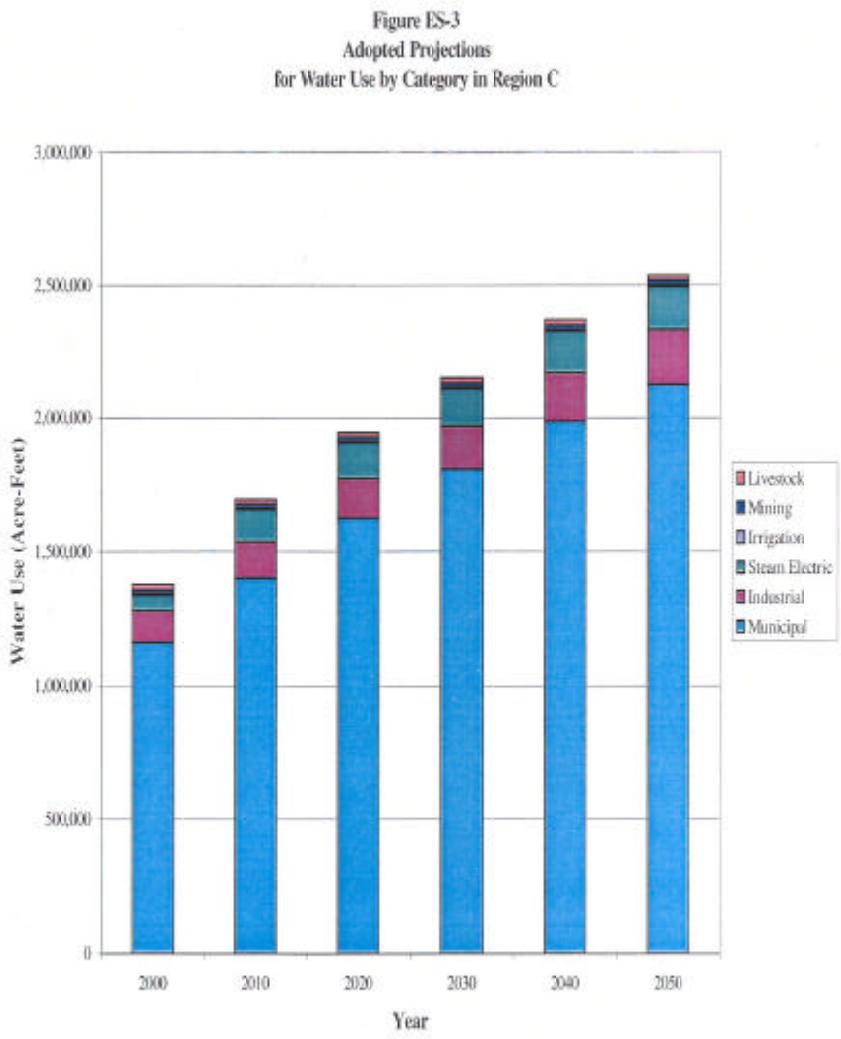


Figure 2-25. Projected Water Demand for Region C By Type of Use.

demands. No changes were made to the TWDB's previous projections for manufacturing, mining, irrigation, or livestock demands.

One of the most important reasons for the increase in projected per capita demand for Region C is the high water use recorded for many Region C water suppliers in 1996 and 1998. This high water use occurred despite significant water conservation efforts in the region and despite the impact of low flow plumbing fixtures. There are several factors that tend to increase per capita municipal water use in the region:

- In many communities, new development consists of large houses with large lots, sprinkler systems, swimming pools, and other water-using amenities.
- The number of people per household is decreasing in most of Region C. This tends to cause an increase in per capita use because household uses are spread over fewer people.
- Many Region C communities are experiencing rapid commercial development, which increases per capita water use.

Analysis of Water Supply Currently Available to Region C

Total water use in Region C in 1996 was over 1,100,000 acre-feet. About 74% of the region's 1996 water use came from in-region reservoirs. The projected total reliable water supply available to Region C in 2050 from current sources will be about 2,023,000 acre-feet per year. (This figure does not consider supply limitations due to the capacities of current raw water transmission facilities and wells.) Figure 2-26 shows the projected total water availability for Region C. The sources of supply for Region C in 2050 include:

- 1,138,000 acre-feet per year (56%) from in-region reservoirs
- 181,000 acre-feet per year (9%) from groundwater
- 70,000 acre-feet per year (3%) from local supplies
- 82,000 acre-feet per year (4%) from reuse
- 552,000 acre-feet per year (28%) from imports from other regions

The projected supply available to Region C from existing sources in 2050 is significantly less than the projected 2050 water use. Appendix 3 in the water plan analyses the water supply currently available to Region C.

If the supply limitations due to the capacities of current raw water transmission facilities and wells are considered, the available supply for Region C is reduced significantly. Most water user groups will have to make improvements to water transmission facilities or wells to provide for their projected needs. Several major Region C water supplies will require additional raw water transmission facilities before they can be utilized fully.

Current groundwater use in parts of Region C exceeds the projected long-term water supply availability. Supplies from other sources will be needed in these areas so that groundwater use can be reduced. Counties and aquifers where current use exceeds long-term supplies include the following:

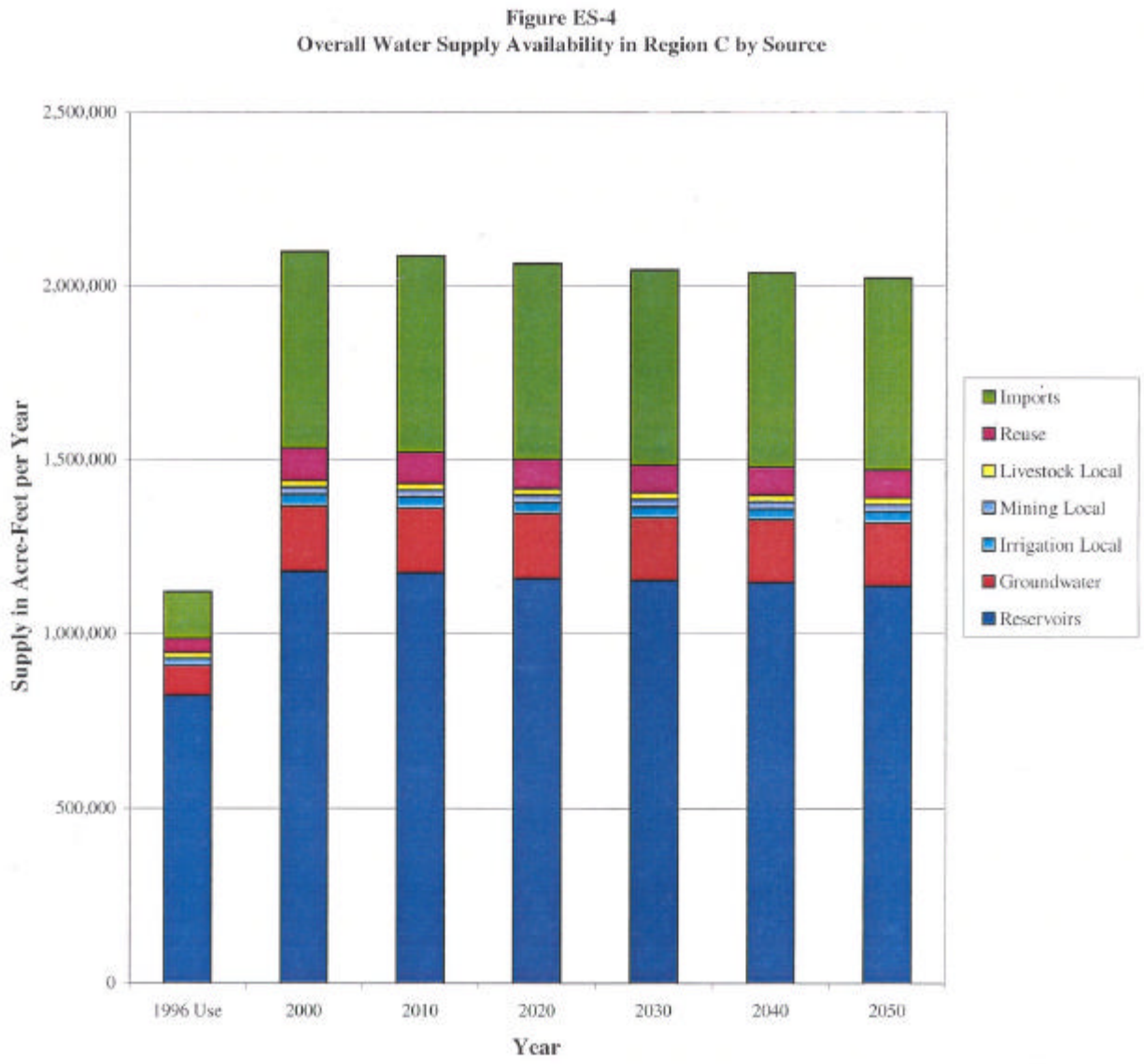


Figure 2-26. Projected Total Water Availability for Region C.

- Trinity aquifer in Cooke County
- Trinity and Woodbine aquifers in Denton County
- Woodbine aquifer in Ellis County
- Trinity and Woodbine aquifers in Grayson County
- Nacatoch aquifer in Kaufman County
- Trinity aquifer in Parker County
- Trinity aquifer in Tarrant County.

Some of the total supply shown as available to Region C will probably not be utilized fully during the period covered by this plan. This includes over 90,000 acre-feet per year of groundwater shown to be available in the Carrizo-Wilcox aquifer in Freestone County.

The five major water providers in Region C (City of Dallas, Tarrant Regional Water District, North Texas Municipal Water District, City of Fort Worth, and Trinity River Authority) provided over 903,000 acre-feet of water in 1996 (80% of the total provided in the region). They have 74% of the 2050 water supply currently available to the region.

The recent dry summers of 1996, 1998, 1999, and 2000 have caused very high water use for many Region C water suppliers. These droughts have put stress on some of the region's major reservoirs, which are designed for a 5 to 7 year drought like that of the 1950's. The high demands also exposed supply limitations for many smaller suppliers (especially those dependent on groundwater) and exposed treatment and distribution limitations for other suppliers.

Comparison of Current Water Supply and Projected Water Demand

Comparison of Supply and Demand. Figure 2-27 shows the comparison of total supply with demand for Region C, including supplies that require additional water transmission facilities before they are available to the region. By 2030, the projected demand for Region C exceeds the total supply, even if all of the supplies available to the region are used in full. Appendix 4 in the water plan compares current water supply to projected water demand.

Considering only currently connected supplies (those with transmission systems already in place), the following facts emerge for Region C:

- In 2000, three Region C counties (Cooke, Dallas, and Parker) show a net need for immediate additional supplies when all demands and all connected supplies are totaled.
- Significant additional supplies need to be connected before 2010 in Region C. (Several major projects to connect existing supplies are already underway.)
- By 2050, 11 of the 16 Region C counties show a need for connection or development of additional supplies to meet projected demands.
- By 2050, 193 of 281 Region C water user groups show a need for connection or development of additional supplies to meet projected demands.
- Current plans call for the connection of significant additional supplies for Region C over the next few years, including the following:

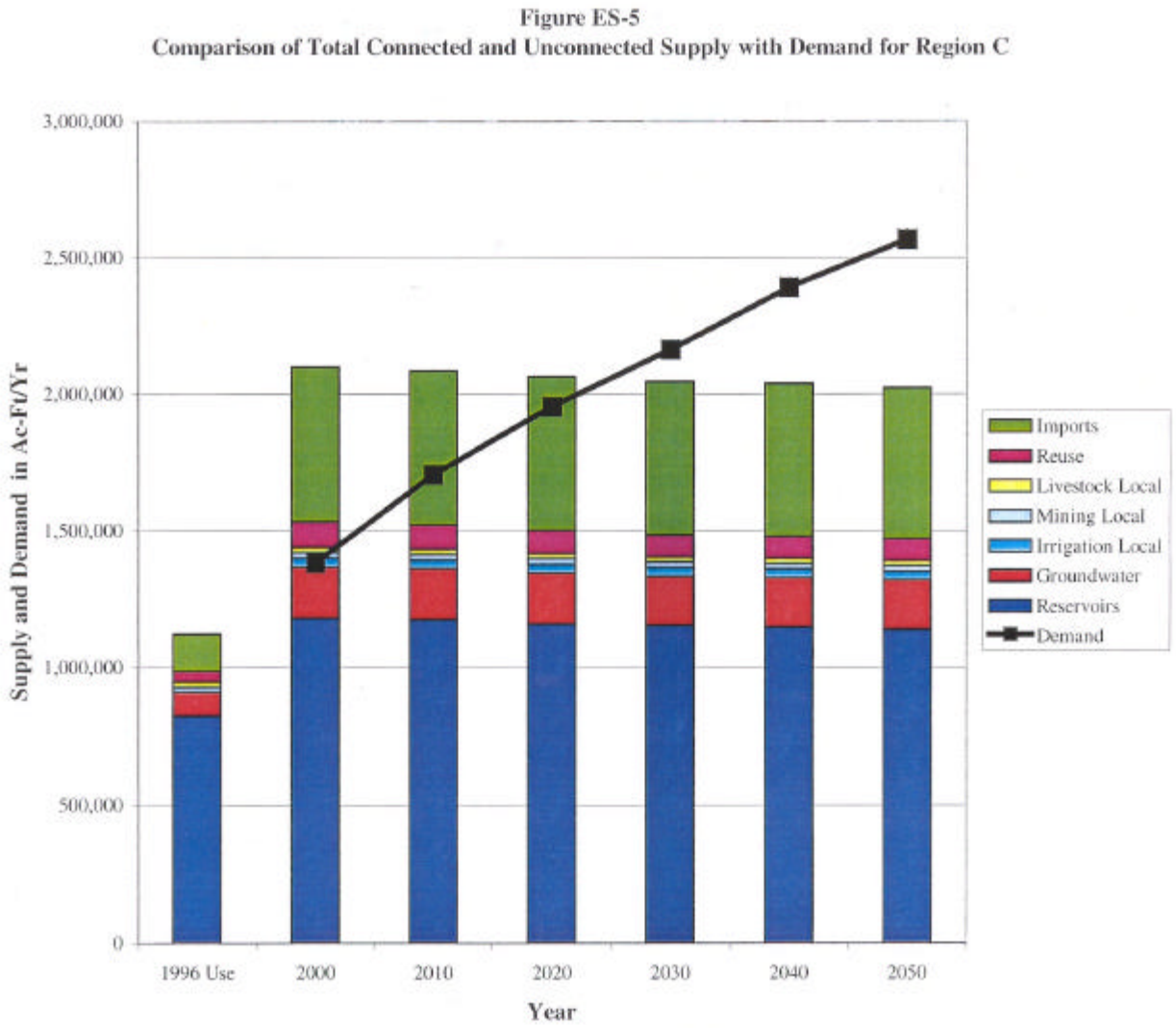


Figure 2-27. Comparison of Total Supply with Demand for Region C.

- Irving and Upper Trinity Regional Water District's Lake Chapman pipeline is scheduled for completion by 2003 and will connect 65,700 acre-feet per year.
- Dallas Water Utilities Lake Fork pipeline is scheduled for completion by 2004 and will connect 120,000 acre-feet per year.
- Tarrant Regional Water District is planning additional capacity for its pipeline to Richland-Chambers Lake that will connect an additional 110,000 acre-feet per year by 2005.

- Many Region C water suppliers depend on the region's major water providers (Dallas Water Utilities, Tarrant Regional Water District, North Texas Municipal Water District, City of Fort Worth, and Trinity River Authority) for all or part of their supplies. Each of those major water providers will need additional supplies by 2050.

A comparison of water demands and current supply by major water provider (Appendix M Table 8 in the region's water plan) is shown in Table 2-51 below.

TABLE 2-51
COMPARISON OF WATER DEMAND WITH CURRENT WATER SUPPLIES BY MAJOR PROVIDER--MUNICIPAL AND MANUFACTURING WATER
(acre-feet-year)

Major Provider	Year					
	2000	2010	2020	2030	2040	2050
Dallas Water Utilities	(70,707)	(118,175)	2,978	21,833	2,866	(7,113)
Fort Worth	11,039	(9,825)	(6,534)	(16,170)	(27,215)	(36,987)
No. Texas Municipal Water Dist.	36,479	(46,508)	(123,089)	(186,798)	(250,985)	(301,274)
Tarrant Regional Water District	14,460	(48,716)	(49,674)	(74,653)	(94,338)	(123,339)
Trinity River Authority	(1,110)	(37,577)	(36,915)	(39,417)	(42,582)	(45,438)

Note: See Appendix M, Table 8, Region C Water Plan.

SOCIOECONOMIC IMPACTS OF NOT MEETING PROJECTED WATER NEEDS

If no additional water supplies are developed, Region C will face substantial shortages in water supply over the next 50 years. The TWDB provided technical assistance to regional water planning groups in the development of information on socioeconomic impacts of failing to meet projected water needs. The TWDB's findings for Region C can be summarized as follows:

- The currently connected supplies in Region C would meet only 52.5% of the projected 2050 demand.
- Without any additional supplies, the region's projected 2050 population would be limited to 6,078,289, instead of 9,481,157, a reduction of 35.9%.
- Without any additional supplies, the region's projected 2050 employment would be limited to 2,605,111, instead of 4,425,184, a reduction of 41.1%.
- Without any additional supplies, the region's projected 2050 income would be limited to $109,505,000,000, instead of $171,199,000,000, a reduction of 36.3%.

EVALUATION AND SELECTION OF WATER MANAGEMENT STRATEGIES

The RWPG went through several steps in the evaluation and selection of water management strategies for Region C:

- Review of previous plans for water supply in Region C, including locally developed plans and the most recent state water plan
- Development of goals, issues, and concerns for the planning process
- General consideration of the types of water management strategies required by SB1 regional planning guidelines
- Development of evaluation criteria for management strategies
- Evaluation of individual strategies
- Development of cost information for individual strategies
- Selection of strategies.

Appendix 5 in the water plan discusses the evaluation and selection of water management strategies by provider and county in Region C.

Development of a water plan covering 50 years for a region as large and populous as Region C is full of uncertainties. Implementation of the resulting plan must be flexible to allow for slower or faster than expected growth, unexpected obstacles in development of water management strategies, and unexpected opportunities. Specific points to remember include the following:

- The order in which steps are taken and the exact amount of supply available from each source are subject to variation.
- Water suppliers may need to turn to other alternatives if the recommended alternatives prove to be impractical.
- Changes in one element of the plan can affect other elements.
- Given the uncertainty in developing future supplies, flexibility in plan implementation is essential to success.
- The details of the plan will probably change as implementation proceeds.

GOALS OF THE PLANNING PROCESS

The goals for the Region C water planning effort are as follows:

- Provide sufficient water to meet realistic estimates of demand in a timely manner.
- Develop an effective continuing planning process to maintain reliable estimates of supply, maintain realistic estimates of demand, and identify appropriate programs and facilities to meet the water supply needs of Region C.
- Provide for the water supply needs of Region C in a manner that supports continued economic strength of both Region C and the state as a whole.

- Develop a water supply plan that recognizes the economic, environmental, and cultural importance of natural resources and provides for the maintenance of those resources.
- Address the water supply needs of small cities and rural areas as well as large metropolitan areas.
- Provide for sustainable groundwater use in areas where groundwater is an essential component of the water supply plan.

TYPES OF WATER MANAGEMENT STRATEGIES CONSIDERED

As required by SB1 guidelines, the Region C RWPG considered specific types of water management strategies as means of developing additional water supplies:

- Water conservation and drought response planning
- Reuse of wastewater
- Expanded use or acquisition of existing supplies
- Reallocation of reservoir storage to new uses
- Voluntary redistribution of water resources
- Voluntary subordination of water rights
- Enhancement of yields of existing sources
- Control of naturally occurring chlorides
- Interbasin transfers
- New supply development
- Water management strategies in the current State water plan
- Brush control, precipitation enhancement, and desalination
- Water right cancellation
- Aquifer storage and recovery
- Other measures.

METHODOLOGY FOR EVALUATING WATER MANAGEMENT STRATEGIES

The Region C RWPG considered the following factors in the evaluation of potential water management strategies:

- Quantity of water made available
- Reliability of supply
- Unit cost of delivered and treated water
- Difficulty of addressing environmental issues
    - In-stream flows
    - Bay and estuary flows
    - Wildlife habitat
    - Cultural resources
    - Wetlands

    - Water quality
    - Other
- Impacts on water resources and other management strategies
- Impacts on agricultural and natural resources
- Consistency with plans of Region C water suppliers
- Consistency with other regions.

Development of cost estimates for water management strategies followed guidelines provided by the TWDB. The costs include a 30% allowance for engineering and contingencies for pipelines and a 35% engineering and contingency allowance for other projects. Costs are for development of new supplies and do not include costs for:

- Facilities already in place
- Replacement or upgrading of aging facilities
- Improvements to meet changing regulatory requirements
- Improvements for water distribution to retail customers

RECOMMENDED WATER MANAGEMENT STRATEGIES FOR MAJOR WATER PROVIDERS

A large part of the water supplied in Region C is provided by the five major water providers in the region: Dallas Water Utilities, Tarrant Regional Water District, North Texas Municipal Water District, City of Fort Worth, and Trinity River Authority. These five entities will continue to provide the majority of the water supply for Region C through 2050, and they will also develop most of the new supply developed in that time period. Recommended water management strategies to meet the needs of these major water providers include the following:

- **Marvin Nichols I Lake**
    - Major new reservoir in the Sulphur River Basin in the northeast Texas Region (Region D)
    - Cooperative effort of Region C and Region D water suppliers
    - Total yield of 619,100 acre-feet per year
        - 123,800 acre-feet per year to Region D
        - 112,000 acre-feet per year to Dallas Water Utilities
        - 156,000 acre-feet per year to Tarrant Regional Water District
        - 163,300 acre-feet per year to North Texas Municipal Water District
        - 25,000 acre-feet per year to Irving
        - 39,000 acre-feet per year to meet other Region C needs.
    - Estimated capital cost for Region C (including transmission to Region C but not including treatment) of $1,625,190,000.

- **Dallas Water Utilities**
    - Figure 2-28 shows the overall comparison of supply and demand for Dallas Water Utilities with recommended water management strategies.

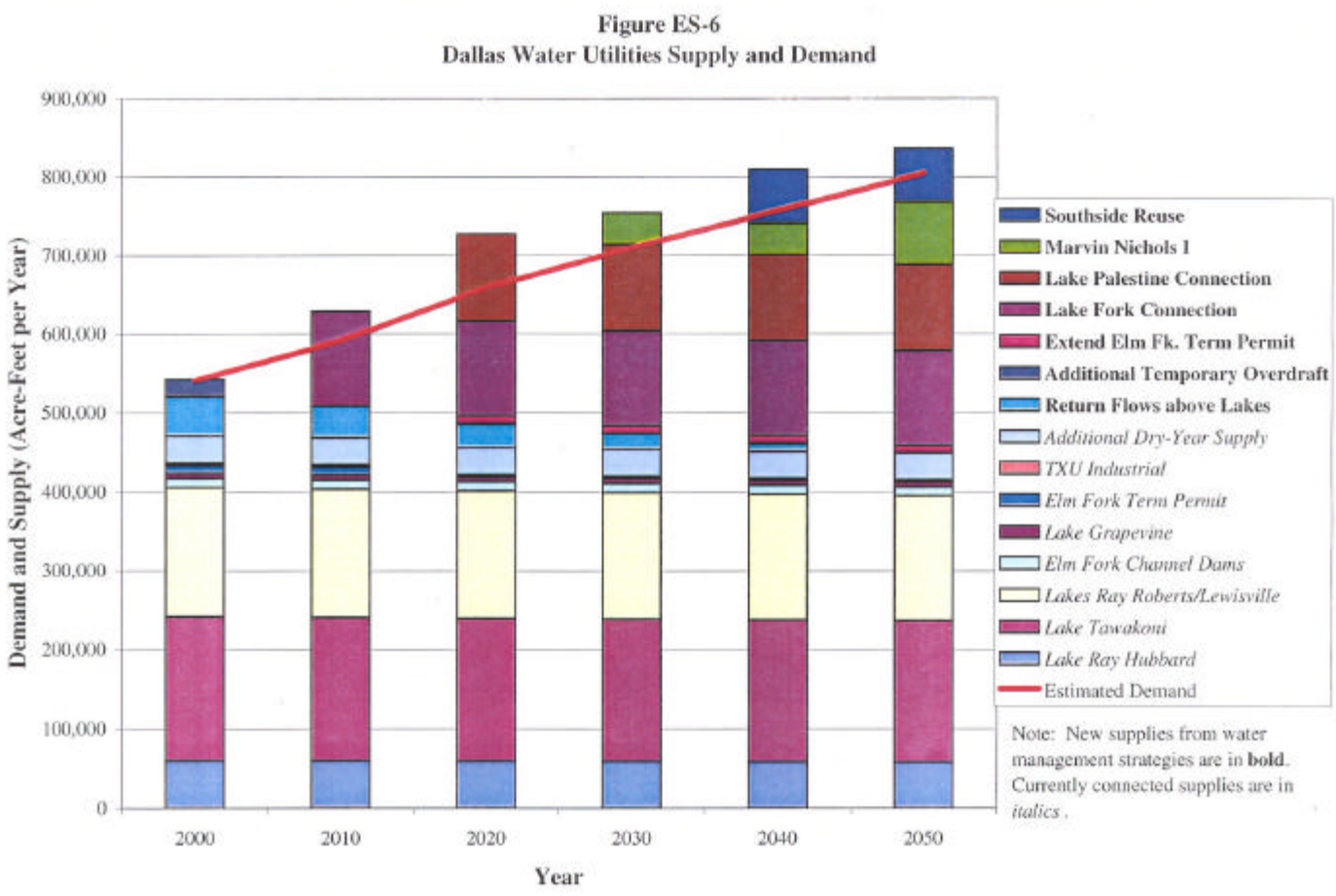


Figure 2-28. Overall Comparison of Supply and Demand for Dallas Water Utilities With The Recommended Water Management Strategies.

- Continue to use return flows above its lakes (50,000 acre-feet per year in 2000, decreasing to 0 by 2050).
- Temporarily overdraft its reservoirs in 2000 (22,000 acre-feet per year in 2000).
- Extend the Elm Fork permit for wet weather diversions (10,000 acre-feet per year).
- Connect Lake Fork Reservoir to its system (120,000 acre-feet per year).
- Connect Lake Palestine to its system (109,600 acre-feet per year).
- Participate in the Marvin Nichols I project (112,000 acre-feet per year).
- Develop a reuse project (68,300 acre-feet per year).
- Renew contracts with existing customers as they expire.
- Develop additional water treatment capacity as needed.
- Other alternatives for Dallas Water Utilities include additional reuse and development of yield from return flows in the watersheds of water supply reservoirs.

- **Tarrant Regional Water District**
  - Figure 2-29 shows the overall comparison of supply and demand for Tarrant Regional Water District with recommended water management strategies.
  - Add pumps and a booster pump station to develop additional capacity in the pipeline from Richland-Chambers Lake to Tarrant County (110,000 acre-feet per year).
  - Develop the West Fork Connection to allow water to be transferred among the parts of the water supply system.
  - Develop the proposed reuse project to pump water from the Trinity River into Cedar Creek Lake and Richland-Chambers Lake to supplement yields (115,500 acre-feet per year).
  - Develop a water supply from existing water sources in Oklahoma (12,000 acre-feet per year)
  - Develop a third pipeline from Cedar Creek Lake and Richland-Chambers Lake to Tarrant County.
  - Participate in the Marvin Nichols I project (156,000 acre-feet per year).
  - Other alternatives for Tarrant Regional Water District include developing Lake Tehuacana and obtaining water from Lake Texoma.

- **North Texas Municipal Water District**
  - Figure 2-30 shows the overall comparison of supply and demand for North Texas Municipal Water District with recommended water management strategies.
  - Develop additional water supplies in Lake Lavon from reuse (35,900 acre-feet per year).
  - Develop additional water supplies from Lake Texoma (10,000 acre-feet per year).
  - Develop a water supply from existing water sources in Oklahoma (50,000 acre-feet per year).
  - Develop Lower Bois d'Arc Creek Reservoir on Bois d'Arc Creek (98,000 acre-feet per year).
  - Participate in the Marvin Nichols I project (163,300 acre-feet per year).

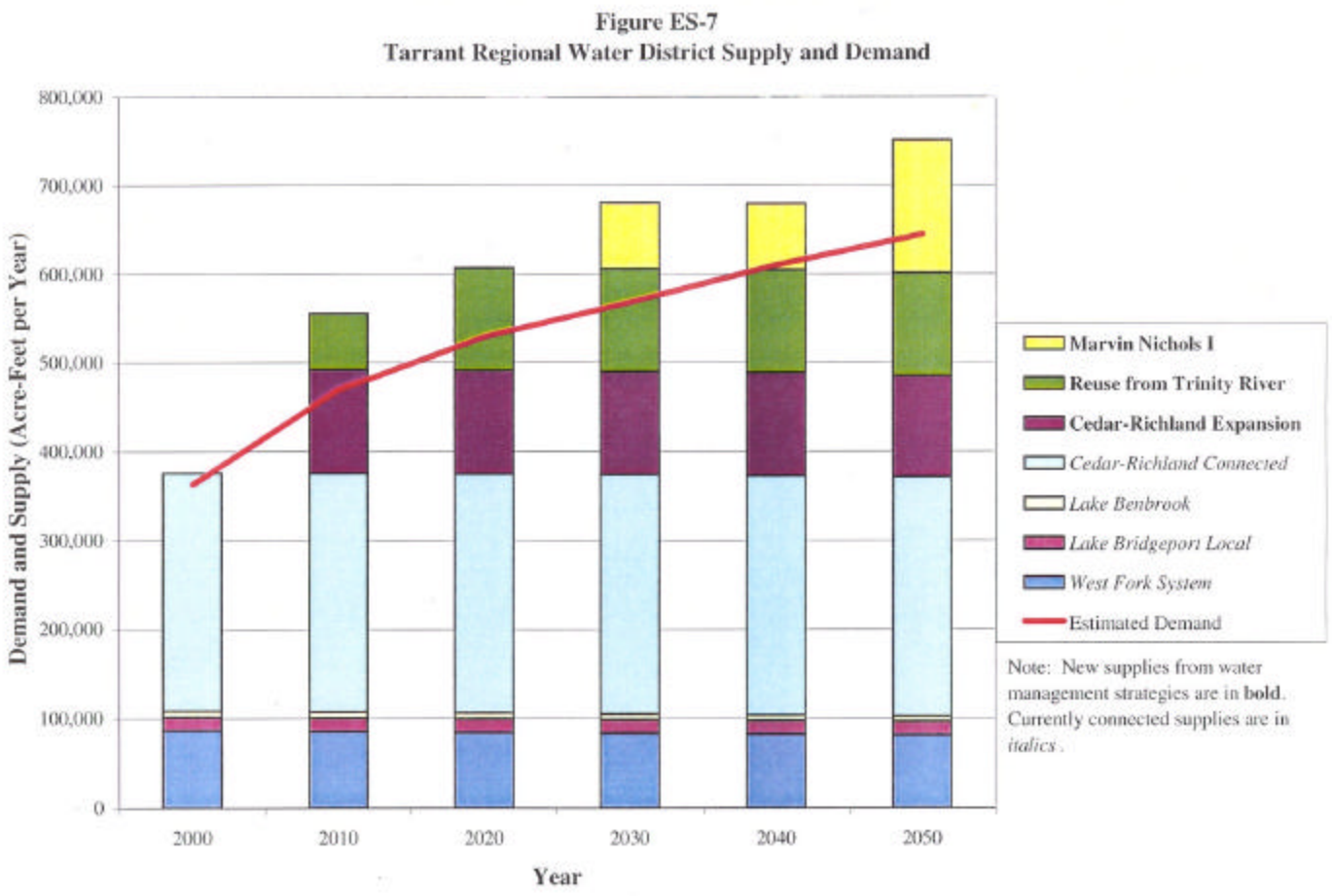


Figure 2-29. Overall Comparison of Supply and Demand For Tarrant Regional Water District With The Recommended Water Management Strategies.

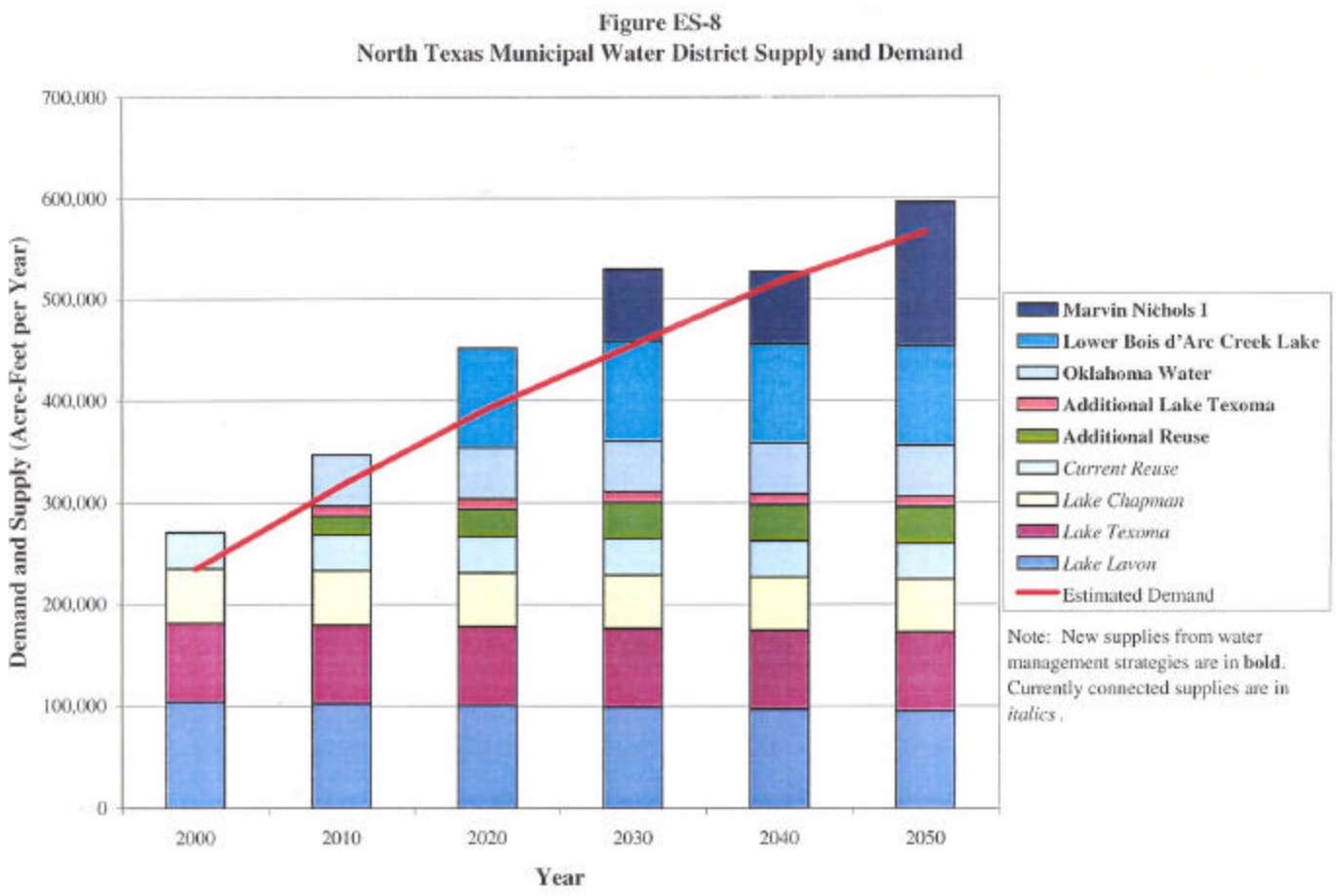


Figure 2-30. Overall Comparison of Supply and Demand For North Texas Municipal Water District With The Recommended Water Management Strategies.

- Develop additional water treatment capacity and treated water transmission system improvements as needed.
- Other alternatives for North Texas Municipal Water District include obtaining a substantial additional supply from Lake Texoma and extending the existing Lake Texoma pipeline to minimize channel losses.

- **City of Fort Worth**
  - Continue to obtain essentially all raw water from Tarrant Regional Water District.
  - Renew contracts with its existing customers as they expire.
  - Develop additional water treatment capacity as needed.

- **Trinity River Authority**
  - Continue to obtain raw water from Tarrant Regional Water District for its Tarrant County water supply project.
  - Expand Tarrant County water supply project raw water transmission, water treatment, and treated water transmission facilities as needed to meet growing demands.
  - Obtain raw water from Tarrant Regional Water District to implement the Ellis County water supply project.
  - Develop raw and treated water transmission lines to implement the Ellis County water supply project.
  - Develop reuse projects:
    - Additional golf course and landscape irrigation in the Las Colinas area,
    - Golf course and landscape irrigation in Denton and Tarrant counties,
    - Steam-electric power supply in Dallas and Ellis counties, and
    - Reuse for municipal supply in Dallas County through Joe Pool Lake and Lake Grapevine.

Table 2-52 summarizes the total new supply from 2000 through 2050 and the estimated capital cost to develop the supply for the five major water providers in Region C.

TABLE 2-52

NEW SUPPLY FROM WATER MANAGEMENT STRATEGIES AND ESTIMATED CAPITAL COSTS FOR REGION C MAJOR WATER PROVIDERS

Major Water Provider	New Supply, 2000-2050 (acre-feet per year)	Estimated Capital Cost
Dallas Water Utilities	419,900	$1,492,649,000
Tarrant Regional Water District	393,500	$1,167,652,000
North Texas Municipal Water District	357,200	$1,435,447,000
Fort Worth	*	$ 221,475,000
Trinity River Authority	81,500*	$ 166,081,000
Total	1,252,100	$4,483,304,000

New supplies for Fort Worth and Trinity River Authority are included in the Tarrant Regional Water District total.

RECOMMENDED WATER MANAGEMENT STRATEGIES BY COUNTY

The recommended strategies for each county in Region C are summarized below:

- **Collin County**
  - Most Collin County water user groups will continue to obtain treated water from North Texas Municipal Water District.
  - Blue Ridge will develop new wells and continue to rely on the Woodbine aquifer.
  - Celina will obtain treated water from the Upper Trinity Regional Water District.
  - Dallas Water Utilities will supply the part of Dallas in Collin County.
  - Prosper will purchase treated water from North Texas Municipal Water District and Upper Trinity Regional Water District.
  - Water suppliers will temporarily overdraft groundwater while developing surface supplies.
  - Water for steam-electric power will be provided by a direct reuse project.

Table 2-53 shows the potential new reservoirs for Region C water supply.

- **Cooke County**
  - Current groundwater use in Cooke County exceeds the TWDB's estimated long-term reliable supply.
  - Gainesville is currently developing transmission and treatment facilities to connect to its existing Moss Lake surface water supply.
  - Muenster is planning to develop a 500 acre-foot per year supply from the proposed Muenster Lake in the next few years.
  - The Cooke County water supply system will be developed using raw water from Gainesville's Moss Lake to provide surface water supplies for water users in the county.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - Water users in Cooke County might consider formation of a groundwater management district.
  - The Upper Trinity Regional Water District will supply treated water to Valley View and a portion of Cooke County Other.

- **Dallas County**
  - Most water user groups in Dallas County will continue to obtain treated water from Dallas Water Utilities and North Texas Municipal Water District, renewing contracts as they expire.
  - Irving will complete facilities to bring its water supply from Lake Chapman to Lake Lewisville for treatment by Dallas and use by Irving.
  - Irving will develop a supply from Marvin Nichols I Reservoir.
  - Grapevine will implement its authorized direct reuse project.
  - Dallas County Other demands will be met from Dallas Water Utilities, Trinity River Authority reuse projects, and the proposed Marvin Nichols I project.

TABLE 2-53

POTENTIAL NEW RESERVOIRS FOR REGION C WATER SUPPLY

Name	Region	County	Basin	Stream	Yield in Acre-Feet/Year			Estimated Capital Cost		
					Holding All Inflow	With Releases*	Source	Previous Estimate	Base Year	1999 Cost
Tehuacana	C	Freestone	Trinity	Tehuacana Creek	68,300		A,D	$113,121,000	1989	$148,189,000
Muenster	C	Cooke	Trinity	Brushy Elm Creek	500		B			
Lower Bois d'Arc Creek	C	Fannin	Red	Bois d'Arc Creek	124,700	123,000	C	$95,961,000	1995	$106,517,000
Upper Bois d'Arc Creek	C	Fannin	Red	Bois d'Arc Creek						
Ralph Hall	C	Fannin	Sulphur	North Sulphur River						
George Parkhouse I (South)	D	Delta/Hopkins	Sulphur	North Sulphur River	122,900	119,100	A,C,D	$167,598,000	1995	$186,034,000
George Parkhouse II (North)	D	Delta/Lamar	Sulphur	South Sulphur River	141,200	129,700	A,C,D	$112,095,000	1995	$126,667,000
Marvin Nichols I (North)	D	Red River/Morris/ Titus	Sulphur	Sulphur River	641,700	619,100	A,C,D	$384,521,000	1995	$426,818,000
Marvin Nichols II (South)	D	Morris/Titus	Sulphur	White Oak Creek	294,800		A	$191,081,000	1989	$250,316,000

TABLE 2-53 (Continued)

Name	Year 1999 Cost Per Ac-Ft/Yr	Approximate Delivery (Miles)	Environmental Impacts					Interbasin Transfer Required	Region C Entities Interested
			Acres Flooded	Wetland Impacts	Bottomland Hardwoods	Endangered Species	Other Issues		
Tehuacana	$2,170	90	14,900	Moderate	Moderate	Low	Lignite	No	TRWD
Muenster		5		Low	Low	Low		No	Muenster
Lower Bois d'Arc Creek	$854	80	16,400	Moderate	Moderate	Low	National Grassland	Yes	NTMWD
Upper Bois d'Arc Creek		10		Low	Low	Low		No	Fannin Co.
Ralph Hall		15		Low	Low	Low		Yes	Fannin Co.
George Parkhouse I (South)	$1,514	100	29,700	Moderate	Moderate	Low	Mitigation Land	Yes	Several
George Parkhouse II (North)	$897	100	12,300	Moderate	Low	Low	Prime Farmland	Yes	Several
Marvin Nichols I (North)	$665	130	62,100	High	High	Low	Lignite	Yes	Several
Marvin Nichols II (South)	$849	130	35,900	High	Moderate to High	Low	Mitigation Land Oil Wells	Yes	Several

Sources: A. Freese and Nichols, Inc., and Alan Plummer Associates, Inc.; *Regional Water Supply Plan*, prepared for the Tarrant County WCID #1 in conjunction with the Texas Water Development Board, Fort Worth, 1990.
B. Texas Water Development Board Yield Estimates.
C. Freese and Nichols, Inc.; *Preliminary Study of Sources of Additional Water Supply*, prepared for North Texas MWD, Fort Worth, 1996.
D. Texas Parks and Wildlife Department: *An Assessment of Direct Impacts to Wildlife Habitat From Future Water Development Projects*, Austin, 1990.

Notes: * Releases are to allow full diversions for downstream water rights and to satisfy TWDB consensus criteria for instream flows.

- Water for steam-electric power generation and mining will come from Dallas Water Utilities and a Trinity River Authority reuse project.

- **Denton County**
  - Current groundwater use in Denton County exceeds the TWDB's estimated long-term reliable supply.
  - Upper Trinity Regional Water District will continue to develop its surface water supply system. Most Denton County water suppliers will purchase raw or treated water from the Upper Trinity Regional Water District.
  - Upper Trinity Regional Water District will deliver raw water from Lake Chapman to Lewisville Lake through lines constructed by Irving.
  - Upper Trinity Regional Water District will develop reuse of water imported from Lake Chapman.
  - Upper Trinity Regional Water District, Denton, and Lewisville will continue to purchase raw water from Dallas Water Utilities.
  - Lewisville will purchase raw water from Lake Chapman from the Upper Trinity Regional Water District.
  - Dallas Water Utilities, North Texas Municipal Water District, and City of Fort Worth will continue to supply treated water to current customers in Denton County, renewing contracts as they expire.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - Water users in Denton County might consider formation of a groundwater management district.
  - Trinity River Authority will develop a reuse project for golf course and landscape irrigation.
  - Additional mining supplies will be obtained from other local supplies.
  - Water for steam-electric power will be provided by a direct reuse project.

- **Ellis County**
  - Current groundwater use in Ellis County exceeds the TWDB's estimated long-term reliable supply.
  - The Trinity River Authority and water suppliers in Ellis County will develop the Ellis County water supply system using raw water from Tarrant Regional Water District, treatment capacity from Waxahachie, and transmission facilities developed for the project.
  - Dallas Water Utilities will continue to provide treated water to Ellis County water suppliers, renewing contracts as they expire.
  - Ennis, Mansfield, and Midlothian will obtain raw water from Tarrant Regional Water District.
  - Milford will continue to obtain treated water from Files Valley Water Supply Corporation.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - Water for steam-electric power will be provided from the Trinity River Authority (TRA), the Ennis reuse projects, and TRA's Joe Pool Lake and Lake Bardwell.

- **Fannin County**
  - Fannin County water user groups will develop a regional surface water supply system.
  - Until that system is developed, Fannin County water suppliers will continue to rely on groundwater.

- **Freestone County**
  - Fairfield will develop an additional well in the Carrizo-Wilcox aquifer.
  - Wortham will obtain treated water from Mexia.
  - Water for steam-electric power will be provided from the TRWD's Richland-Chambers Lake.

- **Grayson County**
  - Current groundwater use in Grayson County exceeds the TWDB's estimated long-term reliable supply.
  - Development of the Grayson County water supply system is proposed to deliver water to users throughout the county. The system includes a raw water pipeline from Lake Texoma, a treatment and desalination plant, and treated water pipelines.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - Water users in Grayson County might consider formation of a groundwater management district.
  - Denison will sell treated water to Pottsboro (using raw water rights obtained by Pottsboro).

- **Henderson County**
  - Most Henderson County water user groups have an adequate supply to meet projected water demands through 2050.
  - Malakoff will develop a surface water supply system using raw water from the TRWD's Cedar Creek Lake.

- **Jack County**
  - All Jack County water user groups have an adequate supply to meet projected water demands through 2050.

- **Kaufman County**
  - Current groundwater use in Kaufman County exceeds the TWDB's estimate of long-term reliable supply.
  - North Texas Municipal Water District, Terrell, and Dallas Water Utilities will continue to supply their current customers in Kaufman County.
  - Treated wastewater from Garland will be reused for steam-electric power demand.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - The TRWD will supply surface water for mining.

- Additional irrigation local supplies will be developed for irrigation demands.

- **Navarro County**
  - Corsicana will continue to provide treated water for most of the water suppliers in Navarro County, and Corsicana has an adequate water supply.
  - A new well will be developed in the Carrizo-Wilcox aquifer for mining use.

- **Parker County**
  - Current groundwater use in Parker County exceeds the TWDB's estimated long-term reliable supply.
  - Weatherford is constructing a pump station and 36-inch pipeline to bring water from Lake Benbrook to Lake Weatherford. That project is planned for completion in 2002.
  - Weatherford will treat raw water made available by Tarrant Regional Water District and sell treated water to Aledo, Annetta, Hudson Oaks, and Willow Park, all of which currently use the Trinity aquifer for their water supply.
  - TRWD will provide additional water for Azle, Briar, Reno (through Springtown), and Springtown.
  - Additional county other and manufacturing supplies will be developed from the TRWD through Weatherford.
  - Water for steam-electric power will be provided by reuse of treated wastewater from Weatherford and by water from the TRWD's Lake Benbrook.
  - Water for mining will be provided by increased local water supply diversions.
  - Water users will temporarily overdraft groundwater while developing surface supplies.
  - Water users in Parker County might consider formation of a groundwater management district.

- **Rockwall County**
  - Dallas Water Utilities will continue to supply the part of Dallas in Rockwall County.
  - Most water suppliers in Rockwall County will continue to obtain treated water from the North Texas Municipal Water District.
  - Water for steam-electric power will be provided by reuse.

- **Tarrant County**
  - Current groundwater use in Tarrant County exceeds the TWDB estimate of reliable long-term supply.
  - Tarrant Regional Water District will continue to provide raw water for most of the water suppliers in Tarrant County.
  - The City of Fort Worth and the Trinity River Authority's Tarrant County water supply project will continue to supply treated water to many Tarrant County water suppliers, renewing contracts as they expire.
  - Arlington, Benbrook, Fort Worth, Mansfield and the Trinity River Authority Tarrant County water supply project will expand water treatment plants to keep pace with increasing demands.
  - Kennedale and Pantego will obtain treated water from Arlington and Fort Worth.

- Dallas Water Utilities will provide supplies for Grand Prairie and Grapevine, renewing contracts as they expire.
- Grapevine will develop its direct reuse project.
- Water for steam-electric power and golf course and landscape irrigation will be provided from reuse.
- Water users will temporarily overdraft groundwater while developing surface supplies.

- **Wise County**
  - Walnut Creek Special Utility District will serve Aurora, Boyd, Newark, and Rhome with treated water, using water purchased from Tarrant Regional Water District.
  - Alvord will add an additional well and continue to use the Trinity aquifer.
  - Briar, Bridgeport, and Decatur will obtain additional supplies from the Tarrant Regional Water District.
  - Upper Trinity Regional Water District will supply a portion of county other needs through Bolivar WSC.
  - Steam-electric power needs will be provided by sales from Tarrant Regional Water District.

Table 2-54 summarizes the estimated capital costs of the recommended water management strategies (by county) for major water providers and others. The estimated capital costs for all recommended water management strategies in the Region C plan total $6,157,941,000.

TABLE 2-54
CAPITAL COSTS FOR REGION C
RECOMMENDED WATER MANAGEMENT STRATEGIES

Major Water Provider/Others (By County)	Estimated Capital Cost
Major Water Providers	
Dallas Water Utilities	$1,492,649,000
Tarrant Regional Water District	$1,167,652,000
North Texas Municipal Water District	$1,435,447,000
City of Fort Worth	$ 221,475,000
Trinity River Authority	$ 166,081,000
Subtotal for Major Water Providers	**$4,483,304,000**
Others (by County)	
Collin County	$ 14,371,000
Cooke County	$ 42,380,000
Dallas County	$ 553,801,000
Denton County	$ 581,277,000
Ellis County	$ 15,232,000
Fannin County	$ 70,658,000
Freestone County	$ 14,995,000
Grayson County	$ 98,785,000

Henderson County	$ 7,809,000
Jack County	$ 0
Kaufman County	$ 29,912,000
Navarro County	$ 5,670,000
Parker County	$ 83,017,000
Rockwall County	$ 4,795,000
Tarrant County	$ 83,452,000
Wise County	$ 68,483,000
Subtotal for Others	**$1,674,637,000**
Total	**$6,157,941,000**

LIVESTOCK DEMANDS

In 13 of the 16 Region C counties, the estimated county-wide water supply for livestock purposes can meet projected demands for the county as a whole. However, these overall county-wide supply and demand figures do not show areas of shortages that exist within the counties under drought conditions. The Region C RWPG recommends several special measures to address localized livestock water shortages

- Overdrafting of aquifers during droughts
- Local brush control projects
- Maintaining existing stock ponds and adding new stock ponds
- Improving and maintaining existing Natural Resource Conservation Service dams
- Survey on agricultural water use to gather data for future planning.

CONSISTENCY WITH THE REGIONAL WATER PLAN

In evaluating consistency with this regional water plan, the TNRCC and the TWDB should consider the following factors:

- Willing buyer/willing seller transactions should be allowed.
- Maximum flexibility should be afforded to water suppliers. Changes in timing, order, amount of supply, and details of project development should be allowed.
- Consistency requirements should be waived, if appropriate.
- Small uses that do not affect water supplies should be regarded as consistent with this plan.
- Projects to repair or replace existing facilities should be regarded as consistent with this plan.
- Projects for internal distribution improvements and other projects that do not involve development or connection of a new supply should be regarded as consistent with this plan.
- Projects intended to improve water quality or meet regulatory requirements should be regarded as consistent with this plan.

- Projects that promote regional cooperation should receive State support and be regarded as consistent with this plan.
- TWDB and TNRCC should support fast-track efforts by water suppliers when such efforts are needed.

REGULATORY, ADMINISTRATIVE, LEGISLATIVE, AND OTHER RECOMMENDATIONS

The Region C RWPG makes the following recommendations for regulatory, administrative, legislative, and other changes:

- Recommendations related to the SB1 planning process:
  - Allow alternative strategies for near- and long-term planning needs.
  - Encourage the TWDB to exercise discretion in the consideration and approval of funding for alternatives not presented as part of the regional water plan.
  - Encourage the TNRCC to exercise discretion in the consideration and approval of water right permit applications not part of the regional water plan.
  - Allow regional water planning groups to assume that contracts for water supply will be renewed when they expire.
  - Provide clarification of the impact of designating a unique stream segment.

- Recommendations related to TNRCC policy and water rights:
  - Make some water rights exempt from cancellation for 10 years of non-use.
  - Reduce the regulatory and legislative obstacles to indirect reuse of treated wastewater.
  - Remove barriers to interbasin transfers of water.

- Recommendations for State and Federal programs to address water supply issues:
  - Increase funding for TWDB loans and the State participation program to assist with the development of water supply projects.
  - Accelerate studies of groundwater availability for the Trinity aquifer.
  - Increase State participation in water conservation efforts.
  - Provide a program for education of board members of water supply corporations, special utility districts, and municipal utility districts.
  - Increase State participation in watershed protection planning.
  - Encourage Federal funding for development, maintenance, and upgrading of Natural Resource Conservation Service structures.
  - Provide State assistance with maintenance and construction of stock ponds.
  - Encourage the Texas Agricultural Statistics Service to include water supply questions on its survey of farmers and ranchers.

- Recommendations for ecologically unique river and stream segments:
  - Provide clarification of the impacts of designating a unique stream segment.

- Recommendations for unique sites for reservoir construction:
  - Marvin Nichols I
  - Lower Bois d'Arc Creek
  - Muenster
  - Tehuacana

These recommendations are discussed in detail in Appendix 6 of the Water Plan.

PLAN APPROVAL PROCESS AND PUBLIC PARTICIPATION

The Region C Water Planning Group made special efforts to inform and seek input from the general public, water suppliers, and others with special interest in the planning process. Appendix 7 discusses this process and public participation in detail.

REGIONAL WATER PLANNING GROUP

The original legislation for SB1 and the TWDB planning guidelines establish regional water planning groups to control the planning process. The Region C RWPG held regular meetings open to the public during development of the plan, including 9 meetings in 1998, 11 meetings in 1999, and 15 meetings in 2000.

OUTREACH TO WATER SUPPLIERS AND REGIONAL PLANNING GROUPS

The Region C RWPG made special efforts to contact water suppliers in the region and obtain their input in the planning process.

- The planning group sent out questionnaires early in the planning process seeking information on population and water use projections and other water supply issues.
- The planning group appointed a technical review committee composed of experienced water resource planners to review population and water demand projections.
- The planning group instructed its consultants to contact water suppliers as planning progressed.

The Region C and Region D RWPG's formed the Sulphur River Task Group, including members of both water planning groups, to coordinate water supply planning involving the Sulphur River Basin. As a result of cooperative efforts, both planning groups support the development of Marvin Nichols I Reservoir on the Sulphur River in Region D.

OUTREACH TO THE PUBLIC

The Region C RWPG outreach efforts for the public included the following:

- *Publication of newsletters to inform the public.*
- *Public awareness presentations to interested groups throughout the region.*
- Media outreach program to involve the news media.
- Publication of the draft of the *Initially Prepared Region C Water Plan* on the Freese and Nichols web page, at http://www.freese.com/senbill1/regionc/index.htm.

PUBLIC MEETINGS AND PUBLIC HEARINGS

The Region C RWPG has held the following public meetings and hearings to bring the Region C Water Plan to the public:

- Required initial meeting on the planning process.
- Public hearing on population and water use
- Five public meetings throughout the region on water needs and potential strategies
- Five public meetings and a public hearing on draft initially prepared plan in September 2000.

IMPLEMENTATION STRATEGIES

Section 7.2 of the report includes a discussion of implementation strategies for complex elements of the water supply plan for Region C:

- Conservation
- Reuse of reclaimed wastewater
- Marvin Nichols I Reservoir
- Water from Oklahoma.

PART IIC - WATER SUPPLY AND DEMAND - LOUISIANA AND ARKANSAS

INTRODUCTION

This section of the municipal and industrial evaluation focuses on water use in Louisiana. The information presented is taken from the 1993 LRR to document water use from the Red River in Louisiana. Current efforts are an attempt to capture potential benefits for existing and potential use of Red River water by reduction in TDS and chlorides in the Wichita River Basin as represented by concentration-duration curves in the Shreveport/Bossier City area. Contacts with Bossier City and an industrial plant in Campti, Louisiana, have reafffirmed that these entities are continuing their use of Red River water.

In this part of the study, detailed information is presented on municipal and industrial Red River water usage and existing and potential water supply sources in the vicinity of the Red River in Louisiana[1]. (See Table 2-55.) In addition, estimated costs of alternative water supply sources are developed. The cost of Red River water and of alternative water sources is found in the next section. Those costs are for existing use of Red River water required to calculate benefits in this reach. Reaches 2 and 3A, in Arkansas, have no current or potential use of Red River water for municipal and industrial water supply.

STUDY AREA

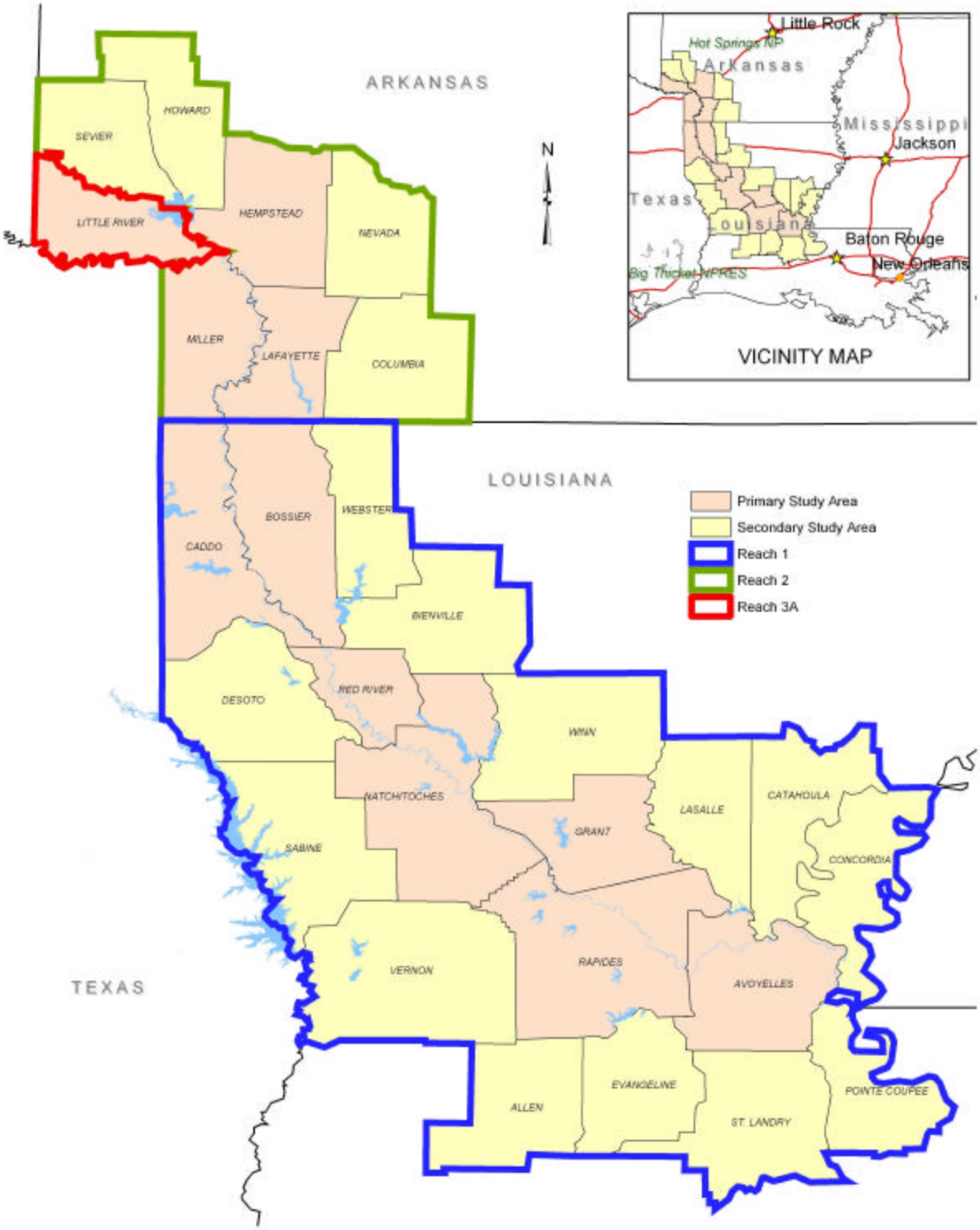
Portions of Louisiana adjacent to the Red River comprise the study area; specifically, two parishes located adjacent to the Red River. Water resources and uses in this area were investigated in great detail in the LRR and updated in this evaluation since the potential for use of Red River water is greatest in areas near the river. A second group of parishes located adjacent to the primary area was also investigated. The purpose of including the secondary tier of counties and parishes was to identify potential water resources that might satisfy demands in the primary area as well as potential demands for Red River water in the secondary study area. Thus, the secondary study area was not examined in as great a detail as the primary study area. Both the primary and secondary study areas are depicted in Figure 2-31.

TABLE 2-55

POTENTIAL USE OF RED RIVER WATER BY LARGE MUNICIPAL SYSTEMS: REACH 1

City	Parish	Average Production (mgd)	Potential Use
Bunkie	Avoyelles	0.73	Not surveyed
Marksville	Avoyelles	1.00	No
Bossier City	Bossier	7.50	Already uses
Princeton	Bossier	0.53	Not surveyed
Blanchard	Caddo	0.58	Not surveyed
Shreveport	Caddo	36.00	Yes
Colfax	Grant	0.53	Yes
Natchitoches	Natchitoches	5.00	Maybe in distant future
Alexandria	Rapides	22.50	Yes
Pineville	Rapides	6.00	Maybe, if industrial needs expand
Tioga (Rapides Parish Water District #3)	Rapides	3.19	Yes
Source: Gulf Engineers & Consultants, Inc., 1992 Water Use Survey.			

[1] Investigation of Existing and Potential Sources of Water Supply in Louisiana and Arkansas and Demand for Water in Louisiana, Arkansas, Oklahoma, and Texas. Red River Chloride Control Project, by Gulf Engineers and Consultants, Inc., Baton Rouge, Louisiana, September 1992.



GENERAL LOCATION OF REACHES 1, 2 and 3A

Figure 2-31.

BACKGROUND

The reach designation is the basic unit of presentation in this report. Although there are three reaches in the Louisiana and Arkansas portions of the Red River drainage area, only Reach 1, which includes the Avoyelles, Rapides, Natchitoches, Red River, Bossier, Grant, and Caddo parishes in Louisiana is discussed in this section since only the Bossier and Caddo parishes have existing use of Red River water. The configuration of each reach is also presented in Figure 2-31.

Bossier City, with a 2000 Census city population of over 56,000, has used Red River water for years and plans to continue using it. Four large users (Shreveport, Alexandria, Colfax, and Tioga) reported a definite interest in Red River water, one (Pineville) reported a possible interest, and one (Natchitoches) indicated a possible need of Red River water in the far-distant future. One reporting a definite interest is in Grant Parish (Colfax); two reporting a definite interest and one reporting a possible interest are in Rapides Parish (Alexandria, Tioga, and Pineville); one reporting a definite interest is in Caddo Parish (Shreveport); and one reporting a possible interest is in Natchitoches Parish (Natchitoches). The large potential users are:

a. Shreveport (Caddo Parish) which serves a population of 193,000 (252,000 in the parish and 126,000 in the city according to the 2000 Census), produces an average of 36 mgd and secures most of its water (33.0 mgd) from Cross Lake. The lake has a dependable yield of 33 mgd, which is occasionally exceeded during summer months of dry years. The city uses Twelve-Mile Bayou overflow (10 mgd) as a supplemental source to Cross Lake. The city has a water supply project under construction that will pipe water directly from Caddo Lake (10 mgd) when it is not overflowing into Twelve-Mile Bayou. This project is due to be completed and in operation by 1993. The whole water supply system will then have a dependable yield of 43 mgd. The city is considering a distant future plan to construct two off-channel reservoirs near Twelve-Mile Bayou and fill them with water from Twelve-Mile Bayou overflow. The combined storage capacity of the two reservoirs would be 70,000 acre-feet of water. However, Shreveport is definitely interested in Red River water if the chloride level is reduced and stabilized.

b. Alexandria (Rapides Parish), which serves a population of 65,000 (56,000 in the city proper according to the 2000 census), produces an average of 22.5 mgd and secures its water from two separate well fields, one in the city that taps the Miocene sands (27 wells) and another in Kisatchie National Forest that primarily taps the Terrace deposits of Pleistocene age (34 wells). Although the water quality is excellent, there has been a decline of water levels in the city wells and, to a lesser degree, in the Kisatchie wells. Currently, the dependable yield of the combined well fields is 28 mgd. Peak demand during summer months reaches 27 mgd. The city is looking to other sources of water supply and has studied several alternatives. One alternative is reclaimed water from a wastewater treatment plant that would be used for industrial purposes (possibly Pineville Kraft Paper Company which uses about 11 mgd). Another alternative is development of a reservoir at Castor Plunge in Kisatchie National Forest. The Red River has been considered in the past and would be considered again as an alternative if water treatment costs are not too high and if excessive chloride concentrations in the river are not a problem. However, the city would probably use Red River water only for its industrial customers and would continue to use its wells to supply residential customers.

c. Colfax (Grant Parish), which serves a population of 3,400, produces an average of 0.53 mgd and has a dependable yield of 1.05 mgd from two wells. The water is good, but a little acidic and difficult to find. The two wells currently producing water were drilled in 1982 and 1985. The city drilled 20 holes to find the 1982 well. Water-bearing sands are patchy and often test salty. Colfax would definitely consider using Red River water if the chloride levels were reduced to an acceptable standard. However, treatment costs would be a factor. Use of Red River water might require the joint efforts and participation of several water systems along the river to be a feasible alternative.

d. Tioga (Rapides Parish Water District No. 3), which serves 15,000, produces an average of 3.19 mgd, and secures its water primarily from Big Creek. The creek contains a great deal of water, but during periods of peak demand, use approaches Big Creek's dependable yield of 4.0 mgd. The district has four wells, which are used during periods of maximum demand and for some industrial customers. Groundwater has been difficult to find. The water district has looked at other possible supply sources, but they were not pursued because of high costs. Therefore, the Tioga Water District is very interested in the possibility of using Red River water, but is concerned about treatment costs.

e. Pineville (located across the river from Alexandria in Rapides Parish), which serves a population of 22,500, produces 6.0 mgd of water from eight wells with a dependable yield of 8.0 mgd. The quantity and quality of water is good. The city may have a need for Red River water in the future if new industry locates in the area and requires large amounts of water, but there is no indication at present of any specific need.

f. Natchitoches (Natchitoches Parish), which serves a population of 20,000, produces an average of 5.0 mgd and secures its water from Sibley Lake, which has a dependable yield of 8.0 mgd. The lake was built about 1960 to replace the old well field. Both quantity and quality are good. The only condition under which the city would have need of Red River water would be if the city population was to exceed the lake's capacity. With current growth rates, the city sees no near-term need for Red River water; but in the distant future, a new source might be needed.

Reach 2

Potential Use of Red River Water. On the basis of personal interviews with selected city water managers and county agricultural agents in Reach 2, it was determined that there were no potential applications for improved quality Red River water in 1992 (Table 2-56), except perhaps through increased use as irrigation water. Due to the availability of other sources, it is unlikely communities would use Red River water in the future. The largest municipal water system in the reach, Texarkana, expressed no interest in Red River water since it does not have any supply problems and does not expect any in the future. At present, Texarkana pumps about 11.5 mgd to the city population as well as to a number of industries and small towns. It is currently permitted to withdraw and treat 37 mgd from Wright Patman and Millwood lakes, which far exceeds its present needs. In addition, Texarkana supplies about 40 mgd of raw water to the International Paper Company near Queen City, Texas. Texarkana has been allocated 60 mgd from Lake Wright Patman and 50 mgd from Millwood Lake and currently only uses a

fraction of this amount. Therefore, Texarkana has no immediate or expected future need for Red River water. The only other large municipal user (Hope) has no interest in Red River water. Hope, which serves a population of 10,400, produces an average of 2.48 mgd and has a dependable yield of 8.88 mgd from its treatment plant on Little River (6 mgd) and 10 wells (2.88 mgd). Hope's treatment plant on Little River at Fulton has the capability to expand its output to 24 mgd, which exceeds any foreseeable needs.

TABLE 2-56

POTENTIAL USE OF RED RIVER WATER BY LARGE MUNICIPAL SYSTEMS: REACH 2

City	County	Average Production (mgd)	Potential Use
Hope	Hempstead	2.48	No
Texarkana	Miller	11.50	No
Source: Gulf Engineers & Consultants, Inc., 1992 Water Use Survey.			

Two of the larger small systems in Reach 2, Stamps and Lewisville (Lafayette County), have no interest in Red River water. Stamps, which serves a population of 2,897, produces 0.45 mgd and has a dependable yield of 2.30 mgd from two wells. Groundwater is plentiful and is less expensive to treat than Red River water. Lewisville, which serves a population of 1,653, produces 0.38 mgd and has a dependable yield of 1.50 mgd from three wells. The water is plentiful and the quality is good. The city anticipates no future needs and has no interest in Red River water.

The other potential users of Red River water in Reach 2 are the farmers in the alluvial valley who would likely increase their use of irrigation if good quality Red River water were readily available.

Reach 3A

Potential Use of Red River Water. Except for the poor quality of Red River water, no major water supply problems exist in Reach 3A. There are problems with high iron content in groundwater in some areas. Ashdown, with a population of 5,150, is the only large municipal water user and gets adequate quantities of water of good quality from its six Terrace wells. The dependable yield of these wells, 3.5 mgd, is nearly three times greater than Ashdown's average daily use of 1.2 mgd. Therefore, Ashdown has no need for Red River water. The quality of Millwood Reservoir and tributaries is very good. It is the availability of these sources of surface water that lessens the potential need for Red River water. The only potential use of Red River water in Reach 3A is for irrigation. Large acreages of soybeans are presently being grown which could be irrigated with Red River water were it to be improved in quality. Also, irrigated corn acreage would most likely expand with the availability of good quality Red River water.

Current Usage of Red River Water

Although Red River water is acknowledged to be of poor quality, with high chloride and suspended sediment content, it is presently being used in limited applications in various locations in the study area. In keeping with the format of other sections of this report, use of Red River water will be described by reach. In general, use is limited to two isolated cases in Reach 1 and some minor irrigation withdrawals in Reach 2 in Miller County, where Millwood Reservoir releases periodically improve the quality. A summary of the usage of Red River and alluvium water appears in Table 2-57 based on the 1992 survey.

TABLE 2-57

CURRENT USAGE OF RED RIVER AND ALLUVIUM

Parish/County	User	Usage	Source
Reach 1			
Bossier	Bossier City	7.50	Red River
Natchitoches	Paper company	8.56	Red River
Avoyelles	Irrigators	22.00	Alluvium
Reach 2			
Miller	Irrigators	17.51	Alluvium
Miller	Irrigators	8.00	Red River
Lafayette	Irrigators	21.42	Alluvium
Lafayette	Irrigators	1.90	Red River
Source: Gulf' Engineers & Consultants, Inc., 1992 Water Use Survey.			

Reach 1. In Reach 1, Red River water is utilized in two separate applications. In Bossier Parish, Bossier City withdraws about 7.5 mgd daily for municipal purposes. The water is expensive to treat, and problems occur in the summer when flows are lowest and the system's reservoir cannot be replenished. Another user of Red River water in this reach is the Western Kraft paper plant in Natchitoches Parish. This company withdrew approximately 8.56 mgd of Red River water in 1990. In general, when Red River water levels are high, the water is high in suspended solids and low in hardness and chlorides; and when the Red River is low, the water is high in hardness and chlorides and low in suspended solids. Currently, Red River water is not utilized for irrigation or thermoelectric purposes in Reach 1.

Reach 2. Red River is utilized fairly extensively in Reach 2 for irrigation. There were no reports of Red River water usage for any of the other categories of water usage. An average of about 10.0 mgd of Red River water was used in 1990 for irrigation. Most of this usage was recorded in Miller County, where farmers can time withdrawals from the river with releases from Millwood Reservoir through Little River, thereby minimizing chloride concentrations. This arrangement is not suitable for long-term irrigation on a single parcel of land, and rotation is necessary to prevent salt buildup in the soil.

Reach 3A. There was no reported 1990 usage of Red River water in Little River County for crop irrigation, except for old Red River oxbows. The whole of this county is upstream from

the confluence of the Red and Little Rivers, so the periodic water quality improvements available downstream for irrigation withdrawals are not available in this reach.

SOURCES OF WATER

In this section, the sources of available water in the study area are described. The greatest attention is given to sources located within the primary study area. However, significant sources of water located in the secondary tier of counties (the secondary study area) are listed for later evaluation as water sources for the primary study area. Water sources are described by reach for both existing and potential supplies. A summary of existing sources is provided first, along with information on source names, yields, locations, and usage by category. Next, an inventory of all water sources (both existing and potential) available by reach is provided in both narrative and tabular displays.

The water resources of the two reaches are described in terms of their dependable yield. Dependable yield is a conservative measure of the ability of a water body or groundwater resource to provide specified minimum withdrawals**.** Most surface water bodies are evaluated according to the 95% exceedance criterion. According to this standard, withdrawals or flows would be equalled or exceeded 95% of the time. Yields according to the standard were developed by both the Louisiana Office of Public Works and the U.S. Geological Survey (USGS). Dependable yields for Corps of Engineers lakes in Arkansas and for the Red River in Louisiana and Arkansas are based on different standards. Low flow or dependable yield on the Red River is estimated according to the 7-day-10 standard, which represents the lowest flow that can be expected for 7 consecutive days during a 10-year period. Corps of Engineers lakes in Arkansas (Millwood, Dierks, DeQueen, and Gillham) are evaluated in relation to a 50-year drought with a 5-year refill. It should be pointed out that dependable yields on lakes and reservoirs usually represent the amount of water that can be safely withdrawn from that water body. For a stream such as the Red River, the low flow or dependable yield merely indicates the lowest expected flows under adverse conditions. The amount of water available from a stream is actually unspecified.

The dependable yields of groundwater resources in this study were calculated according to the recharge characteristics of the various aquifers. In no case is the estimated yield greater than the annual recharge of water into the aquifer. In other words, dependable groundwater yields can be theoretically withdrawn year after year with no overall decline in the water table. The dependable groundwater yields, as calculated by Gulf South Research Institute (GSRI) with the assistance of the USGS in the 1979 study, are assumed to still be reliable for planning purposes and were used in this report.

Summary of Existing Sources By Reach

In this section, the existing sources of water are listed for each reach in the primary study area with appropriate user information. In general, surface water is the most important source of water in each of the two reaches in terms of absolute quantities. Groundwater is also important, however, since it is widely utilized by smaller communities and industries.

Reach 1. In terms of absolute quantities supplied, surface water is the most important source of water in this reach (Table 2-58). Significant surf ace water sources are the Red River, which supplies 7.5 mgd of municipal water to Bossier City and 8.56 mgd to a paper mill in Natchitoches Parish; Caddo Lake in Caddo Parish, which supplies 43.53 mgd for steam-electric purposes; and Cross Lake in Caddo Parish, which supplies 33.0 mgd of municipal water to the city of Shreveport. Most of the larger industries and municipalities and all steam-electric plants utilize surface water supplies.

TABLE 2-58
SUMMARY OF EXISTING WATER SOURCES: REACH 1

Source	Yield (mgd)	Location	Usage (mgd)	Category
Stored Surface				
Georgetown Reservoir		Georgetown (Grant)	N/A	Municipal
Sibley Lake	8.0	City of Natchitoches (Natchitoches)	5.0	Municipal
Black Lake	70.0	Natchitoches Parish	N/A	Industrial
Caddo Lake	99.5**	Mooringsport (Caddo)	43.53	Steam-Electric
Cross Lake	33.0**	Shreveport (Caddo)	33.0	Municipal
Stream Water				
Twelve-Mile Bayou	10.0	Shreveport (Caddo)	10.0	Municipal
Little River	10.0	Pollock (Grant)	N/A	Industrial
Bayou Boeuf	0.3	Avoyelles Parish	N/A	Industrial
Red River	860.0	Bossier City (Bossier)	7.5	Municipal
Red River	860.0	Campti (Natchitoches)	N/A	Industrial
Cane River	4.8	Natchitoches Parish	N/A	Irrigation
Big Creek	4.0	Tioga (Rapides)	2.53	Municipal
Groundwater				
Carrizo Sand	5.13	1 town (Caddo)	N/A	Municipal
Alluvium	412.0	8 towns throughout reach	N/A	Municipal
Alluvium	412.0	2 industries (Avoyelles)	N/A	Industrial
Alluvium	412.0	Avoyelles Reach	22.0	Irrigation
Wilcox	118.0	16 towns throughout reach	N/A	Municipal
Wilcox	118.0	1 industry (Bossier)	N/A	Mun. – Ind.
Miocene	21.0	23 towns throughout reach	N/A	Municipal
Miocene	21.0	5 industries (Avoyelles & Rapides)	N/A	Industrial
Terrace	155.0	12 towns throughout reach	N/A	Municipal
Terrace	155.0	2 industries (Rapides)	12.05	Mun. – Ind.
Terrace	155.0	1 industry (Bossier)	0.85	Industrial

* Unmeasured.
** Use can exceed dependable yield since yield is a conservative measure of water supply that will, in fact, be greater than the given figure most of the time. Also, once-through cooling for steam-electric usage returns most of the water to the source.
N/A = Not Available
Sources: Gulf South Research Institute, 1979 Water Use Survey; and Gulf Engineers Consultants, 1992 Water Use Survey.

Groundwater is widely used by the smaller communities and industries in the primary study area. The only large groundwater development is in the vicinity of Alexandria in Rapides Parish where 22.5 mgd of good quality groundwater is withdrawn, about half of which is supplied to one industry near the city. In general, groundwater is not available in very high well yields except in the Alluvial aquifer of the Red River. Some use of this alluvial groundwater is currently being made in Avoyelles Parish (22.0 mgd) for irrigation. However, this water is very hard and is not currently used for municipal purposes when other sources are available. Total industrial self-supplied use of groundwater in this reach is 0.79 mgd. Most of the industries and industrial groundwater use are concentrated in Rapides and Bossier parishes.

Present withdrawals of groundwater from aquifers in the seven-parish area of Reach 1 include 8.02 mgd from the Carrizo-Wilcox Sands for municipal, industrial, and irrigation purposes; 16.85 mgd from the Mississippi and Red Rivers alluvial aquifers for municipal, industrial, and irrigation purposes; 22.49 mgd from the Jasper aquifer (Miocene sands) for municipal and industrial purposes; 13.77 mgd from the northern Louisiana Terrace aquifer for municipal and industrial purposes; and 3.27 mgd from various other aquifers (including Sparta, Catahoula, and Evangeline) for municipal and industrial purposes. Most of the alluvial water is used for irrigation. The city of Alexandria (along with one industry that is tied into the city system) accounts for about half (8.0 mgd) of the Miocene withdrawals and for about all (11.0 mgd) of the Terrace withdrawals.

The Carrizo Sand is located in Bossier and Caddo parishes and has a total available supply of 5.126 mgd. The Alluvium, which is located in all seven parishes, has a total available supply of more than 412 mgd. The Terrace, with 155 mgd, and the Wilcox, with 118 mgd, both have large underutilized supplies. The Terrace is located in all seven parishes, and the Wilcox is located in four parishes. The Miocene, which presently supplies towns throughout the four parishes in which it is located, has a total supply of 21 mgd. The only area in which present withdrawals approach the estimated available supply is at Alexandria, where withdrawals of 8.0 mgd from the Miocene place a great burden on the 13.0 mgd that is estimated to be available for the parish as a whole.

Reach 2. The water supply situation in Reach 2 is much the same as in Reach 1, with surface water sources supplying most of the large users and groundwater supplying most of the small municipal systems (Table 2-59). In spite of quality problems, the Red River is currently the most significant source of surface water in Reach 2. About 10.0 mgd of Red River water was withdrawn in 1978 for irrigation purposes. No other use is currently being made of Red River water in this area. Texarkana in Miller County utilizes surface water, but this water is supplied from Wright Patman Reservoir in Texas and Millwood Reservoir in Arkansas. The city of Hope is using Millwood water from Little River. Lake Erling in Lafayette County is a good source of surface water, but this company-owned lake is presently only supplying water to a paper industry downstream in Louisiana. Other surface water bodies presently supplying small amounts of water include the Sulphur River, Keller Lake, and Old River, all of which supply irrigation water.

Jim, the title of this table refers to Reach 3A. There is no text for a Reach 3A.

TABLE 2-59
SUMMARY OF EXISTING WATER SOURCES: REACH 3A

Source	Yield (mgd)	Location	Usage (mgd)	Category
Stored Surface				
Millwood Reservoir	265.0	Ogden (Little River)	N/A	Industrial
Stream Water				
Red River	924.0	Little River County	N/A	NA
Groundwater				
Terrace	17.5	Four towns (Little River County)	N/A	Municipal
Terrace	17.5	Industries (Little River County)	N/A	Industrial
Alluvium	9.0	Little River County	N/A	Irrigation
Alluvium	9.0	Little River County	N/A	Municipal

N/A = Not Available.
Sources: Gulf South Research Institute, 1979 Water Use Survey; and Gulf Engineers & Consultants, Inc., 1992 Water Use Survey.

Inventory of Existing and Potential Water Sources By Reach

In the preceding paragraphs, existing sources of water supply were discussed by reach. In each reach, however, existing sources of water are not currently being utilized. These potential sources of water will now be inventoried for later evaluation in the screening and costing phase of this report. Surface and groundwater sources available by reach will be discussed, with appropriate quality and quantity information. Both narrative and tabular descriptions are provided. Significant potential sources of water in the secondary study area will also be included in this section.

Reach 1: Primary Study Area.

***Surface Water*.** There are 21 lakes and reservoirs in Reach 1 (Table 2-60) whose total dependable yield is 818 mgd. However, most reservoirs constructed in Louisiana were created for recreation and conservation purposes. For example, in the primary study area, 11 of the 21 water bodies were constructed for recreation and conservation, with none of the storage capacity currently available for water supply. The 10 remaining water bodies were constructed for water supply and have a total dependable yield of 451 mgd, of which 210 mgd is currently used or allocated. There are several reservoirs with a dependable yield of 100 mgd or greater. However, these large water supplies are located far from the areas of greatest need (i.e., Shreveport-Bossier City) and/or their yield is allocated for other purposes.

Stream water in Reach 1 is not used as extensively as stored surface water. The largest stream in the area is the Atchafalaya River, with a dependable yield of 25,000 mgd. It is not used and is located well away from any major water use centers in Reach 1. The only other stream in the area with a large dependable yield is the Red River, with its attendant quality problem. Of the eight streams listed as existing or potential water sources, four are current

TABLE 2-60

EXISTING AND POTENTIAL SURFACE WATER SOURCES: REACH 1, PRIMARY STUDY AREA

County	Name	Date	Purpose	Dependable Yield (mgd)	Use or Allocation (mgd)	Quality Problems
Stored Surface						
Caddo	Black Bayou Reservoir	1955	R,C	20.0	0.288 mgd (Bayou State oil)	
Red River/ Natchitoches	Black Lake	1934	R,C	70.0	Unallocated	
Natchitoches	Cane River Lake	1949	R,C	4.8	0.45 mgd irrigation allocation	
Bossier	Lake Bistineau	1941	R,C	5.0		
Rapides	Lake Cocodrie	1959	R,C	210.0		
Bossier	Cypress-Black Reservoir No. 2	1976	R, WS	13.8	11.7 mgd irrigation allocation	
Bossier	Cypress-Black Reservoir No. 2	1979	R,WS	4.9	3.7 mgd irrigation allocation	
Grant	Georgetown Reservoir	1961	WS	N/A	0.025 mgd (city of Georgetown)	Fairly good quality
Grant	Iatt Lake	1957	R,C	5.0		
Rapides	Indian Creek Reservoir	1970	R,WS	17.0	15.9 mgd irrigation allocation	
Bossier	Ivan Reservoir	1958	R	N/A		
Grant	Nantachie Reservoir	1964	R	7.2		
Natchitoches	Saline Reservoir	1959	R,C	50.0		
Natchitoches	Sibley Lake	1963	WS	8.0	5.0 mgd (city of Natchitoches	Fairly good quality
Red River	Grand Bayou Reservoir	1993	WS,R	13.1	NA water supply recreation	
Bossier	Bayou Bodcau Reservoir	1949	R,C	No pool	None	
Caddo	Caddo Lake	1970	R,WS	99.5	43.53 mgd (SWEPCO)	
Rapides	Cotile Reservoir	1965	R,WS	111.2	16.6 mgd irrigation allocation	

TABLE 2-60 (Continued)

County	Name	Date	Purpose	Dependable Yield (mgd)	Use or Allocation (mgd)	Quality Problems
Stored Surface (Continued)						
Caddo	Cross Lake	1925	WS	33.0	33.0 mgd (City of Shreveport)	
Rapides	Kincaid Reservoir	1972	R,WS	164.8	17.7 mgd irrigation allocation	
Caddo	Wallace Lake	1946	R,C	N/A		
Stream Water						
Bossier	Red River	NA	NA	860.0	7.5 mgd (Bossier City)	Chlorides, sediment and hardness
Natchitoches	Red River	NA	NA	860.0	8.56 mgd (Western Kraft Corp.)	Sediment
Bossier	Red Chute Bayou	NA	NA	6.9	None	
Caddo	Twelve-Mile Bayou	NA	NA	5.1	10.0 mgd (Shreveport)	
Rapides	Big Creek	NA	NA	5.0	2.53 mgd (Tioga)	Color and bacteria
Avoyelles	Bayou Boeuf	NA	NA	0.8	None	
Natchitoches	Saline Bayou	NA	NA	N/A	None	
Grant	Little River	NA	NA	10.0	1.87 mgd (Farmland Industries)	
Rapides	Calcasieu River	NA	NA	22.6	None	
Avoyelles	Atchafalaya River	NA	NA	25,548.0	None	

Legend:
R = Recreation
C = Conservation
WS = Water Supply
NA = Not Applicable
N/A = Not Available
Sources: Gulf South Research Institute, 1979 Water Use Survey; Louisiana Office of Public Works Biennial Report; and Gulf Engineers & Consultants, Inc., 1992 Water Use Survey.

suppliers. The four that are unused have small dependable yields (less than 12 mgd) and are located at considerable distances from areas of need. The Red River is the only significant source of stream water in the primary portion of Reach 1.

Groundwater. Existing and potential sources of groundwater in Reach 1 are presented, by parish, in Table 2-61 along with information on potential yield per square mile per day and total potential yield. The total potential yield figure was derived by multiplying an estimate of the gallons per square mile per day that each aquifer can yield by the number of square miles that the water-bearing sands of the aquifer occupy beneath each parish. Thus, the figures are estimates and do not have predictive value for specific locations.

TABLE 2-61

EXISTING AND POTENTIAL GROUNDWATER SOURCES: REACH 1, PRIMARY STUDY AREA

Parish	Aquifer	Potential Yield (gals/sq. mi./day)	Total Available Yield (mgd)
Avoyelles	Miocene	10,000	2.000
	Pliocene	10,000	0.160
	Alluvium	160,000	100.000
	Terrace	120,000	15.000
Parish Total			117.160
Bossier	Wilcox	45,000	30.000
	Carrizo Sand	10,700	3.200
	Cane River Formation	18,000	1.530
	Alluvium	160,000	40.000
	Terrace	120,000	40.000
	Sparta Sand	48,000	20.400
Parish Total			135.130
Caddo	Wilcox	45,000	40.500
	Carrizo Sand	10,700	1.926
	Cane River Formation	18,000	1.620
	Alluvium	160,000	57.600
	Terrace	120,000	8.000
	Sparta Sand	48,000	2.160
Parish Total			111.800
Grant	Miocene	10,000	3.350
	Alluvium	160,000	16.000
	Terrace	120,000	60.000
	Cockfield Formation	80,000	5.200
Parish Total			84.550
Natchitoches	Wilcox	45,000	29.250
	Miocene	10,000	2.600
	Alluvium	160,000	93.600
	Terrace	120,000	7.000
	Sparta Sand		6.240

	Cockfield Formation		15.600
Parish Total			154.290
Rapides	Miocene	10,000	13.000
	Alluvium	160,000	83.200
	Terrace	120,000	78.000
Parish Total			174.200
Red River	Wilcox	45,000	18.000
	Alluvium	160,000	22.400
	Terrace	120,000	12.200
Parish Total			52.600
Reach Total			829.730
Sources: U.S. Geological Survey and Gulf South Research Institute, 1979 Water Use Survey.			

There are nine water-bearing aquifers underlying the seven parishes that compose Reach 1. These aquifers have the capacity to supply about 135 mgd. The aquifers and their individual potential yields are as follows: Miocene (20.95 mgd); Pliocene (0.16 mgd); Alluvium (412.8 mgd); Terrace (220.02 mgd); Carrizo Sand (5.126 mgd); Cane River Formation (3.15 mgd); Sparta Sand (28.8 mgd); Wilcox (117.3 mgd); and Cockfield Formation (20.8 mgd). Only the Carrizo Sand, Alluvium, Wilcox, Miocene, and Terrace are presently used for any significant municipal, agricultural, or industrial purposes in Reach 1. Thus, the Pliocene, Cane River Formation, Sparta Sand, and Cockfield Formation represent potential groundwater sources.

Water-bearing sands of the Pliocene underlie the extreme southwest and southeast corners of Avoyelles and occupy large portions of the secondary study area below Rapides and Avoyelles parishes. The Cane River Formation is located only in the northern portions of Bossier and Caddo parishes and extends from there into Reach 2. The Sparta Sand is located in portions of Natchitoches, Bossier, and Caddo parishes and occupies a large portion of the secondary study area northeast of the river. The Cockfield Formation underlies only a small portion of southwest Natchitoches Parish and a small portion of northern Grant Parish, but occupies a large part of the secondary study area above Grant Parish.

If gross figures for water availability alone are considered, the presently used aquifers must be judged as underutilized, since their potential yield far exceeds current use. However, the true potential of both the underutilized and non-utilized aquifers in Reach 1 depends on such things as availability, water quality, and well yield.

Wilcox. Sands of the Wilcox group constitute the oldest geological unit in Louisiana that is known to contain fresh groundwater. Fresh groundwater in the Wilcox strata is limited to northwestern Louisiana. Yields of wells completed in the Wilcox group are generally small (ranging from a few gallons to 500 gpm) owing to the fine-grained texture and lenticularity of the water-bearing sands. Water quality in these deposits is variable. In Bossier and Caddo parishes, wells yield soft to moderately hard water of low mineral content. In Red River Parish, the water is a moderately hard calcium bicarbonate type and contains an excessive amount of iron. In Natchitoches Parish, the water becomes more mineralized, with higher concentrations of sodium bicarbonate and dissolved solids.

Cane River Formation. The Claiborne group of Eocene age comprises, in ascending order, the Cane River, Sparta, Cook Mountain, and Cockfield formations. No significant amounts of fresh water are taken from the Cook Mountain Formation. In northern Bossier and Caddo parishes, the interfingering sands of the Cane River Formation contain small quantities of fresh water, but they have been little used. Water from wells screened in the Cane River generally is clear and soft, but is reported by some users to have the taste and odor of iron.

Sparta Sand. The Sparta Sand contains fresh water in two separate areas: (1) a narrow belt in Natchitoches Parish, and (2) the northeastern portions of Bossier and Caddo parishes. The quantity of water pumped from the Sparta Sand in Natchitoches Parish is small. Well yields are small because of the relative thinness of the sand, and the water is high in iron. The Sparta Sand in northeastern Bossier and Caddo parishes represents a largely undeveloped groundwater source. Water quality data indicate that the water from the Sparta Sand is generally soft, of the sodium bicarbonate type, and low in iron.

Cockfield Formation. Like the Sparta Sand, the Cockfield Formation contains fresh groundwater in two separate areas in Reach 1. A small band reaches into the southwest corner of Natchitoches Parish, and a large deposit reaches into the northern portion of Grant Parish. In both areas, the water is soft to moderately hard, and the chloride content is low.

Miocene. Fresh water occurs in sediments of Miocene age in a broad east-west trending belt that extends across the south-central part of Louisiana. Although this belt is continuous, it is almost severed in the central part by a zone containing saltwater that runs through Avoyelles Parish. This aquifer underlies the whole of Rapides Parish and the southern portions of Natchitoches and Grant parishes. Yields of up to 2,000 gpm are available. The water is a very soft sodium bicarbonate type and contains small amounts of iron. Although fluorides are a problem in some areas, the water is generally of such a high quality that it can be used for most purposes without treatment.

Pliocene. Like the Miocene, the Pliocene extends in a broad belt across southwest Louisiana and is broken by a saltwater zone. However, fresh water from this aquifer is available in Reach 1 only in the extreme southwest and southeast portions of Avoyelles Parish. Well yields are less than in the Miocene. The water is a soft sodium bicarbonate type of good quality.

Alluvium The floodplain of the Red River, which includes an area of 2,000 square miles, is underlain by alluvial deposits of Quaternary age consisting of clay, silt, sand, and gravel ranging in thickness from 75 feet near the Arkansas line to 150 feet at the southern end of the valley in Avoyelles Parish. The lower half of the Alluvium yields large quantities of water. The water is generally very hard and has a high total iron content. However, the high yields of wells make these deposits an excellent source of water for irrigation and some industrial purposes.

Terrace. Terrace deposits, which are also of Quaternary age, flank the stream valleys of northern Louisiana and therefore are closely related to the Alluvial deposits. The well yield is generally small because of the relatively thin saturated thickness. The water is soft and low in dissolved solids but very high in iron content.

Reach 1: Secondary Study Area.

Surface Water. The secondary study area contains an additional nine lakes and reservoirs with a total dependable yield of 829 mgd. The existing and potential sources of surface water in the secondary portion of Reach 1 are presented in Table 2-62. A situation very similar to that of the primary study area exists in the secondary portion. Of the nine major reservoirs and lakes located in the secondary study area, seven were constructed primarily for recreation purposes. Unless administrative rules and procedures are changed, these sources would not be available for water supply purposes. Most of the water storage capacity, however, is contained in the area's two water supply reservoirs. Lake Vernon in Vernon Parish, with a dependable yield of 55 mgd, and Toledo Bend Reservoir in DeSoto and Sabine parishes, with a dependable yield of 715 mgd, both offer water supply potential for areas in Reach 1. Toledo Bend in particular is a tremendous source of good quality water. However, because of the availability of other alternatives, Toledo Bend water has not been used in the primary study area.

There are no major stream water resources in the secondary study area, with the exception of the Mississippi River. The potential of the Mississippi River and the other streams for providing water supplies to the primary portion of Reach I will be investigated later in this report. However, none of the sources appear to offer significant potential for water transfer purposes.

Groundwater. There are no water-bearing aquifers in the secondary portion of Reach 1 that are not also in the primary portion. Thus, the, secondary study area does not contain any potential groundwater supply sources for Reach 1.

Reach 1: Potential Reservoirs. A list of potential reservoirs in Reach 1 for the primary and secondary study areas appears in Tables 2-63 and 2-64. There is no priority for developing these reservoirs. Actual investigation of the merits and constraints of each site proceeds only upon initiation of local support. The Louisiana Office of Public Works (OPW), the chief sponsor of water developments in Louisiana, has no plans for creation of reservoirs in the study area. The OPW has developed one reservoir in the study area since the 1980 study - Grand Bayou Reservoir in Red River Parish, with a dependable yield of 13.1 mgd. Construction of this reservoir should be completed.

TABLE 2-62

EXISTING AND POTENTIAL SURFACE WATER SOURCES: REACH 1, SECONDARY STUDY AREA

County	Name	Date	Purpose	Dependable Yield (mgd)	Use or Allocation (mgd)	Quality Problems
Stored Surface						
Vernon	Anacoco Lake	1951	R	25.0	None	None
Evangeline	Chicot Lake	1953	R	--	None	None
Pointe Coupee	False River	1948	R	--	None	None
Bienville	Kepler Lake	1958	R	20.0	None	None
Vernon	Lake Vernon	1961	WS	55.0	None	None
Catahoula	Lake Larto	1959	R	--	None	None
Bienville	Mill Creek Lake	1971	R	--	None	None
Desoto	Smithport Lake	1953	R, C	13.9	None	None
Desoto-Sabine	Toledo Bend Reservoir	1969	R, C, WS	715.0	23.45	None
Stream Water						
Webster	Bayou Bodcau	NA	NA	0.1	17.6 (a)	None
St. Landry	Bayou Teche	NA	NA	82.7	8.9	None
St. Landry	Mermentau River	NA	NA	-0-	6.3	Zero – Low Flow
St. Landry	Vermilion River	NA	NA	-0-	2.7	Zero – Low Flow
Evangeline	Bayou Cocodrie	NA	NA	37.5	288.0 (b)	None
Evangeline	Bayou Teche	NA	NA	74.3	3.9	None
Evangeline	Mermentau River	NA	NA	-0-	15.7	Zero - Low Flow
Allen	Calcasieu River	NA	NA	23.9	11.3	None
Allen	Mermentau River	NA	NA	-0-	1.3	Zero – Low Flow
Concordia	Mississippi River	NA	NA	74,302.00	-0-	None
Allen	Bandick Creek	NA	NA		None	None

(a) According to 1975 USGS Survey.
(b) Withdrawals are greater than low flow, but consumed water is very low because the water is used in a once-through cooling operation.
Legend: R = Recreation; WS = Water Supply; C = Conservation; NA = Not Applicable.
Note: None of the water is used in the primary study area.
Sources: Louisiana Office of Public Works *Biennial Report;* and Gulf South Research Institute, 1979 Water Use Survey.

TABLE 2-63
POTENTIAL RESERVOIRS: REACH 1, PRIMARY STUDY AREA

Parish	Name	Drainage (sq. mi.)	Elevation (Feet)	Area (Acres)	Volume (Acre-Feet)	Yield (mgd)
Red River	Boggy Lake	10.9	143.0	600	47,000	1.6
Grant	Big Creek	99	141.0	3,800	43,000	29.3
Bossier	Black Bayou	22	187.0	680	5,400	3.5
Caddo	Black Bayou*	231	199.0	11,000	137,000	65.3
Red River	Black Lake No. 3	535	140.0	8,250	4,900	89.3
Natchitoches	Black Lake*	630	137.5	19,780	272,000	100.0
Rapides	Brown Creek	13	109.2	725	9,000	9.75
Red River	Bull Lake	4.7	143.0	220	1,700	NA
Rapides	Castor Creek	35	102.0	3,000	37,500	25.0
Grant						
LaSalle	Catahoula*	2,672	34.0	28,000	132,000	NA
Rapides	Cedar Lake	22	75.0	1,000	4,850	8.9
Evangeline Rapides	Cocodrie*	240	75.0	19,500	285,000	220.0
Bossier	Cypress Bayou	149.1	177.0	2,690	17,000	7.5
Bossier	Cypress Bayou	149	197.0	7,330	116,500	51.0
Caddo	Cypress Bayou	65	210.1	4,300	61,000	34.0
Natchitoches	Goldonna	280	140.5	12,500	160,000	100.0
Natchitoches	Halls and Berry Brake	49	135.0	4,075	49,500	31.0
Grant	Iatt Lake*	242	93.0	12,500	125,000	70.0
Rapides	Indian Creek*	23	90.0	2,650	33,000	19.9
Natchitoches	Kisatchie	278	120.0	5,800	65,000	60.0
Bossier-Bienville	Lake Bistineau*	1,410	164.5	46,000	870,000	421.6
Rapides	Longleaf	499	156.5	12,300	199,000	215.0
Rapides	Longleaf	499	164.5	16,100	300,000	269.0
Red River	Pine Tumbly Creek	5.2	143.0	190	1,540	NA
Red River-Winn	Saline	232	140.0	1,730	12,000	22.0
Red River-Winn	Saline	232	150.0	3,950	40,000	52.5
Natchitoches	Sibley*	40	120.0	2,775	29,200	13.0
Rapides	Spring Creek	67	116.7	2,240	40,000	58.8
Rapides	Valentine	36	92.0	2,100	26,000	29.5

* Enlargements
NA = Not Available.
Source: Louisiana Office of Public Works, *Biennial Report.*

TABLE 2-64

POTENTIAL RESERVOIRS: REACH 1, SECONDARY STUDY AREA

Parish	Name	Drainage (Square Miles)	Elevation (Feet)	Area (Acres)	Volume (Acre-Feet)	Yield (mgd)
Allen	Barnes Creek	133	52.0	4,400	33,500	37.2
Webster	Bayou Bodcau	612	175.0	1,130	3,230	NA
DeSoto	Bayou Castor	95	223.0	5,150	77,000	27.0
Webster	Bayou Dorcheat	1,022	200.0	46,500	826,000	250.0
Webster	Bayou Dorcheat	995	200.0	33,750	810,000	100.0
Sabine	Bayou LaNana	93	214.7	6,000	88,000	26.7
DeSoto	Bayou Na Bon Chasse	20	200.0	704	8,200	5.0
Sabine	Bayou San Miguel	113	217.0	6,700	129,000	39.0
Sabine	Bayou San Patrico	135	228.0	5,950	75,000	34.0
Sabine	Bayou Toro	91	215.0	3,400	41,600	32.0
DeSoto	Clement Creek	44	216.0	2,000	32,000	13.6
Bienville-Jackson	Coulee Creek	12	180.0	1,320	20,600	6.0
Bienville	Dukedahl	18	192.5	1,340	17,600	8.8
Bienville-Jackson	Dukedahl-Coulee	30	183.0	2,250	32,800	15.8
DeSoto	Grand Cane	74	220.9	4,800	70,000	24.3
Winn	Kiesche	31	162.8	2,950	45,000	18.3
Winn	Kiesche	57	125.0	1,870	20,600	20.0
DeSoto	Mansfield Cow Bayou	7.8	275.0	930	15,700	- 4.0
Winn	Nantachie	39.6	160.0	3,700	35,900	10.8
DeSoto	Rambin	31.0	172.0	2,650	50,000	13.0
Bienville	Saline	206	160.0	2,800	22,000	35.9
Bienville	Saline	154	190.0	7,450	96,400	52.0
Allen	Sixmile Creek	164	129.0	7,300	90,000	130.0
Vernon	Upper Sixmile Creek	58	180.0	1,525	17,000	NA
Vernon	Middle Sixmile Creek	91	150.0	1,525	17,000	NA
Vernon	Lower Sixmile Creek	139	129.0	1,540	15,000	NA
DeSoto	Smithport*	205	147.0	7,800	92,000	48.2
Catahoula	Turkey Creek*	163	50.0	4,600	59,500	34.0
Winn	Winnfield	654	120.0	22,400	255,000	168.0
Winn	Winnfield	654	110.0	11,100	89,600	75.0

NA = Not Available.
*Enlargement
Source: Louisiana Office of Public Works, *Biennial Report*.

SCREENING OF WATER SUPPLY SOURCES

In the initial phases of this study, water usage and sources of water were analyzed. In addition to water supply sources currently supplying water, water sources not currently being used as well as potential sources of water in the secondary study area and potential water supply developments in the primary study area were listed. No attempt was made in the initial listings to evaluate the likelihood of each source supplying water in the future. In this phase of the overall study effort, potential sources of water are screened to eliminate those sources with water quality, environmental, physical, legal, or institutional problems. Sources that pass initial screening will be evaluated to produce cost estimates for the various sources of water supply. The sources of water evaluated in this phase of the report include existing and potential ground and surface water. Reuse of steam-electric wastewater is not considered because once-through cooling systems are employed in the reaches involved in this study. There is no necessity, therefore, to treat the wastewater since it is only polluted thermally.

Methodology

The methodology for screening potential sources of water was defined in the 1980 economic reanalysis. The basic elements of the screening methodology are displayed in Table 2-65. Four criteria were added because of prevalent conditions in Louisiana and Arkansas. First, in some water bodies, water supply has been totally used or allocated. If this situation exists, the water body cannot be considered available for other uses. Second, although many reservoirs have been constructed, particularly in Reach 1, most were authorized on the basis of recreation and conservation benefits. Consequently, no water supply storage is available. Third, streams are often used directly for water supply purposes, particularly in Louisiana. Most low flow estimates are based on a 95% exceedance criterion and water quality maintenance flows are based on the 7-day-10 standard, which approaches 95% exceedance levels. Consequently, in smaller streams and rivers, dependable water yield after allowance for flow maintenance would not be large enough to warrant transportation. Finally, there are instances in which data are simply not available on stream flows, quality, or administrative designations. In most instances, only small sources of water are involved. In these cases, the supplies are excluded from further evaluation.

TABLE 2-65
SCREENING CRITERIA FOR SUPPLY SOURCES

A.	Water Quality
	1. Chloride content above 250 mg/l
	2. Dissolved solids content above 500 mg/l
	3. Sulfate content above 250 mg/l
	4. Iron exceeds 0.3 mg/l
B.	Environmental and Other Problems
	1. Endangered wildlife habitat
	2. Endangered species in area
	3. Stream cannot be dammed--engineering
	4. Scenic river designation
	5. Groundwater being depleted
	6. Water table being lowered substantially
	7. Possible saline encroachment
	8. Surface pollution affecting quality
	9. Lake cannot develop over 5,000 acre-feet of storage
	10. Stream flow sustained by sewage effluent
	11. Reservoir authorized or designated for non-water supply purposes*
	12. Low stream flow of less than 15 mgd--water quality maintenance flow approaches dependable yield*
	13. Inadequate data available*
	14. Water supply totally used or allocated*
* Additional criteria added by Gulf South Research Institute, 1979 Water Use Survey. Source: U.S. Army Corps of Engineers, Southwestern Division.	

Screening

The objective of the screening process has been to identify those sources of water that exhibit significant potential for water supply within the study area. Once identified, costs for development of water supplies from each source and delivery to the appropriate demand centers will be estimated. The results of the screening process for water resources in Reaches 1 and 2 appear in Table 2-66.

TABLE 2-66
SUMMARY OF SUPPLY SOURCES TO BE USED FOR COST COMPUTATIONS

Reach	Source	Status
1	Twelve-Mile Bayou	Stream
	Cypress Black Reservoir No. 1	Existing
	Atchafalaya River	Stream
	Red River	Stream
	Castor Creek	Stream
	Terrace and Miocene Deposits	Aquifer
	Toledo Bend Reservoir	Existing*
* Secondary Study Area. Source: Gulf Engineers & Consultants, Inc., 1992 Water Use Survey.		

Table 2-67 lists in a comprehensive manner all water supplies that were subjected to the screening process and the basis for screening of the excluded sources. The information presented in Table 2-67 gives an overview of the rationale for the screening status of each source of water. However, a more detailed description of the factors that influence the status of each supply source is needed. In the following paragraphs, the water resources subjected to the screening criteria are described in detail, with emphasis on factors that warrant inclusion or exclusion of the resources. Figure 2-32, which depicts surface water features, provides a visual representation of the major resources in relation to the demand centers in each reach.

Reach 1. There are 10 existing reservoirs, 9 potential reservoirs, and 10 streams in the primary study area and 1 reservoir in the secondary study area that offer potential for water supply development before the screening process (Table 2-67). The sources of water are dominated by the large yields of the Atchafalaya River within the primary study area and Toledo Bend Reservoir in the secondary study area. Following the screening process, only 5 of the original 30 surface sources of water remain for future consideration.

In addition to the potential surface water resources of Reach 1, there are nine potential groundwater developments that must be studied. The total volume of water is quite large in absolute terms. However, once consideration is given to the screening criteria, only the Cockfield Formation in Natchitoches Parish and the Terrace and Miocene sands in Rapides Parish exhibit real potential for water development. The rationale for the screening status given each potential source of water is presented in the following paragraphs.

Georgetown Reservoir. Georgetown Reservoir is a very small lake owned by the city of Georgetown. Current usage is approximately 0.025 mgd for municipal purposes. The lake's yield is unspecified. Because of the small size and unknown yield, this lake was screened from additional consideration as a potential source of water.

Sibley Lake. Sibley Lake is owned by the city of Natchitoches. It has a dependable yield of 8.0 mgd compared to a current usage of approximately 5.0 mgd. Since all the water supply in this lake is owned by and allocated to the city of Natchitoches, Sibley Lake has been screened from additional consideration as a future source of water available for transport.

Caddo Lake. There are many administrative problems surrounding usage of Caddo Lake as a source of water. The lake is jointly owned by the states of Louisiana and Texas. No specific water supply yield is allocated, although there is currently some usage of the water. The city of Shreveport was unable to use the water in the past, except for 100 mgd when Twelve-Mile Bayou in not receiving overflow from Caddo Lake. The city has recently completed a project to acquire this water allocation. For these reasons, Caddo Lake has been screened from consideration as an additional future source of water.

Cross Lake. The city of Shreveport owns the 32.0-mgd water supply storage of Cross Lake. In 1979, an average daily use of 33.5 mgd exceeded the lake's long-term water supply capacity. Since no water in addition to the city's needs is available, Cross Lake was screened from the list of water sources offering potential for additional future development.

TABLE 2-67
SCREENING EVALUATION OF SUPPLY SOURCES

Reach	Supply Source	Water Quality Information							
		Status	Yield (mgd)	Total Use (mgd)	Sulfates (mgd)	Chlorides (mgd)	TDS (mg/l)	Iron (mg/l)	Screening Status
1	Georgetown Reservoir	Existing	---	0.025	---	---	---	---	B.9, B.13
	Sibley Lake	Existing	8.0	5.0	---	---	---	---	B.14
	Caddo Lake	Existing	---	122.4	---	---	---	---	B.13
	Cross Lake	Existing	32.0	33.5	---	---	---	------	B.14
	Cypress Black No. I	Existing	13.8	---	-------	---	---	---	--
	Cypress Black No. 2	Existing	4.9	---	---	---	---	------	B.14
	Indian Creek Reservoir	Existing	15.9	3.0	---	---	---	------	B.14
	Cotile Reservoir	Existing	16.6	3.0	---	---	---	---	B.14
	Kincaid Reservoir	Existing	17.7	2.99	---	---	---	---	--
	Toledo Bend Reservoir	Existing*	108.0	1.5	10-29	4-42	---	0.25-3.0	B.14
	Grand Bayou Reservoir	Existing	13.1	---	---	---	---	---	--*
	Big Creek Reservoir	Potential	29.3	---	---	---	---	------	B.11, B.13
	Black Lake No. 3	Potential	89.3	---	---	---	---	---	B.11, B.13
	Brown Creek Reservoir	Potential	8.9	---	---	---	---	---	B.11, B.13
	Goldonna Reservoir	Potential	100.0	---	---	---	---	------	B.11, B.13
	Halls & Berry Brake Res.r	Potential	31.0	---	-------	---	---	---	B.11, B.13
	Kisatchie Reservoir	Potential	60.0	---	---	---	---	---	B.11, B.13
	Longleaf Reservoir	Potential	269.0	---	---	---	---	---	B.11, B.13
	Spring Creek Reservoir	Potential	58.8	---	---	---		------	B.11, B.13
	Valentine Reservoir	Potential	29.5	---	---	---	---	------	B.11, B.13
	Castor Creek	Stream	25.0	---	---	---	---	---	--
	Red Chute Reservoir	Stream	6.9	---	---	---	---	---	B.12, B.13
	Twelve-Mile Bayou	Stream	5.1	1.5	---	---	---	---	B.12
	Little River	Stream	10.0	2.0	---	---	---	---	B.12
	Bayou Boeuf	Stream	0.8	0.1	---	---	---	---	B.12
	Cane River	Stream	4.8	0.45	---	---	---	---	B.12
	Big Creek	Stream	5.0	1.5	---	---	---	---	B.12
	Calcasieu River	Stream	11.6	---	63	36	---	-------	B.4
	Atchafalaya River	Stream	25,548.0	---	N/A	N/A	205	N/A	--
	Red River	Stream	860.0	18.0	---	---	N/A	---	A.1

TABLE 2-67 (Continued)

Reach	Supply Source	Water Quality Information							
		Status	Yield (mgd)	Total Use (mgd)	Sulfates (mgd)	Chlorides (mgd)	TDS (mg/l)	Iron (mg/l)	Screening Status
	Carizzo Sand	Aquifer	5.1	30.5	---	8,000	---	6	B.13
	Alluvium	Aquifer	412.0	7.0	---	---	---	---	A.1, A.4
	Wilcox	Aquifer	118.0	2.26	---	---	---	---	A.4
	Miocene	Aquifer	21.0	14.6	---	---	---	1.2-5.6	---
	Terrace	Aquifer	155.0	23.54	---	---	---	---	---
	Pliocene	Aquifer	0.16	---	---	101-565	0.3+	---	A.4
	Cane River Formation	Aquifer	3.15	---	---	---	---	---	A.2
	Sparta Sand	Aquifer	28.8	---	---	---	0.4	---	A.4
	Cockfield Formation	Aquifer	15.6	---	---	---	---	---	---*
2	Keller Lake	Existing	---	0.67	---	---	---	---	B.13
	Old River Lake	Existing	---	0.33	---	---	---	---	B.13
	Lake Erling	Existing	---	17.6	---	---	---	---	B.13
	Sulphur River	Stream	---	0.93	---	---	---	---	B.13
	Ozan Creek	Stream	0.2	---	6.5	3.5	112	0.01	B.12
	Bois d'Arc Creek	Stream	1.3	---	---	---	---	---	B.12
	Terre Rouge Creek	Stream	1.2	---	---	---	---	---	B.12
	Nacatoch Sand	Aquifer	10.8	1.6	---	---	---	---	B.6
	Tokio Formation	Aquifer	10.5	1.3	---	---	1,000	---	A.2
	Cane River Formation	Aquifer	18.9	0.98	---	---	---	---	---*
	Carizzo Sand	Aquifer	8.22	0.05	---	---	---	---	---*
	Terrace	Aquifer	26.6	0.04	---	---	---	---	---*
	Sparta Sand	Aquifer	13.8	0.06	---	---	---	2.7	A.4
	Alluvium	Aquifer	34.5	9.86	600	---	---	2.3	A.1, A.4
	Wilcox	Aquifer	11.4	---	---	---	---	---	---*
	Millwood Reservoir	Existing	265.0	22.0	---	---	---	---	---*
	Little River	Stream	19.0	---	7.2	6.4	60	0.03-0.37	B.13

* Since there are no immediate or near-future water supply needs expected to exceed current use or existing allocations in the area of this water source, it was not evaluated in the costing portion of the report.
N/A = Not Available.
Sources: U.S. Geological Survey and Louisiana Office of Public Works.

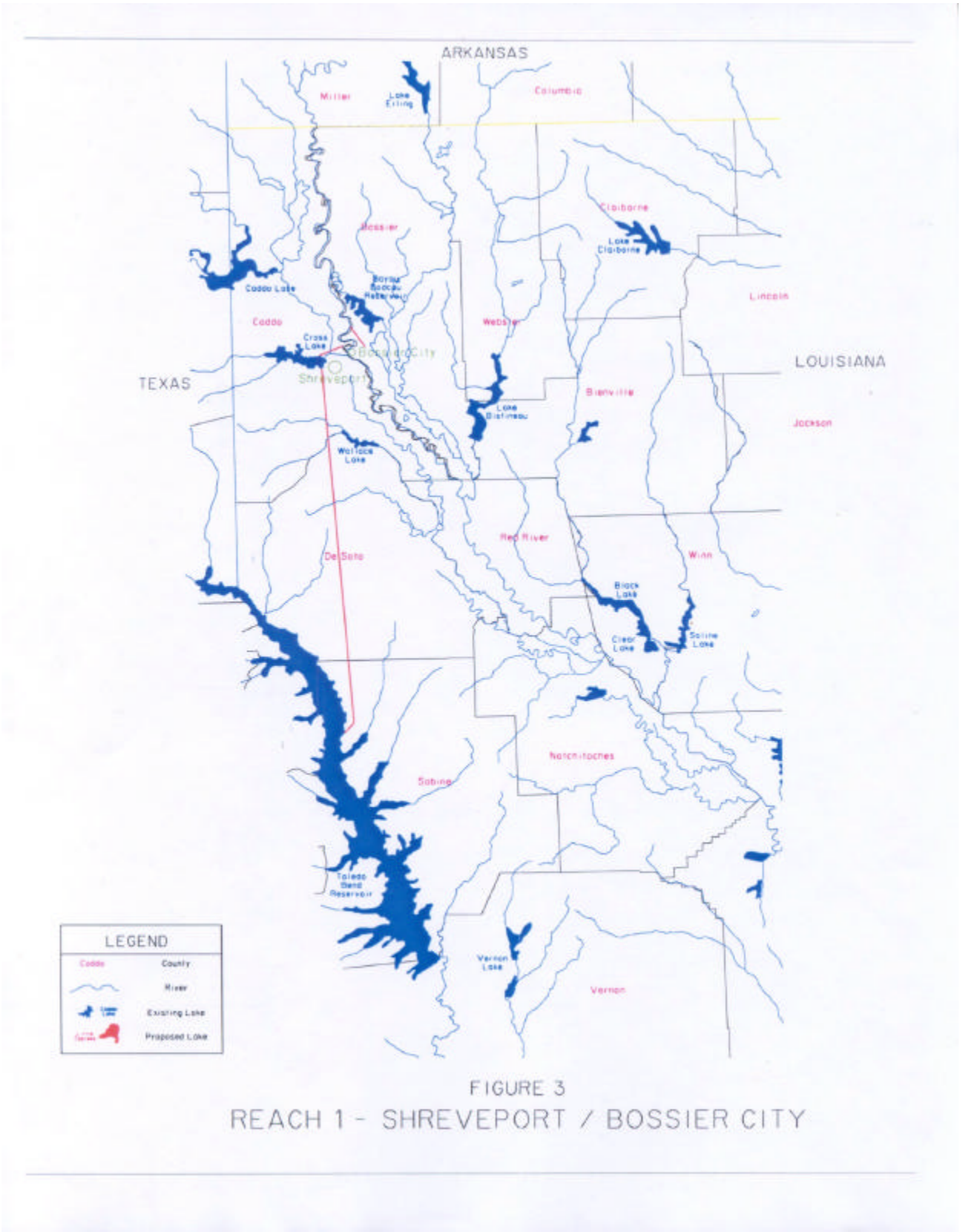


FIGURE 3
REACH 1 - SHREVEPORT / BOSSIER CITY

Figure 2-32. Surface Water Features.

Cypress Black Reservoir No. 1. Cypress Black is a reservoir developed primarily for agricultural water storage. It is administered by the Bossier Recreation and Water Conservation District. Of the 13.8-mgd water supply yield available, 11.7 mgd has been allocated for agricultural use with only 2.1 mgd available for other uses. However, Bossier City has acquired permission to use some of the water and is considering the reservoir's possibilities for meeting the city's needs. Consequently, Cypress Black Reservoir has been included for additional evaluation as a source of water supply for Bossier City.

Cypress Black Reservoir No. 2. Also administered by the Bossier Recreation and Water Conservation District, this reservoir has a water supply yield of 4.9 mgd, of which 3.7 mgd is allocated for area agricultural use and 1.2 mgd is allocated for municipal and industrial water supply. The large allocation of the reservoir's water for agricultural purposes necessitates that it be screened from consideration as a significant source of future water in the area.

Indian Creek Reservoir. Indian Creek Reservoir is owned and administered by the Rapides Parish Police Jury. The 15.9-mgd water supply yield of the reservoir is totally allocated for agricultural purposes. Because the water is totally allocated, Indian Creek Reservoir was screened from additional consideration as a future source of water in the study area.

Cotile Reservoir. The circumstances surrounding Cotile Reservoir are identical to Indian Creek Reservoir. The 16.6 mgd water supply yield of the reservoir is totally allocated for agricultural purposes and therefore precludes Cotile from further consideration.

Kincaid Reservoir. Also administered by the Rapides Parish Police Jury, Kincaid Reservoir has a water supply yield of 17.7 mgd. The yield is totally allocated for agricultural use. As a result, the reservoir was screened from additional consideration as a water source.

Toledo Bend Reservoir. This reservoir, located in the secondary study area, represents a large (81 mgd) potential source of water. It was constructed for water supply use, among other purposes, and has no quality or institutional problems to preclude transport of its waters into the primary portion of the study area. Transportation cost will be the primary factor influencing future usage of Toledo Bend water within the primary portion of the study area. Although at certain locations the iron content in Toledo Bend water occasionally exceeds desirable limits, the fact that this water is being increasingly utilized by communities and industries in the area warrants its further consideration. Toledo Bend is included for additional evaluation in the costing section of this report.

Grand Bayou Reservoir. This reservoir will have a dependable water supply yield of 13.1 mgd. About 3.1 mgd is believed to be needed in the immediate area (northern Red River Parish), with 10.0 mgd possibly available for transport. However, because of the size of this water supply relative to its distance from major water demand centers (Shreveport-Bossier City), it was not included in the costing section of this report.

Big Creek Reservoir. Big Creek Reservoir is a development that was judged to have potential in the early 1970’s by the Louisiana OPW. If constructed, it would have an estimated total yield of 29.3 mgd. The amount of water that would be allocated for water supply use is

unknown, particularly since reservoirs constructed by the OPW are primarily for flood control. Because of the uncertainties surrounding potential reservoirs listed by the OPW, Big Creek Reservoir was excluded from consideration as a significant future source of water.

Black Lake No. 3. Black Lake No. 3 is another potential reservoir listed by the Louisiana OPW in past studies. It would have a total yield of 89.3 mgd if constructed. However, development of the reservoir has not been actively pursued, and it would probably not be constructed for water supply. Black Lake No. 3 was excluded from evaluation in the costing section of this report.

Brown Creek Reservoir. The situation of Brown Creek Reservoir is identical to other potential reservoirs listed by the Louisiana OPW. Therefore, this potential reservoir is excluded from additional consideration as a significant future source of water.

Goldonna Reservoir. With an estimated total dependable yield of 100 mgd, Goldonna Reservoir might be a significant source of water if constructed. However, since it is not known whether construction is feasible or whether water supply would be available, this potential reservoir was screened from additional consideration.

Halls and Berry Brake Reservoir. If constructed, Halls and Berry Brake would have a total dependable yield of 31.0 mgd. However, as with other potential reservoirs listed by the OPW, there is no reason to assume that the reservoir is feasible or that it would have water supply storage. Therefore, it will not be included in the costing portion of this study.

Kisatchie Reservoir. Kisatchie Reservoir represents a potential source of 60.0 mgd according to the Louisiana OPW. As with the other potential reservoirs, the uncertainties surrounding this reservoir are too great to consider it in the costing portion of this report.

Longleaf Reservoir. Longleaf is the largest of the potential reservoirs, at an estimated 269.0 mgd. However, questions concerning the water supply yield, engineering and environmental feasibility, and the availability of the reservoir site preclude additional consideration of this potential reservoir.

Spring Creek Reservoir. Identical to the other potential reservoirs in its uncertainties, the 58.8-mgd potential of spring Creek Reservoir must be regarded as too questionable to warrant inclusion in the costing portion of this report.

Valentine Reservoir. The last of the potential reservoirs is Valentine Reservoir. Estimated to have a total yield of 29.5 mgd if constructed, Valentine Reservoir was excluded from additional consideration because of the uncertainties surrounding its construction and water supply yield.

Castor Creek. Castor Creek at Castor Plunge in Kisatchie National Forest near Alexandria (Rapides Parish) has been mentioned as a water supply source in the past and was again discussed during the water use survey. From the evidence presented in USGS reports,

water quality appears to be good. Castor Creek will be considered in the costing portion of the report as a water supply alternative for the city of Alexandria.

Red Chute Bayou. This bayou, with a dependable yield or low flow of 6.9 mgd, was formerly used as a source of irrigation water. No water quality information is available, but it can be assumed that quality may still be sufficient for agricultural use. However, the 6.9-mgd low flow estimate for Red Chute Bayou does not represent water available for water supply use. The amount available on a dependable yield basis once in-stream water supply requirements are taken into consideration would no doubt be considerably less than 6.9 mgd. Developing and transporting such a small quantity of water would not be economically feasible. Therefore, Red Chute Bayou has been excluded from further consideration as a water supply source.

Twelve-Mile Bayou. Twelve-Mile Bayou has a low flow or dependable yield of 5.1 mgd. In 1990, about 10.0 mgd was utilized by the city of Shreveport to supplement its main source of water. Because of the very low stream flow, Twelve-Mile Bayou is questionable as a significant potential source for water supply development and transport. However, Shreveport is considering construction of two off-channel storage reservoirs that would be filled with water from Twelve-Mile Bayou when it is at a high flow stage and when Caddo Lake is overflowing. Therefore, Twelve-Mile Bayou will be considered in the costing analysis as a water supply source for Shreveport.

Little River. Little River has a low flow or dependable yield of 10 mgd. Currently, about 2.0 mgd are being utilized by an industry in Grant Parish. The remaining yield that might be available for water supply purposes is unknown.

Bayou Boeuf. With a low flow of only 0. 8 mgd, Bayou Boeuf must be screened from additional consideration as a significant source of water.

Cane River. Cane River is another stream with a small dependable yield or low flow (4.8 mgd). There is currently some agricultural use of the water (0.45 mgd), but the yield is too small to warrant costing of the source. Cane River has therefore been screened from additional consideration.

Big Creek. Big Creek, with a low flow of 5.0 mgd, currently supplies about 1.5 mgd of municipal water in the Pineville area of Rapides Parish. Its available water supply, although unspecified, is obviously too low to warrant development and transport. Big Creek has therefore been excluded from costing in the next section of this report.

Calcasieu River. The Calcasieu River is located in southern Rapides Parish. It has a low flow or dependable yield of 11.6 mgd, with no known water quality problems. However, the Calcasieu River has been designated a scenic stream by the State of Louisiana. In combination with the stream's low dependable yield, this makes it necessary to remove the Calcasieu River from additional consideration as a future source of water.

Atchafalaya River. With an estimated low flow of 25,548 mgd, the Atchafalaya River represents a tremendous source of water. This river, which is the Mississippi River's main

distributary, exhibits no water quality or administrative problems that would preclude its consideration as a source of water. The only problem that might be associated with use of the Atchafalaya River is its location in the extreme southern portion of Reach 1. It is located 50 miles from the nearest demand center (Alexandria), and transportation costs may preclude future use. However, these factors will be addressed in detail in the chapter on costing.

Red River. The Red River has been and is being used by Bossier City for water supply in spite of its water quality problems. Bossier City has plans for another storage reservoir off channel of the Red River to provide additional water supplies at times when Red River water quality has deteriorated or water flow is low. Therefore, although the Red River did not pass the screening test, it will be evaluated as a source of water for Bossier City under this particular water supply alternative.

Carrizo Sand. The Carrizo Sand is found only in the extreme northwestern portion of Reach 1 and does not underlie the Shreveport-Bossier City area. Little is known about the quality of the water because it is little utilized, but it appears to be of the soft, sodium bicarbonate type. Only about 5.0 mgd are available from this aquifer, and this figure (which is an estimate) probably exaggerates real availability because of the variations in thickness that characterize the aquifer in Reach 1. Because of the large need in the Shreveport-Bossier City area and the small quantity available from the Carrizo Sand, it had been excluded from consideration as a potential supply source.

Alluvium Deposits. The basal sand and gravel of the alluvial deposits are a prolific source of water, and wells in the deposits yield as much as 4,000 gpm. However, the water is not suitable for municipal purposes because of hardness and high iron content and local problems with chlorides. Analyses of water from these deposits conducted by the USGS indicate that the average hardness is 500 mg/1 and the average iron content is 6 mg/1, both far above the concentrations desirable for potable water. In addition, the aquifer is contaminated in a few places by upward leakage of saltwater from underlying formations. One of the larger areas of saltwater contamination is at Clarence in Natchitoches Parish, where the water has concentrations of chloride as great as 8,000 mg/1. For these reasons, the alluvial aquifer has been excluded from additional consideration as a future source of water.

Wilcox Group. Shreveport and Bossier City used water from Wilcox sands until better quality surface water supplies were developed in 1926-1928. Wilcox water is generally hard and high in chlorides and iron, but there is wide local variability. In the outcrop areas in Bossier and Caddo parishes, some wells yield soft to moderately hard acid-tending water of low mineral content. Water from wells in the outcrop area generally must be treated to remove iron. In Red River Parish, the water is a basic-tending, moderately hard, sodium bicarbonate type and contains an excessive amount of iron. In Natchitoches Parish, the water becomes more mineralized, with higher concentrations of sodium, bicarbonate, and dissolved solids. Thus, the water is not generally suitable for widespread municipal usage and will not be evaluated in the costing section of this report.

Miocene. Miocene water is generally of good quality, although excessive amounts of fluorides have been reported from many wells in Avoyelles Parish. Because of its high quality

and the potential of deeper Miocene sands in the Alexandria area, it is included for additional consideration as a source for Alexandria.

Terrace Deposits. Well yields from the Terrace are generally small because of the relatively thin saturated thickness of the deposits. The water from these deposits is soft and has a very low dissolved solids content, but the concentrations of iron are excessive. Wells analyses conducted by the USGS in Grant and Rapides parishes indicate a total iron content ranging from 1.2 to 5.8 mg/l. However, based on USGS information, Terrace deposits may offer a feasible alternative for water in the Alexandria area of Rapides Parish. Therefore, they are included in the costing section of the report for Alexandria's water needs.

Pliocene. Only 0.2 mgd of water is available from the Pliocene in Reach 1, and all of this is in the extreme southwest and southeast corners of Avoyelles Parish. In the secondary study area, Pliocene wells in Allen and Evangeline parishes show iron content greater than 0.3 mg/l. There is also a problem with fluorides, which exist in concentrations high enough to cause mottling of the teeth of children. It has therefore been screened from additional consideration.

Cane River Formation. Water from the Cane River is generally clear and soft but is reported by some users to have the taste and odor of iron. Chemical analyses show hardness ranging from 23 to 77 mg/l, chloride content from 11 to 55 mg/1, and dissolved solids from 101 to 565 mg/1. The aquifer is located only in the extreme northern portions of Bossier and Caddo Parishes and must be excluded from consideration because of the very.small quantity (3.1 mgd) that is available.

Sparta Sand. The Sparta Sand is an important aquifer in north-central Louisiana, but of only minor importance in Reach l, since it generally runs to the east of the study area and touches only the eastern portions of Red River and Bossier Parishes. In Bossier Parish, water in the outcrop area is highly corrosive, and water under artesian conditions is high in iron. A narrow belt of Sparta Sand cuts into the study area from the east in Natchitoches Parish. This narrow belt was used by the city of Natchitoches until abandoned for surface supplies. The dissolved solids content averages slightly more than 300 mg/l, and hardness is less than 10 ppm, but iron generally exceeds 0.3 mg/l. The Sparta Sand was therefore excluded from additional consideration as a future source of water in the area.

Cockfield Formation. The Cockfield Formation is located in portions of Natchitoches and Grant parishes. The portions of the aquifer located within Natchitoches Parish are estimated to contain 15.6 mgd of dependable water yield. Currently, there are no users of the Cockfield Formation. Since the major water system (Natchitoches) has no immediate future water supply needs, the Cockfield Formation will not be evaluated in the costing portion of the report.

REACH 1

There are seven potential sources of water for which costs will be calculated for Reach 1, including the Atchafalaya River in lower Avoyelles Parish, Red River in Bossier Parish, Castor Creek at Castor Plunge in Rapides Parish, Cypress Black Reservoir No. 1 in Bossier Parish,

Toledo Bend Reservoir in DeSoto Parish in the secondary study area, Twelve-Mile Bayou in Caddo Parish, and the Terrace and Miocene groundwater aquifers in Rapides Parish.

Atchafalaya River

With a low flow estimated at 25,500 mgd, the Atchafalaya River in Avoyelles Parish represents a large potential water supply source. It is located approximately 50 miles from the Alexandria, Louisiana, demand center. As mentioned previously, there are no water quality problems or legal restraints that would inhibit utilization of Atchafalaya River water. Since it is doubtful that it would be feasible to transport water to the Shreveport demand center, only the cost of developing Atchafalaya River water to the city of Alexandria was calculated.

For demonstration purposes, development of a 20-mgd supply from the Atchafalaya River was estimated. The 20-mgd figure was chosen because it appears to be reasonable in light of current water usage in the area. The cost of Atchafalaya River water delivered to Alexandria included the annualized cost of developing and operating and maintaining the pumps and transmission facilities between Alexandria and the river. In addition, the annual cost for major replacement of equipment in present value terms was included. Converting every cost to an annual basis yielded an estimated cost of $0.91 per thousand gallons.

Toledo Bend Reservoir (Secondary Study Area)

This large reservoir is located in the secondary portion of the Reach 1 study area. The dependable yield of Toledo Bend has been estimated at 715 mgd for the Louisiana portion. The actual amount of water available for water supply use depends upon many variables. Most of the storage, however, has been allocated for power generation. Louisiana's share of the remainder is about 108 mgd. To date, allocations within the reservoir have totaled 37 mgd. This figure represents allocations only, since current usage is only about 1.5 mgd. It is reasonable to assume that Toledo Bend water is a potential source for certain areas within the Reach 1 primary study area since it has been studied by companies for possible use in pulp and paper and steam-electric generating plants.

For this analysis, 81 mgd in Toledo Bend water was costed to the Shreveport demand center. The cost elements involved in this exercise included: 1) the cost of purchasing water from the Toledo Bend Authority - 5¢/1,000 gallons; 2) the cost of pumps and transmission lines; 3) operation and maintenance costs associated with operating the transmission facility; and 4) annual major replacement value. The resulting cost for delivering 81 mgd of Toledo Bend water to Shreveport was $0.77 per thousand gallons.

Terrace and Miocene Aquifers

In this reach, both aquifers of the Terrace and Miocene Sands are capable of supporting additional development. These aquifers have an estimated combined dependable yield of 176.0 mgd with no long-term adverse effects on the aquifers. Historically, these aquifers have supported productive wells in the Alexandria demand center in Rapides Parish.

It has been estimated that wells in the Terrace and Miocene Sands could produce water in the range of 200 to 1,000 gpm. For wells producing 1,000 gpm, it would be necessary to install 14 wells to produce quantities to match the current average daily use of Alexandria. The total cost of developing a new well field and constructing a 54-inch transmission line to deliver this amount of water to Alexandria 28 miles away is estimated to be about $43 million. Annualizing all costs of this project results in an estimated raw water cost of $0.64 per thousand gallons.

Castor Creek

Castor Creek at Castor Plunge in Kisatchie National Forest, about 10.5 miles from Alexandria, has been considered as a possible site for a water supply reservoir for Alexandria. However, owing to the excellent groundwater resources in the area, it was never pursued. Water in streams in the vicinity of Castor Plunge is generally of good quality, normally very low in dissolved constituents. It has been suggested that a reservoir in this area could impound the waters of three creeks (Loving Creek, Long Branch, and Castor Creek at Castor Plunge). The impoundment, aside from providing the city a source of water, would probably help recharge the present well field aquifers. Converting all costs to an annual basis, it was estimated that this alternative water supply would cost $0.40 per thousand gallons.

Cypress Black Bayou Reservoir No. 1

Bossier City (Bossier Parish) has examined several alternative water sources to the Red River. One that would use water from the existing Cypress Black Bayou impoundment is included in this cost analysis. Details of costs of getting raw water from the lake to a treatment plant were developed. Raw water costs of the project were estimated to be $0.57 per thousand gallons.

Red River

Another water supply alternative that Bossier City has explored is the construction of a second water storage reservoir to aid in storing Red River water when the water quality of the river improves periodically, and also to have adequate water supplies in times of low river flow. Costs of raw water for this water supply alternative were estimated to be $1.13 per thousand gallons.

Twelve-Mile Bayou

Shreveport, which supplements its main water supply in Cross Lake with water from Twelve-Mile Bayou (when Caddo Lake is overflowing), has experienced problems during months when Twelve-Mile Bayou is in a low flow stage. To solve this problem and to provide the city with an alternative future water supply, Shreveport is considering construction of two huge reservoirs off the channel of Twelve-Mile Bayou. During months when Twelve-Mile Bayou is experiencing high flows and/or Caddo Lake is overflowing into Twelve-Mile Bayou, the reservoirs could be pumped full of water. This alternative was examined, and annualized costs per thousand gallons were estimated to be $0.46.

REACH 2

There were no potential sources of water in Reach 2 for which costs were calculated. All public water systems had adequate water supplies to meet current and future needs.

REACH 3A

As previously noted, Reach 3A was not included in the screening and costing process, since all public water systems had adequate supplies of water for current and future needs. Aside from a large surplus of groundwater, Lake Millwood provides a dependable supply of good quality surface water for current and future use.

PART III - PROJECT EVALUATION
MUNICIPAL AND INDUSTRIAL - EXISTING AND POTENTIAL SOURCES OF WATER SUPPLY AND COST OF RED RIVER WATER

OVERVIEW

Part III of the Economics Appendix presents data and information that is used to determine the availability and cost of Red/Wichita River water and other sources of water supply that could be used to meet the water needs in the region. The cost of Red/Wichita river water is in terms of desalinizing the water to acceptable levels of water quality in order to compare those unit costs with the unit costs of alternative sources of water supply. A major assumption of the analysis is that an existing source of water supply would not be abandoned for another source until its dependable yield is exhausted. Therefore, if Lake Kemp or Lake Texoma water is currently being used or expected to be used based on the findings found in the region reports of the Texas State Water Plan, then those existing sources will continue to be used. Also if the water management strategy recommends the use an alternative source to the Red/Wichita River, then those alternative sources would be used first even if the Red/Wichita River is less costly on a per unit basis. Other important decision factors must be considered than just unit cost. Water management strategies were determined on a regional basis and have a regional consensus. These strategies must be taken into account in the evaluation. In sum, the costs that are important in the derivation of project benefits are the costs associated with desalinization and blending of Red/Wichita River water.

BACKGROUND

Approximately 3,300 tons of chlorides (Cl) are introduced into the Red River and its tributaries daily from natural sources. The large chloride concentration along with high sulfates (SO_4) and total dissolved solid (TDS) make the water unsuitable for most municipal, industrial, and agricultural uses.

Studies began in 1957 to identify these natural sources and possible methods to reduce the chloride pollution. Ten major sources were identified in the initial studies. By 1966, chloride control plans were developed for the three identified sources in the Wichita River Basin and five of the six sources in the Upper Red River Basin. In 1976, detailed studies were completed and a formal chloride control plan was recommended in *Design Memorandum No. 25*[2]. The recommended plan involved collection and disposal of brine prior to its reaching the Red River. Low flow dams were proposed to collect the brine. The collected brine would then be pumped to brine lakes for evaporation.

In 1980, the U.S. Army Corps of Engineers, Tulsa District prepared a supplement to *Design Memorandum No. 25*. The purpose of the study was to further quantify benefits of the proposed project. Based on the supplemental data, construction was funded and completed for Area VIII of

[2] Department of the Army, Tulsa District Corps of Engineers, *"Arkansas-Red River Basin Chloride Control, Red River Basin, Design Memorandum No. 25"*, July 1976.

the project. Since completion of this area, budgetary cutbacks and continuing questions as to the need and necessity have followed the project. At the same time, significant changes were occurring within the river basin. Tremendous population growth along with increasing water demands has occurred especially within the Dallas/Fort Worth metropolitan area. Usage of untreated Red River water has also increased in the basin.

In 1991, the Assistant Secretary of the Army (ASA) (Civil Works) requested that a current economic analysis be performed to accurately reflect current conditions within the basin and evaluate various combinations of the remaining portions. The *Limited Reevaluation Report*[3] (LRR) evaluated six possible plans for completion of the project. The LRR updated cost and damages data from the 1980 study using the same methodology and recommended the project be completed as originally proposed.

In the following years, environmental opposition to the project increased and political support for the project decreased in Oklahoma. Strong opposition from the State of Oklahoma made construction of the proposed Area VI, XIV, and XIII facilities unlikely. Updates were again needed for both the Environmental Impact Study and economic benefits for the changed project.

The *Supplemental Assessment Report* (SAR)[4] was prepared by the Tulsa District to explore the feasibility of desalination, mixing/blending, and partnership options. One recommendation of the SAR was to complete the Wichita River Basin portion of the project. A follow-up economic study[5] was also prepared by the Tulsa District to determine if there was a reasonable chance of economic justification for the Wichita River Basin portion of the project.

Based on the economic report, a formal reevaluation of the Wichita River Basin was requested by the ASA (Civil Works). The reevaluation study is to include development of the cost of using Red and Wichita River (and/or affected tributaries) water. The cost categories to be considered include:

(a) Treatment of Red/Wichita River water to acceptable water quality standards as a source of water supply.
(b) Damages to municipal and industrial users of the Red River and Wichita River.
(c) Costs of blending Red River water with existing sources of water supply for municipal and industrial use.

Costs developed in this study are to be incorporated into the economic reevaluation of salinity control measures in the Wichita River Basin. The purpose of economic evaluation of the Wichita River portion of the Red River Chloride Control Project (RRCCP) is to measure the improvement of water quality by comparing the "without project" condition to the "with project" condition. Modifications to the Wichita River Basin features of the authorized RRCCP may then be made to meet or exceed acceptable water quality standards and to maximize National

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[3] Department of the Army, Tulsa District Corps of Engineers, "*Limited Reevaluation Report*", June 1993.
[4] Department of the Army, Tulsa District Corps of Engineers, "*Red River Chloride Control Project, Supplemental Assessment Report*", February 1997.
[5] Department of the Army, Tulsa District Corps of Engineers, "*Red River Chloride Control Project, Evaluation of Wichita River Basin Completion*", October 1987.

Economic Development (NED) benefits. The area of primary focus for this study is the Wichita Falls, Dallas/Fort Worth, and Sherman/Denison areas of Texas and the Shreveport/Bossier City area of Louisiana.

REVIEW OF PAST ASSUMPTIONS

Past economic updates of the RRCCP have used Engineering News Record (ENR) construction index values and Bureau of Reclamation index values to update anticipated alternate source costs and transportation costs and to determine associated damages from using Red River water. A major task of this study is to re-examine past methodology and major assumptions used in previous studies for their applicability to current conditions.

Since the 1950's, most major municipalities in the study area have been aggressively pursuing new and/or alternate sources of water. Many communities are no longer satisfied with poor quality, high mineral content drinking water. Environmental legislation has also required utilities to test and treat their water for numerous pollutants.

Treated Water Quality

One assumption of past studies has been to evaluate treatment of Red River water to the U.S. Environmental Protection Agency (EPA) drinking water standard limits of 500 mg/l of TDS, 250 mg/l of Cl, and 250 mg/l of SO_4. Many of the smaller communities (<50,000 population) in the Red River Basin do not currently meet this limit. All groundwater within the Red River Basin exceeds these limits. The State of Texas has established its own water quality limits of 1,000 mg/l of TDS, 300 mg/l of Cl, and 300 mg/l of SO_4. Most communities in the study area do meet the State of Texas limits with their current supplies; however; many of these same communities are the ones also looking to improve their treated water quality. As such, the EPA limits remain a better indication of the acceptable and desired water quality.

Alternate Source Thresholds

Another assumption of past studies has been to evaluate Red River water against assumed threshold levels for all alternate sources available to a demand center. A review of water quality data indicates that these thresholds may have been too high for several reaches. We have averaged the TDS levels for existing sources and researched the anticipated water quality for proposed reservoirs to develop new alternate source threshold values. These thresholds are shown in Table 3-1. The net result is some benefits may have been understated in past studies. The adjusted Alternate Source Threshold(s) will more accurately capture benefits in the Dallas/Fort Worth and Wichita Falls areas.

TABLE 3-1

WATER QUALITY THRESHOLDS FOR ALTERNATE WATER SUPPLY SOURCES

Reach	Old Assumed TDS Threshold (mg/l)	New Assumed TDS Threshold (mg/l)
1	200	200
5-NTMWD(4TA1)	200	200
5-GTUA AND GRAY/DEN	500	500
5-DAL(5TA1)	400	200
5TRWD(5TA2)	200	200
8	500	315
9-11	500	500

Note: The reach designations used in previous studies and in the Huitt-Zollars report are in parentheses. Reaches 2, 3, 4, 6, 7, 9, 10, and 11 had no municipal and industrial benefits.

See Figure 3-1 for the general location of the Study Area, Reach Boundaries, and significant reservoirs.

Wastewater Reuse

Initial studies envisioned wastewater reuse as a way to supplement future water supplies. In the 30+ years of this project, only a few reuse projects have been developed. The majority of these utilize wastewater plant effluent for irrigation and/or to maintain aesthetic lake levels at golf courses. No reuse projects exist that use the water to supplement drinking water supplies. Public sentiment is still against direct reuse and may continue to be this way for many years to come. One pilot project is underway by the Tarrant Regional Water District (TRWD, formerly know as Tarrant County Water Control and Improvement District No. 1). The TRWD discharges its treated wastewater to the Trinity River in the Dallas-Fort Worth (DFW) area. The TRWD then withdraws water from the Trinity River near the Richland-Chambers Reservoir, approximately 90 miles downstream. The river water is pumped to a wetlands system, which it flows through before entering the reservoir. The attempt to permit this withdrawal is facing opposition due to the possible over-allocation of river flows within the Trinity River Basin. Furthermore, Texas SB1 requires any request for a “bed and banks” conveyance permit for the indirect reuse of wastewater to consider downstream water rights and environmental resources. Senate Bill 1 also allows the TNRCC to amend water rights permits to require a minimum return flow which possibly may limit the ability to directly reuse wastewater[6]. Based on current legislation and downstream water users, the TRWD would most likely need to pipe its treated wastewater directly to the wetlands. This would effectively make the project cost prohibitive and unfeasible. Overall, the concept of any significant wastewater reuse is unlikely during the planning period of this study.

[6] Texas Water Development Board, *Water For Texas*, August 1997, p.2-33.

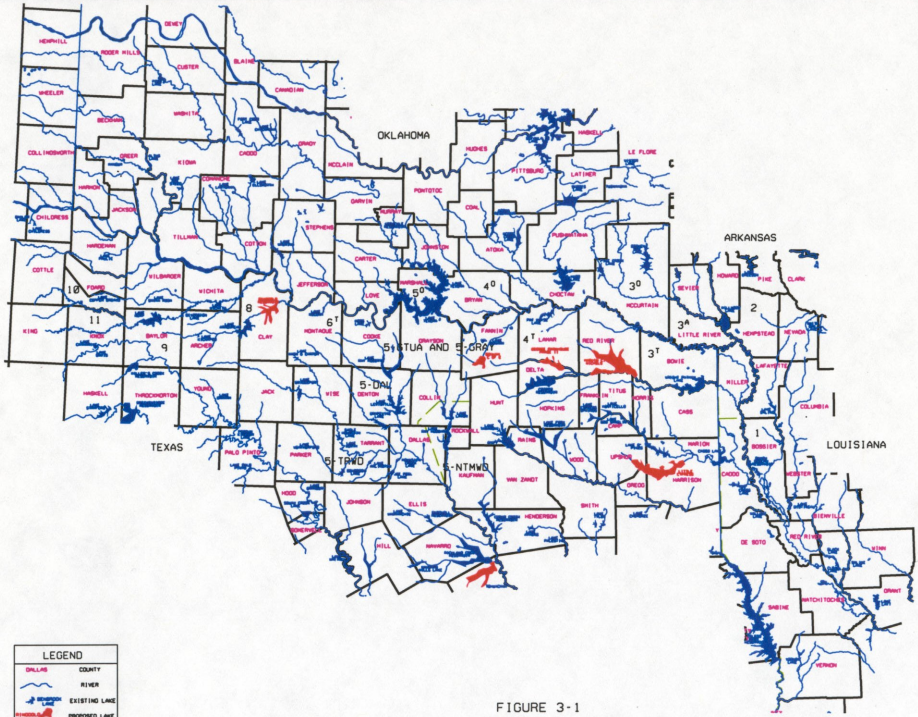

FIGURE 3-1
MUNICIPAL AND INDUSTRIAL STUDY AREA AND REACH SUBDIVISIONS

The Least Costly Source Will Be Used First

The basis of benefit allocation in past studies has been predicated on the premise that the least costly source will be used first. This is not necessarily the case. Three separate situations fall into this category.

- Artificially Low Alternate Source Costs.
  Many of the alternative sources identified have lower unit costs than the same quantity of Red River water. This is due to the alternate sources having very large yields. These alternate sources also have capital commitments exceeding $100 million. Few cities in the study area (with the possible exception of Dallas and Fort Worth) can service the debt on this magnitude of investment making these alternate sources impractical.

- Any Community Can Build An RO/EDR Plant.
  A small 1-mgd RO or EDR plant, complete with all site peripherals and brine disposal facilities, will cost between $3 and $5 million to construct. Even for many of the smaller communities, $3 million of debt service would be difficult to support without State or Federal assistance.

- Prior Use of Red River Water.
  Past use of Red River water also affects the concept of using the least costly source. The city of Dallas used Red River water during the drought of the late 1950's. Millions of dollars of damage to water pipes, water heaters, and household fixtures was blamed on the poor quality water. Even though it has been over 40 years since this occurred, the city of Dallas remains opposed to even considering Lake Texoma (Red River) as a possible future water supply source, even though it appears to be more economical than other alternative sources.

In summary, many alternatives with higher unit costs may be selected due to their reduced capital commitments or perceived impact. In addition, the Texas State Water Plan through extensive coordination by regional planning groups has prioritized use of potential water sources.

New Reservoirs Can Be Built to Meet Demand

In the early stages of the RRCCP, new reservoirs were a viable alternative for cities to increase their water supply. Federal and State funds assisted with the building of many reservoirs in Texas in the 1960's and 1970's. Since that time, stronger environmental regulations, increased use of litigation, and stronger competition for available funds have virtually stopped reservoir construction. The current process takes on average over 30 years to complete with relatively small reservoirs costing over $100 million to build. The process includes numerous planning studies, environmental impact studies, mitigation plans, public hearings, acquisition and/or condemnation of land, contracts for water purchases, water rights permitting, operational agreements, financing agreements, design of the reservoir, and relocation of affected structures (roads, utilities, etc.) all before construction can begin. The last reservoirs

to be built in the State of Texas (Richland-Chambers Reservoir, Joe Pool Lake, Cooper Reservoir) all began this process back in the late 1960's. Planning studies have been done for several potential reservoirs in the study area; however; only Ringgold Reservoir has even begun informal land acquisition. Given today's environmental constraints, construction of new reservoirs is uncertain at best.

Another drawback to new reservoirs is the high unit costs during the initial years of use. The calculated costs for reservoirs deal with utilization of the entire yield. Partial use of the yield can raise the unit costs by several orders of magnitude.

Damages

The concept of "damages" related to the use of water with high TDS, Cl, and/or SO_4 has been the subject of considerable debate throughout the life of the RRCCP. Much of the criticism of past studies has centered on the debate of the relative magnitude of the damages and thresholds below which no damages would occur. Several users of Red River water, including the NTMWD, have taken the position that minimal or no adverse effects[7] will occur at blended threshold levels of 200 mg/l TDS and below. Our investigation has not discovered any research to support this position. In fact, published papers[8] tend to indicate that the relationship of TDS to damages is fairly linear over the TDS entire range of 0 mg/l to 3,000 mg/l. Furthermore, the high TDS values have been shown to decrease the life expectancy of household items thus reinforcing the concept of real damages.

MUNICIPAL DAMAGE COEFFICIENT

There is a significant amount of published research related to water quality and plumbing fixtures; however, very little of the research has specifically addressed decreased life expectancy of plumbing devices as a function of TDS or Cl in the water. While some recent research has been conducted on the effects of TDS on water heaters, very little recent research has been done on other household items. Initial research into the effects of high TDS water on household components was published in a 1968 article[9]. This data served as the basis for development of the municipal damage coefficient in a 1975 study[10] for the Corps of Engineers. The major household items factored into the coefficient were:

Water Pipes	Wastewater Pipes	Water Heaters
Faucets	Toilet Mechanisms	Garbage Grinders
Washing Equipment	Washable Fabrics	Detergent Use

[7] James M. Montgomery, Consulting Engineers, "*A Study of Water Quality Blending Lake Lavon and Red River*", December 1980, Page 5-30.
[8] Tihansky, Dennis, Damage Assessment of Household Water Quality, Journal of the Environmental Engineering Division of the American Society of Civil Engineers, Vol. 100, No. EE4, August 1974, pp 905-918
[9] Patterson, W.L., and Banker, R.F., "Effects of Highly Mineralized Water on Household Plumbing and Appliances", *Journal of the American Water Works Association*, Vol. 60, No. 9, Sept. 1968, pp 1060-1069.
[10] Black and Veatch, "*Report on Determination of Economic Values for Improved Water Quality in the Red River Basin*", prepared for the US Army Corps of Engineers, Tulsa District, 1975.

Additional municipal factors related to the utility's facilities were also included in the domestic damage coefficient. They were:

Water Supply and Production Facilities
Distribution System Piping and Valves
Distribution System Storage
Utility Service Lines
Water Meters
Sewage Facilities

The initial study calculated the annual capital cost differential between the listed items at 250 mg/l and 1750 mg/l of TDS. The annual cost differential was distributed over the annual residential usage of 100,000 gallons. This value was further distributed over the difference in TDS to develop a "damage coefficient" in terms of dollars per 1,000 gallons per 100 mg/l of TDS. This methodology remains a logical approach for the calculation of the municipal damage coefficient. As such, we have revised the costs for the listed items based on 1999 costs and indexed these costs to January 2001 using the appropriate consumer price indexes. Appendix A summarizes the calculation of the household and municipal components. Table 3-2 combines these factors to develop a "new municipal damage coefficient" of $0.1636 per 1,000 gallons per 100 mg/l of TDS. It should be noted that this new coefficient is ±64.7% of the expected value of $0.2527 based on straight indexing using the ENR Building Cost Index (BCI) from 1967 to January 2001. Further indexing to November 2001 price levels would change the value by about 1 to 2%; however, the relative difference between different alternatives would remain about the same. Interest rate changes to 6-1/8 % would be insignificant on the damage coefficient.

While some construction methods and materials have changed since the late 1960's, many residential construction items remain the same. The use of plastic pipe and materials is now quite common. Virtually all wastewater piping used in residential construction is now PVC, thus lowering the negative effect of water quality on wastewater piping. However, most under slab water piping remains copper and is still affected by water quality. Decorative faucets and plumbing fixtures have also become a more significant expense in residential construction, both of which are affected by poor water quality. The damage coefficient is assumed to be a linear value across the range. While this may not be the case at very low (below 100 mg/l) and very high (above 5,000 mg/l) values, it does adequately depict the relationship within the anticipated TDS range examined in this report.

TABLE 3-2
COMBINED MUNICIPAL DAMAGE COEFFICIENT
(2001 Basis)

Component	Average Annual Cost
Residential:	
Water Piping	$22.55
Wastewater Piping	$12.54
Water Heaters	$39.86
Faucets	$48.35
Toilet Flushing Mechanisms	$11.64
Garbage Disposals	$10.96
Washing Equipment (Dishes & Clothes)	$36.05
Cooking Utensils	$6.10
Washable Fabrics (4 people @ $800/ea.)	$27.64
Soap and Detergent Use	$18.55
Subtotal Residential Damages	$234.25
Public:	
Supply & Production Equipment	$3.49
Distribution Piping	$0.45
Storage Facilities	$0.38
Utility Service Lines	$0.28
Water Meters	$0.25
Sewage Facilities	$6.32
Subtotal Public Damages	$11.17
Total Annual Damage Cost Differential	$245.42
Damage Cost per 1,000 Gallons (With Assumed 100,000 Gallon Annual Usage)	$2.454
Damages per 1,000 Gal per 100 mg/l TDS	$0.1636

One relevant study did evaluate the effects of water quality on water heaters. The Gas Research Institute (GRI) conducted a 4-year study on the "Effect of Water Quality on Residential Water Heater Life-Cycle Efficiency"[11]. This study evaluated identical water heaters on identical plumbing systems at four geographic locations (Columbus, Ohio; Lisle, Illinois; Roswell, New Mexico; and Marshall, Minnesota). Each test site evaluated six gas and six electric water heaters using "hard water", "softened water", and "softened water with phosphate". The water heaters were operated under similar water draw cycles at all sites. As expected, the "hard water" units developed tremendous amounts of scale which led to decreased efficiency and failure of the heating elements in the electric units and overheating (burn-through) of the metal tanks on the gas units. The "softened water" units developed less scale, but the increased Cl from softening led to increased anode consumption and quicker failure of the tanks due to corrosion. The study also documented increased steel and galvanized steel corrosion at the sites with higher chloride levels. The sites with higher sulfates produced more copper and brass corrosion.

[11] S. G. Talbert, D. C. Newman, G. H. Stickford, Jr., W. N. Stiegelmeyer, and D. W. Locklin, *The Effect of Water Quality on Residential Water Heater Life-Cycle Efficiency*, (Columbus, OH: Battelle Columbus Laboratories for the Gas Research Institute, June 1983, October 1984, December 1985, May 1987).

While the GRI study did not address the specific variables of concern for the Wichita River Basin Reevaluation, some conclusions can be drawn. The natural conditions of the Red River water represent the "worst case" conditions from the GRI study. The water is hard (high TDS) and has the high chlorides of softened water. The expected result would be significant scaling and rapid anode consumption in the water heater at the same time. With the average life expectancy of a hot water heater at 10-15 years, increased TDS and/or Cl can shorten the water heater life expectancy to 7-10 years.

INDUSTRIAL DAMAGE COEFFICIENT

The industrial damage coefficient is somewhat more difficult to quantify. Poor quality water affects process water, boiler feed, and cooling water operations among others. These processes typically require the addition of chemicals to control scaling, fouling, and corrosion. Industrial users must increase the quantity of chemicals needed for water pre-treatment when the raw water used is high in TDS, Cl, and/or SO_4. High-pressure boilers require a very pure water supply. Demineralization and chemical treatment are typically required. The treatment costs for demineralization of the boiler feed water also increase. One study[12] prepared for the NTMWD estimated the chemical usage for industrial users to increase by 50 to 55% for an increase in TDS from 110 mg/l to 255 mg/l. The increase in TDS was due to the anticipated blending of Red River water into Lake Lavon. Another indirect cost to the industrial customer is the additional water used. Additional water use is necessitated by more frequent blow-downs of cooling water systems to offset the concentrating effects of evaporation and scale formation.

A 1975 report[13] developed the original Industrial Damage Coefficient. The coefficient was a composite value of $0.014 per 1,000 gallons per 100 mg/l of TDS (in 1967 dollars). The value was compiled from an average of four previous studies prepared between 1959 and 1972. These reports were summarized in a 1974 report[14] that attempted to quantify the benefits derived from reductions in TDS.

The complexity of the variables in the industrial damage coefficient makes the development of a new coefficient a difficult process. An extensive survey of industrial water users in each Standard Industrial Classification (SIC) code over a 3-5 year period would be required along with water quality monitoring. A simplified approach is to factor the original Industrial Damage Coefficient by the corresponding increase in the BCI and then reduce down by a proportion similar to the reduction calculated in the new Municipal Damage Coefficient. Therefore, the original industrial damage coefficient will be indexed and adjusted (as described below) using the ENR BCI.

As previously stated, if the municipal damage coefficient had been indexed from 1967, its value would have been $0.2527/1,000 gallons/100 mg/l TDS instead of the $0.1636/1,000 gallons/100 mg/l TDS that was calculated. The recalculated value is only ±64.7% of the indexed

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[12] James M. Montgomery, Consulting Engineers, p. 5-32.
[13] Black & Veatch, 1975, p. D-24.
[14] Daniel, Mann, Johnson & Mendenhall/Koebig & Koebig, Inc., *"Comprehensive Water Quality Control Plan – Los Angeles River Basin"*, 1974.

value. For consistency, we will use 64.7% of the indexed value for the industrial damage coefficient or $0.0489/1,000 gallons/100 mg/l TDS (see Table 3-3). Updating to November price levels would result in about a 1% change, based on a BCI of 3596.

TABLE 3-3
INDUSTRIAL DAMAGE COEFFICIENT
($/1,000 Gallons/100 mg/l of TDS)

Year	ENR BCI	Indexed Coefficient	Adjusted Coefficient
1967 (Average)	676	$0.0144	-
1980 (January)	1895	$0.0404	-
1999 (January)	3425	$0.0730	$0.0445
2000 (January)	3503	$0.0746	$0.0448
2001 (January)	3545	$0.0755	$0.0489

Past studies have calculated the estimated treatment costs for industrial users of Red River water based on a calculated average daily water use for each SIC code. The water usage data were obtained from a Department of Commerce report, *Census of Manufacturers - Water Use in Manufacturing.* This report was discontinued after 1982. No similar information could be located to provide revised average industrial water use. As such, the consensus average daily water use per establishment values from the 1980 study was maintained for continuity. These are summarized in Table 3-4.

TABLE 3-4
AVERAGE DAILY WATER USE PER INDUSTRY

SIC	Description	Average Daily Water Use (mgd)	TDS Threshold (mg/l)
20	Food and Kindred Products	0.70	500
22	Textile Mill Products	1.00	200
24	Lumber and Wood Products	2.00	500
26	Paper and Allied Products	12.00	500
28	Chemicals and Allied Products	2.00	800
291	Petroleum and Coal Products	3.00	800
33	Primary Metal Industries	29.00	900
35	Machinery, except Electrical	0.50	750
371	Motor Vehicles and Equipment	1.00	750
39	Miscellaneous Manufacturing Industries	0.50	750

ANTICIPATED WATER QUALITY

A primary goal of this study is to evaluate the cost of alternative water supplies and the associated costs of Red River water for five possible water quality scenarios. The scenarios represent different combinations of projects in the original RRCCP. Figure 3-2 shows the

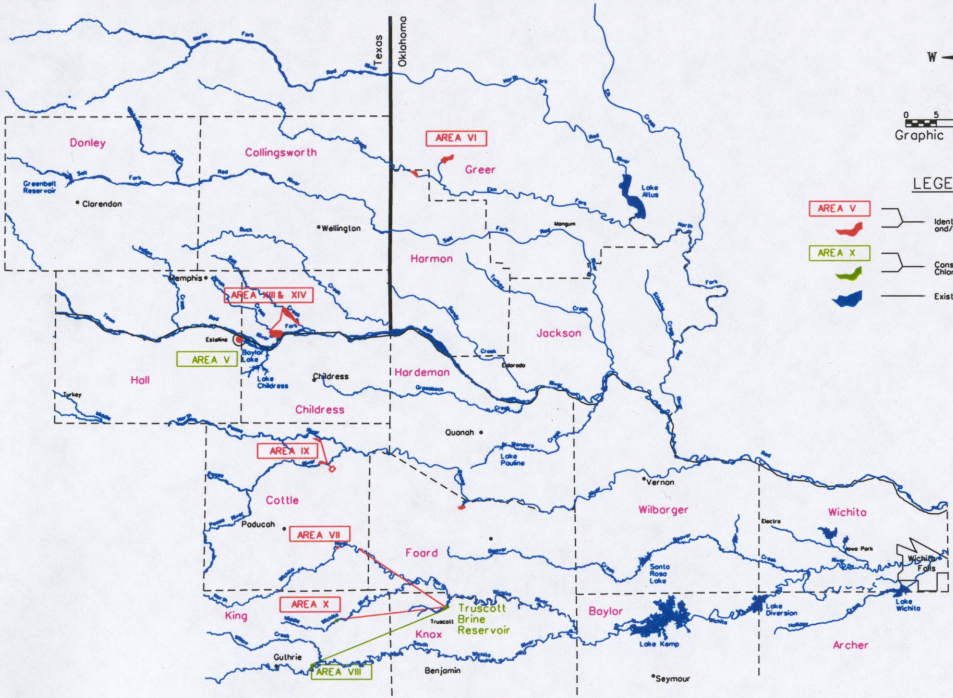


FIGURE 3-2
WICHITA RIVER BASIN PROJECT FEATURES

significant features of the originally proposed project. The possible water quality plans evaluated are:

Plan 1 Natural: No portion of the RRCCP constructed (Pre-Project)
Plan 2: Only Area VIII constructed and operational (Existing Condition)
Plan 3: Area(s) VIII and X constructed and operational
Plan 4: Area(s) VII and VIII constructed and operational
Plan 5: Area(s) VII, VIII, and X constructed and operational

For the 14 Corps alternatives evaluated, Plan 2 (without project condition) was compared to Plans 3, 4, and 5 (with project condition) to determine the benefits of completing collection and disposal facilties are either Area VII, Area X, or for both Areas VII and X.

The weighted averages of the TDS loads are summarized in Table 3-5. The weighted averages of the Cl loads are summarized in Table 3-6. The weighted averages of the SO_4 loads are summarized in Table 3-7. Shaded areas in the tables represent values that exceed the allowable EPA limit. Curves have also been developed for +10% and –10% loading to further define the ranges of the expected treatment costs.

TABLE 3-5
WEIGHTED AVERAGE TDS CONCENTRATIONS (mg/l)
EXPECTED LOADING

Reach	Natural	Area VIII	Areas VIII & X	Areas VII & VIII	Areas VII, VIII, & X
1	446	441	435	424	419
5	973	944	933	909	898
8	3,789	2,829	2,449	1,669	1,288
9	3,279	2,426	2,103	1,420	1,092

EPA limit of 500 mg/l; shaded numbers exceed allowable limit.
Source: U.S. Army Corps of Engineers, Tulsa District

TABLE 3-6
WEIGHTED AVERAGE CL CONCENTRATIONS (mg/l)
EXPECTED LOADING

Reach	Natural	Area VIII	Areas VIII & X	Areas VII & VIII	Areas VII, VIII, & X
1	120	116	115	110	109
5	338	323	319	307	303
8	1,603	1,143	1,013	636	506
9	1,349	914	793	440	319

EPA limit of 250 mg/l; shaded numbers exceed allowable limit.
Source: U.S. Army Corps of Engineers, Tulsa District

TABLE 3-7
WEIGHTED AVERAGE SO_4 CONCENTRATIONS (mg/l)
EXPECTED LOADING

Reach	Natural	Area VIII	Areas VIII & X	Areas VII & VIII	Areas VII, VIII, & X
1	86	85	84	83	82
5	221	218	215	213	209
8	612	512	419	344	249
9	734	640	550	481	391

EPA limit of 250 mg/l; shaded numbers exceed allowable limit.
Source: U.S, Army Corps of Engineers, Tulsa District

Several facts are apparent from the revised concentration-duration curve data. There is minimal improvement in water quality in and downstream of Lake Texoma from any of the proposed plans. The most comprehensive plan ("Plan 7, 8, & 10") offers only a 7.7% reduction in the anticipated TDS loads at Lake Texoma. The TDS levels in Lake Texoma will exceed allowable limits 99% of the time, the chloride levels will exceed allowable limits between 50 and 80% of the time, and the sulfate levels will exceed allowable limits between 20% and 50% of the time. Demineralization treatment or significant blending with a better quality source will still be required to utilize water from Lake Texoma.

Farther upstream, the Wichita River at Wichita Falls (Reach 8) will exceed allowable TDS limits between 90 and 99% of the time. Chloride levels will be exceeded between 90 and 99% of the time, and sulfate levels will be exceeded between 50 and 95% of the time. This indicates that the water in the Wichita River will require demineralization at least 90% of the time under any of the proposed plan to reduce the TDS, Cl, and SO_4 to acceptable limits. The revised curves for Reach 9 (Lake Kemp/Lake Diversion) indicate reduced water quality over those expected in Reach 8. Total dissolved solids, chlorides, and sulfates will require demineralization at least 95% of the time. The project will increase the blendable quantities of water in Lake Kemp/Lake Diversion over the current natural conditions.

EXISTING AND POTENTIAL WATER SUPPLY SOURCES

Reach 1: Shreveport/Bossier City, Louisiana

Reach 1 includes the parishes of Avoyelles, Rapides, Natchitoches, Red River, Bossier, Grant, and Caddo in Louisiana. Only the Shreveport/Bossier City (Caddo and Bossier parishes) areas are included in this Wichita River Basin Reevaluation. These cities utilize a combination of ground and surface water for their water supplies. Figure 3-3 details the features of this reach.

Existing Water Supplies. Caddo Lake straddles the State line between Texas and Louisiana in the Cypress River Basin approximately 20 miles northwest of Shreveport, Louisiana. Caddo Lake has excellent quality water with a dependable yield of 99.5 mgd; however; use of the water is regulated under the *Red River Compact*. The city of Shreveport currently uses water from Caddo Lake that overflows into Twelve-Mile Bayou. The city has pumps in place to transfer water from Caddo Lake into Twelve-Mile Bayou during low water

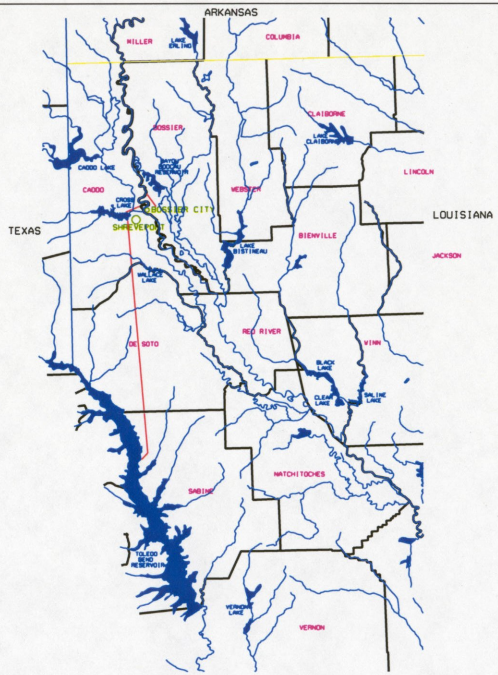


FIGURE 3-3
SHREVEPORT / BOSSIER CITY
WATER SOURCES AND TRANSPORTATION SYSTEMS

periods; however; these pumps have never been used. Caddo Lake is located in an environmentally sensitive natural area that all but precludes it from further development as a significant water supply. Caddo Lake is the only naturally occurring lake in the State of Texas; all other lakes in the State are man-made.

Twelve-Mile Bayou is a low flow stream downstream of Caddo Lake. The reported dependable yield is 5.1 mgd. The city of Shreveport pumps ±10 mgd from the Bayou into Cross Lake. The Bayou receives natural overflow from Caddo Lake during normal periods to supplement its yield. Completion of Lock and Dam No. 5 on the Red River in 1996 raised the river pool 5 feet above the low head structure on Twelve-Mile Bayou. This has led to a reported decrease in water quality in Twelve-Mile Bayou.

Cross Lake is the third major supply for the city of Shreveport. The lake has a dependable yield of 33.0 mgd. The lake is owned by the city of Shreveport, which utilizes the entire available yield. The lake has good quality water.

Groundwater sources for the Shreveport/Bossier City area are of poor quality or limited quantity and therefore are not considered adequate potential sources.

Bossier City is currently using the Red River as a water supply source. The city pumps water from the Red River into a city reservoir (approximately 100 acres) and from the reservoir to the head of the treatment works. This has allowed the city to minimize the transfer of water from the river when water quality is poor.

Potential Water Supplies. There are no reservoirs proposed for construction in this portion of the study area. Three existing reservoirs are potential future water supplies for the region. Cypress Black Reservoir No. 1 is an agricultural water storage reservoir operated by the Bossier Recreation and Water Conservation District. The lake has a dependable yield of 13.8 mgd; however; only 2.1 mgd is available for municipal use and 11.7 mgd is allocated to agricultural uses. Reallocation of the agricultural allotment may be possible to meet the anticipated demands of Bossier City.

Cypress Black Reservoir No. 2 is another agricultural water storage reservoir operated by the Bossier Recreation and Water Conservation District. The lake has a limited dependable yield of 4.9 mgd, with 3.7 mgd allocated to agriculture and 1.2 mgd available for municipal use. The small overall yield makes this reservoir impractical as a possible water supply source.

Toledo Bend Reservoir, on the Texas/Louisiana border, is the fifth largest body of water in the United States based on surface area. The lake has a dependable yield of 1,851 mgd, which is equally shared by Texas and Louisiana. Approximately 81 mgd of the Louisiana portion remains unallocated. The lake is owned and operated by the Sabine River Authority (SRA). The water is of fairly good quality. The lake also provides a significant amount of hydroelectric power to the region. Water is available to transport to the Shreveport/Bossier City area.

Existing and potential water supply sources are listed in Table 3-8.

TABLE 3-8
EXISTING AND POTENTIAL WATER SUPPLY SOURCES: REACH 1

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
Caddo Lake	Shreveport	99.5	43.5	0.0	0.0 (a)
Cross Lake	Shreveport	33.0	33.0	33.0	0.0
Twelve Mile Bayou	Shreveport	5.1	5.1	10.0	0.0
Red River	Bossier City	860.0	430.0	9.5	0.0
Terrace (GW)	Bossier Parish	155.0	0.9	0.9	0.0
Carrizo Sand (GW)	Caddo Parish	5.1	0.0	0.0	0.0
Cypress-Black Reservoir No. 1	Bossier Parish	13.8	13.8 (b)	0.0	13.8
Cypress-Black Reservoir No. 2	Bossier Parish	4.9	4.9 (c)	0.0	4.9
Toledo Bend Reservoir	Desoto and Sabine Parishes	1,851	1,851	925.5	81.0

(a) Environmental concern will restrict possible use.
(b) Includes agricultural allocation of 11.7 mgd.
(c) Includes agricultural allocation of 3.7 mgd.

Reach 5-NTMWD: North Texas Municipal Water District (Collin County, Texas)

This reach (reach 4-TA1 in the Huitt-Zollars report) is comprised of Collin County and portions of Kaufman, Rockwall, and Dallas counties in north-central Texas. The general boundary of this reach is the area served by the NTMWD. The NTMWD provides wholesale water and wastewater service to numerous communities within its boundary. The cities of Plano, Richardson, Garland, Mesquite, and McKinney are a few of the larger municipalities receiving all or part of their service from the NTMWD. The main water treatment plant for NTMWD is located near Lake Lavon. The district receives it surface water supply from three primary sources. Figure 3-4 details the feature of this reach.

Existing Water Supplies. Lake Lavon is located on the East Fork of the Trinity River approximately 1 mile northwest of Lavon, Texas. The Corps of Engineers built Lake Lavon in 1953 for flood control and water supply. The lake has a dependable yield of 92.0 mgd. The entire yield is allocated and contracted to the NTMWD. The lake also receives up to 24.0 mgd of effluent from the Wilson Creek Wastewater Treatment Plant and is the receiving point for interbasin transfers of water from Lake Texoma and Lake Cooper. Facilities are in place to utilize the entire available yield of Lake Lavon.

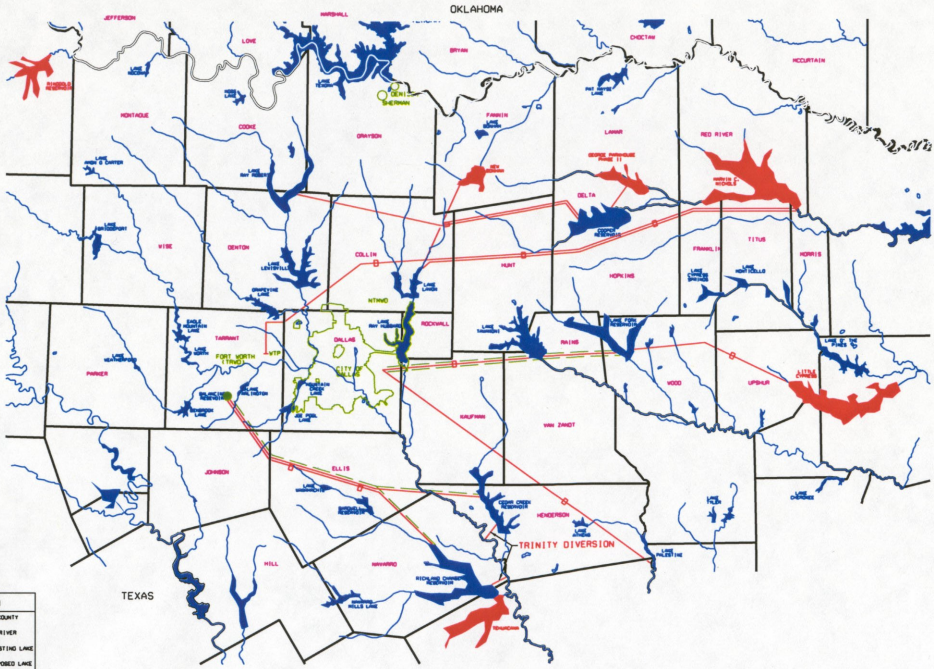


FIGURE 3-4

NORTH CENTRAL TEXAS
WATER SOURCES AND TRANSPORTATION SYSTEMS

Cooper Reservoir (aka Jim Chapman Lake) is a Corps of Engineers reservoir on the South Sulphur River completed in 1992. The reservoir has a dependable yield of ±107.1 mgd. Three entities share the allocated water rights; NTMWD - 39.5 mgd, the city of Irving - 39.5 mgd, and the Sulphur River Municipal Water District (SRMWD) - 28.1 mgd. Each entity is permitted to divert at a maximum rate of 122% of allocated yield. The SRMWD has contracted a portion of its yield to the Upper Trinity Regional Water District (UTRWD) for use in the Denton County, Texas, area. The NTMWD has facilities in place to transfer up to 110 mgd of water from Cooper Lake to Lake Lavon.

Lake Texoma on the Red River near Denison, Texas, is the third surface water source utilized by the NTMWD. Lake Texoma water is pumped and gravity flowed to Lake Lavon and blended for subsequent use. The NTMWD has contractual rights to divert up to 75.0 mgd of water from Lake Texoma. The blending of this water will be discussed in more detail in a later section.

Groundwater sources for the NTMWD area are of poor quality or limited quantity and therefore are not considered adequate potential sources.

Potential Water Supplies. There are no reservoirs proposed for construction in this reach. New Bonham Reservoir, George Parkhouse, and Marvin C. Nichols Reservoir are under consideration by the NTMWD as possible water supply sources outside the reach.

George Parkhouse Reservoir is a potential impoundment proposed for development on the Sulphur River immediately downstream from Cooper Reservoir. The reservoir is suited for two-stage development with an ultimate estimated combined yield of ±227.4 mgd. Stage I would be constructed on the South Sulphur River and have a yield of ±107.4 mgd. Stage II would be constructed on the North Sulphur River and have a yield of ±120.0 mgd. Several entities, including the NTMWD, have examined potential development of George Parkhouse I and II as a future source. George Parkhouse II was included in the 1997 State Water Plan's list of recommended projects; however; it has been omitted from the current State Water Plan[15].

New Bonham or Bois d'Arc Reservoir is proposed on Bois d'Arc Creek, a tributary of the Red River in Fannin County (Reach 4T). The estimated yield is 83.7 mgd. The reservoir is under consideration by both the NTMWD and the Red River Authority. This project is included in the *Water for Texas* list of recommended projects.

Marvin Nichols Reservoir is another potential two-stage impoundment on the Sulphur River and White Oak Creek in southwestern Bowie and Morris counties. Stage I will have an estimated yield of ±420 mgd (±557 mgd if Parkhouse is not developed), and Stage II will have an estimated yield of 263.2 mgd. The NTMWD, the TRWD, and the DWU are all evaluating the project as a potential future supply. Phase I of this project is included in the *Water for Texas – Summary of Regional Water Plans, February 2001*.

Existing and potential water supply sources are listed in Table 3-9.

[15] Texas Water Development Board, *Water For Texas*, Summary of Regional Water Plans, February 1, 2001, p. 8.

TABLE 3-9

EXISTING AND POTENTIAL WATER SUPPLY SOURCES - REACH 5-NTMWD

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
Lake Lavon	NTMWD	92.0	92.0	92.0	0.0
Lake Texoma (a)	NTMWD	150.0	150.0	75.0	0.0 (b)
Lake Cooper (c)	NTMWD	39.5	39.5	39.5	0.0
George Parkhouse II	Proposed	120.0	120.0	-	120.0
Marvin Nichols I	Proposed	420.0	120.0 (d)	-	120.0 (d)
New Bonham Reservoir	Proposed	89.7	89.7	-	89.7

(a) Available yield of Lake Texoma is 150.0 mgd allocated to each state (TX & OK). The NTMWD has contracted for 75.0 mgd.
(b) A total of 75 mgd is the maximum blendable quantity with existing supplies.
(c) Total yield of lake is 107.1 mgd of which 39.5 mgd is allocated to the NTMWD.
(d) Proposed available yield split between reaches.

Reach 5-GTUA and GRAY/DEN: Sherman/Denison, Texas, Area

Reach 5-GTUA and GRAY/DEN (reach 5-T in the Huitt-Zollars report) is made up of Grayson County, Texas, and bordered on the north by Lake Texoma. The cities of Sherman and Denison jointly make up the demand center for this reach. This reach includes the Greater Texoma Utilities Authority Service area and the remainder of Grayson County and Denison not served by the authority. This area is divided into two areas for water use and potential benefit calculations. Figure 3-4 also details this portion of the study area.

Existing Water Supplies. Lake Texoma is a Corps of Engineers lake completed in 1944. It is the largest impoundment within the Red River Basin. The primary purpose of the reservoir is flood control and power generation. The lake currently has 150.0 mgd allocated to each state (Texas and Oklahoma) for water supply purposes. Less than 5 mgd of the available Oklahoma water rights have been allocated. Approximately half of the Texas water rights have been allocated. Water quality within Lake Texoma is high in TDS and Cl^-. These levels exceed EPA drinking water limits on public water supplies; thus, water from the lake requires desalination treatment or blending prior to conventional water treatment for potable use.

The only reservoir other than Lake Texoma is Lake Randell, located northwest of Denison, Texas. The dependable yield is 4.7 mgd. The reservoir is primarily used to regulate diversions of water from Lake Texoma for treatment and use by the city. Due to the high TDS levels in the water, demineralization treatment is necessary.

Groundwater supplies in this reach are high in dissolved solids and are generally unsuitable for use. Many smaller communities still must use the groundwater due to the lack of any other suitable supplies.

The city of Sherman obtains approximately 60% of its water from wells. The other 40% is from Lake Texoma and is demineralized by EDR. The city of Denison obtains approximately 0.12 mgd of its 3.5-mgd average demand from wells. Denison also has the capacity to transfer 6.0 mgd from Lake Texoma to Lake Randell.

Potential Water Supplies. No reservoirs have been proposed, identified, or investigated for this reach.

Existing and potential water supply sources are listed in Table 3-10.

TABLE 3-10
EXISTING AND POTENTIAL WATER SUPPLY SOURCES: REACH 5-GTUA AND GRAY/DEN

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
Lake Texoma (a)	Sherman	150.0	75.0	10.0	65.0
Lake Randell	Denison	4.7	4.7	4.7	0.0
Groundwater	Sherman	(b)	0.0	0.0	0.0
Groundwater	Denison	(b)	0.0	0.0	0.0

(a) Available yield of Lake Texoma is 150.0 mgd allocated to each state. The NTMWD has contracted for 75.0 mgd which is blended into Lake Lavon. The city of Sherman has contracted for 10.0 mgd. The Lake Texoma water used by Sherman is treated using demineralization (EDR).
(b) Groundwater yield undetermined.

Reach 5-DAL: Dallas Water Utilities (including Denton County, Texas)

Reach 5-DAL (reach 5-TA1 in the Huitt-Zollars report) includes most of Dallas, Denton, and portions of Rockwall and Kaufman counties. For this study, the city of Dallas/Dallas Water Utilities (DWU) is the major demand center and wholesale service supplier to this reach. In actuality, several other wholesale water suppliers exist in this reach, including the city of Denton, the Upper Trinity Regional Water District (UTRWD), and the Trinity River Authority (TRA). This reach comprises the majority of the demands found within the entire study area. The cities of Dallas, Irving, Grand Prairie, Carrollton, and many others receive all or part of their water service from the DWU. This reach is supplied from six major existing reservoirs, with three other existing reservoirs awaiting connection and/or completion of their transportation systems. Figure 3-4 also details this portion of the study area.

Existing Water Supplies. Lake Lewisville is a Corps of Engineers reservoir constructed in 1955 for flood control, water supply, and recreation. It is located on the Elm Fork of the Trinity River approximately 6 miles east of Lewisville, Texas. The total dependable yield of the reservoir is approximately 168.9 mgd (including Ray Roberts), of which 144.8 mgd is allocated to DWU and 24.1 mgd to the city of Denton. Water from Lake Lewisville and Ray Roberts is

released into the Elm Fork of the Trinity River and withdrawn downstream by the DWU at both the Carrollton Dam and the Frasier Dam for diversion to the Elm Fork (300-mgd capacity) and the Bachman Lake (115 mgd) Water Treatment Plants (WTP).

Lake Ray Roberts is another impoundment on the Elm Fork of the Trinity River above Lake Lewisville. This Corps of Engineers reservoir was completed in 1987 for flood control, water supply, water quality, recreation, and fish and wildlife conservation. The yield of Ray Roberts is combined with that of Lake Lewisville for reporting purposes. As part of construction of Ray Roberts, the level in Lewisville was raised by 7 feet and some flood control storage was reallocated to Ray Roberts. Water in Ray Roberts flows by gravity to Lake Lewisville and continues on by gravity to the treatment plants. Existing facilities are in place to utilize the entire available yield from both reservoirs.

Lake Grapevine is a Corps of Engineers reservoir completed in 1952 for flood control, water supply, and recreation. The dam is located on Denton Creek, a tributary of the Elm Fork of the Trinity River approximately 2 miles northeast of Grapevine, Texas. The dependable yield of the reservoir is 19.3 mgd. Dallas Water Utilities, Grapevine, and the Park Cities Municipal Utility District all hold water rights in the reservoir. The reservoir is over-permitted well beyond its dependable yield. Diversions of 143.95 mgd are allocated.

Lake Ray Hubbard is owned by the city of Dallas and is located on the East Fork of the Trinity River approximately 2 miles upstream from U.S. Highway 80. The lake is directly downstream of Lake Lavon. The dependable yield of Lake Ray Hubbard is 54.1 mgd. All water rights are owned by the city of Dallas. Water from Ray Hubbard is pumped to the Eastside WTP (400-mgd capacity) for treatment. The reservoir can also be used for interim storage of water diverted from Lake Tawakoni. Facilities are in place to utilize all the available water from this reservoir.

Lake Tawakoni is located on the Sabine River approximately 50 miles east of Dallas, Texas. The lake was constructed for water supply purposes as a joint venture between the Sabine River Authority (SRA) and the city of Dallas. Dallas has the contractual rights to 162.6 mgd (±80%) of the reservoir's total yield of 204.3 mgd. The DWU has a 72-inch and an 84-inch pipeline in place from Lake Tawakoni to the Eastside Treatment Plant with a combined capacity of 275.0 mgd. Water from Lake Tawakoni can be temporarily stored in Lake Ray Hubbard when the water level in Lake Ray Hubbard is below elevation 432.0.

Lake Fork is an SRA impoundment with a dependable yield of 167.0 mgd on Lake Fork Creek approximately 5 miles west of Quitman, Texas. In 1981, the city of Dallas acquired the rights to utilize water previously allocated to the Texas Utilities Generating Company. The DWU acquired the rights to 74% of the dependable yield of Lake Fork with a 107.1-mgd diversion limitation. To date, the DWU has no facilities in place to utilize its portion of the yield. Preliminary design has been completed and right-of-way acquired for the pump station and pipeline to transport the yield to Lake Tawakoni for subsequent retransmission to the Eastside WTP. The contract between the DWU and the SRA will require renewal in 2014. The DWU anticipates this reservoir will be the next source added to their system and should be on-line by 2010.

Lake Palestine is another out of basin supply for the DWU. The lake is located on the Neches River, approximately 90 miles southeast of Dallas. The lake is owned and operated by the Upper Neches Municipal Water Authority. The DWU has contractual rights to divert up to 102.0 mgd to the Trinity River Basin. The current yield of the lake is approximately 193.6 mgd. The maximum authorized diversion rate for the DWU is 120.0 mgd. The DWU has no facilities in place to utilize Lake Palestine at this time. Planning studies and route selection have been completed. Preliminary design and right-of-way acquisition for the pipeline is ongoing.

Joe Pool Lake on the Mountain Creek tributary of the West Fork of the Trinity River was completed in 1986. The lake has a dependable yield of 14.2 mgd and was constructed for flood control, water supply, and recreation. The Corps of Engineers constructed the lake, with the TRA as the local sponsor. The water rights are contracted to the cities of Midlothian (39.2%), Duncanville (7.0%), Cedar Hill (43.2%), and Grand Prairie (10.6%). Only the city of Midlothian currently has facilities to utilize its available yield.

Lake Cooper (aka Jim Chapman Lake) is discussed under Reach 5-NTMWD.

Potential Water Supplies. There are no proposed or potential reservoirs within the immediate reach area. George Parkhouse II, Marvin C. Nichols I Reservoir, and Little Cypress Lake are under consideration as future sources behind Lake Fork and Lake Palestine for the DWU. George Parkhouse II and Marvin C. Nichols Reservoir(s) are discussed under Reach 5-NTMWD.

Little Cypress Lake is proposed on Little Cypress Bayou approximately 6 miles northwest of Marshall, Texas, in Harrison County. Two different potential reservoirs are proposed at this location. The first is a reservoir with an estimated yield of 115.0 mgd. Unlike all other proposed reservoirs in this study, Little Cypress Lake has been approved by the TNRCC, and a water rights permit has been issued to the Little Cypress Utility District. It is anticipated that the entire permitted portion of the yield will be needed within the Cypress River Basin. The second proposed reservoir at this site involves a modification of the project to increase the total yield to 232.7 mgd. The incremental 117.6 mgd and its associated cost have been studied by several entities as a potential future water supply source for Reach 5-DAL. This project is no longer included in the State Water Plan's list of recommended projects.

Existing and potential water supply sources are listed in Table 3-11.

TABLE 3-11
EXISTING AND POTENTIAL WATER SUPPLY SOURCES: REACH 5-DAL

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
Lakes Lewisville/ Ray Roberts	DWU, City of Denton	168.9	168.9	168.9	0.0
Grapevine Lake	DWU, Park Cities MUD, Grapevine	19.3	19.3	19.3	0.0
Lake Ray Hubbard	DWU	54.1	54.1	54.1	0.0
Lake Tawakoni	DWU, SRA	162.6	162.6	162.6	0.0
Lake Palestine	DWU	101.7	101.7	0.0	101.7
Lake Fork	DWU	107.0	107.0	0.0	107.0
Lake Joe Pool	DWU for others	14.2	14.2	14.2	0.0
Lake Cooper	DWU for others	107.1	67.6 (a)	67.6	67.6 (a)
George Parkhouse II	Proposed	120.0	120.0	-	120.0
Marvin C. Nichols I	Proposed	420.0	180.0 (b)	-	180.0 (b)
Little Cypress Reservoir	Proposed	233.0	117.6 (c)	-	117.6 (c)

(a) Available yield split between demand centers and/or reaches.
(b) Proposed yield split between DWU (180 mgd), NTMWD (120 mgd), and TRWD (120 mgd).
(c) Proposed yield split between DWU (117.6 mgd) and Little Cypress Utility District (115.0 mgd).

Reach 5-TRWD: Tarrant Regional Water District (Tarrant County, Texas)

Reach 5-TRWD (reach 5-TA2 in the Huitt Zollars report) is mainly comprised of Tarrant County, Texas. The Tarrant Regional Water District (TRWD) is the predominant wholesale supplier to the city of Fort Worth, the city of Arlington, the TRA, and many other municipalities within this reach. This reach has eight reservoirs in operation and planning documents on several more. Figure 3-4 also details this portion of the study area.

Existing Water Supplies. Lake Bridgeport is located on the West Fork of the Trinity River approximately 4 miles west of Bridgeport, Texas, in Wise County. The reservoir was completed in 1931 and is owned by and allocated to TCWCID No. 1. The reservoir is part of the "West Reservoir System" of the TCWCID. The dependable yield of the combined West Fork Reservoir System is 70.5 mgd. Water is released from Lake Bridgeport and flows by gravity to Eagle Mountain Lake in northern Tarrant County.

Eagle Mountain Lake, also on the West Fork of the Trinity River, is the second of three reservoirs in the West Fork Reservoir System. Eagle Mountain Lake is located approximately 14 miles northwest of Fort Worth, Texas, and was completed in 1932. The city of Fort Worth has their Eagle Mountain WTP (30-mgd capacity) at the reservoir. The remainder of the yield from

Eagle Mountain Lake and Lake Bridgeport is released for gravity flow downstream to Lake Worth. The dependable yield of the entire West Fork Reservoir System is 70.5 mgd.

Lake Worth is the third member of the West Fork Reservoir System. Built in 1914 by the city of Fort Worth, the lake has minimal yield of its own. Water is delivered to the reservoir from Lake Bridgeport and Eagle Mountain Lake and, in turn, delivered to the Fort Worth Holly WTP which has a capacity of 150 mgd.

Richland-Chambers Reservoir is the largest impoundment supplying Reach 5-TRWD. The reservoir is located on the Richland Creek and Chambers Creek tributaries of the Trinity River southeast of Corsicana, Texas. The reservoir was completed in 1987 by the TRWD, which holds the permit to the entire dependable yield of 187.5 mgd. Current pipeline facilities are in place to transport up to 150 mgd to the Rolling Hills WTP in southeast Fort Worth. It should be noted that this relatively new pipeline failed during a period of high demand during the summer 1998 drought causing widespread water supply shortages and a total ban on outdoor water use in Tarrant County for several weeks.

Cedar Creek Reservoir is the second largest impoundment in the TCWCID system. It is located on the Cedar Creek tributary of the Trinity River approximately 3 miles northeast of Trinidad, Texas. Construction was completed in 1966. The lake is owned, operated by, and allocated to the TRWD. The dependable yield of the reservoir is 138.4 mgd. Water from the reservoir is pumped via a pipeline over 90 miles to the Fort Worth Rolling Hills WTP. Additional deliveries are made from the pipeline to Lake Arlington, the city of Mansfield, and the TRA. Modifications to the pump stations since the 1980 report now allow the system to utilize the entire yield.

Lake Arlington is a small impoundment on the Village Creek tributary of the West Fork of the Trinity River in western Arlington. The dependable yield of the lake is only 4.3 mgd. The lake was completed in 1957. The city of Arlington's Pierce-Burch WTP with a capacity of 136 mgd is located on the lake. As mentioned above, the lake receives diversions from the Cedar Creek and Richland-Chambers pipeline systems.

Lake Benbrook is a Corps of Engineers reservoir on the Clear Fork of the Trinity River approximately 10 miles southwest of Fort Worth, Texas. The reservoir was constructed in 1950 for navigation. The dependable yield of the navigation storage is ±6.5 mgd. To date, the yield has not been needed for navigation and is under interim contracts for use as water supply. Facilities are in place to utilize the available yield.

Lake Weatherford is located on the Clear Fork of the Trinity River in Parker County approximately 7 miles west of the city of Weatherford, Texas. The dependable yield of this impoundment is only 1.5 mgd and is entirely permitted to the city of Weatherford. The Texas Water Development Board (TWDB) has a proposed project to pump up to 5 mgd from Lake Benbrook to Lake Weatherford to meet future demands in the Parker County area.

Potential Water Supplies. Two potential out of basin projects are proposed for supplying this reach. Tehuacana Reservoir is proposed for development by the TRWD on the

Tehuacana Creek tributary of the Trinity River. This proposed reservoir would be immediately south of the Richland-Chambers Reservoir. The proposed yield is 61.0 mgd. Due to the topography of the area, water can flow by gravity from Tehuacana to Richland-Chambers and then be pumped to the Rolling Hills WTP through a new pipeline system that would parallel the existing system. Extensive lignite coal deposits in the vicinity prevented Tehuacana's construction at the same time as the Richland-Chambers Reservoir. Due to the lignite deposits, Tehuacana cannot be constructed until 2035-2040 at the earliest.

The second potential water supply project for this reach is the Trinity River Diversion. This project has been selected as the first choice of the TRWD to expand their existing supply[16]. The project is a downstream indirect wastewater reuse project. The project proposes to divert return flows from the Trinity River into Cedar Creek and Richland-Chambers reservoirs. Estimates are for diversions of ±50.0 mgd for Richland-Chambers and ±15.6 mgd for Cedar Creek, resulting in a net gain to the TRWD system of ±65.6 mgd. The majority of the costs associated with this project involve increasing the transmission systems from each reservoir to accommodate the increased yield along with construction of the wetlands system. The Trinity River downstream of Dallas has a significant portion of its total flow comprised of treated wastewater. All wastewater plants in Dallas, Denton, Tarrant, and Collin counties discharge into the Trinity River watershed. While the total proposed diversion is less than return flows from the Fort Worth Village Creek WWTP, the project is strongly opposed by downstream water rights holders, including the city of Houston. The Trinity River Basin is over-allocated, and downstream users depend on the upstream return flows to fully develop the dependable yield in their reservoirs. As discussed in the wastewater reuse section of this report, the TNRCC has taken the tentative position that a water rights holder may not reclaim treated wastewater once it has been discharged into the waters of the state. In the interim, a pilot scale program continues to evaluate potential water quality issues and any undesirable effects from the reclaimed water.

Existing and potential water supply sources are listed in Table 3-12.

[16]Freese and Nichols, Inc. and Alan Plummer and Associates, Inc., *Regional Water Supply Plan, Tarrant County Water Control And Improvement District Number One*, 1990.

TABLE 3-12
EXISTING AND POTENTIAL WATER SUPPLY SOURCES: REACH 5-TRWD

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
West Fork System	TRWD	70.5	70.5	70.5	0.0
Richland-Chambers	TRWD	187.5	187.5	150.0	37.5
Cedar Creek	TRWD	138.4	138.4	138.4	0.0
Lake Arlington	Arlington	4.3	4.3	4.3	0.0
Lake Benbrook	TRWD	6.5	6.5	6.5	0.0
Tehuacana Reservoir	Proposed	61.0	61.0	0.0	61.0
Trinity River Diversion	Proposed	65.6	65.6	0.0	0.0 (a)
Marvin Nichols I	Proposed	420.0	120.0 (b)	0	120.0 (b)

(a) Over-allocation of the existing river yield may not allow diversion to occur.
(b) Available yield split between TRWD, DWU, and NTMWD.

Reach 8: Wichita Falls, Texas

Wichita, Archer, and Clay counties combine to form Reach 8 of the study area. The demand center and largest city within this area is Wichita Fall, Texas. While the Red River borders this reach to the north, this reach and its concentration-duration curves deal with the Wichita River watershed, a tributary to the Red River. Ten existing reservoirs and one potential project were evaluated in this reach. Figure 3-5 details this portion of the study area.

Existing Water Supplies. Lake Arrowhead is located approximately 13 miles southwest of Wichita Falls on the Little Wichita River. The reservoir is a significant part of Wichita Falls water supply with a dependable yield of 37.5 mgd. The water quality is considered excellent for this reach. All water is allocated to the city of Wichita Falls, and facilities are in place to utilize the yield.

Lake Kickapoo is located upstream of Lake Arrowhead on the North Fork of the Little Wichita River, approximately 10 miles northwest of Archer City, Texas. Wichita Falls owns, operates, and has the water rights permit to the reservoir. The dependable yield is 19.1 mgd. The water quality is also considered to be excellent for this region. Facilities are in place to utilize the available yield.

Lake Wichita is located on Holiday Creek on the southern edge of Wichita Falls. Municipal use of the lake was discontinued in the late 1940's when Lake Kickapoo became available. Water quality in the lake is unacceptable due to high TDS concentrations. The reported dependable yield of the reservoir is 0 mgd. The lake is an emergency supply to Wichita Falls.

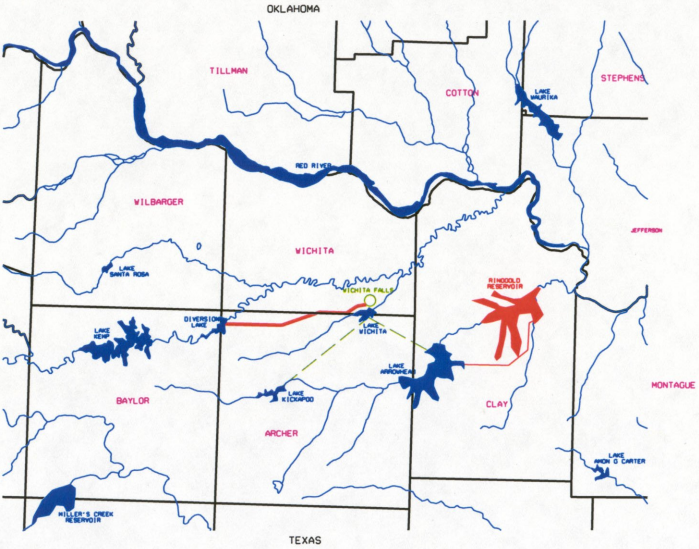


FIGURE 3-5
WICHITA FALLS AREA
WATER SOURCES AND TRANSPORTATION SYSTEMS

Lake Kemp is the largest reservoir in the Wichita Falls area. It has a dependable yield of ±103.0 mgd and allocated diversions total 172.3 mgd. The reservoir is located on the Wichita River approximately 6 miles north of Seymour, Texas, and is physically located inside Reach 9. The reservoir is jointly owned by the city of Wichita Falls and WCWID No. 2. The reservoir was constructed in 1922; however, the dam was reconstructed by the Corps of Engineers in 1974 to provide flood control storage in addition to the existing uses of irrigation, water supply, and recreation. Lake Kemp is operated in conjunction with Lake Diversion, which is downstream on the Wichita River. The water quality in the reservoir is poor (See Reach 9 Concentration-Duration curves). The water is used mainly for irrigation purposes. Yield and development of the Lake Kemp-Lake Diversion System is regulated under the *Red River Compact*.

Lake Diversion, approximately 20 miles downstream of Lake Kemp on the Wichita River, straddles the Archer/Baylor County line. The lake has no dependable yield of its own and acts as a distribution point for water from Lake Kemp. The Lake Kemp-Lake Diversion System supplies much of the irrigation water to Wichita, Archer, and Clay counties.

Existing and potential water supply sources are listed in Table 3-13.

TABLE 3-13
EXISTING AND POTENTIAL WATER SUPPLY SOURCES: REACH 8

Source	User	Total or Potential Yield (mgd)	Acceptable Source Yield (mgd)	Useable Quantity (mgd)	Additional Available to Transport (mgd)
Lake Arrowhead	Wichita Falls	37.5	37.5	37.5	0.0
Lake Kickapoo	Wichita Falls	19.1	19.1	19.1	0.0
Lake Wichita	Wichita Falls	0.0	0.0	0.0	0.0
Lake Kemp – Lake Diversion	Wichita Falls & WCWID #2	172.3	0.0	0.0	172.3
Lake Ringgold	Proposed	24.6	24.6	0.0	24.6

Potential Water Supplies. One potential project exists within this reach. Lake Ringgold is proposed on the Little Wichita River downstream of Lake Arrowhead. The estimated yield of the lake is ±24.6 mgd. The reservoir is under consideration by the city of Wichita Falls as a future supply source; however, the reservoir is not included in the *Water for Texas – Summary of Regional Water Plans, February 2001* list of recommended projects.

TRANSPORTATION COSTS FOR POTENTIAL WATER SUPPLY SOURCES

Current cost indices were used to update many of the facility costs. These values are listed in Appendix C in the Huitt-Zollars report. The significant exceptions were pipeline costs and power costs. Current material cost data and installation cost data were obtained for all pipeline sizes. In all cases, the revised installed cost of the pipelines increased by more than if the values had simply been factored. Current power costs have also been incorporated to reflect

actual anticipated operating conditions. In the final derivation of project benefits, costs were updated to November 2001 values.

Reach 1: Shreveport/Bossier City, Louisiana

Transportation costs for two potential water supply sources will be evaluated for this reach. The potential sources are Toledo Bend Reservoir and Cypress Black Reservoir No.1.

Toledo Bend Reservoir, with a dependable yield of 1,817 mgd, is capable of supplying all the anticipated future demand for the Shreveport and Bossier City areas. For this analysis, only 50 mgd will be transported to Shreveport. The required pipeline from Toledo Bend to Shreveport would be approximately 56.5 miles. Table 3-14 summarizes the anticipated source and transportation costs for this project.

TABLE 3-14
ALTERNATE SOURCE COSTS
($ per 1,000 Gallons; January 2001 Cost Basis)

Reach	Source	Demand Center	Qty. (mgd)	Source Cost	Trans. Costs	Total Costs
1	Toledo Bend Reservoir	Shreveport	50.0	$0.060	$1.137	$1.197
	Cypress Black Bayou No. 1	Bossier City	13.8	$0.060	$0.403	$0.463
5-NTMWD	New Bonham Reservoir*	NTMWD	83.7	$0.289	$0.487	$0.776
	George Parkhouse II*		120.0	$0.446	$0.220	$0.666
	Marvin Nichols Reservoir I*		120.0	$0.220	$0.760	$0.980
5-DAL	Lake Fork	DWU	107.0	$0.000	$1.064	$1.064
	Lake Palestine		101.7	$0.000	$1.352	$1.352
	Cooper Reservoir		67.6	$0.063	$1.338	$1.401
	Little Cypress Reservoir*		117.6	$0.261	$1.542	$1.803
	George Parkhouse II*		100.0	$0.446	$1.413	$1.859
	Marvin Nichols Reservoir I*		180.0	$0.220	$0.907	$1.127
5-TRWD	Richland-Chambers Reservoir	TRWD	37.5	$0.000	$0.231	$0.231
	Tehuacana Reservoir* (Post 2035)		61.0	$0.656	$1.541	$2.197
	Trinity River Diversion		65.6	$0.083	$1.292	$1.375
	Marvin Nichols Reservoir I*		120.0	$0.220	$1.284	$1.504
8	Ringgold Reservoir*	Wichita Falls	24.6	$1.117	$0.656	$1.773
* Proposed New Impoundment						

Cypress Black Reservoir No. 1, with a dependable yield of 13.8 mgd, will be transported to Bossier City, Louisiana. The reservoir is located northwest of Bossier City and will require approximately 9.9 miles of pipeline to reach the city. For this analysis, the entire 13.8 mgd will be transported. It should be noted that this use would require reallocation of existing agricultural water rights and authorized uses for the reservoir. This project is presented as an option for a potential water supply and is not intended to imply that any reallocation has been authorized. Table 3-14 summarizes the anticipated source and transportation costs for this project.

Reach 5-NTMWD: North Texas Municipal Water District (NTMWD)

Transportation costs for three potential water supply sources will be evaluated for this reach - New Bonham Reservoir, George Parkhouse II, and Marvin Nichols I Reservoir.

Water from the proposed New Bonham Reservoir will require approximately 27.5 miles of pipeline to reach the headwaters of Lake Lavon. The entire yield of 89.7 mgd will be transported to Lake Lavon for use by the NTMWD. Table 3-14 summarizes the anticipated source and transportation costs for this project.

George Parkhouse II Reservoir is proposed on the North Sulphur River downstream of Lake Cooper. It is anticipated that development costs for George Parkhouse II would be shared by the NTMWD and local interests. For this analysis, it is anticipated that the water from George Parkhouse II will be pumped to Lake Cooper for subsequent retransmission on to Lake Lavon (for NTMWD) or Lake Ray Roberts (for DWU). The entire yield of 120.0 mgd will be costed for both the NTMWD and the DWU. This project would most likely involve constructing a parallel pipeline from Lake Cooper to Lake Lavon. The 2001 *Water for Texas* Plan no longer includes this reservoir.

Marvin Nichols I Reservoir is proposed to have a dependable yield of ±420 mgd. This reservoir alone could meet most of the future water needs of north and northeast Texas. Serious environmental issues may be raised since the project is anticipated to submerge over 36,000 acres of bottomland hardwood forest while inundating over 68,000 total acres. The cost to develop the reservoir and transportation systems will approach $1 billion[17]. At this time, the project appears too large to finance even for a joint effort between the NTMWD, DWU, and TRWD. Significant State or Federal assistance would be needed to allow for construction of this project. For this analysis, 120 mgd will be transported to NTMWD, 180 mgd to DWU, and 120 mgd to TRWD.

One additional scenario has re-emerged from earlier RRCCP studies. Sardis Lake and Lake Hugo in Oklahoma are again being evaluated as potential water supply sources for both NTMWD and TRWD. While once considered politically impossible, legislative inroads in Oklahoma and the need to develop additional supplies in Texas have led to further discussions on the possible inter-state transfer of water. No transportation costs have been developed for this study due to the uncertainty of the availability; however, the *2001 Water for Texas* plan does include conveyance systems for the Oklahoma water to both NTMWD and TRWD.

Reach 5-GTUA and GRAY/DEN: Sherman/Denison, Texas

No proposed alternative water supply sources have been identified for this reach.

[17] Jack Z. Smith, "The Future of Water", *Fort Worth Star Telegram*, August 8, 1998.

Reach 5-DWU: Dallas Water Utilities (DWU) including Denton County, Texas

Five alternative water supply sources have been evaluated for the DWU system. The sources are Lake Palestine, Lake Fork, Lake Cooper, Little Cypress, George Parkhouse II Reservoir, and Marvin Nichols I Reservoir.

Lake Fork has been identified by the DWU as its next water supply source to be brought on-line. The source costs for this reservoir have previously been included in the DWU water rate structure, thus no source costs are attributed in this study (i.e., The reservoir costs are incurred regardless of whether the water is ever used). The intake structure, pump station, and pipeline have been designed to transport the water 21.9 miles to Lake Tawakoni for subsequent re-transmission on to the DWU Eastside WTP.

Lake Palestine will be the second new source brought into the DWU system. It will require approximately 81.2 miles of pipeline with one booster station to deliver the 101.7 mgd to the Southeast WTP. As with Lake Fork, DWU has previously included the source costs for Lake Palestine in their water rate structure since they have contracted for the water. No additional source costs will be added for this analysis.

Lake Cooper (aka Jim Chapman Lake) is another potential water source for the DWU demand center. The city of Irving and the Upper Trinity Regional Water District (UTRWD) have contracted for a combined 67.6 mgd from Lake Cooper (39.5 mgd for Irving, 28.1 mgd for UTRWD). The NTMWD currently has a pipeline from Lake Cooper to Lake Lavon with interim capacity to transport this water until George Parkhouse or Marvin Nichols is built. The most likely scenario would be to extend the existing pipeline on to Lake Ray Roberts. This would provide additional water for the UTRWD treatment plant at Lake Ray Roberts and allow Irving to gravity flow down the Trinity to either the DWU Elm Fork Treatment Plant or construct its own treatment plant.

Little Cypress Reservoir is a potential impoundment near Marshall, Texas. A 63-mile-long pipeline would be needed to transport the available 117.6 mgd of water to Lake Fork where the DWU system would then transport the water to Lake Tawakoni and eventually to the Eastside WTP.

The George Parkhouse II Reservoir and Marvin Nichols I Reservoir projects are discussed under the Reach 5-NTMWD analysis. Table 3-14 summarizes the transportation costs for the potential projects for this reach.

Reach 5-TRWD: Tarrant Regional Water District (Tarrant County, Texas)

Three potential projects have been evaluated for this reach. Tehuacana Reservoir, a diversion of return flows from the Trinity River, and Marvin Nichols I Reservoir are being considered by the TRWD.

The Tehuacana project would be constructed adjacent to the Richland-Chambers Reservoir. Water would be able to flow via gravity into the Richland-Chambers Reservoir. Transportation

costs would primarily involve booster station improvements. Construction of this reservoir cannot begin until after 2040 due to extensive deposits of lignite coal under the proposed reservoir. The LRR[18] estimated the 1992 value of the coal lignite to be in excess of $500 million. This project is included in the State Water Plan's list of recommended projects; however; transportation costs for this system are summarized in Table 3-14.

The second project under consideration is the Trinity River Diversion. This indirect reuse project has been discussed in several other portions of this report. The State Water Plan includes this project in the list of recommended projects; however; the plan also indicates this project may not be feasible. The third project is Marvin Nichols I Reservoir, which is discussed under Reach 5-NTMWD. Transportation costs for these projects are shown in Table 3-14.

Reach 8: Wichita Falls, Texas

Although Wichita Falls is in Reach 8, in this evaluation, Wichita Falls is expected to obtain future water supplies from Lake Kemp in reach 9. One alternative water supply source has been examined for this reach. Lake Ringgold is proposed for construction downstream of Lake Arrowhead on the Little Wichita River. The reservoir is expected to have excellent water quality with a dependable yield of ±24.6 mgd. The lake would require ±27 miles of pipeline to reach the mixing reservoir for the city of Wichita Falls. This project is no longer included in the State Water Plan's list of recommended projects. Transportation costs for this system are summarized in Table 3-14.

Comparison to the State Water Plan

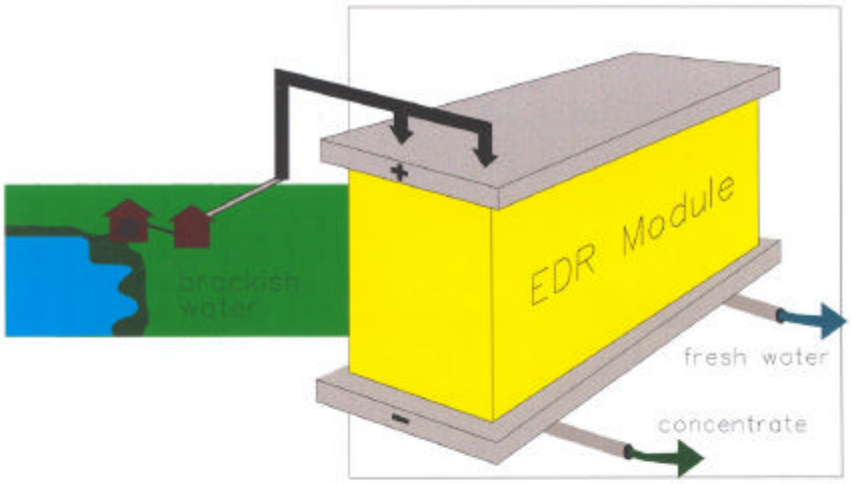
The alternate source costs listed in the State Water Plan differ from those listed in Table 3-14. In most cases, the State Water Plan numbers are somewhat lower. Several factors contribute to the variances, including amortization periods, interest rates, quantities being transported, and variances in estimated pipeline lengths. Another factor is that in the State Water Plan, many values represent dual pipeline systems. The State costs are based on 1999 cost data, and pipeline construction costs have risen in the last few years. The methodology used in this report is somewhat more conservative on facility costs and avoids the large contingencies used in the State Water Plan values. Regardless of which methodology proves to eventually be more accurate, since all transportation and source costs are calculated on the same basis in this report, any incremental cost savings between alternative sources would remain relatively unchanged.

TREATMENT METHODS AND COSTS[19]

Desalination is a treatment process to reduce the concentration of salts and minerals in a solution. Conventional water treatment alone is not capable of removing some dissolved solids, which includes chlorides and sulfates, from the raw feed water. Two membrane processes are

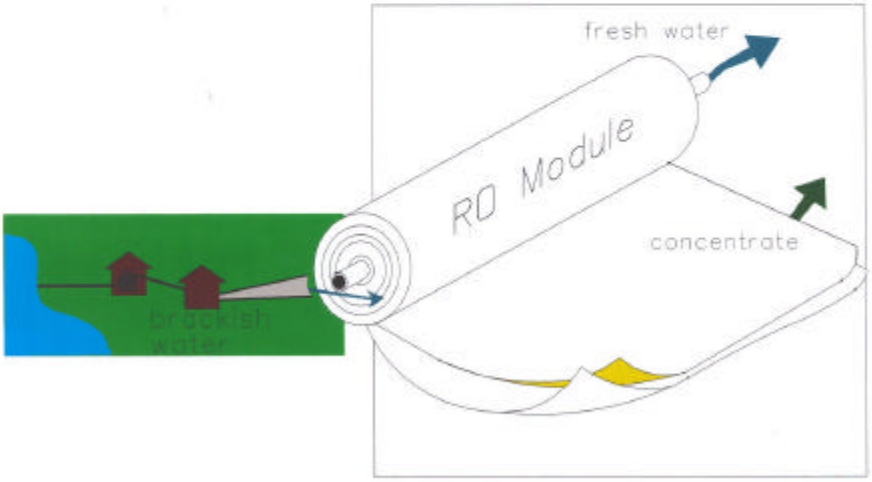
[18] Department of the Army, Tulsa District Corps of Engineers, "*Limited Reevaluation Report*", June 1993, p. II-142.
[19] Department of the Army, Tulsa District Corps of Engineers, "Red River Chloride Control Project – Supplemental Assessment Report", February 1997.

commonly used to remove or reduce these components, reverse osmosis (RO) and electrodialysis reversal (EDR). Figure 3-6 details these two processes.



Electrodialysis Reversal (EDR)

In EDR, impurities are electrically removed from the water. A DC current transfers ions through the membranes, resulting in desalted fresh water and a more concentrated mineral stream. By reversing polarity two to four times per hour, the system provides constant, automatic self-cleaning that enables improved efficiency in operation and less downtime for periodic cleaning.



Reverse Osmosis (RO)

In RO, the water is forced through a membrane under pressure. Purified water filters through the membrane while the impurities remain behind and are collected in a concentrated mineral stream.

FIGURE 6

Figure 3-6. Conventional Surface Water Treatment and EDR Water Treatment Flow Diagrams.

Reverse osmosis is the most effective membrane desalination process. This process utilizes high pressures to reverse the natural osmotic process and force clean water from a source solution through a semi-permeable membrane leaving a concentrated brine solution (concentrate) on one side and clean water (permeate) on the other. Modern advances in membrane materials have allowed the membranes to become highly efficient at rejecting contaminants and more durable to high pressures, with units now capable of removing over 90% of TDS, including chlorides and sulfates, from the feed water during each pass. Reverse osmosis treatment is also able to remove bacteria, organics, and dissolved silica from the feed water. Health contaminants, including arsenic, asbestos, lead, mercury, and radium, can also be removed in the RO process.[20] For each pass through an RO unit, 20-30% of the total water input is wasted to the concentrated brine discharge stream. Reverse osmosis units are capable of demineralizing feedwater with TDS concentrations of up to 45,000 mg/l (seawater).

Electrodialysis reversal is an electrochemical separation process that uses a direct electrical current to transfer ions through membranes from a less concentrated to a more concentrated solution. The current is reversed at set intervals (3-4 times per hour) to minimize scaling and fouling of the membranes. The stacks are comprised of thousands of alternating layers of anion and cation membranes. The membranes are resistant to pH changes and are impermeable to water under pressure. Electrodialysis reversal is typically a low-pressure process that can recover 85-90% of the feed water. Salt removal from a given volume of water is directly proportional to the current and inversely proportional to the flow rate through each stage.[21] Electrodialysis reversal units' average removal of 50% of the salts in the feed water per stage, with higher purity achieved by increasing the number of EDR stages. The EDR process does not remove bacteria, organic, dissolved silica, or uncharged particles from the feed water. Electrodialysis reversal is typically used on raw water with a TDS concentration of 2,000 mg/l or less. For each pass through an EDR unit, 10-20% of the total feed water is lost to the concentrated brine discharge stream.

Cost data for these treatment processes was analyzed in a 1992 study of U.S. desalination plants[22]. The study contains detailed cost data for 73 operating desalination plants (43 RO plants, 15 EDR plants, 7 membrane-softening plants, and 8 seawater RO plants). Two notable findings from the study were:

1. Only 146 mgd of water is produced by desalination for potable use. This figure does not include the 72-mgd Yuma Desalting Plant operated by the Bureau of Reclamation to treat agricultural runoff.

2. The median selling price of potable water from desalination is ±$2.00/1,000 gallons from plants with a capacity of 3 mgd or more.

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[20]Water Quality Research Council, *What Is...Reverse Osmosis*, Water Review Technical Brief, Volume 10, No. 3, 1995.
[21]Floyd H. Meller, ed., *Electrodialysis (ED) & Electrodialysis Reversal (EDR) Technology* (Watertown, MA: Ionics, Incorporated, 1984), pp. 42.
[22] Leitner, W., "*Potable Water Desalination in the U.S.: Capital Costs, Operating Costs and Water Selling Prices*," National Water Supply Improvement Association, 1992.

The 1992 study indicated that there were at least 169 desalination plants in operation in the U.S, of which 124 utilized RO and only 16 utilized the EDR process. The largest number of desalination plants is located in Florida, followed by the U.S. Virgin Islands, Texas, and California. Furthermore, the data indicate that there are only ±32 plants (19%) of the 169 total with a capacity of 1 mgd or greater and only 10 plants (6%) with a capacity of 3 mgd or greater. (Note: The study was performed prior to the Sherman, Texas, EDR plant becoming operational.)

The cost data indicated that the values used for RO and EDR costs in the SAR[23] may have been ±$0.40 per 1,000 gallons too low. Another apparent trend indicates that the vast majority of desalination plants currently in operation are much smaller than many of the proposed plants evaluated in previous RRCCP studies. The Bureau of Reclamation plant in Yuma, Arizona, is the only operational U.S. facility with a capacity in excess of 15 mgd. In the previous RRCCP studies, only Reach 5-GTUA (5T) was projected for facilities in the conventional 5-10 mgd range. All other reaches were evaluated with considerably larger plants. Given the magnitude of the estimated capital costs for desalination plants in the 25-75 mgd range, along with the ongoing maintenance and brine disposal costs, construction of these large plants is unlikely.

Current Desalination Applications in the Red River Basin

Greater Texoma Utility Authority. The city of Sherman, Texas, operates a 10-mgd surface water treatment plant with demineralization capabilities to utilize water from Lake Texoma. Construction of the plant was financed by the Greater Texoma Utility Authority (GTUA). The plant was placed in operation in May 1993 and has received considerable publicity, including a segment on the NBC Nightly News "Fleecing of America" series on August 20, 1996, as an economical alternative to completion of the RRCCP.

The treatment plant receives raw water from Lake Texoma (±15 miles away) which undergoes conventional surface water treatment (coagulation, flocculation, and filtration) prior to demineralization. After filtration, a portion of the total flow (40-90%) is pumped to the EDR system for removal of dissolved solids. The plant has four EDR units manufactured by Ionics, Inc. Each unit has a capacity of 1.5 mgd (total of 6.0 mgd) and has two stages, with space available for the possible addition of a third stage in the future.

It should be noted that while the treated water quality for the Sherman water treatment plant meets all State of Texas criteria and standards, the treated water *does not* meet the Secondary Water Quality Limits for drinking water established by the EPA. The basis of all Red River Chloride Control studies to date has been to deliver water that would meet the EPA limits 98% of the time.

Brine from the EDR process units is diverted to a holding pond. The holding pond then discharges by gravity to the city sanitary sewer system. This results in an additional sanitary sewer flow of between 300,000 and 700,000 gallons per day. While the water plant does not incur direct costs to have the brine flow treated, the entire city must absorb the additional

[23] U.S. Army Corps of Engineers, Tulsa District, *"Red River Chloride Control Project Supplemental Assessment Report*", February 1997.

wastewater treatment costs and loss of capacity at the wastewater treatment plant. The city of Sherman attempted to discharge brine effluent to a local stream but withdrew its permit application due to strong opposition from downstream property owners. The current method of discharging brine from holding ponds through the city wastewater treatment facility to dilute the brine concentration avoids the necessity for TNRCC permitting and reduces potential impacts to the receiving stream.

The entire cost of the Sherman, Texas, WTP project was approximately $19.1 million. Of this, ±$14.9 million is associated with the conventional treatment plant and ±$4.2 million was for the EDR equipment and building. Addition of the fourth EDR unit cost an additional $1.0 million. The original EDR building was constructed with space for the fourth unit. The city estimated the EDR treatment costs[24] to be an additional $0.58 to $0.71 per 1,000 gallons above conventional treatment costs prior to the addition of the fourth EDR unit. Ionics, Inc., estimates the additional capital costs to add a third stage to the existing four units for improved water quality at ±$700,000.

The city of Seymour is constructing an RO plant to reduce sulfates, chlorides, nitrates, and hardness in their well water. The city evaluated the possibility of treating water from Lake Kemp but determined its cost to be approximately twice that of treating existing well water supplies[25]. The city of Seymour estimated the cost of treating Lake Kemp water at $2.00 per 1,000 gallons.

West Texas Utilities. West Texas Utilities is another consumer of Red River water using desalinization facilities. The Oklaunion Power Plant has a contract to divert up to 20,000 acre-feet per year (17.9 mgd) of water from Lake Kemp and Lake Diversion. Of this total diversion, the plant has a 0.29-mgd RO facility to treat boiler make-up water. The plant currently operates at an average flow of 0.08 mgd. The RO plant utilizes approximately $75,000 per year in chemicals and other consumable items. Labor, maintenance, and power costs for the RO plant account for an additional $250,000 per year of expense.

The majority of the diverted water is used for make-up water in the plant's cooling towers. The current average is approximately 7 mgd. Due to the high mineral content and conductivity of the water, the facility must treat the water with flocculent, add scale inhibitors, and treat with microbial inhibitors. The plant annually spends approximately $500,000 on chemicals for these processes. The plant manager indicates that the chemical usage is significantly reduced after heavy rains when the water quality from Lake Diversion is "improved". This usage forms the basis for the plant managers' estimated savings[26] of $100,000 per year from improved water quality in the basin.

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[24]Information in an August 29, 1996, letter to Jim Sullivan, Tulsa District, Corps of Engineers from Jerry Chapman of the Greater Texoma Utility Authority

[25] Information in a September 14, 1998, letter to Jim Sullivan, Tulsa District Corps of Engineers from Ken Martin, P.E. with Jacobs & Martin, Inc. Consulting Engineers.

[26] Information in an October 23, 1999 letter to Jim Sullivan, Tulsa District Corps of Engineers from Mark Burton, West Texas Utilities Company, Oklaunion Power Station Plant Manager.

Estimated Treatment Costs

Past studies have used complex formulas for equipment and treatment costs that were developed in the 1960's and indexed to provide current values. Improvements in technology along with tougher environmental regulations make these old formulas unreliable. For this study, we have developed new formulas to calculate the approximate treatment costs for both RO and EDR plants. Capital equipment for the proposed plants is sized based on the 5% exceedance value from the concentration-duration curves. For this study, the EDR process is used to calculate the treatment costs for sources with TDS values of 2,000 mg/l or less. Reverse osmosis is used for TDS values over 2,000 mg/l. Appendix C in the Huitt-Zollars report details the formulas used for this analysis. Appendix D, also in the Huitt-Zollars report, contains the calculations for the treatment costs and damages for the municipal and industrial users in the study area. Figure 3-7 details the treatment processes involved in both conventional and EDR treatment of surface water. The basic components included in the treatment cost for this study include:

Capital Costs:

- Site Costs
- Desalination Equipment Costs
- Peripheral Facilities
- Construction Costs
- Conventional Pre- and Post-Treatment Facilities
- Brine Disposal Facilities

O&M Expenses

- Labor
- Chemicals
- Power
- Miscellaneous Maintenance
- Brine Disposal O&M
- Depreciation

Table(s) 3-15 through 3-19 summarize the estimated municipal costs for use of Red River water with and without desalination treatment. Tables 3-20 through 3-24 summarize the estimated industrial costs for the use of Red River water with and without desalination treatment.

Pipeline systems for Reaches 1 and 8 are indicated on Figure(s) 3-3 and 3-5, respectively. Pipeline systems for transportation of Red River water to the north-central Texas area are shown on Figure 3-8.

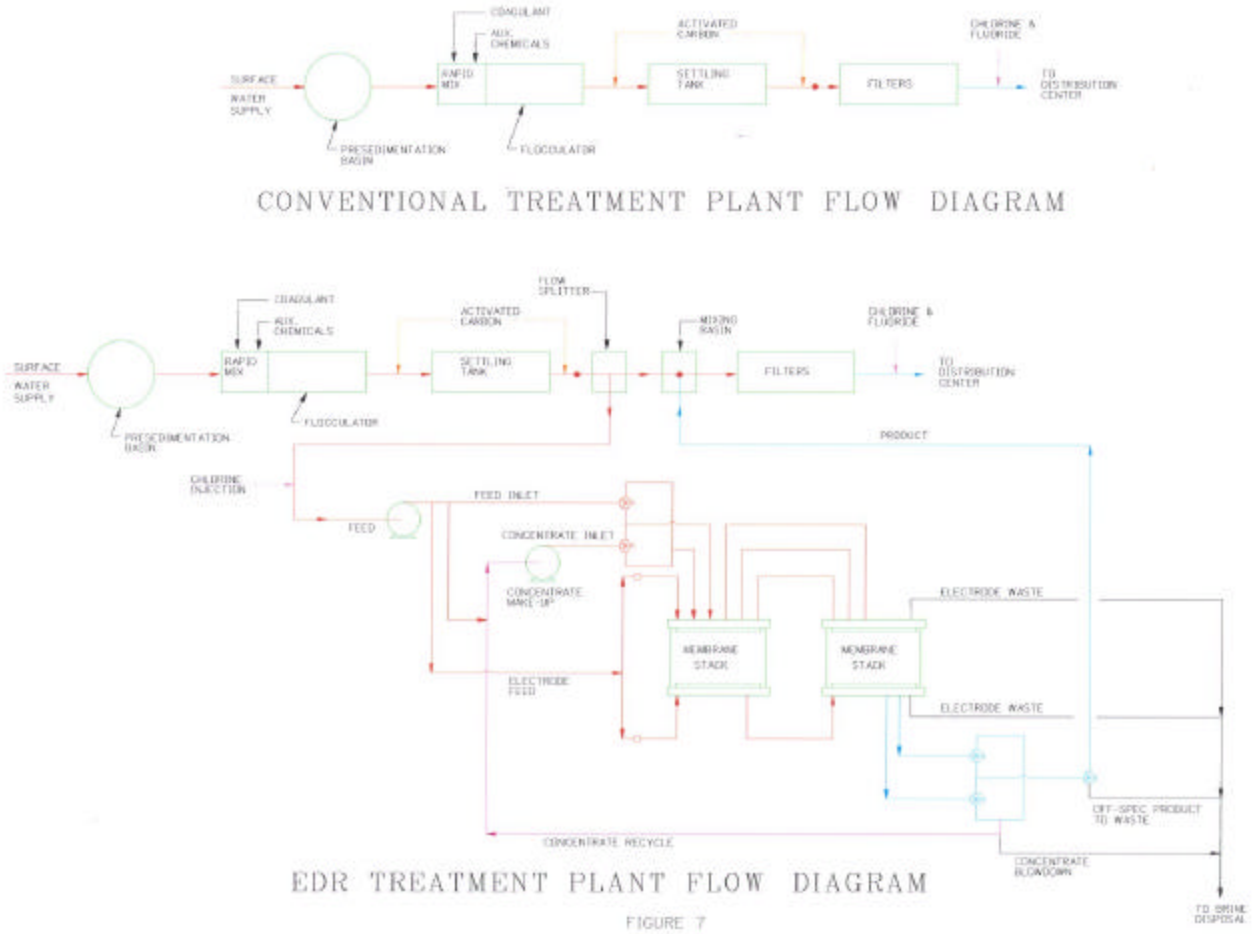


Figure 3-7. Reverse Osmosis and Electrodialysis Reversal Treatment Processes.

TABLE 3-15

MUNICIPAL COST OF RED RIVER WATER
NATURAL CONDITIONS
($ per 1,000 Gallons)

Reach	Demand Center	Alt. Source Threshold (mg/l)	Source Costs	Treatment Costs	Transport Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Bossier City, LA	200.0	$0.060	$1.691	$0.424	$0.280	$0.425	$2.455	$0.909
1	Shreveport, LA	200.0	$0.060	$1.623	$0.290	$0.280	$0.425	$2.253	$0.775
5	Sherman, TX (GTUA)	500.0	$0.060	$1.881	$0.070	$ -	$0.785	$2.011	$0.915
5	Denison, TX	500.0	$0.060	$1.932	$0.228	$ -	$0.785	$2.220	$1.072
5-NTMWD	NTMWD	200.0	$0.060	$1.771	$0.086	$0.495	$1.280	$2.413	$1.426
5-DAL-DAL	DWU	200.0	$0.060	$1.771	$0.579	$0.495	$1.280	$2.905	$1.919
5-TRWD-TRWD	TRWD	200.0	$0.060	$1.771	$1.314	$0.495	$1.280	$3.641	$2.654
8	Wichita Falls	315.0	$0.060	$2.823	$0.218	$0.306	$5.750	$3.407	$6.028
9	Wichita Falls	315.0	$0.060	$2.268	$0.775	$0.306	$4.906	$3.409	$5.740

TABLE 3-16

MUNICIPAL COST OF RED RIVER WATER
AREA VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Demand Center	Alt. Source Threshold (mg/l)	Source Costs	Treatment Costs	Transport Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Bossier City, LA	200.0	$0.060	$1.681	$0.424	$0.277	$0.418	$2.443	$0.902
1	Shreveport, LA	200.0	$0.060	$1.614	$0.290	$0.277	$0.418	$2.241	$0.768
5-GTUA	Sherman, TX (GTUA)	500.0	$0.060	$1.863	$0.070	$ -	$0.737	$1.993	$0.867
5-GRAY/DEN	Denison, TX	500.0	$0.060	$1.913	$0.228	$ -	$0.737	$2.201	$1.025
5-NTMWD	NTMWD	200.0	$0.060	$1.754	$0.086	$0.494	$1.231	$2.395	$1.378
5-DAL-DAL	DWU	200.0	$0.060	$1.754	$0.579	$0.494	$1.231	$2.887	$1.870
5-TRWD-TRWD	TRWD	200.0	$0.060	$1.754	$1.314	$0.494	$1.231	$3.622	$2.605
8	Wichita Falls	315.0	$0.060	$2.268	$0.218	$0.302	$4.160	$2.848	$4.438
9	Wichita Falls	315.0	$0.060	$2.212	$0.775	$0.306	$3.494	$3.353	$4.329

TABLE 3-17

COST OF RED RIVER WATER
AREAS VIII & X ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Demand Center	Alt. Source Threshold (mg/l)	Source Costs	Treatment Costs	Transport Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Bossier City, LA	200.0	$0.060	$1.671	$0.424	$0.274	$0.410	$2.429	$0.894
1	Shreveport, LA	200.0	$0.060	$1.604	$0.290	$0.274	$0.410	$2.228	$0.759
5-GTUA	Sherman, TX (GTUA)	500.0	$0.060	$1.856	$0.070	$ -	$0.718	$1.986	$0.849
5-GRAY/DEN	Denison, TX	500.0	$0.060	$1.906	$0.228	$ -	$0.718	$2.194	$1.006
5-NTMWD	NTMWD	200.0	$0.060	$1.747	$0.086	$0.494	$1.213	$2.387	$1.359
5-DALDAL	DWU	200.0	$0.060	$1.747	$0.579	$0.494	$1.213	$2.880	$1.851
5-TRWDTRWD	TRWD	200.0	$0.060	$1.747	$1.314	$0.494	$1.213	$3.615	$2.587
8	Wichita Falls	315.0	$0.060	$2.244	$0.218	$0.299	$3.532	$2.821	$3.810
9	Wichita Falls	315.0	$0.060	$2.179	$0.775	$0.306	$2.959	$3.320	$3.794

TABLE 3-18

COST OF RED RIVER WATER
AREAS VII & VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Demand Center	Alt. Source Threshold (mg/l)	Source Costs	Treatment Costs	Transport Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Bossier City, LA	200.0	$0.060	$1.652	$0.424	$0.268	$0.394	$2.405	$0.878
1	Shreveport, LA	200.0	$0.060	$1.585	$0.290	$0.268	$0.394	$2.203	$0.744
5	Sherman, TX (GTUA)	500.0	$0.060	$1.842	$0.070	$ -	$0.680	$1.972	$0.810
5	Denison, TX	500.0	$0.060	$1.891	$0.228	$ -	$0.680	$2.179	$0.968
5-NTMWD	NTMWD	200.0	$0.060	$1.733	$0.086	$0.494	$1.173	$2.373	$1.320
5-DAL-DAL	DWU	200.0	$0.060	$1.733	$0.579	$0.494	$1.173	$2.865	$1.812
5-TRWDTRWD	TRWD	200.0	$0.060	$1.733	$1.314	$0.494	$1.173	$3.600	$2.547
8	Wichita Falls	315.0	$0.060	$2.164	$0.218	$0.297	$2.244	$2.739	$2.522
9	Wichita Falls	315.0	$0.060	$2.051	$0.775	$0.306	$1.828	$3.192	$2.663

TABLE 3-19

COST OF RED RIVER WATER
AREAS VII, VIII & X CONDITIONS
($ per 1,000 Gallons)

Reach	Demand Center	Alt. Source Threshold (mg/l)	Source Costs	Treatment Costs	Transport Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Bossier City, LA	200.0	$0.060	$1.643	$0.424	$0.265	$0.386	$2.393	$0.870
1	Shreveport, LA	200.0	$0.060	$1.576	$0.290	$0.265	$0.386	$2.192	$0.736
5	Sherman, TX (GTUA)	500.0	$0.060	$1.835	$0.070	$-	$0.662	$1.965	$0.793
5	Denison, TX	500.0	$0.060	$1.884	$0.228	$-	$0.662	$2.172	$0.950
4T-A	NTMWD	200.0	$0.060	$1.726	$0.086	$0.493	$1.156	$2.366	$1.302
5-DAL	DWU	200.0	$0.060	$1.726	$0.579	$0.493	$1.156	$2.858	$1.794
5-TRWD	TRWD	200.0	$0.060	$1.726	$1.314	$0.493	$1.156	$3.593	$2.530
8	Wichita Falls	315.0	$0.060	$2.092	$0.218	$0.292	$1.616	$2.662	$1.894
9	Wichita Falls	315.0	$0.060	$1.953	$0.775	$0.306	$1.286	$3.095	$2.121

TABLE 3-20

INDUSTRIAL COST OF RED RIVER WATER
NATURAL CONDITIONS
($ per 1,000 Gallons)

Reach	Category	Threshold (mg/l)	Source Costs	Treatment Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Manufact	500.0	$ 0.060	$ 3.134	$ -	$ 0.044	$ 3.194	$ 0.104
5-NTMWD	Manufact	500.0	$ 0.060	$ 3.300	$ -	$ 0.237	$ 3.360	$ 0.297

TABLE 3-21

INDUSTRIAL COST OF RED RIVER WATER
AREA VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Category	Threshold (mg/l)	Source Costs	Treatment Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Manufact	500.0	$ 0.060	$ 3.125	$ -	$ 0.042	$ 3.185	$ 0.102
5-NTMWD	Manufact	500.0	$ 0.060	$ 3.284	$ -	$ 0.223	$ 3.344	$ 0.283

TABLE 3-22

INDUSTRIAL COST OF RED RIVER WATER
AREAS VIII & X ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Category	Threshold (mg/l)	Source Costs	Treatment Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	SIC 20	500.0	$ 0.060	$ 3.116	$ -	$ 0.041	$ 3.176	$ 0.101
5-NTMWD	SIC 20	500.0	$ 0.060	$ 3.278	$ -	$ 0.217	$ 3.338	$ 0.277

TABLE 3-23

INDUSTRIAL COST OF RED RIVER WATER
AREAS VII & VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Category	Threshold (mg/l)	Source Costs	Treatment Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Manufact	500.0	$ 0.060	$ 3.100	$ -	$ 0.038	$ 3.160	$ 0.098
5-NTMWD	Manufact	500.0	$ 0.060	$ 3.266	$ -	$ 0.205	$ 3.326	$ 0.265

TABLE 3-24

INDUSTRIAL COST OF RED RIVER WATER
AREAS VII, VIII, & X CONDITIONS
($ per 1,000 gallons)

Reach	Category	Threshold (mg/l)	Source Costs	Treatment Costs	Treated Damages	Untreated Damages	Treated Cost w/ Damages	Untreated Cost w/ Damages
1	Manufact	500.0	$ 0.060	$ 3.092	$ -	$ 0.036	$ 3.152	$ 0.096
5-NTMWD	Manufact	500.0	$ 0.060	$ 3.260	$ -	$ 0.200	$ 3.320	$ 0.260

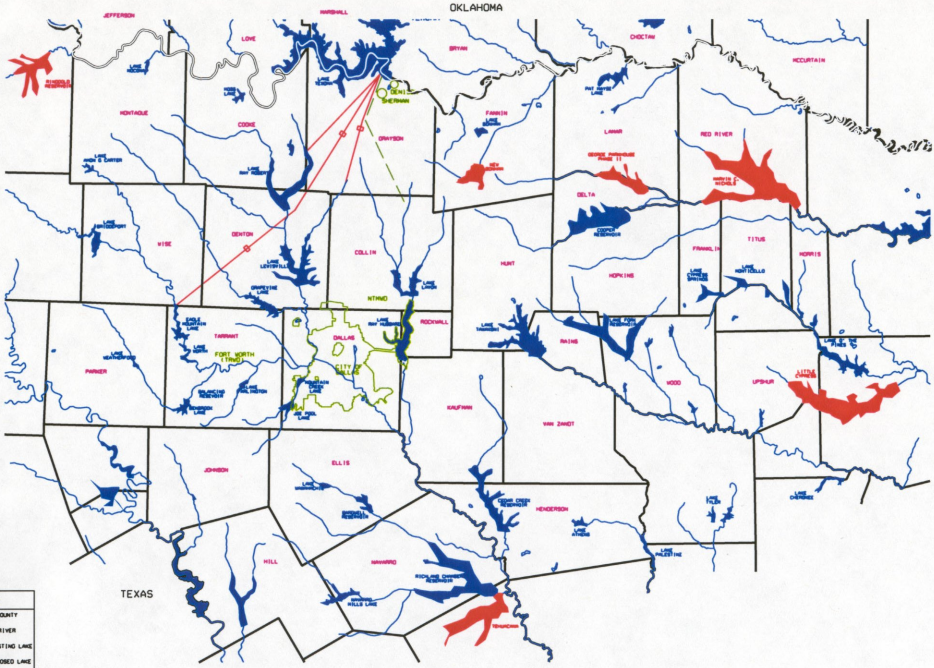


FIGURE 3-8
NORTH CENTRAL TEXAS
TRANSPORTATION OF RED RIVER WATER

BLENDING

Blending is the mixing of "good" quality water with "poorer" quality water to obtain a mixture of "acceptable" quality water. Blending is not a new concept to water treatment. It is best described as treatment through dilution. Blending of Red River water does not reduce or eliminate any of the total pounds of dissolved solids, chlorides, and sulfates introduced into a source. The apparent concentration of contaminates in the mixture is lower per gallon; however; the total gallons affected is much greater. The net effect is that a lower quantity of damages is distributed to the entire water system. Since no threshold has been identified below which damages will not occur, the damages will remain constant per gallon of Red River water used.

Many municipalities blend water from various lakes or groundwater formations. Blending does not eliminate any of the undesirable constituents of a water source; it dilutes them to acceptable levels. All the undesirable constituents are still present in the same quantity. Their apparent concentrations have been reduced. Damages resulting from the use of poor quality water are based on the unit of Red River water used, i.e., dollars per 1000 gallons per 100 mg/l of TDS added. As such, blendable water still has associated damages. The following example can illustrate this principle:

Blend 16.5 mgd of Supply "A" with TDS = 970 mg/l
100.0 mgd of Supply "B" with TDS = 200 mg/l
Alternate supply threshold = 200 mg/l

Result (100.0 mgd)(200 mg/l) + (16.5 mgd)(970 mg/l)
= (100.0+16.5 mgd) (TDS avg) 116.5 mgd of water with TDS avg = 309.06 mg/l

Damages from Supply "A"
(16,500,000 gal/day/1,000 gal)(970-200 mg/l)/100)*$0.1636/1,000 gal/100 mg/l TDS
Damages = $20,785

Damages from Blended Supply "A-B"
(116,500,000 gal/day/1,000 gal)(309.06-200 mg/l)/100)*$0.1636/1,000 gal/100 mg/l TDS
Damages = $20,786

The calculation of blendable quantities is a complex procedure involving analysis of water chemistry, environmental impacts, and reservoir inflows. For this analysis, a simplified procedure is used to calculate a safe blendable quantity that will maintain the TDS of the mixture at or below 500 mg/l at all times. A maximum blendable quantity will also be calculated that will maintain the average annual TDS at or below 500 mg/l.

A sample calculation of the safe blendable quantity and maximum drought quantity is shown below:

Formulas:

$Yield_1 * TDS_1 + Yield_2 * TDS_2 = Yield_3 * TDS_3$

$Yield_3 = Yield_1 + Yield_2$

$Yield_2 = (Yield_1 * (TDS_3 – TDS_1)) / (TDS_2 – TDS_3)$

Blending Source:

Lake Texoma near the Denison Dam (Reach 5 Concentration-Duration Curve)

Area 8 Plan: 677 mg/l <= TDS <=1,306 mg/l

Weighted Average TDS = 983.5 mg/l

Receiving Reservoir:

Lake Lewisville: Yield = 90.7 mgd 165 mg/l <= TDS <= 217 mg/l

Weighted Average TDS = 199 mg/l

Safe Blendable Quantity:

Quantity that will yield a TDS = 500 mg/l when both the source and receiving reservoir are at their maximum annual values.

Safe Quantity $= Yield_2 = (Yield_1 * (TDS_3 – TDS_1)) / (TDS_2 – TDS_3)$
$= (90.7 * (500 –217)) / (1,306 – 500) = 31.8$ mgd

Maximum Blendable Quantity:

Quantity that will yield an annual average TDS = 500 mg/l. TDS values will exceed 500 mg/l at times. (Drought Quantity)

Maximum Quantity $= Yield_2 = (Yield_1 * (TDS_3 – TDS_1)) / (TDS_2 – TDS_3)$
$= (90.7 * (500 –199)) / (983.5 – 500) = 56.5$ mgd

Appendix E contains a sample calculation of the safe blendable quantity and maximum drought quantity. Table(s) 3-25 through 3-31 summarize the costs of transporting and blending Red River water to various sources. Transportation systems are sized to carry the drought quantity of water; however; costs are based on the safe blendable quantity.

TABLE 3-25

EXPECTED SAFE BLENDABLE QUANTITIES
NORMAL OPERATING CONDITIONS
(All Quantities in mgd)

Red River Water Blended With:		**Natural**	**Area VIII**	**Areas VIII & X**	**Areas VIII & VIII**	**Areas VII, VIII, & X**
Reach 5-NTMWD						
	+10% Load		23.1	23.6	24.7	25.1
Lake Lavon	Normal Load	25.6	27.0	27.6	28.9	29.5
	-10% Load		32.3	33.2	34.8	35.6
	+10% Load		39.0	39.8	41.6	42.4
Lake Lavon & Lake Cooper	Normal Load	43.2	45.5	46.5	48.7	49.7
	-10% Load		54.5	55.9	58.7	60.0
Reach 5-DAL						
	+10% Load		25.2	25.7	26.9	27.4
Lake Ray Roberts	Normal Load	27.9	29.4	30.0	31.4	32.1
	-10% Load		35.2	36.1	37.9	38.8
	+10% Load		29.2	29.8	31.2	31.7
Lake Lewisville	Normal Load	32.3	34.0	34.8	36.5	37.2
	-10% Load		40.8	41.9	44.0	45.0
	+10% Load		54.4	55.5	58.0	59.1
Lake Lewisville & Lake Ray Roberts	Normal Load	60.2	63.4	64.9	67.9	69.3
	-10% Load		76.0	78.0	81.8	83.7
Reach 5-TRWD						
	+10% Load		16.7	17.0	17.8	18.1
Eagle Mountain Lake	Normal Load	18.5	19.4	19.9	20.8	21.3
	-10% Load		23.3	23.9	25.1	25.7
Reach 8						
	+10% Load		1.5	1.8	2.7	3.6
Lake Kickapoo & Lake Arrowhead	Normal Load	1.2	1.7	2.0	3.0	4.1
(From Wichita River)	-10% Load		1.9	2.2	3.4	4.7
Reach 9						
	+10% Load		2.3	2.7	4.5	6.1
Lake Kickapoo & Lake Arrowhead	Normal Load	1.8	2.6	3.1	5.1	7.0
(From Lake Diversion)	-10% Load		2.9	3.5	5.9	8.1

TABLE 3-26

MAXIMUM BLENDABLE QUANTITIES
DROUGHT OPERATING CONDITIONS
(All Quantities in mgd)

Red River Water Blended With:		**Natural**	**Area VIII**	**Areas VIII & X**	**Areas VII & VIII**	**Areas VII, VIII, & X**
Reach 5-NTMWD						
	+10% Load		52.8	54.0	56.9	58.2
Lake Lavon	Normal Load	60.1	64.0	65.7	69.5	71.4
	-10% Load		81.4	83.7	89.3	92.1
	+10% Load		79.3	81.1	85.4	87.4
Lake Lavon & Lake Cooper	Normal Load	90.2	96.2	98.7	104.3	107.2
	-10% Load		122.2	125.7	134.2	138.3
Reach 5-DAL						
	+10% Load		43.7	44.7	47.1	48.2
Lake Ray Roberts	Normal Load	49.7	53.0	54.4	57.5	59.1
	-10% Load		67.4	69.3	74.0	76.3
	+10% Load		50.7	51.9	54.6	55.9
Lake Lewisville	Normal Load	57.7	61.5	63.1	66.7	68.5
	-10% Load		78.2	80.4	85.8	88.5
	+10% Load		94.4	96.6	101.7	104.1
Lake Lewisville & Lake Ray Roberts	Normal Load	107.4	114.5	117.5	124.3	127.6
	-10% Load		145.5	149.7	159.8	164.7
Reach 5-TRWD						
	+10% Load		32.9	33.6	35.4	36.2
Eagle Mountain Lake	Normal Load	37.4	39.9	40.9	43.3	44.4
	-10% Load		50.7	52.1	55.6	57.3
Reach 8						
	+10% Load		2.9	3.4	5.6	8.2
Lake Kickapoo & Lake Arrowhead	Normal Load	2.3	3.2	3.9	6.4	9.5
(From Wichita River)	-10% Load		3.7	4.4	7.5	11.4
Reach 9						
	+10% Load		3.5	4.1	7.1	0.7
Lake Kickapoo & Lake Arrowhead	Normal Load	2.7	3.9	4.7	8.2	12.7
(From Lake Diversion)	-10% Load		4.5	5.4	9.7	15.6

TABLE 3-27

BLENDED COST OF RED RIVER WATER
NATURAL CONDITIONS
($ per 1,000 Gallons)

Reach	Red River Blended w/	Qty (mgd)	Source Costs	Transport Costs	Untreated Damages	Untreated Cost w/ Damages
Normal Curves						
5-NTMWD	Lake Lavon	25.6	$0.060	$0.085	$1.265	$1.410
5-NTMWD	Lake Lavon & Lake Cooper	43.2	$0.060	$0.085	$1.265	$1.410
5-DAL	Lake Ray Roberts	27.9	$0.060	$0.715	$1.265	$2.040
5-DAL	Lake Lewisville	32.3	$0.060	$0.640	$1.265	$1.965
5-DAL	Ray Roberts & Lewisville	60.2	$0.060	$0.594	$1.265	$1.919
5-TRWD	Eagle Mountain Lake	18.5	$0.060	$2.028	$1.265	$3.353
8	Kickapoo & Arrowhead	1.2	$0.060	$0.806	$5.684	$6.550
9	Kickapoo & Arrowhead	1.8	$0.060	$2.398	$4.849	$7.307

TABLE 3-28

BLENDED COST OF RED RIVER WATER
AREA VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Red River Blended w/	Qty (mgd)	Source Costs	Transport Costs	Untreated Damages	Untreated Cost w/ Damages
Normal Curves						
5-NTMWD	Lake Lavon	27.0	$0.060	$0.085	$1.217	$1.362
5-NTMWD	Lake Lavon & Lake Cooper	45.5	$0.060	$0.085	$1.217	$1.362
5-DAL	Lake Ray Roberts	29.4	$0.060	$0.691	$1.217	$1.968
5-DAL	Lake Lewisville	34.0	$0.060	$0.740	$1.217	$2.017
5-DAL	Ray Roberts & Lewisville	63.4	$0.060	$0.578	$1.217	$1.855
5-TRWD	Eagle Mountain Lake	19.4	$0.060	$1.955	$1.217	$3.232
8	Kickapoo & Arrowhead	1.7	$0.060	$0.605	$4.112	$4.777
9	Kickapoo & Arrowhead	2.6	$0.060	$1.906	$3.454	$5.420
+10% Curves						
5-NTMWD	Lake Lavon	23.1	$0.060	$0.085	$1.372	$1.517
5-NTMWD	Lake Lavon & Lake Cooper	39.0	$0.060	$0.085	$1.372	$1.517
5-DAL	Lake Ray Roberts	25.2	$0.060	$0.077	$1.372	$1.509
5-DAL	Lake Lewisville	29.2	$0.060	$0.678	$1.372	$2.110
5-DAL	Ray Roberts & Lewisville	54.4	$0.060	$0.631	$1.372	$2.063
5-TRWD	Eagle Mountain Lake	16.7	$0.060	$2.202	$1.372	$3.634
8	Kickapoo & Arrowhead	1.5	$0.060	$0.670	$4.575	$5.305
9	Kickapoo & Arrowhead	2.3	$0.060	$2.131	$3.851	$6.042
-10% Curves						
5-NTMWD	Lake Lavon	32.3	$0.060	$0.085	$1.062	$1.207
5-NTMWD	Lake Lavon & Lake Cooper	54.5	$0.060	$0.085	$1.062	$1.207
5-DAL	Lake Ray Roberts	35.2	$0.060	$0.747	$1.062	$1.869
5-DAL	Lake Lewisville	40.8	$0.060	$0.662	$1.062	$1.784
5-DAL	Ray Roberts & Lewisville	76.0	$0.060	$0.581	$1.062	$1.703
5-TRWD	Eagle Mountain Lake	23.3	$0.060	$1.731	$1.062	$2.853
8	Kickapoo & Arrowhead	1.9	$0.060	$0.554	$3.650	$4.264
9	Kickapoo & Arrowhead	2.9	$0.060	$2.729	$3.058	$4.847
All costs in January 2001 Dollars						

TABLE 3-29

BLENDED COST OF RED RIVER WATER
AREAS VIII & X ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Red River Blended w/	Qty (mgd)	Source Costs	Transport Costs	Untreated Damages	Untreated Cost w/ Damages
Normal Curves						
5-NTMWD	Lake Lavon	27.6	$0.060	$0.085	$1.199	$1.344
5-NTMWD	Lake Lavon & Lake Cooper	46.5	$0.060	$0.085	$1.199	$1.344
5-DAL	Lake Ray Roberts	30.0	$0.060	$0.683	$1.199	$1.942
5-DAL	Lake Lewisville	34.8	$0.060	$0.729	$1.199	$1.988
5-DAL	Ray Roberts & Lewisville	64.9	$0.060	$0.570	$1.199	$1.829
5-TRWD	Eagle Mountain Lake	19.9	$0.060	$1.917	$1.199	$3.176
8	Kickapoo & Arrowhead	2.0	$0.060	$0.532	$3.492	$4.084
9	Kickapoo & Arrowhead	3.1	$0.060	$1.630	$2.925	$4.615
+10% Curves						
5-NTMWD	Lake Lavon	23.6	$0.060	$0.085	$1.352	$1.497
5-NTMWD	Lake Lavon & Lake Cooper	39.8	$0.060	$0.085	$1.352	$1.497
5-DAL	Lake Ray Roberts	25.7	$0.060	$0.760	$1.352	$2.172
5-DAL	Lake Lewisville	29.8	$0.060	$0.670	$1.352	$2.082
5-DAL	Ray Roberts & Lewisville	55.5	$0.060	$0.623	$1.352	$2.035
5-TRWD	Eagle Mountain Lake	17.0	$0.060	$2.171	$1.352	$3.583
8	Kickapoo & Arrowhead	1.8	$0.060	$0.578	$3.891	$4.529
9	Kickapoo & Arrowhead	2.7	$0.060	$1.842	$3.269	$5.171
-10% Curves						
5-NTMWD	Lake Lavon	33.2	$0.060	$0.085	$1.046	$1.191
5-NTMWD	Lake Lavon & Lake Cooper	55.9	$0.060	$0.085	$1.046	$1.191
5-DAL	Lake Ray Roberts	36.1	$0.060	$0.734	$1.046	$1.840
5-DAL	Lake Lewisville	41.9	$0.060	$0.653	$1.046	$1.759
5-DAL	Ray Roberts & Lewisville	78.0	$0.060	$0.572	$1.046	$1.678
5-TRWD	Eagle Mountain Lake	23.9	$0.060	$1.184	$1.046	$2.290
8	Kickapoo & Arrowhead	2.2	$0.060	$0.514	$3.091	$3.665
9	Kickapoo & Arrowhead	3.5	$0.060	$1.470	$2.581	$4.111
All costs in January 2001 Dollars						

TABLE 3-30

BLENDED COST OF RED RIVER WATER
AREAS VII & VIII ONLY CONDITIONS
($ per 1,000 Gallons)

Reach	Red River Blended w/	Qty (mgd)	Source Costs	Transport Costs	Untreated Damages	Untreated Cost w/ Damages
Normal Curves						
5-NTMWD	Lake Lavon	28.9	$0.060	$0.085	$1.160	$1.305
5-NTMWD	Lake Lavon & Lake Cooper	48.7	$0.060	$0.085	$1.160	$1.305
5-DAL	Lake Ray Roberts	31.4	$0.060	$0.665	$1.160	$1.885
5-DAL	Lake Lewisville	36.5	$0.060	$0.566	$1.160	$1.786
5-DAL	Ray Roberts & Lewisville	67.9	$0.060	$0.555	$1.160	$1.775
5-TRWD	Eagle Mountain Lake	20.8	$0.060	$1.855	$1.160	$3.075
8	Kickapoo & Arrowhead	3.0	$0.060	$0.408	$2.218	$2.686
9	Kickapoo & Arrowhead	5.1	$0.060	$1.150	$1.807	$3.017
+10% Curves						
5-NTMWD	Lake Lavon	24.7	$0.060	$0.085	$1.309	$1.454
5-NTMWD	Lake Lavon & Lake Cooper	41.6	$0.060	$0.085	$1.309	$1.454
5-DAL	Lake Ray Roberts	26.9	$0.060	$0.737	$1.309	$2.106
5-DAL	Lake Lewisville	31.2	$0.060	$0.653	$1.309	$2.022
5-DAL	Ray Roberts & Lewisville	58.0	$0.060	$0.607	$1.309	$1.976
5-TRWD	Eagle Mountain Lake	17.8	$0.060	$2.091	$1.309	$3.460
8	Kickapoo & Arrowhead	2.7	$0.060	$0.440	$2.490	$2.990
9	Kickapoo & Arrowhead	4.5	$0.060	$1.276	$2.039	$3.375
-10% Curves						
5-NTMWD	Lake Lavon	34.8	$0.060	$0.085	$1.011	$1.156
5-NTMWD	Lake Lavon & Lake Cooper	58.7	$0.060	$0.085	$1.011	$1.156
5-DAL	Lake Ray Roberts	37.9	$0.060	$0.711	$1.011	$1.782
5-DAL	Lake Lewisville	44.0	$0.060	$0.636	$1.011	$1.707
5-DAL	Ray Roberts & Lewisville	81.8	$0.060	$0.555	$1.011	$1.626
5-TRWD	Eagle Mountain Lake	25.1	$0.060	$1.894	$1.011	$2.965
8	Kickapoo & Arrowhead	3.4	$0.060	$0.373	$1.947	$2.380
9	Kickapoo & Arrowhead	5.9	$0.060	$1.158	$1.575	$2.793
All costs in January 2001 Dollars						

TABLE 3-31

BLENDED COST OF RED RIVER WATER
AREAS VII, VIII, & X CONDITIONS
($ per 1,000 Gallons)

Reach	Red River Blended w/	Qty (mgd)	Source Costs	Transport Costs	Untreated Damages	Untreated Cost w/ Damages
Normal Curves						
5-NTMWD	Lake Lavon	29.5	$0.060	$0.085	$1.142	$1.287
5-NTMWD	Lake Lavon & Lake Cooper	49.7	$0.060	$0.085	$1.142	$1.287
5-DAL	Lake Ray Roberts	32.1	$0.060	$0.656	$1.142	$1.858
5-DAL	Lake Lewisville	37.2	$0.060	$0.699	$1.142	$1.901
5-DAL	Ray Roberts & Lewisville	69.3	$0.060	$0.549	$1.142	$1.751
5-TRWD	Eagle Mountain Lake	21.3	$0.060	$1.823	$1.142	$3.025
8	Kickapoo & Arrowhead	4.1	$0.060	$0.338	$1.597	$1.995
9	Kickapoo & Arrowhead	7.0	$0.060	$1.002	$1.272	$2.334
+10% Curves						
5-NTMWD	Lake Lavon	25.1	$0.060	$0.085	$1.289	$1.434
5-NTMWD	Lake Lavon & Lake Cooper	42.4	$0.060	$0.085	$1.289	$1.434
5-DAL	Lake Ray Roberts	27.4	$0.060	$0.723	$1.289	$2.072
5-DAL	Lake Lewisville	31.7	$0.060	$0.648	$1.289	$1.997
5-DAL	Ray Roberts & Lewisville	59.1	$0.060	$0.600	$1.289	$1.949
5-TRWD	Eagle Mountain Lake	18.1	$0.060	$2.069	$1.289	$3.418
8	Kickapoo & Arrowhead	3.6	$0.060	$0.374	$1.808	$2.242
9	Kickapoo & Arrowhead	6.1	$0.060	$1.125	$1.451	$2.636
-10% Curves						
5-NTMWD	Lake Lavon	35.6	$0.060	$0.085	$0.996	$1.141
5-NTMWD	Lake Lavon & Lake Cooper	60.0	$0.060	$0.085	$0.996	$1.141
5-DAL	Lake Ray Roberts	38.8	$0.060	$0.700	$0.996	$1.756
5-DAL	Lake Lewisville	45.0	$0.060	$0.628	$0.996	$1.684
5-DAL	Ray Roberts & Lewisville	83.7	$0.060	$0.548	$0.996	$1.604
5-TRWD	Eagle Mountain Lake	25.7	$0.060	$1.859	$0.996	$2.915
8	Kickapoo & Arrowhead	4.7	$0.060	$0.310	$1.387	$1.757
9	Kickapoo & Arrowhead	8.1	$0.060	$0.891	$1.093	$2.044
All costs in January 2001 Dollars						

Two options are costed for Reach 5-NTMWD in this analysis. Lake Texoma is blended with Lake Lavon (existing blending operation) and Lake Texoma is blended with Lake Lavon and Lake Cooper water in Lake Lavon (also currently possible). Three scenarios are evaluated for Reach 5-DAL. Lake Texoma is blended with Lake Ray Roberts, Lake Texoma is blended with Lake Lewisville, and Lake Texoma is blended with the combined flows of Lake Ray Roberts and Lake Lewisville in Lake Lewisville. The third scenario is the most likely condition since Lake Ray Roberts flows into Lake Lewisville. Only one blending option exists for Reach 5-TRWD. Lake Texoma is blended with Eagle Mountain Lake. The long transportation distance and relatively small blendable quantity make this alternative unlikely. Two blending options are evaluated for Wichita Falls and the Reach 8 Demand Center. The first involves blending water from the Wichita River at Wichita Falls with the flow from Lake Kickapoo and Lake Arrowhead. The second option involves piping water from Lake Kemp-Lake Diversion to Wichita Falls to blend with the flow from Lake Kickapoo and Lake Arrowhead.

ALTERNATIVE TREATMENT LEVELS

All treatment and damage evaluation up to this point has been based on the EPA drinking water standards of 500 mg/l of TDS, 250 mg/l of Cl, and 250 mg/l of SO_4. The State of Texas drinking water standards allow 1,000 mg/l of TDS, 300 mg/l of Cl, and 300 mg/l of SO_4. Questions have been raised about the relative magnitude of the "damages" from using Red River water when evaluated against the State standards. While the State of Texas standards do allow a 100% increase above EPA standards for TDS levels in treated drinking water, only a 20% increase in Cl and SO_4 levels are allowed. It also should be noted that the State of Louisiana has adopted the EPA standards; therefore, no reduction in treatment levels is possible for Reach 1.

In this study (and all previous studies), the damages only costs have been evaluated against the alternative source thresholds for the respective reaches. For users in Texas reaches with alternative source thresholds below 500 mg/l of TDS (Reach 3, 4, 5-NTMWD, 5-DAL, 5-TRWD, 5T-A3 [OTHER], and 8), State of Texas water quality standards will have no effect on the "damages only" cost of Red River water. The "treated damages" costs will also increase since the degree of treatment is not as great (i.e., more damages). Only the treatment costs will be lowered. It should be noted that the treatment costs were lowered by 20-25%; however; the overall treated costs with damages were only lowered by 10-15%.

PART IV - MUNICIPAL AND INDUSTRIAL BENEFIT EVALUATION

INTRODUCTION

In the previous sections, estimates of existing and future water demands were shown for the Texas Water Plan 2001 for Region B and C and for portions of the study area in Louisiana. Supplies of water, both existing and potential, were described by region and county for the major water provider. A comparison of water demand and supply by county and major water provider determined whether there was a surplus or deficit of water now and in the future to 2050. In addition, water management strategies by county and major water provider were developed as well as an estimated cost of developing future sources of water supply. This section of the report will estimate the potential benefits of chloride control within the Wichita River Basin. To accomplish this, an allocation of sources of water to meet existing and potential demand in the region and in the Shreveport/Bossier City, Louisiana, area was made. The allocation, in turn, depends on the cost of water supply, existing or potential, based on the quantity and quality of the water. The costs assigned to water supply sources allows computation of benefits for chloride control which are measured as either an improvement in water quality; that is, the reduction in treatment and damage costs without the Wichita Basin projects, or the cost of the least costly alternative to the project.

ALLOCATION OF SUPPLIES TO DEMANDS

In this analysis, existing and potential use of Wichita/Red River was first identified through the Texas State Water Plan for Regions B and C. Three sources of water supply, Lake Kemp, Lake Texoma, and the Red River in Louisiana, are identified as either existing or potential sources. In the Wichita River Basin, the city of Wichita Falls has plans underway to utilize Lake Kemp water. Some blending occurred in 2000 during the ongoing drought due to the significant reduction in water supply storage in Lake Arrowhead and Lake Kickapoo. By 2003, the city of Wichita Falls will treat Lake Kemp water by reverse osmosis desalination. West Texas Utilities has contracted for 20,000 acre-feet of Lake Kemp water and currently uses about 8,100 acre-feet of Lake Kemp water. Existing municipal and industrial water use from Lake Texoma was identified for the Greater Texoma Utility Authority (GTUA) and the North Texas Municipal Water District (NTMWD), with potential municipal and industrial water use for Grayson County. Long-range potential water use from Lake Texoma may also occur in other areas in the region, such as in the Tarrant Regional Water District (Fort Worth) and the Dallas Utilities Authority (DUA) service areas. However, the water plan does not specifically allocate water from Lake Texoma to those providers. In Louisiana, existing use of the Red River was identified for Bossier City and Willamette Industries, both on the Red River.

In past economic evaluations when allocating water supplies to demands, demands are satisfied based on priority of use and least costly source. Priority of use meant that municipal and industrial water demands would be met first. The least costly source was chosen based on per unit cost, in terms of dollars per thousand gallons. Since then, considerable effort has been made by State and local entities to plan for future water needs. Therefore, consideration must be given to source identification by the user as evaluated by regional planning groups and as

described in the Texas State Water Plan. These entities may be assumed to have a local or regional perspective of their willingness to pay for additions to water supply. The order of priority of use is established as municipal, then industrial, which would include steam-electric power first based on contractual agreements. Storage and ownership of water for agricultural use is important at Lake Kemp where the Wichita County Irrigation District is one of the reservoir owners. As discussed previously, the least costly source from a cost per thousand gallon perspective may not be appropriate for an individual entity especially since the high capital cost, often in the hundreds of millions dollars, make an alternative cost prohibitive for a water entity. This evaluation will discuss each water provider or user in terms of the amount of water currently being utilized and projected to be utilized in the future based on the Texas Water Plan. Water quality benefits are calculated when Red/Wichita River water is used with or without the project. The benefit is measured as the quality cost of water, either the cost or treatment to an acceptable standard or the damage cost as a result of no treatment, without the project as compared to with the project. A water supply benefit is calculated if Red/Wichita River water is used only with the project and is the difference in values between the cost of Red/Wichita River water with the project and the value of the next least costly alternative with the project. Induced benefits occur if additional water is used with the project above that which is used by the project without the project. Future without-project conditions assume that no current use of Red/Wichita water source would be abandoned for another source. If future net needs exceed the ability of a current source to meet those needs, then the next least costly source would be used.

LOUISIANA

Reach 1 - Bossier City/Industry

In Reach 1, two existing users of Red River water are the city of Bossier City and Willamette Industries of Campti, Louisiana, a paperboard manufacturing facility. The effects of chloride removal in the Wichita Basin are minimal in this reach. The methodology used for determining water quality benefits in this reach is that existing use of Red River water is expected to occur at the present rate without and with the project over the planning period. At the present time, Bossier City utilizes about 9.5 million gallons per day (mgd) of Red River water and Willamette Industries about 12 mgd. Since existing water use is always considered first in that municipalities generally would not abandon existing water sources unless there was a quantity or quality problem, this water use is expected to continue into the future. Existing water use is the least costly alternative at the present time since facilities are in place to pump water from the source. The Bossier City Water Treatment Plant (WTP) was completed in 1958 and was originally designed to treat up to 16 mgd of Red River water with lime softening. At the present time, it is being upgraded to treat 20 mgd. However, the most likely alternative source, Cypress Black Bayou No. 1, is less costly and would be considered for future needs even though it would require reallocation of existing agricultural water rights and authorized uses of the reservoir. The cost of Cypress Black Bayou No. 1 water was estimated at $.463 per 1,000 gallons for 13.8 mgd. Toledo Bend Reservoir, which has 50 mgd of water available for transport to Shreveport, is the next least costly source available at $1.20 per 1,000 gallons. Since the water quality is good, these costs are estimated only for source and transport to Bossier City, however, since the city of Bossier City has recently expanded its treatment plant and will most

likely continue to utilize Red River water, perhaps to an even greater extent. Most of the demand for water in Bossier City is for municipal, commercial, and other non-manufacturing uses. In 1993, only about .5 mgd out of 13.3 total mgd was industrial. Only 7 out of 365 establishments are manufacturing, of which 4 have less than 4 employees, and 1 had greater than 50 employees in 1997. Water demand from the Red River was held constant at 9.5 mgd for Bossier City of which 9.2 mgd was for municipal, 0.3 mgd was for industrial, and 12.0 mgd was for Willamette Industries over the planning period. Table 4-1 summarizes by plan the cost of Red River water municipal damage. Since the source cost and the transport cost are the same without and with the project, the difference in the cost of using untreated Red River water represents the benefit for each alternative. Differences in the total costs by control plan represent the benefits for that plan.

TABLE 4-1
MUNICIPAL COSTS OF RED RIVER WATER BY PLAN
REACH 1, BOSSIER CITY
(Cost per 1,000 gallons)

Cost	Area VIII only	Areas VIII & X	Areas VIII & VII	Areas VIII, X, & VIII
Source Cost	$0.060	$0.060	$0.060	$0.060
Untreated Cost	$0.418	$0.410	$0.394	$0.386
Transport Cost	$0.424	$0.424	$0.424	$0.424
Total Cost	$0.902	$0.894	$0.878	$0.870

Water quality benefits for that portion of industrial use for manufacturing in Bossier City is included in Table 4-2 by plan. These benefits are based on a 2005 base year, October 2001 price levels, and a 6-1/8% discount rate. The chloride load reduction is expected to occur on the average over a 5-year period so that in the first year 20% of the benefits are realized, in the second year 40% of potential benefits are realized, and so on, so that by 2010 full benefits are realized. This assumption is utilized throughout all reaches of the study area, although it is recognized that reaches closest to the source areas are most likely to show a more rapid reduction in chlorides over time.

TABLE 4-2
MUNICIPAL WATER QUALITY BENEFITS BY PLAN

Plan	Benefit
Area X	$24,000
Area VII	$72,200
Areas X and VII	$96,300

Reach 1 – Industry

For self-supplied industrial water use, Standard Industrial Classification (SIC) 26 damage costs for using Red River water are shown in Table 2-100 by plan based on the generic industrial damage coefficient of 5 cents per thousand gallons updated to October 2001 price levels.

TABLE 4-3
INDUSTRIAL DAMAGE COSTS BY PLAN
SIC 26
($/1,000 gallons)

Plan	Cost
Area VIII	$0.042
Areas VIII & X	$0.041
Areas VIII & VII	$0.038
Areas VIII, X, & VII	$0.036

The water quality benefits for 12-mgd industrial use of Red River water in Reach 1 are shown in Table 4-4 by plan. These benefits are based on a 2005 base year and a 6-1/8% discount rate.

TABLE 4-4
INDUSTRIAL WATER QUALITY BENEFITS BY PLAN: REACH 1
SIC 26

Plan	Benefit
Area X	$ 3,900
Area VII	$15,600
Areas X & VII	$23,400

Texas

Reach 5T - GTUA/Sherman Greater Texoma Utility Authority. Operation of the existing Electrodialysis Reversal (EDR) plant for the city of Sherman was discussed in the section about current desalination applications in the Red River Basin. Since a fourth EDR unit will be added for future water needs, costs are developed on the capability to pump 10 mgd from Lake Texoma through the existing pipeline for treatment. No alternative water supply sources have been identified for this provider. Table 4-5 summarizes pertinent data related to EDR treatment for this provider.

TABLE 4-5
EDR FLOWS BY PLAN - GTUA-SHERMAN

Reach 5 -GTUA	5% TDS (mg/l)	Mixed Flow (mgd)	Treated TDS (mg/l)	Bypass Flow (mgd)	Treated Out (mgd)	Treated In (mgd)	Total River Flow (mgd)	Brine (mgd)
Natural	1,234	10.00	246.80	2.56	7.44	9.07	11.63	1.63
Area VIII	1,194	10.00	238.80	2.73	7.27	8.86	11.59	1.59
Area VIII & X	1,179	10.00	235.80	2.80	7.20	8.78	11.58	1.58
Area VII & VIII	1,149	10.00	229.80	2.94	7.06	8.61	11.55	1.55
Area VII, VIII, & X	1,136	10.00	227.20	3.00	7.00	8.53	11.54	1.54

Table 4-6 shows the costs by plan for GTUA-Sherman using a generic 10-mgd EDR treatment facility that includes brine disposal costs.

TABLE 4-6
EDR TREATMENT COSTS FOR REACH 5 - GTUA-SHERMAN

	Natural	Area VIII	Area VIII & X	Area VII & VIII	Area VII, VIII, & X	Areas VII, VIII, & X
Total Red River Water Flow (mgd)	11.63	11.59	11.58	11.55	11.54	11.54
Finished Mixed Flow (mgd)	10.00	10.00	10.00	10.00	10.00	10.00
Treated Flow Output (mgd)	7.44	7.27	7.20	7.06	7.00	7.00
Brine (mgd)	1.63	1.59	1.58	1.55	1.54	1.54
Capital Costs						
Site Costs	$ 237,329	$ 237,329	$ 237,329	$ 237,329	$ 237,329	$ 234,247
EDR Equipment Costs	$ 4,484,521	$ 4,394,313	$ 4,358,907	$ 4,285,322	$ 4,252,229	$ 4,184,733
Peripheral Facilities	$ 2,062,761	$ 2,056,156	$ 2,053,564	$ 2,048,176	$ 2,045,753	$ 2,018,835
Construction Costs	$ 3,016,015	$ 2,947,188	$ 2,920,173	$ 2,864,028	$ 2,838,778	$ 2,799,296
Pre- & Post-Treatment Facilities	$17,603,367	$17,554,302	$17,535,044	$17,495,020	$17,477,019	$17,247,059
Brine Facilities	$ 1,488,485	$ 1,454,516	$ 1,441,184	$ 1,413,475	$ 1,401,013	$ 1,382,579
Subtotal Capital Costs	$28,892,478	$28,643,804	$28,546,201	$28,343,350	$28,252,121	$27,866,748
Capital Recovery Factor 20 yrs @ 6.125%	0.088071	0.088071	0.088071	0.088071	0.088071	0.089857
Annual Debt Service	$ 2,544,599	$ 2,522,698	$ 2,514,102	$ 2,496,237	$ 2,488,202	$ 2,504,031
O&M Costs						
Labor	$ 1,148,239	$ 1,148,239	$ 1,148,239	$ 1,148,239	$ 1,148,239	$ 1,050,000
Chemicals	$ 705,905	$ 689,796	$ 683,473	$ 670,333	$ 664,423	$ 713,820
Power	$ 398,213	$ 389,125	$ 385,558	$ 378,145	$ 374,811	$ 358,446
Misc. Maintenance	$ 459,701	$ 458,229	$ 457,651	$ 456,451	$ 455,911	$ 449,912
Brine O&M	$ 163,733	$ 159,997	$ 158,530	$ 155,482	$ 154,111	$ 152,084
	$ 2,875,791	$ 2,845,386	$ 2,833,452	$ 2,808,650	$ 2,797,495	$ 2,724,262
Depreciation	$ 1,444,624	$ 1,432,190	$ 1,427,310	$ 1,417,168	$ 1,412,606	$ 1,393,337
Subtotal O&M Costs	$ 4,320,415	$ 4,277,576	$ 4,260,762	$ 4,225,817	$ 4,210,101	$ 4,117,600
Total Annual Costs	$ 6,865,014	$ 6,800,274	$ 6,774,864	$ 6,722,054	$ 6,698,303	$ 6,621,630
Costs per 1,000 Gallons	$ 1.881	$ 1.863	$ 1.856	$ 1.842	$ 1.835	$ 1.814

A summary of total costs by plan is shown in Table 4-7. These costs are used to calculate water quality benefits for Reach 5T-GTUA-Sherman (Table 4-8).

TABLE 4-7

TOTAL COSTS BY PLAN FOR REACH 5 - GTUA-SHERMAN

	Area VIII only	**Areas VIII & X**	**Areas VIII & VII**	**Areas VIII, X, & VII**
Source Cost	$0.060	$0.060	$0.060	$0.060
Treated Cost	$1.863	$1.856	$1.842	$1.835
Transport Cost	$0.070	$0.070	$0.070	$0.070
Total Cost	$1.993	$1.986	$1.972	$1.965

TABLE 4-8

WATER QUALITY BENEFITS BY PLAN - REACH 5 - GTUA-SHERMAN

Plan	**Benefit**
Area X	$22,800
Area VII	$68,300
Areas X & VII	$91,000

Reach 5 - Grayson/Denison - Grayson County Water Supply Project. The Texas State Water Plan for Region C indicated a need for additional water from Lake Texoma by 2010. This net need ranged from about 4.1 mgd in 2010 to 6.3 mgd by 2050. The Grayson County Water Supply Project would meet an estimated 5-mgd need utilizing a desalination treatment facility that would most likely be an EDR facility. The quality of water used to size the facility and the quantities of water required and produced are shown in Table 4-9 by plan.

TABLE 4-9

EDR FLOWS BY PLAN FOR GRAYSON COUNTY

Reach 5-Grayson	**5% TDS (mg/l)**	**Mixed Flow (mgd)**	**Treated TDS (mg/l)**	**Bypass Flow (mgd)**	**Treated Out (mgd)**	**Treated In (mgd)**	**Total River Flow (mgd)**	**Brine (mgd)**
Natural	1,234	5.00	246.80	1.28	3.72	4.53	5.82	0.82
Area VIII	1,194	5.00	238.80	1.37	3.63	4.43	5.80	0.80
Area VIII & X	1,179	5.00	235.80	1.40	3.60	4.39	5.79	0.79
Area VII & VIII	1,149	5.00	229.80	1.47	3.53	4.31	5.77	0.77
Area VII, VIII, & X	1,136	5.00	227.20	1.50	3.50	4.27	5.77	0.77

The EDR treatment costs for these flows are shown in Table 4-10

TABLE 4-10
EDR COSTS BY PLAN - REACH 5 - GRAYSON/DENISON

	Natural	Area VIII	Area VIII & X	Area VII & VIII	Area VII, VIII, & X
Total Red River Water Flow (mgd)	5.82	5.80	5.79	5.77	5.77
Finished Mixed Flow (mgd)	5.00	5.00	5.00	5.00	5.00
Treated Flow Output (mgd)	3.72	3.63	3.60	3.53	3.50
Brine (mgd)	0.82	0.80	0.79	0.77	0.77
Capital Costs					
Site Costs	$ 145,034	$ 145,034	$ 145,034	$ 145,034	$ 145,034
EDR Equipment Costs	$ 2,388,770	$ 2,335,773	$ 2,314,972	$ 2,271,741	$ 2,252,298
Peripheral Facilities	$ 1,031,380	$ 1,028,078	$ 1,026,782	$ 1,024,088	$ 1,022,876
Construction Costs	$ 1,508,008	$ 1,473,594	$ 1,460,087	$ 1,432,014	$ 1,419,389
Pre- & Post-Treatment Facilities	$ 9,305,724	$ 9,278,361	$ 9,267,621	$ 9,245,299	$ 9,235,261
Brine Facilities	$ 744,242	$ 727,258	$ 720,592	$ 706,738	$ 700,507
Subtotal Capital Costs	$15,123,159	$14,988,098	$14,935,087	$14,824,914	$14,775,365
Capital Recovery Factor 20 yrs @ 6.125%	0.088071	0.088071	0.088071	0.088071	0.088071
Annual Debt Service	$ 1,331,917	$ 1,320,022	$ 1,315,353	$ 1,305,650	$ 1,301,286
O&M Costs					
Labor	$ 574,119	$ 574,119	$ 574,119	$ 574,119	$ 574,119
Chemicals	$ 352,953	$ 344,898	$ 341,737	$ 335,166	$ 332,211
Power	$ 199,106	$ 194,563	$ 192,779	$ 189,073	$ 187,406
Misc. Maintenance	$ 229,851	$ 229,115	$ 228,826	$ 228,225	$ 227,955
Brine O&M	$ 81,867	$ 79,998	$ 79,265	$ 77,741	$ 77,056
	$ 1,437,896	$ 1,422,693	$ 1,416,726	$ 1,404,325	$ 1,398,747
Depreciation	$ 756,158	$ 749,405	$ 746,754	$ 741,246	$ 738,768
Subtotal O&M Costs	$ 2,194,054	$ 2,172,098	$ 2,163,480	$ 2,145,570	$ 2,137,516
Total Annual Costs	$ 3,525,970	$ 3,492,120	$ 3,478,834	$ 3,451,221	$ 3,438,802
Costs per 1,000 Gallons	$ 1.932	$ 1.913	$ 1.906	$ 1.891	$ 1.884

A summary of the total costs by plan is shown in Table 4-11.

TABLE 4-11
SUMMARY OF COSTS BY PLAN - REACH 5 - GRAYSON/DENISON

	Area VIII Only	Areas VIII & X	Areas VIII & VII	Areas VIII, X, & VIII
Source Cost	$0.060	$0.060	$0.060	$0.060
Treated Cost	$1.913	$1.906	$1.891	$1.884
Transport Cost	$0.228	$0.228	$0.228	$0.228
Total Cost	$2.201	$2.194	$2.179	$2.172
Finished Water Flow	5 mgd	5 mgd	5 mgd	5 mgd

Water quality benefits, that is, the same water demand without and with the project, are shown in Table 4-12 by plan.

TABLE 4-12
WATER QUALITY BENEFITS BY PLAN - REACH 5 - GRAYSON/DENISON

Plan	Benefit
Area X	$ 9,400
Area VII	$29,500
Areas X & VII	$38,900

Reach 5- NTMWD - North Texas Municipal Water District. The Texas State Water Plan for Region C has indicated a net need for additional water for the NTMWD in the future. Existing sources of water supply are Lake Lavon, Lake Cooper, and Lake Texoma, with some limited groundwater sources. The NTMWD can contractually divert up to 75 mgd of water from Lake Texoma, although the water plan estimates 77,300 acre-feet or about 69 mgd. This water is blended with the other sources. Potential sources of water supply are George Parkhouse II, Marvin Nichols I, and New Bonham. The water district is also seeking other sources of supply in Oklahoma. Development of potential sources of water supply would require partnerships with other water providers, such as DWU and the TRWD in the case of Marvin Nichols I. Since the capital cost of new projects is large, it is unlikely that any one entity could afford to develop sources of water supply alone. Alternative source costs for some potential projects may be less than utilization of Lake Texoma water on a thousand gallon basis. The initial capital investment and the environmental mitigation that may be required make utilization of existing sources of water supply more attractive if water quality can be addressed at relatively less cost through blending or treatment to acceptable standards.

Alternative source costs at 2001 price levels for Reach 5 are shown in Table 4-13.

TABLE 4-13
ALTERNATIVE SOURCE COSTS
REACH 5 – NORTH TEXAS MUNICIPAL WATER DISTRICT

Potential Source	First Cost (Million $)	Quantity (mgd)	Unit Cost ($/1,000 gal)
New Bonham Reservoir	$ 212.7	83.7	$0.776
George Parkhouse II	$ 126.7	120.0	$0.666
Marvin Nichols I	$1,565.0	120.0	$0.980

Although Huitt-Zollars developed the costs for this study, the Texas State Water Plan costs were developed by Freese and Nichols and are slightly different. Appendix R of the Water Plan provides detailed cost data (2000 costs) for the potential reservoirs. The New Bonham or Lower Bois d'Arc site would have a first cost of about $212.7 million, of which about $143.8 million (including 35% contingencies) is for the dam and reservoir. George Parkhouse II (North) has an estimated capital cost of about $126.7 million. Although Marvin Nichols I would cost $1.6 billion total, the NTMWD share would be about one-third the total cost. The dam and reservoir is estimated to cost about $341.5 million of which NTMWD's cost would be about $105.9 million. Their share of the pipeline cost would be about $212.1 million. The Texas Water Plan estimates also that additional supply from Lake Texoma would occur after 2030 and that a desalination plant with 45-mgd capacity would cost about $160.0 million.

Since the current practice is to blend water, maximum safe blending quantities of Lake Texoma water with Lake Lavon and Lake Cooper water were determined. These quantities of water varied by plan; that is, the better the quality of water, the more that could be blended. Furthermore, since the municipal and industrial damage coefficients differ, only that portion of water used for municipal purposes would result in municipal damages. An examination of manufacturing demands over time for this provider indicated that only about 3% of the total water was used for manufacturing and power demands did not increase over time. It was assumed that 3% of the blendable water without and with the project would be used for manufacturing and that SIC 20 would predominate in water use. Since differences in costs without and with the project determine the benefits of a plan, differences between the various SIC's are minimal.

Water demand by category for 2000 to 2050 is shown in Table 4-14.

TABLE 4-14

WATER DEMAND BY CATEGORY, 2000-2050
REACH 5 – NORTH TEXAS MUNICIPAL WATER DISTRICT
(acre-feet)

	2000	2010	2020	2030	2040	2050
Municipal	221,082	300,593	373,945	434,419	494,310	540,085
Manufacturing	9,000	10,356	11,535	12,570	14,666	16,980
Power	4,180	4,200	4,250	4,250	4,250	4,250
Total	234,262	315,149	389,730	451,239	513,226	561,315
Municipal	197.4	268.4	333.9	387.9	441.3	482.2
Manufacturing	8.0	9.2	10.3	11.2	13.1	15.2
Power	3.7	3.8	3.8	3.8	3.8	3.8
Total	209.2	281.4	348.0	402.9	458.2	501.2
% Manufacturing	4.0	3.0	3.0	3.0	3.0	3.0

MGD = 1,120 acre-feet.

The quantities that are blendable for municipal use and the total costs that include damages, transport, and source costs by plan are shown in Table 4-15. Source costs are $.06 per thousand gallons and transport costs are $.09 per thousand gallons for each alternative.

TABLE 4-15

BLENDABLE QUANTITIES AND TOTAL COST BY PLAN
REACH 5 – NORTH TEXAS MUNICIPAL WATER DISTRICT

Plan	Municipal		Industrial		Total Quantity (mgd)
	Quantity (mgd)	Cost ($/1,000 gal)	Quantity (mgd)	Cost ($/1,000 gal)	
Existing Area VIII	44.1	$1.38	1.4	$0.368	45.5
Area VIII & X	45.1	$1.36	1.4	$0.362	46.5
Area VIII & VII	47.2	$1.32	1.5	$0.350	48.7
Areas VIII, VII, & X	48.2	$1.30	1.5	$0.345	49.7

An example of the allocation of Lake Texoma water for blending for municipal use is shown in Table 4-16. Similar calculations can be made for manufacturing water use without and with the project.

TABLE 4-16

WICHITA RIVER BASIN CHLORIDE CONTROL ALLOCATION BASED ON BLENDING OPTIONS
LAKE LAVON AND LAKE COOPER BLEND ONLY, NO TREATMENT
MUNICIPAL LESS MANUFACTURING

Year	Reach NTMWD — North Texas Municipal Water District						
	Area VIII Plan 2 Lake Texoma Existing Without MGD	Area VII & X Plan 3 With MGD	Additional With MGD	Water Quality Benefit (without & with project)		Additional Water Quality Benefit	
				$/1,000 gallons	Dollars	$/1,000 gallons	Dollars
2000	0	0	0	0	0	0	
2005	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3, 495
2015	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3,495
2025	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3,495
2035	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3,495
2045	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3,495
2055	44.135	48.209	0.126	$0.08	$1,224,305	$0.08	$3,495

Note: The water quality benefit of $.02/1000 gallons is the difference in damage costs for the existing (without-project) condition and the with-project condition or plan being evaluated.

Average annual water quality benefits for municipal and industrial use are shown by plan in Table 4-17. Additional water quality benefits are due to increased amounts of blendable water of improved quality with the project.

TABLE 4-17
TOTAL MUNICIPAL AND INDUSTRIAL AVERAGE ANNUAL BENEFITS
REACH 5 – NORTH TEXAS MUNICIPAL WATER DISTRICT

Plan 3, With Area X
Blend With Lake Lavon and Lake Cooper

Reach/Category		Year 2005 Present Worth	6-1/8% Interest Average Annual Benefits
Municipal	Quality	$4,439,592	$272,640
	Additional Quality	$97,573	$5,992
Industrial	Quality	$43,360	$2,663
	Additional Quality	$953	$59
Total	Quality	$4,482,952	$275,303
	Additional Quality	$98,526	$6,051
Total Reach		$4,581,479	$281,353

Plan 4, With Area VII
Blend With Lake Lavon and Lake Cooper

Reach/Category		Year 2005 Present Worth	6-1/8% Interest Average Annual Benefits
Municipal	Quality	$13,552,439	$832,269
	Supply	$953,139	$58,533
Industrial	Quality	$130,080	$7,988
	Supply	$9,149	$562
Total	Quality	$13,682,519	$840,257
	Supply	$962,287	$59,095
Total Reach		$14,644,806	$899,352

Plan 5, With Areas X and VII
Blend With Lake Lavon and Lake Cooper

Reach/Category		Year 2005 Present Worth	6-1/8% Interest Average Annual Benefits
Municipal	Quality	$16,848,871	$1,034,706
	Supply	$50,698	$3,113
Industrial	Quality	$157,701	$9,685
	Supply	$15,343	$942
Total	Quality	$17,006,572	$1,044,391
	Supply	$66,041	$4,056
Total Reach		$17,072,613	$1,048,446

Reach 5 - DWU - Dallas Water Utilities. The Region C Water Plan does not recommend the use of Lake Texoma as one of its water management strategies. The DWU currently has developed sources of water supply that are scheduled to be brought on-line in the future as the need arises, with Lake Fork first at 107 mgd, followed by Lake Palestine at 101.7 mgd. Cooper Reservoir is an existing source that could be utilized with the NTMWD. George Parkhouse II and Marvin Nichols I are potential sources and could be developed in partnerships with others such as the NTMWD and the TRWD in the case of Marvin Nichols I. Little Cypress is another potential source. Although not addressed formally in the water plan, Lake Texoma continues to be considered by the DWU and has not been eliminated in their long-term planning.

Reach 5 - TRWD - Tarrant Regional Water District. The city of Fort Worth obtains nearly all of its raw water from the TRWD. The city is planning to expand its treatment capacity and is exploring development of reuse water. Potential water supply projects in this service area are limited to Tehuacana Reservoir, a diversion of return flows from the Trinity River, and Marvin Nichols I. Tehuacana, yielding 61 mgd, would be constructed adjacent to the existing Richland-Chambers Reservoir; however, due to lignite coal contracts, it would not be feasible until after 2040. The Trinity River Diversion, though recommended in the water plan, may not be feasible although the water plan indicates demands on this source by 2010. Marvin Nichols I would be constructed with partners as previously discussed and would be the primary source for meeting demands by 2030. Supplies from Lake Texoma and sources in Oklahoma are also mentioned in the water plan for this provider.

Reach 9 - Lake Kemp - Wichita Falls. The Region B Water Plan evaluated water management strategies for the region's water user groups, principally the cities of Wichita Falls and Vernon, as well as other smaller communities. The strategies include wastewater reuse, utilization of Lake Kemp water, and development of Lake Ringgold in the Little Wichita Basin. Existing sources of supply for Wichita Falls are Lakes Arrowhead and Kickapoo in the Little Wichita Basin. Most communities in the region rely on groundwater for most of their supply; however, groundwater has become increasingly contaminated by nitrates from agricultural activities. Lake Ringgold is expected to have excellent water quality with a dependable yield of about 24.6 mgd. The total cost per thousand gallons is estimated at $1.77, of which $1.12 is for development of the reservoir and about $.65 is for the pipeline. The high capital cost is expected to be about $160 million for construction and $128 million for pipeline related costs, or about $288 million total cost. The State Water Plan estimates the cost per thousand gallons at $2.80. If only a portion of the yield was utilized then, in the early years, the unit cost could be much higher. The RWPG does not recommend pursuing Lake Ringgold at this time, rather it would be considered beyond the 50-year State planning horizon. However, during the public involvement phase of development of the regional water plan, some in the Wichita Falls community would prefer Lake Ringgold at the present time. Lake Ringgold is in the same Little Wichita River Basin as Lakes Kickapoo and Arrowhead. Water deficiencies in the Little Wichita Basin would then adversely affect all the city of Wichita Falls' water supplies. Wastewater reuse was evaluated as a potential source of water supply. Wastewater reuse capital cost was estimated at $48.7 million while making an additional 11,000 acre-feet or 9.8 mgd of water available for use in the region. The concept of wastewater reuse in the region has its own set of problems as previously discussed in regard to the TRWD. Lake Kemp, on the other hand, has a total yield of

about 172.3 mgd. The city of Wichita Falls and the Wichita County Irrigation District jointly own Lake Kemp, while the Corps of Engineers operates the lake for flood control. Wichita Falls has water rights of 25,150 acre-feet (22.5 mgd). Other water rights holders are for irrigation, 120,000 acre-feet; industrial, 40,000 acre-feet; mining, 2,000 acre-feet; and recreation, 5,850 acre-feet, for a total of 193,000 acre-feet. About 20,000 of the 40,000 acre-feet of the industrial water right is contracted to West Texas Utilities for its Oklaunion power plant. The recreation water right of 5,850 is for replenishment of Lake Wichita on an as-needed basis. The State Fish Hatchery below Lake Diversion receives water without cost from the irrigation district.

The city of Wichita Falls is constructing a reverse osmosis (RO) treatment facility that would use about 10 mgd of Lake Kemp water. This facility, to be located near the Cypress Water Treatment Plant, is discussed in the strategic regional plan and does not assume that the Wichita Basin Chloride Control Project would be completed. During the recent drought, with the drawdown of Lakes Arrowhead and Kickapoo along with water conservation measures undertaken by the city as well as other communities in the region, water shortages have been common. Reliance on one river basin for total water supply needs may have certain shortfalls sometimes due to the pattern of regional precipitation.

The cost of desalination treatment has been evaluated for the different control plans since there are no discernable net needs, although shortages do exist periodically. Electrodialysis Reversal treatment would be preferable at certain TDS threshold levels while RO treatment would occur with poorer quality of water. Table 4-18 displays the quantities of water pertaining to RO/EDR treatment for the different plans.

TABLE 4-18
QUANTITIES OF WATER
RO/EDR TREATMENT
REACH 9 - WICHITA FALLS

Reach 9 – Wichita Falls	5% TDS (mg/l)	Mixed Flow (mgd)	Treated TDS (mg/l)	Bypass Flow (mgd)	Treated Out (mgd)	Treated In (mgd)	Total River Flow (mgd)	Brine (mgd)
Natural	4,305	10.00	430.50	0.18	9.82	13.09	13.27	3.27
Area VIII	3,158	10.00	315.80	0.65	9.35	12.47	13.12	3.12
Area VIII & X	2,735	10.00	273.50	0.92	9.08	12.11	13.03	3.03
Area VII & VIII*	1,818	10.00	363.60	0.94	9.06	11.05	11.99	1.99
Area VII, VIII, & X*	1,430	10.00	286.00	1.87	8.13	9.91	11.78	1.78
* EDR Treatment								

The development of RO/EDR treatment costs by plan is shown in Table 4-19.

TABLE 4-19
RO/EDR TREATMENT COSTS BY PLAN
REACH 9 - WICHITA FALLS

	Natural	**Area VIII**	**Area VIII & X**	**Area VII & VIII**	**Area VII, VIII, & X**
Total Red River Water Flow (mgd)	13.27	13.12	13.03	11.99	11.78
Finished Mixed Flow (mgd)	10.00	10.00	10.00	10.00	10.00
Treated Flow Output (mgd)	9.82	9.35	9.08	9.06	8.13
Brine (mgd)	3.27	3.12	3.03	1.99	1.78
Capital Costs					
Site Costs	$ 237,329	$ 237,329	$ 237,329	$ 237,329	$ 237,329
Equipment Costs	$ 5,221,090	$ 4,971,902	$ 4,827,251	$ 5,349,501	$ 4,853,589
Peripheral Facilities	$ 2,353,841	$ 2,326,135	$ 2,310,052	$ 2,126,094	$ 2,089,784
Construction Costs	$ 3,983,654	$ 3,793,525	$ 3,683,158	$ 3,675,989	$ 3,297,612
Pre- & Post-Treatment Facilities	$19,765,678	$19,559,861	$19,440,387	$18,073,844	$17,804,109
Brine Facilities	$ 2,985,469	$ 2,842,981	$ 2,760,268	$ 1,814,199	$ 1,627,460
Subtotal Capital Costs	$34,547,061	$33,731,733	$33,258,445	$31,276,956	$29,909,884
Capital Recovery Factor 20 yrs @ 6.125%	0.088071	0.088071	0.088071	0.088071	0.088071
Annual Debt Service	$ 3,042,606	$ 2,970,799	$ 2,929,116	$ 2,754,604	$ 2,634,204
O&M Costs					
Labor	$ 1,148,239	$ 1,148,239	$ 1,148,239	$ 1,148,239	$ 1,148,239
Chemicals	$ 932,384	$ 887,883	$ 862,052	$ 860,374	$ 771,814
Power	$ 575,063	$ 547,617	$ 531,685	$ 485,351	$ 435,392
Misc. Maintenance	$ 524,570	$ 518,396	$ 514,812	$ 473,815	$ 465,723
Brine O&M	$ 328,402	$ 312,728	$ 303,629	$ 199,562	$ 179,021
	$ 3,508,658	$ 3,414,863	$ 3,360,417	$ 3,167,340	$ 3,000,189
Depreciation	$ 1,727,353	$ 1,686,587	$ 1,662,922	$ 1,563,848	$ 1,495,494
Subtotal O&M Costs	$ 5,236,011	$ 5,101,450	$ 5,023,339	$ 4,731,188	$ 4,495,683
Total Annual Costs	$ 8,278,617	$ 8,072,249	$ 7,952,455	$ 7,485,792	$ 7,129,887
Costs per 1,000 Gallons	$ 2.268	$ 2.212	$ 2.179	$ 2.051	$ 1.953
	(1 Stage RO)	(1 Stage RO)	(1 Stage RO)	(EDR)	(EDR)

A summary of total costs by plan is shown in Table 4-20 for RO/EDR treatment and in Table 4-21 for blended water

TABLE 4-20
SUMMARY OF TOTAL COSTS BY PLAN
RO/EDR TREATMENT

	Area VIII only	**Areas VIII & X**	**Areas VIII & VII**	**Areas VIII, X, & VII**
Source Cost	$0.06	$0.06	$0.06	$0.06
Treated Cost	**$2.21**	**$2.18**	**$2.05**	**$1.95**
Transport Cost	$0.77	$0.77	$0.77	$0.77
Damages (315 mg/l threshold)	$0.31	$0.31	$0.31	$0.31
Total Cost	**$3.35**	**$3.32**	**$3.19**	**$3.09**
Finished Water Flow	10 mgd	10 mgd	10 mgd	10 mgd
	RO	RO	EDR	EDR

TABLE 4-21
SUMMARY OF TOTAL COSTS BY PLAN
BLENDED WATER

	Area VIII only	**Areas VIII & X**	**Areas VIII & VII**	**Areas VIII, X, & VII**
Source Cost	$0.06	$0.06	$0.06	$0.06
Blended Cost	**$3.49**	**$2.96**	**$1.83**	**$1.29**
Transport Cost	$2.11	$1.80	$1.27	$1.11
Total Cost	**$5.66**	**$4.82**	**$3.16**	**$2.46**
Quantity—Safe blended yield	2.6	3.1	5.1	7.0
Quantity—Drought blended yield	3.9	4.7	8.2	12.7

Table 4-22 shows the water quality benefit by decade for Plan 5, with Areas VII and X based on the costs for EDR treatment without and with the project. The $.26/1000 gallons difference in cost is the unit measure of the reduction in treatment costs without compared to with the project for Plan 5.

TABLE 4-22

SUMMARY OF MUNICIPAL BENEFITS
WICHITA FALLS, WITH PLAN 5

Reach 9 Wichita Falls	Area VIII Plan 2 Lake Kemp Existing-without mgd	Areas X & VII Plan 5 With mgd	Additional With mgd	Water Quality Benefit	
Year				$/1000 gal	Dollars
2000	0	0	0	0	0
2005	10	10	0	$0.26	$945,350
2015	10	10	0	$0.26	$945,350
2025	10	10	0	$0.26	$945,350
2035	10	10	0	$0.26	$945,350
2045	10	10	0	$0.26	$945,350
2055	10	10	0	$0.26	$945,350

A summary of potential municipal and industrial water quality benefits for RO/EDR chloride removal for Wichita Falls is shown in Table 4-23 by plan.

TABLE 4-23

MUNICPAL AND INDUSTRIAL BENEFITS
RO/EDR TREATMENT
REACH 9 - WICHITA FALLS

Plan	Year 2005 Present Worth	Average Annual Benefits
With Area X	$ 1,747,100	$107,300
With Area VII	$ 8,523,800	$523,500
With Areas X & VII	$13,712,200	$842,100

A summary of potential municipal and industrial water quality benefits for blending various quantities of Lake Kemp water for Wichita Falls is shown in Table 4-24 by plan.

TABLE 4-24

MUNICPAL AND INDUSTRIAL BENEFITS
BLENDABLE-NORMAL
REACH 9 - WICHITA FALLS

Plan	Year 2005 Present Worth	Average Annual Benefits
With Area X	$12,996,500	$ 798,100
With Area VII	$34,838,500	$2,139,500
With Areas X & VII	$55,630,800	$3,416,300

Although the maximum blendable quantity of water to meet water quality standards is only 7 mgd, the potential benefits for reduction in damage costs with all areas controlled is much higher on a unit basis.

Reach 9 - Oklaunion - West Texas Utilities. The principal use of water in steam-electric power generation is for condenser cooling purposes. Small amounts of relatively pure water are required for boiler use and much larger amounts of untreated water serve for condenser cooling. The water requirement in the boiler circuit is the feed water make-up to replace water losses. Losses also occur in the condenser cooling system when condenser flows pass through cooling towers or ponds. The steam-electric power generation industry is similar in many respects to other segments of the overall industrial base when considering the physical and financial effects of water quality characteristics. Treatment of water for condenser cooling is generally economically feasible in re-circulation systems. Reductions in the dissolved solids content of the raw water supply would provide a benefit to the user through reduction in treatment costs, maintenance, and pipe and valve replacement costs. Cost savings would occur with improved water quality. In addition, additional capital costs for construction of the plant have been incurred due to its use of poor quality water. Some components in power plants in other regions that use better quality water would be constructed of materials that would be less costly and would not be as affected by corrosive water.

The Oklaunion power plant owned by WTU is another user of Wichita River water, diverting water from Lake Diversion. Although most of the water is used for cooling purposes, the utility does have a small RO treatment plant to produce about 0.3 mgd of high quality boiler feed water. West Texas Utilities can divert up to 20,000 acre-feet of water a year from Lake Kemp. This is contracted storage and the water is pumped from Lake Diversion, below Lake Kemp. The regional water plan indicates that current water demand for power is about 7 mgd, with the expected demand to reach 17.9 mgd by 2035. Other power companies have shown an interest in use of Lake Kemp water through discussions with water rights holders. For this analysis, it is assumed that a 0.5-mgd RO facility would treat water for boiler feed, and the remainder of the water would be for cooling purposes. No growth for water consumption for power is assumed in this analysis.

Quantities of water required by plan are shown in Table 4-25 below. The costs associated with RO treatment and damages for existing use of Lake Kemp water is shown in Table 4-26. Since a damage coefficient pertaining to power plants is not known to exist, the untreated damage costs shown in the table, as well as development of treatment cost for other manufacturing is based on its average daily water use. Source costs and pipeline would be the same for each plan and are sunk costs. Water quality benefits are derived from differences between the without and with project costs.

TABLE 4-25

QUANTITIES OF WATER REQUIRED BY PLAN - REACH 9

Plan	5% TDS (mg/l)	Mixed Flow (mgd)	RO Treated TDS (mg/l)	Bypass Flow (mgd)	Treated Out (mgd)	Treated In (mgd)	Total River Flow (mgd)	Brine (mgd)
Natural	4,305	0.50	430.50	0.01	0.49	0.65	0.66	0.16
Area VIII	3,158	0.50	315.80	0.03	0.47	0.62	0.66	0.16
Areas VIII & X	2,735	0.50	273.50	0.05	0.45	0.61	0.65	0.15
Areas VII & VIII	1,818	0.50	363.60	0.05	0.45	0.55	0.60	0.10
Areas VII, VIII, & X	1,430	0.50	286.00	0.09	0.41	0.50	0.59	0.09

	Natural	Area VIII	Areas VIII & X	Areas VII & VIII	Areas VII, VIII, & X
Total Red River Water Flow (mgd)	0.66	0.66	0.65	0.60	0.59
Finished Mixed Flow (mgd)	0.50	0.50	0.50	0.50	0.50
Treated Flow Output (mgd)	0.49	0.47	0.45	0.45	0.41
Brine (mgd)	0.16	0.16	0.15	0.10	0.09
Capital Costs					
Site Costs	$ 61,969	$ 61,969	$ 61,969	$ 61,969	$ 61,969
Equipment Costs	$ 475,620	$ 468,144	$ 463,805	$ 516,688	$ 501,810
Peripheral Facilities	$ 117,692	$ 116,307	$ 115,503	$ 106,305	$ 104,489
Construction Costs	$ 199,183	$ 189,676	$ 184,158	$ 183,799	$ 164,881
Pre- & Post-Treatment Facilities	$1,076,042	$1,063,376	$1,056,024	$ 971,929	$ 955,330
Brine Facilities	$ 456,000	$ 456,000	$ 456,000	$ 456,000	$ 456,000
Subtotal Capital Costs	$2,386,506	$2,355,473	$2,337,458	$2,296,690	$2,244,479
Capital Recovery Factor 20 yrs @ 6.125%	0.088071	0.088071	0.088071	0.088071	0.088071
Annual Debt Service	$ 210,183	$ 207,450	$ 205,863	$ 202,273	$ 197,674
O&M Costs					
Labor	$ 344,472	$ 344,472	$ 344,472	$ 344,472	$ 344,472
Chemicals	$ 46,619	$ 44,394	$ 43,103	$ 43,019	$ 38,591
Power	$ 28,753	$ 27,381	$ 26,584	$ 24,268	$ 21,770
Misc. Maintenance	$ 26,229	$ 25,920	$ 25,741	$ 23,691	$ 23,286
Brine O&M	$ 16,420	$ 15,636	$ 15,181	$ 9,978	$ 8,951
	$ 462,493	$ 457,803	$ 455,081	$ 445,427	$ 437,069
Depreciation	$ 119,325	$ 117,774	$ 116,873	$ 114,834	$ 112,224
Subtotal O&M Costs	$ 581,818	$ 575,576	$ 571,953	$ 560,261	$ 549,293
Total Annual Costs	$ 792,001	$ 783,026	$ 777,817	$ 762,534	$ 746,967
Costs per 1,000 Gallons	$ 4.340 (RO)	$ 4.291 (RO)	$ 4.262 (RO)	$ 4.178 (EDR)	$ 4.093 (EDR)

TABLE 4-26

RO/EDR COSTS BY PLAN
REACH 9 - INDUSTRY

	Area VIII only	**Areas VIII & X**	**Areas VIII & VII**	**Areas VIII, X, & VII**
Source Cost	$0.06	$0.06	$0.06	$0.06
Treated Cost	**$4.29**	**$4.26**	**$4.18**	**$4.093**
Transport Cost	$0.00	$0.00	$0.00	$0.00
Total Cost	**$4.35**	**$4.32**	**$4.24**	**$4.15**
Finished Water Flow	.5 mgd	.5 mgd	.5 mgd	.5 mgd
	RO	RO	EDR	EDR
Untreated Cost with Damages	**$0.84**	**$0.68**	**$0.34**	**$0.17**

Average annual benefits are shown in Table 4-27.

TABLE 4-27

AVERAGE ANNUAL BENEFITS
REACH 9 - INDUSTRY
($1,000, 6-1/8%)

Category		**Year 2005 Present Worth**	**Average Annual Benefits**
Plan 3, With Area X - .3 mgd RO Only			
Power	Quality	$ 46,060	$ 2,829
Plan 4, With Area VII - .3 mgd RO Only			
Power	Quality	$179,476	$11,022
Plan 5, With Areas X and VII - .3 mgd RO Only			
Power	Quality	$314,480	$19,313

Power plants are usually constructed with dedicated sources of water of known quality. In areas of poor quality water, materials are selected that resist the deteriorating effects of poor quality water in order to minimize damages to cooling systems. Prior studies of chloride control on the Arkansas River, Oklahoma, were unable to determine a specific damage coefficient for power plants although these plants are operated to minimize damages caused by poor quality water. For this analysis, a conservative approach was used although WTU estimates that good quality water would reduce treatment and project savings greater than $100,000 per year. This would not include any capital costs associated with construction utilizing corrosion resistant materials. For sensitivity purposes, estimates of the derivation of benefits for cooling water, assuming no RO treatment and limited use of 7 mgd over the project life, are shown in Table 4-28.

TABLE 4-28
POWER WATER QUALITY
REACH 9 - OKLAUNION

	Year 2005 Present Worth	6-1/8% Average Annual Benefits
Plan 3, With Area X	$ 6,003,700	$ 368,700
Plan 4, With Area VII	$18,641,100	$1,144,800
Plan 5, With Areas X & VII	$24,370,900	$1,496,600

SUMMARY OF MUNICIPAL AND INDUSTRIAL BENEFITS

Municipal and industrial benefits are calculated by reach for each major water provider that currently uses or plans to use Wichita River and/or the Red River as a source of water supply. Existing use of the river occurs in Louisiana by the city of Bossier City and an industrial user at Campti, Louisiana. Although the impacts of the Wichita Basin Chloride Control Project are slight this distance from the chloride control points, potential economic benefits are developed for the plans under consideration based on differences in the TDS concentration-duration curves for the without and with project condition. No water use from the Red River for municipal and industrial purposes in Arkansas and Oklahoma occurs at the present time. Other sources of water supply are generally of better quality and are utilized in the basin. In Texas, where recurrent shortages of water occur in some regions, use of Lake Texoma water and Lake Kemp water currently exists and is expected to continue to occur in the future. Full utilization of existing surface water may be less costly and result in fewer environmental impacts than developing a new source of surface water supply. Table 4-29 summarizes the municipal and industrial benefits by reach and plan.

TABLE 4-29

SUMMARY OF MUNICIPAL AND INDUSTRIAL BENEFITS BY PLAN

	Demand Center	Quantity Demanded (mgd)	Plan 3 Area X ($1,000)	Quantity Demanded (mgd)	Plan 4 Area VII ($1,000)	Quantity Demanded (mgd)	Plan 5 Areas X & VII ($1,000)
1	Bossier City/Municipal & Industrial	10	$24.0	10	$72.2	10	$96.3
	Industrial/Manufacturing	12	$3.9	12	$15.6	12	$23.4
5T-GTUA	GTUA-Sherman EDR	10	$22.8	10	$68.3	10	$91.0
5T-GRAY	Grayson County	5	$9.4	5	$29.5	5	$38.9
5T-NTMWD	North Texas Municipal Water District						
	Blend Lake Lavon & Lake Cooper	46.5	$281.4	48.7	$899.4	49.7	$1,048.4
9-WICHFALL	Wichita Falls						
	10 mgd RO/EDR with dam	10	$107.3	10	$523.5	10	$842.1
9-INDUSTRY	Steam-electric Oklaunion	0.3	$2.8	0.3	$11.0	0.3	$19.3
Total M & I		88.8	$439.4	91	$1,551.9	92	$2,144.0

PART V - AGRICULTURE

INTRODUCTION

Scope of Agricultural Evaluation Studies

Texas A&M University (TAMU), Texas Agricultural Experiment Station (TAES), and the Blacklands Research Center (BRC) conducted the agricultural evaluation studies, with some data and information provided by the U.S. Army Corps of Engineers, Tulsa District. Several revisions have occurred during the course of this study regarding water quality data and water availability. Portions of several reports provided by the TAES are included in this economic evaluation and in the general reevaluation report. This part of the economic evaluation is organized, first, by a brief description of the study area and reach designations. The description is followed by a more complete explanation of the utilization of Geographic Information System (GIS) techniques to describe the land use/cover with changes over the last two decades. Second, a discussion of water quality and availability and salinity impacts on crop yields occurs. Third, the agricultural optimization modeling of different alternatives using the General Algebraic Modeling System (GAMS) is discussed. Crop budgets along with other types of input data are discussed. Results of the evaluation and average annual benefits by plan are also presented. The evaluation report was completed in September 2000. Modifications, including changes in crop prices and interest rates along with various scenarios dealing with availability of Lake Kemp irrigation water, were completed in September 2001. Results of that economic analysis are provided at the end of Part III. Finally, since a Federal discount rate of 6-1/8% for FY 2002 occurred in October 2001, the model was run with only the interest rate change. The results are carried forward to the summary of benefits tables.

DESCRIPTION OF AGRICULTURAL STUDY AREA

Agricultural Study Area

The agricultural study area falls entirely within the Rolling Plains eco-region of Texas. This eco-region is characterized by slightly undulating land surface dominated by native rangelands. Brush, weeds, and cacti have gradually invaded this eco-region. This area is sparsely populated, and a significant portion of the uplands is actively managed for crop production. Area precipitation averages 28 inches annually. Rainfall is greater in the eastern portion of the study area, gradually decreasing toward the west. Precipitation is uniformly distributed throughout the year with a slight peak occurring in the spring. The Wichita River Basin and its intermittent tributaries provide drainage for this region. Figure 5-1 shows the extent of the study area.

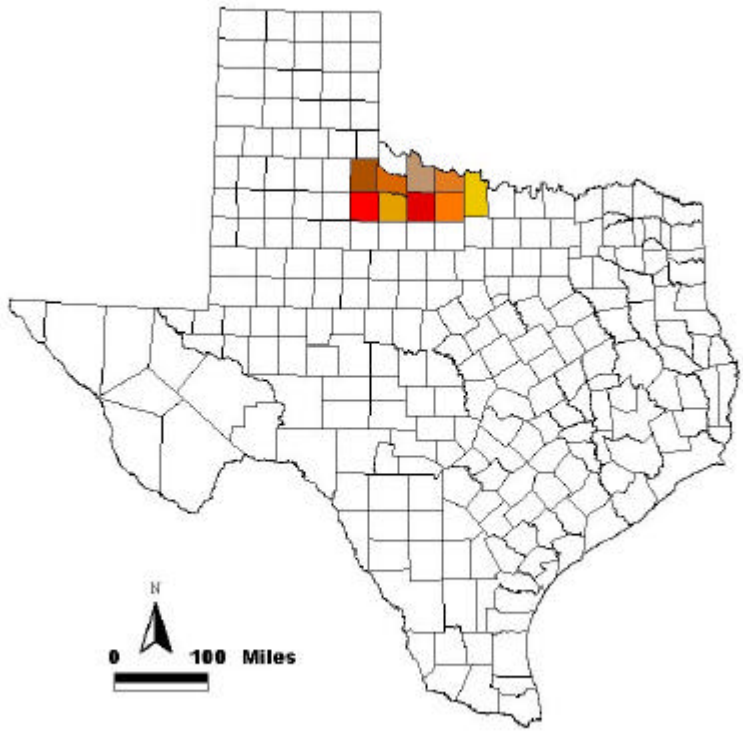


Figure 1: Location of the study area

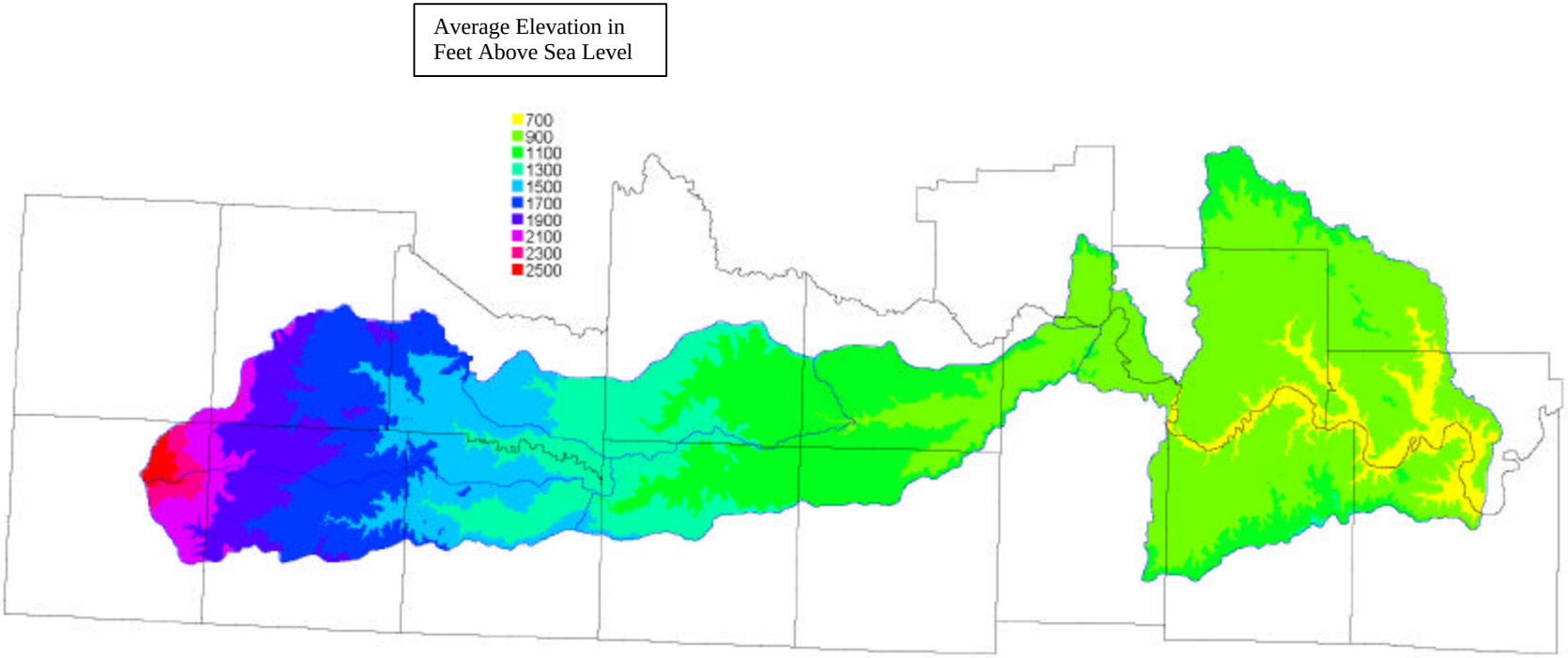
The Wichita River is part of the Red River watershed. The North and South Wichita Rivers flows through King and Cottle counties and forms the western boundary for the present study. The confluence of these two rivers is at the western end of Baylor County where they form the Wichita River. Several creeks empty their waters in the Wichita along its path before the river merges with the Red River in Clay County, with Lake Kemp in Baylor County, and with Lake Diversion in Baylor and Archer counties along the river's course.

Topography

The study area rises from about 600 feet in elevation at the eastern end of Reach 5, near the upper end of Lake Texoma, to nearly 2,600 feet above sea level in the western limits of the Wichita River Basin near East Afton in Dickens County. More than half of this 2,000-foot rise in elevation occurs west of the confluence of the North and South Wichita Rivers near the Knox-Baylor County line. Chart 1 is a topographic map of the study area.

The topography in the western third of the study area is considerably more rugged than is found in the eastern two-thirds of the basin. The higher plains are relatively flat and gently sloped, but they are deeply cut by the valleys of the streams in the area. The stream channels and their riparian flood zones are much narrower than found downstream. These features place considerable limitations on the potential for cropland agriculture in the western third of the basin. Most of the cropland in this region is limited to the relatively flat plains high above the stream-carved valleys.

Chart 1: Elevation Zones in the Wichita-Red River Salinity Control Project Study Area



The topography is somewhat less rugged, but still quite hilly, in the middle portion of the basin above Lake Diversion. The builders took advantage of this topography when they constructed Lake Kemp and Lake Diversion.

Below Lake Diversion, the hills flatten out and the stream valleys widen. Most of the steeper slopes in this eastern region are along the breaks that separate the river floodplains from the rolling plains above them. Cropland is found widely spread in both the valleys and the plains in this area.

The river channel, however, is deeply incised into the riparian floodplain downstream from Wichita Falls, and the channel banks are almost vertical along much of the river. The banks are typically about 20 feet high but appear to range from about 6 feet to as much as 40 feet high above the river bottom.

This is a fact that severely restricts recharge of the riparian aquifer from the river itself in Reach 7. Except for periods of flood runoff, groundwater in the riparian aquifer in this reach can be expected to be flowing toward and into the river rather than seeping from the river outward to the aquifer.

These high, almost vertical, banks also present other implications for the river hydrology since the soils in the banks are erodible. This affects the formation and movement of streambed silts, sands, and gravels, which in turn will affect the quality of water and fish and wildlife habitat in the area. There does not appear to be, however, a severe threat of erosion to croplands by the river through most of this reach. This may be because, with some areas excepted, the banks are fairly well protected by trees, tree roots, and other vegetation along the banks.

Agricultural Reaches or Impact Areas

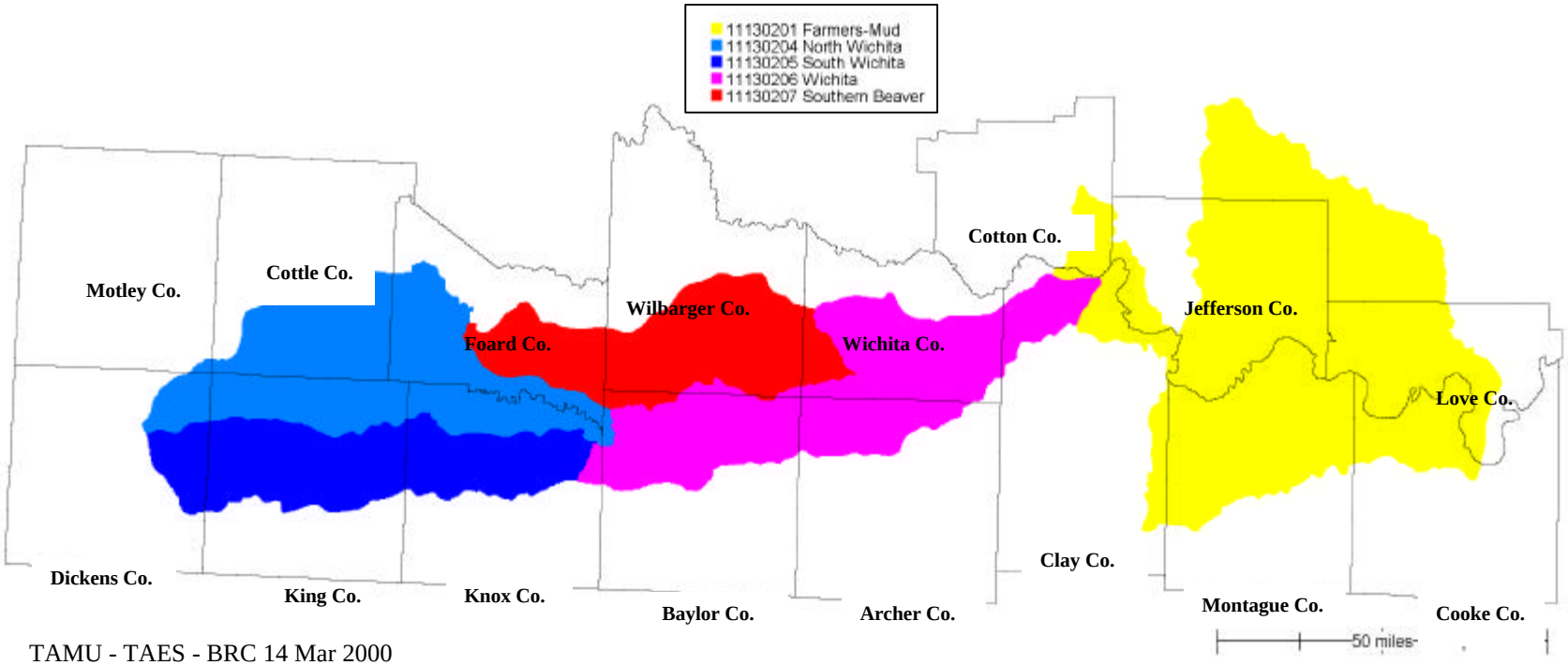
The general area in this evaluation includes all of the Wichita River Basin in Texas, the main stream, and the riparian area of the Red River downstream from the mouth of the Wichita River to the headwaters of Lake Texoma in Texas and Oklahoma. This includes parts of 13 counties in Texas and 3 counties in Oklahoma. The particular area of study lies within five Hydrologic Cataloging Unit (HCU) areas delineated by the U.S. Water Resources Council. Chart 2 displays the study area, the counties, and the HCU's that include and surround it.

Within this larger area, this evaluation focuses primarily on areas near the river that are most likely to be affected by constructing salt control facilities at Areas VII and/or X. In previous studies, the agricultural irrigation evaluation was defined as irrigable and potentially irrigable land within 1.5 miles of the Wichita River and the Red River. Recent developments of geographic information system (GIS) technology made it possible in this study to redefine the particular evaluation reaches as follows:

- Reach 5 is the Red River and its riparian land area in Texas and Oklahoma from Lake Texoma upstream to the Montague-Clay County line.
- Reach 6 is the Red River and its riparian land area in Texas and Oklahoma from the Montague-Clay County line upstream to the mouth of the Wichita River.

Chart 2: Counties and Hydrologic Cataloging Unit (HCU) Watersheds Involved in the Wichita-Red River Salinity Control Study.

HCU Numbers and
Names as Assigned by the
U.S. Water Resources Council



TAMU - TAES - BRC 14 Mar 2000

- Reach 7 is the Wichita River in Texas from its mouth upstream to Lake Diversion and all the land lying within 50 feet in elevation above the Wichita River that is also lying below the elevation of the main canals of the Wichita County Water Improvement District (WCWID).
- Reach 9 includes Lake Diversion, Lake Kemp, the Wichita River, and all land lying within 50 feet in elevation above these water bodies upstream from Lake Diversion to the confluence of the North and South Wichita Rivers.
- Reach 10 includes the North and Middle Wichita Rivers and all land lying within 50 feet in elevation of those rivers from the confluence of the North and South Wichita Rivers upstream to Areas VII and X.
- Reach 11 includes the South Wichita River and land lying within 50 feet of elevation of that stream.
- Reach 12 includes all land between Lake Diversion and the mouth of the Wichita River that lies within 50 feet in elevation above the main canals of the WCWID.

Previous evaluations designated the reaches in a different manner. The agricultural evaluation developed slightly different reach descriptions. The area defined in previous evaluations as Reach 8, the area on the Wichita River below Lake Diversion to the Red River, is now subdivided into Reaches 7 and 12. In the municipal and industrial evaluation, Reach 5 refers to Lake Texoma only. Lake Texoma was not evaluated as a source of water for agricultural purposes in this evaluation or in previous evaluations. Chart 3 is a map showing the locations of these redefined evaluation reach areas.

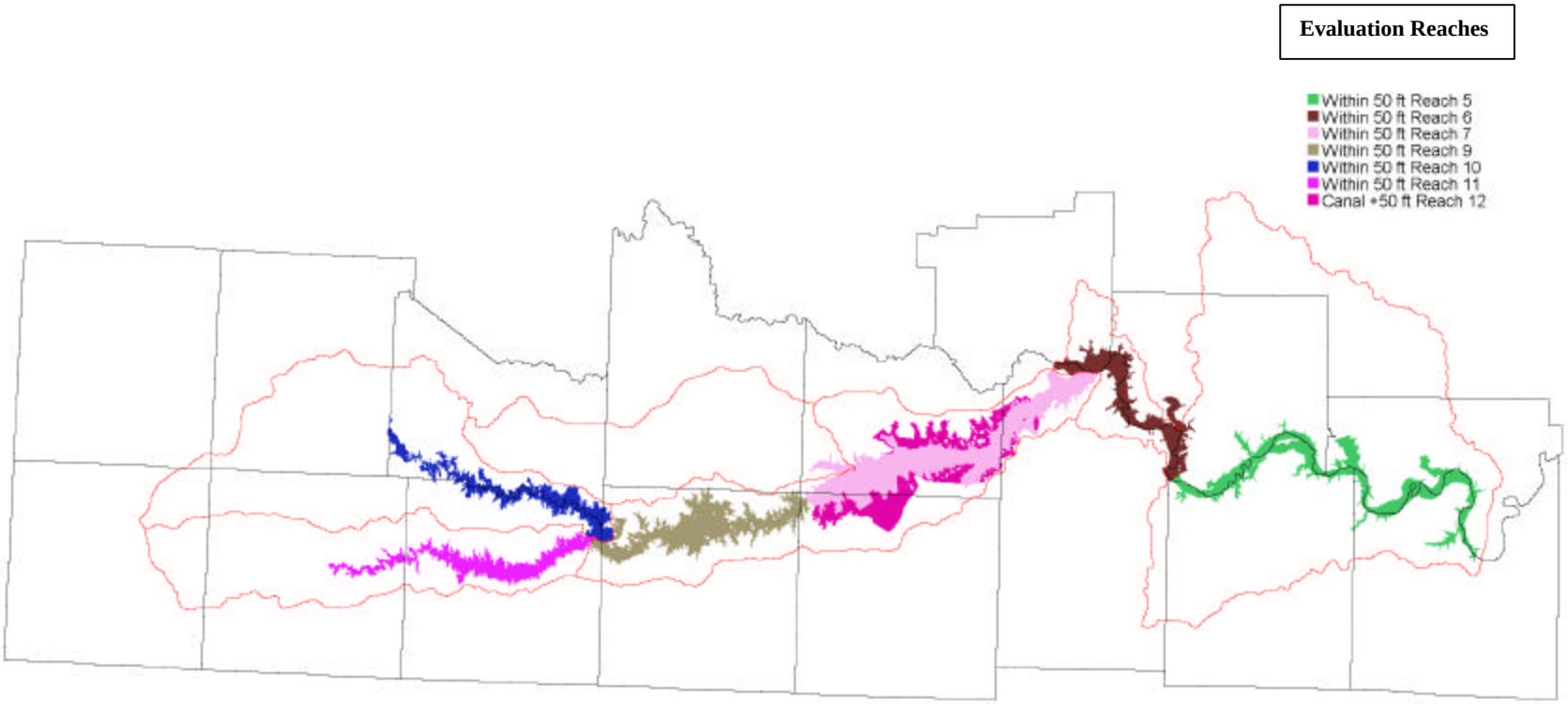
ANALYSIS OF LAND COVER/LAND USE CHANGES FOR 1977-1997

Land Cover/Land Use (LC/LU) data for 1977, 1987, and 1997 for nine counties along north-central Texas through which the Wichita River flows were generated to detect changes in the major LC/LU types of this area over a period of two decades. LANDSAT satellite imagery was used as the source for deriving the LC/LU information. Changes in the acreage of major LC/LU classes were estimated.

LAND COVER/LAND USE CHANGE DETECTION

The multi-temporal remotely sensed data have to meet several criteria prior to comparison of the LC/LU information generated from it. As far as the sensor is concerned, the entire data should be collected preferably by the same sensor under similar atmospheric and sun angle conditions. These criteria are often difficult to meet. The life span of the sensor/satellite does not extend beyond 10 years. Even under similar atmospheric and sun angle conditions, it is extremely difficult to obtain cloud free images. The resolution, both spatial and spectral, of the data collected should be similar in order to perform direct comparisons of the results (Jensen 1996). Re-sampling of one data to match the spatial resolution of the other often results in loss of information. Accurate geometric registration and minimal seasonal differences between the data are other conditions that should be considered before using multi-temporal data for change analysis (Avery and Berlin 1992).

Chart 3: Agricultural Evaluation Reaches



TAMU - TAES - BRC March 13, 2000

For this study, LANDSAT data acquired in 1977, 1987, and 1997 were used as the primary source for deriving LC/LU information. The spectral and spatial resolutions of this multi-temporal data changed over these 20 years. The 1977 and 1987 data were collected by a Multi Spectral Scanner (MSS) mounted in LANDSAT Satellites 3 and 4, at a spatial resolution of 79m, whereas the 1997 data were collected by the Thematic Mapper (TM) sensor mounted in LANDSAT Satellite 5 at a spatial resolution of 28.5m. The MSS data had only four spectral bands (two visible and two infrared), whereas the TM data has seven spectral bands (three visible, three infrared, and one thermal). The geographic extent covered by each scene also varied from time to time. Hence, there are some limitations for comparing the extent of land cover classes from one time period to another.

Materials

Image Data. The LANDSAT scenes (MSS and TM) were purchased from the EROS Data Center (EDC), Sioux Falls, South Dakota.

LANDSAT TM Data. After discussions with U.S. Army Corps of Engineers, Tulsa District experts who were familiar with the local vegetation and crop phenology, it was decided to acquire the May and October 1997 scenes. According to the experts, these 2 months should provide maximal spectral difference between the agricultural and range cover types of this region.

LANDSAT MSS Data. Six MSS scenes were acquired for this study, three for 1987 and three for 1997.

Aerial Videography. Digital aerial videography for an area approximating a 5-mile buffer along either side of the Wichita River was acquired. This aerial video mosaic was used to generate ground truth points for assessing the accuracy of the classified images.

Vector Data. All the vector data used in this project were either available or generated in ESRI's Arc Info format.

Methodology

Processing of the LANDSAT imagery was performed in ERDAS IMAGINE 8.3.1. Both TM and MSS data were processed similarly except for certain minor differences.

- Seven land cover types were recognized in the classification scheme used. Urban, bare ground, and cloud/cloud shadow were grouped together in the Other class. Vegetation types are grassland, shrubland, upland hardwood, bottomland hardwood, and agriculture. However, agriculture areas also include ploughed fields and other exposed farmlands. A brief description of each vegetation type is presented in Table 5-1.

TABLE 5-1
VEGETATIVE COVER TYPE DESCRIPTIONS

Cover Type	Description
Grassland	Grasses and other herbaceous species dominate this land cover type. It primarily consists of natural grasslands.
Shrubland	This brushy rangeland is characterized by mesquite invading herbaceous species. Lotebush, redberry juniper, and prickly pear may accompany the mesquite. It is often found on dry, highly erodible ridges.
Upland hardwood	This vegetation type is comprised primarily of oak, mesquite, hackberry, and redberry juniper. It is found on dry ridges and shallow soils and is not prevalent in the study area.
Bottomland hardwood	Bottomland hardwood occurs on floodplains and flats along river channels. Species commonly found in this type include mesquite, willow, and cottonwood.
Agriculture	This vegetation type encompasses land that is managed for crop production. It includes plowed fields of exposed soil and intensively managed pastureland.

Accuracy Assessment

The video mosaics were displayed in ArcView, and several points were created corresponding to each LC/LU type. A photo interpreter familiar with the local ground conditions identified the land cover type of the sample point.

A problem with collecting ground truth points using this method is the potential offset of the two data sources. The points collected off the aerial video mosaics could be geographically shifted while displayed on the satellite image. Several random points were displayed on the satellite image to check for geographic overlay. No visible shift was found between these ground truth points and the image; therefore, the ground truth points were considered reliable.

Results and Conclusions

Relative to the aerial videography, the accuracy of the LC/LU classification from the fall 1997 images was 91% for 2836/2837 and 84% for 2937. The accuracy was 72% for the spring 1997 images. The majority of the confusion of the spring imagery was between young growing crops and hardwood classifications. The percent accuracy of the fall 1997 images is well beyond the accepted levels used in similar projects. It was possible to distinguish agricultural fields from range and pastures using this single imagery alone. Classification of the spring 1997 scenes was intended to provide additional data, if necessary, to resolve overlap between these LC/LU types.

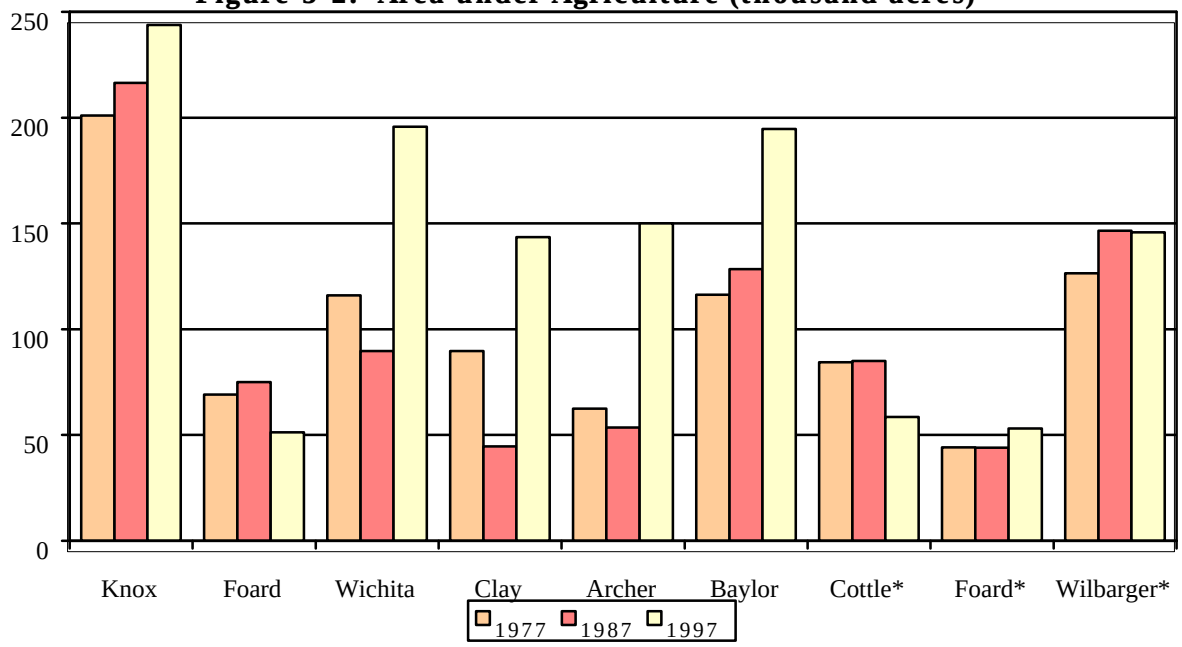
To evaluate changes from 1977 to 1997, area estimates of major vegetative cover types for individual counties in the study area were considered. The area under agriculture, hardwood, grassland, and shrubland was reported for each county that was fully encompassed in the imagery. Table 5-2 contains the area under agricultural cover types for 1977, 1987, and 1997 for the six counties. The change in agriculture cover for each county is presented in Figure 5-2.

TABLE 5-2
AREA UNDER AGRICULTURAL COVER TYPE BY DECADE

County	Area in 1,000 acres			Percent Change		
	1977	1987	1997	1977-1987	1987-1997	1977-1997
Knox	200.94	216.46	243.84	7.7	12.6	21.3
Foard	69.19	75.04	51.27	8.5	-31.7	-25.9
Wichita	115.99	89.70	195.75	-22.7	118.2	68.8
Clay	89.65	44.58	143.47	-50.3	221.8	60.0
Archer	62.44	53.50	149.99	-14.3	180.4	140.2
Baylor	116.31	128.37	194.67	10.4	51.6	67.4
Cottle*	84.46	84.95	58.59	0.6	-31.0	-30.6
Foard*	44.11	44.06	53.10	-0.1	20.5	20.4
Wilbarger*	126.37	146.48	145.81	15.9	-0.5	15.4
Total	909.45	883.14	1,236.49	-2.9	40.0	36.0

* Incomplete coverage for these counties.

Figure 5-2. Area under Agriculture (thousand acres)



Area under agriculture decreased from 1977 to 1987 then increased from 1987 to 1997 for an overall increase during the 20-year time period. National Agricultural Statistics Service (NASS) agriculture data show a similar trend in major agriculture crops for the same time period. It is evident from the above chart that Knox, Wichita, Clay, Archer, and Baylor counties had more land under agriculture in 1997 than in 1977. These are the counties through which the South Wichita and Wichita rivers flow.

The area occupied by the hardwood cover type in 1977, 1987, and 1997 for the six counties is presented in Table 5-3. The hardwood cover type declined in all the counties for the 20-year period except in Wichita County. This county witnessed a 114% increase in total hardwood cover during these 20 years. Changes in hardwood cover type for each county is presented in Figure 5-3. There is less saturated ground and growing vegetation in scenes acquired during a period of low rainfall, as was the case with the 1987 imagery. Classification of these scenes tends to define fewer hardwoods, particularly in bottomland areas, grouping hardwood clusters with the normally dryer shrubland class. This may account for the two counties that show no hardwood in 1987 but exhibit an increase in shrubland for the same time period.

The area occupied by the shrubland and grassland cover in 1977, 1987, and 1997 for each county is presented in Tables 5-4 and 5-5. The area under shrubland is shown in Figure 5-4. The shrubland class declined in all counties from 1977 to 1997. All but two counties experienced an increase in shrubland cover in the first decade (1977-1987) whereas the second decade (1987-1997) witnessed significant declines.

TABLE 5-3

AREA UNDER HARDWOOD COVER TYPE BY DECADE

County	Area (in acres)			Percent Change		
	1977	**1987**	**1997**	**77-78**	**87-97**	**77-97**
Knox	16108.45	0.00	6661.82	-100.0		-58.6
Foard	10395.50	0.00	1692.64	-100.0		-83.7
Wichita	3412.45	6718.65	7296.86	96.9	8.6	113.8
Clay	44510.12	32968.08	34072.62	-25.9	3.4	-23.4
Archer	19948.38	13251.97	6901.50	-33.6	-47.9	-65.4
Baylor	8576.84	2468.53	6983.05	-71.2	182.9	-18.6
Cottle *	7711.99	0.00	2216.49	-100.0		-71.3
Foard *	6782.90	0.00	1734.64	-100.0		-74.4
Wilbarger *	6617.34	6436.96	6627.22	-2.7	3.0	0.1
Total	124063.97	61844.19	74186.83	-50.2	20.0	-40.2

* Incomplete coverage for these counties.

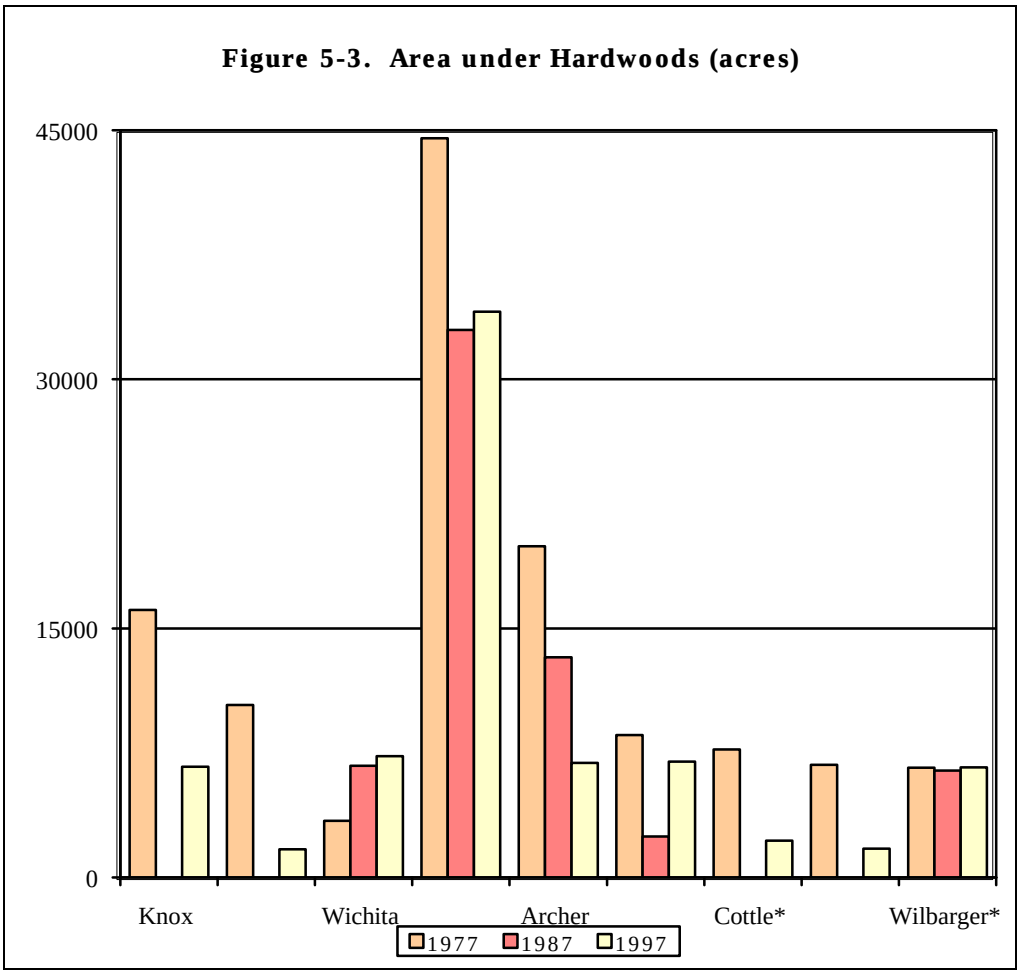


TABLE 5-4
AREA UNDER SHRUBLAND COVER TYPE BY DECADE

County	Area (in acres)			Percent Change		
	1977	1987	1997	1977-1987	1987-1997	1977-1997
Knox	39,091.22	45,740.68	23,664.77	17.0	-48.3	-39.5
Foard	27,008.03	42,108.31	7,810.83	55.9	-81.5	-71.1
Wichita	42,797.72	29,476.56	5,418.90	-31.1	-81.6	-87.3
Clay	82,620.36	162,483.08	9,160.00	96.7	-94.4	-88.9
Archer	73,816.18	78,004.53	4,185.87	5.7	-94.6	-94.3
Baylor	54,814.19	41,325.00	11,653.24	-24.6	-71.8	-78.7
Cottle*	29,904.04	37,613.56	10,452.33	25.8	-72.2	-65.0
Foard*	21,574.30	24,786.60	7,892.37	14.9	-68.2	-63.4
Wilbarger*	45,058.69	12,283.34	6,543.21	-72.7	-46.7	-85.5
Total	416,684.73	473,821.66	86,781.52	13.7	-81.7	-79.2

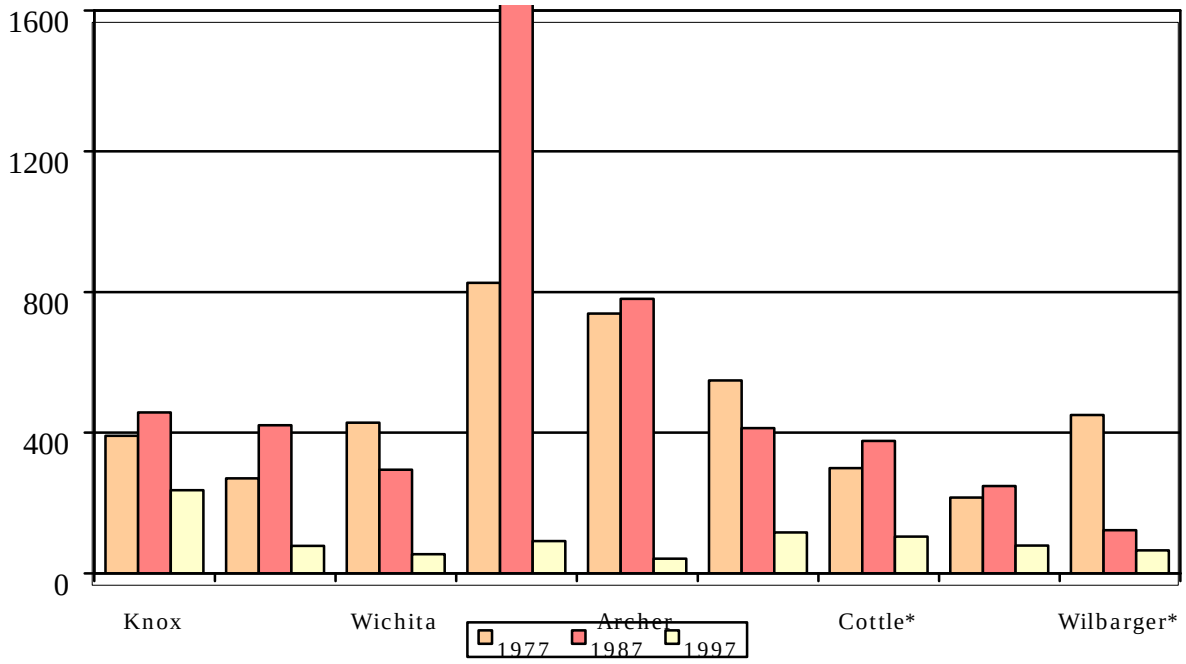
* Incomplete coverage for these counties.

TABLE 5-5
AREA UNDER GRASSLAND COVER TYPE BY DECADE

County	Area (in hectares)			Percent Change		
	1977	1987	1997	1977-1987	1987-1997	1977-1997
Knox	120,789.89	111,516.23	177,642.66	-7.7	59.3	47.1
Foard	104,864.30	101,454.32	107,651.59	-3.3	6.1	2.7
Wichita	135,173.58	150,528.38	153,518.29	11.4	2.0	13.6
Clay	375,248.53	276,826.13	475,820.70	-26.2	71.9	26.8
Archer	316,268.23	290,829.29	372,602.09	-8.0	28.1	17.8
Baylor	216,214.97	199,545.61	264,409.36	-7.7	32.5	22.3
Cottle*	71,053.61	31,295.22	111,545.88	-56.0	256.4	57.0
Foard*	76,166.10	68,402.22	107,016.54	-10.2	56.5	40.5
Wilbarger*	158,989.08	151,736.70	189,113.04	-4.6	24.6	18.9
Total	1,574,768.30	1,382,134.10	1,959,320.15	-12.2	41.8	24.4

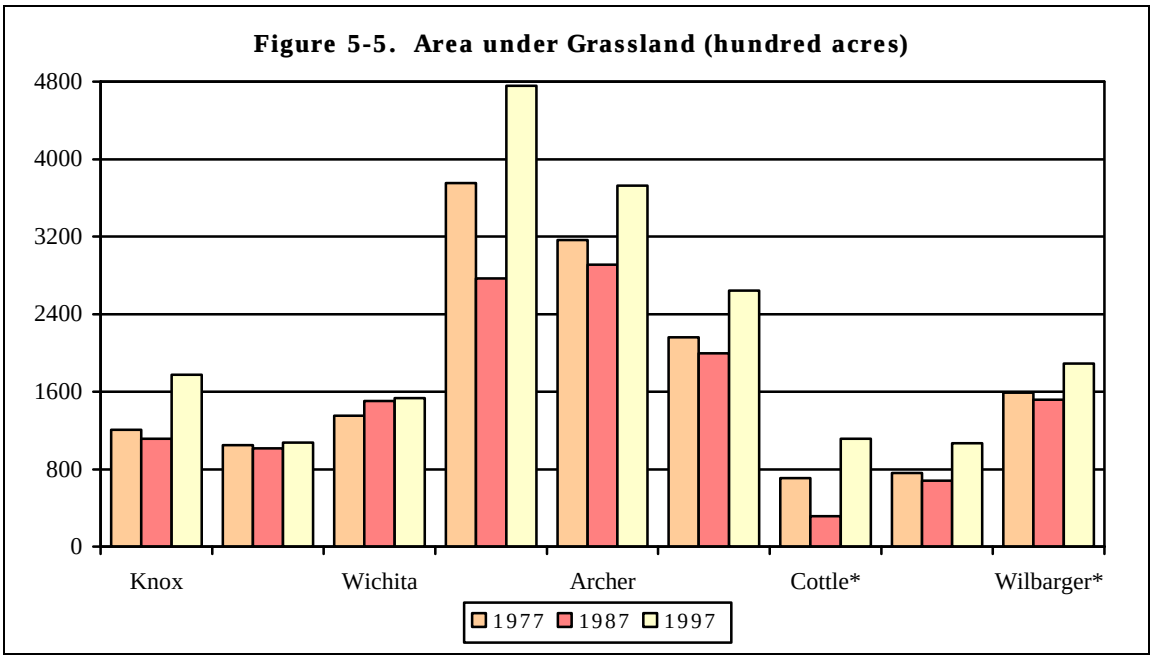
* Incomplete coverage for these counties.

Figure 5-4. Area under Shrubland (hundred acres)



The grassland cover type increased acreage in all counties for the 20-year time period. All but one county experienced a decline in the first decade (1977-1987), whereas all increased in the second decade (1987-1997). The area under grassland is shown in Figure 5-5. As stated, shrubland increased in 1987 before dropping significantly in 1997. Grassland witnessed an opposite trend when compared to the shrubland class. Marginal low-density shrubland and sparse grassland are classes that frequently overlap due to the similarity of spectral reflectance.

This similarity results in overlap between the two classes, particularly in the coarser resolution MSS data. This overlap is increased in scenes acquired during a dryer than normal time period, as was previously mentioned of the 1987 imagery. Data of higher resolution coupled with ground truth data and ancillary data, such as aerial photographs, would minimize interpretation confusion between these two classes in 1977 and 1987.

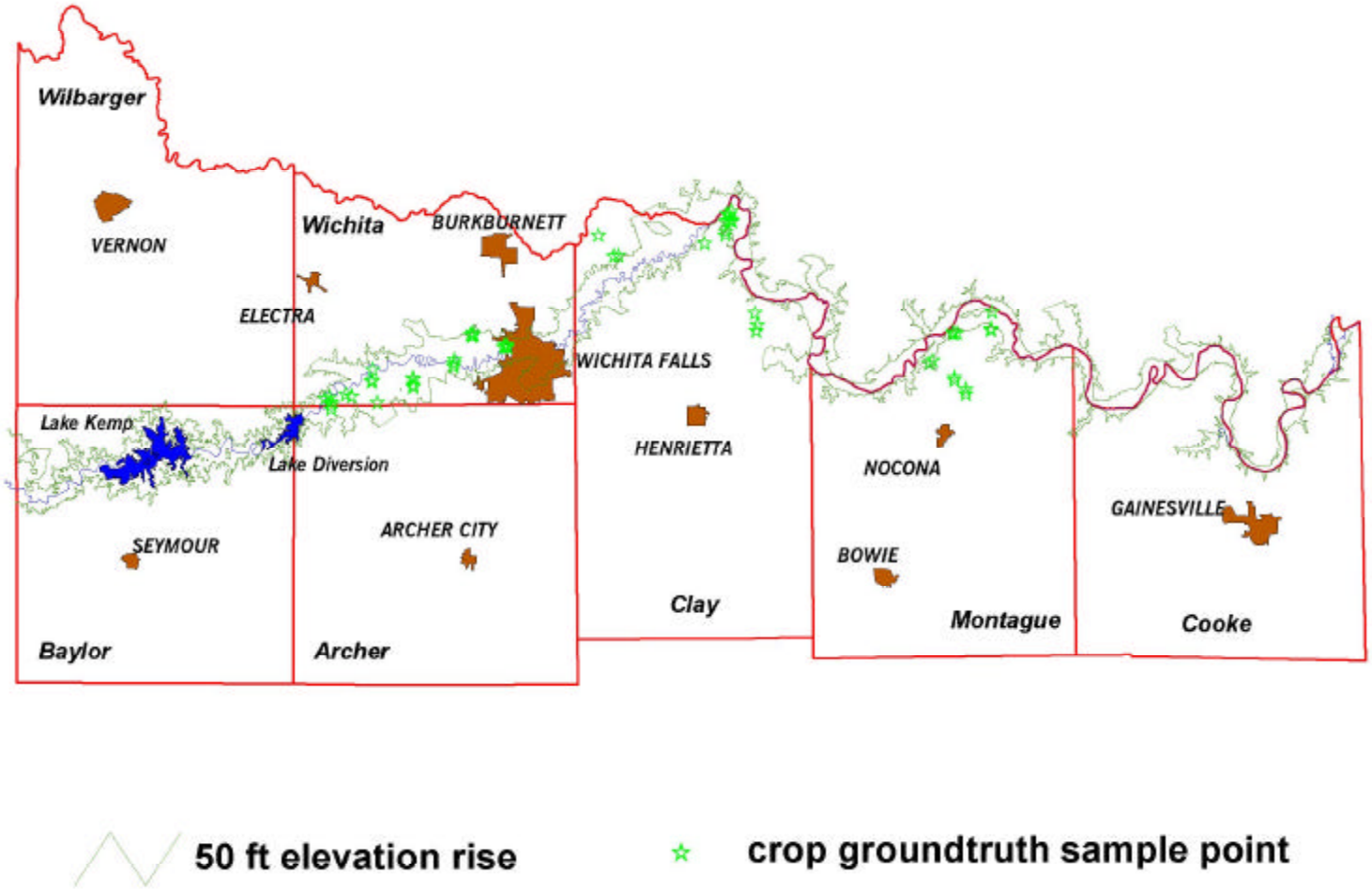


Recent Cropping Practices

In addition to the general classifications presented in the previous sections, an effort was also undertaken to classify the image pixels (where possible) by specific crop for the 1997 photo images. This corresponded to the late May and early October TM scenes. Ground truth points were obtained for areas within or near Reaches 6, 7, and 9 (Figure 5-6). These areas correspond to currently cropped areas within the study area. This effort was made to supplant traditional reliance on county level statistics, which could not be broken down to the area actually served by irrigation from the river.

Offices of the Natural Resource Conservation Service (NRCS) were visited in late August 2000 to obtain information on the crops grown in Wichita, Clay, and Montague counties for the 1997 cropping year. Records from that time period were less robust than what one might hope due to changes in the Federal farm programs. Historically, producers of major crops would have filed reports with the NRCS to qualify for farm program benefits. Support for those programs changed in 1996, and participation fell drastically. A total of 54 sample points, however, were located for various crops and geo-referenced by direct consultation with NRCS personnel. Personnel in those offices aided TAES personnel in locating the specific field either on a laptop computer-generated photo or within paper copies of photos in soil survey publications. Ground truth points obtained by the latter procedure were later added to the GIS coverage depicting those sample point locations. Figure 5-6 depicts the locations of the sample points taken. Some are exterior to the 50-foot elevation rise from the river sub-area used in the

Figure 5-6. Crop Ground Truth Sample Points



overall chloride control project analysis, but were useful in classifying image pixels and estimating cropped acreages for the study area itself. A summary of the type of points obtained appears in Table 5-6. This sample corresponds with the apriori notion obtained from local extension personnel that winter wheat is the primary crop grown in the region.

TABLE 5-6
GROUND TRUTH SAMPLE POINT COMPOSITION

Crop	No. of Sample Points
Alfalfa	1
Coastal bermuda grass	3
Cotton	8
Grain sorghum	4
Winter wheat for grazeout or hay	6
Winter wheat for grain	32*
* 2 of the 32 points were not in the 50-foot elevation rise study area.	

May TM Scene Classification

The ground truth points obtained were used to more accurately classify individual pixels within the two sets of 1997 TM photo scenes for the region. As noted earlier, Reaches 6, 7, and 9 were the focus of this portion of the effort as the vast majority of current cropped agriculture lay within those reaches. Preliminary classification of the pixels for the May 1997 TM scenes resulted in potential acreage estimates as shown in Table 5-7.

TABLE 5-7
MAY TM SCENE PRELIMINARY CLASSIFICATION ACREAGES

Crop	Reach 6	Reach 7	Reach 9	Total
Crop 1	38,350	24,057	14,156	76,562
Crop 2	10,333	6,567	1,815	18,714
Grassland	118,641	56,418	93,804	268,862
Bare Agriculture	18,617	8,775	37,274	64,666

Two major spectral signatures stood out initially (crops 1 and 2). Strict classification, however, was complicated by the fact that wheat harvest may start by mid-May in the region, resulting in two or more possible spectral reflectance values for wheat. Some sample points likely were nearly bare when the late May photos were taken. Twenty of the sample points had standing crops at sample locations in the initial generalized classification schemes with ten more points showing either harvested or barren fields. Seven of the initial 20 points identified as standing crops were identified as either grassland or woodland. This apparent discrepancy likely results from digitization errors, as crop 1 and crop 2 locations were found adjacent to the specific locations digitized in the groundtruthing effort. NRCS and TAES personnel identified crop locations using general outlines of specific fields (based on NRCS records), and the actual outline of those fields may have been different from conditions occurring in 1997. Given these conditions, crops 1 and 2 were classified as winter wheat. A portion of the bare agriculture acreage (Table 5-7) likely corresponds to harvested wheat acreage for the 1997 crop year, and

the acreage values obtained by summing values for crops 1 and 2. Table 5-8 is likely an underestimate of actual wheat grown in the area during that period.

TABLE 5-8
PREDICTED WHEAT ACREAGES BY REACH
MAY TM SCENE CLASSIFICATION

Crop	Reach 6 (acres)	Reach 7 (acres)	Reach 9 (acres)	Total (acres)
Wheat	48,682	30,624	15,970	95,276

The May scenes were of little aid in estimating additional acreages of alfalfa or grain sorghum. The single alfalfa observation was insufficient to isolate additional alfalfa acreage from the previously obtained grassland classification, and grain sorghum acreages had not yet been planted when the May 1997 photo was taken.

October TM Scene Classification

Cotton and winter wheat are the likely crops visible in the October TM photos. Unfortunately, grain sorghum harvest likely preceded the relevant period for the October photo. In addition, winter wheat (planted in September) may or may not have had sufficient time to emerge with a unique spectral signature. Classification as grassland or range might occur. Preliminary classification resulted in the acreages shown in Table 5-9.

TABLE 5-9
OCTOBER TM SCENE PRELIMINARY ACREAGE CLASSIFICATIONS

Crop	Reach 6 (acres)	Reach 7 (acres)	Reach 9 (acres)	Total (acres)
Crop 1	4,124	2,920	3,871	10,916
Crop 2	9,909	9,238	18,199	37,346
Crop 3	20,746	10,607	14,463	45,815
Bare Agriculture	43,124	31,135	43,476	117,735

Crops 1 and 2 were preliminary classified as cotton. County agricultural statistics, however, listed only 14,500 acres for the relevant counties. Drought conditions during the year likely forced abandonment of significant acreages of cotton. Crop 2 was therefore not included in the final cotton acreage prediction. Acreages for the crop 2 classification are consequently listed as unknown or failed cotton. In addition, 6 of the 30 wheat points were classified as Crop 3. Within the images, these pixels appeared mostly as wet barren ground. Given the young age of winter wheat and the likelihood of recent irrigation to aid the crop in emergence, crop 3 pixels were classified as winter wheat. All grain sorghum locations were identified as bare agriculture in the preliminary classification. Alfalfa and coastal bermuda locations were identified as grassland, similar to the classification effort with the May TM scenes. No further refinement was possible. Final acreage estimates for cotton and winter wheat for the October TM scenes appear in Table 5-10.

TABLE 5-10
PREDICTED CROP ACREAGES BY REACH
OCTOBER TM SCENE CLASSIFICATION

Crop	Reach 6	Reach 7	Reach 9	Total
Cotton	4,124	2,920	3,871	10,916
Wheat	20,746	10,607	14,463	45,816
Unknown or Failed Cotton	9,909	9,238	18,199	37,346

Summary

LANDSAT TM scenes acquired in the fall of 1997 generated a LC/LU map of the Wichita River watershed that returned an average level of accuracy of 87.5%. Delineation of agriculture from range and pasture was possible with the fall imagery.

Using coarser resolution MSS scenes, changes in major land cover types from 1977 to 1997 were measured. Agriculture and grassland cover types showed an overall increase in area for the time period. Hardwood and shrubland witnessed an overall decline during the 20 years. Additional classification was attempted for the 1997 TM scenes by obtaining crop specific ground truth points for 54 sites in the region. Further classification reinforced the notion that winter wheat is the primary crop grown in the study area with minor acreages of cotton occurring as well. Estimated acreages are likely low for winter wheat due to the fact that the May photos occurred during harvest. Further refined classification was also hampered by the fact that the grain sorghum growing season was not captured in the two sets of photos. Attempts to further separate coastal bermuda and alfalfa acreages from the preliminary grassland classification were unsuccessful due to the small number of ground truth points and the similarity in spectral signatures for those crops. Technical difficulties, possibly in combination with abandonment due to drought, resulted in an unknown classification for acreages originally classified as cotton.

Land Uses and Irrigated Area Trends

Most of the land use information used in this study has been derived from information developed by the Soil Conservation Service (SCS) (now the Natural Resources Conservation Services [NRCS]). In the late 1970's and early 1980's, SCS conservationists prepared digitized maps of lands uses and soils for most of the agricultural counties in the nation. In Texas, this project was known as the Computer Based Mapping System (CBMS). In Oklahoma and other states, the project was known as the Map Information and Display System (MIADS). In both systems, grids were created that divided the county maps into small area cells. For MIADS, these were 4-hectare (about 10-acre) cells. For CBMS, they were 6-hectare (about 15-acre) cells. Each cell was labeled with symbols that defined the dominant land use and the name of a typical soil in the cell area.

The most important advantages gained in using the CBMS and MIADS data, in the counties for which they are available, is that the descriptions of land uses and soils are quite well detailed and they show specific locations of irrigated land. In fact, the detailed information in the CBMS and MIADS data has been consolidated in this study to reduce the computational work required to complete the analyses. For example, the number of different kinds of land uses

has been consolidated from 38 in the CBMS and MIADS database to 12 major land use groups in this study.

Other reasons to want to use the CBMS and MIADS data are: 1) the land use interpretations were made by visual inspection of the ground and aerial photographs by persons familiar with their survey areas, and 2) the data were directly linked to the completed soil survey maps where those were available.

Unfortunately, there are some disadvantages as well. One is that there was not a diligent attempt to merge the CBMS and MIADS data at the county boundaries. While there were national standard instructions for defining the land uses and soils selected for all the cells, the MIADS and CBMS maps do reveal that different persons made somewhat different interpretations of land use in each county. Another disadvantage is that the data are somewhat stale. The data were assembled more than two decades ago.

Nevertheless, the advantages of using the CBMS and MIADS data are somewhat more significant than the disadvantages because they include more detailed information than is available in other digital sources of land use data.

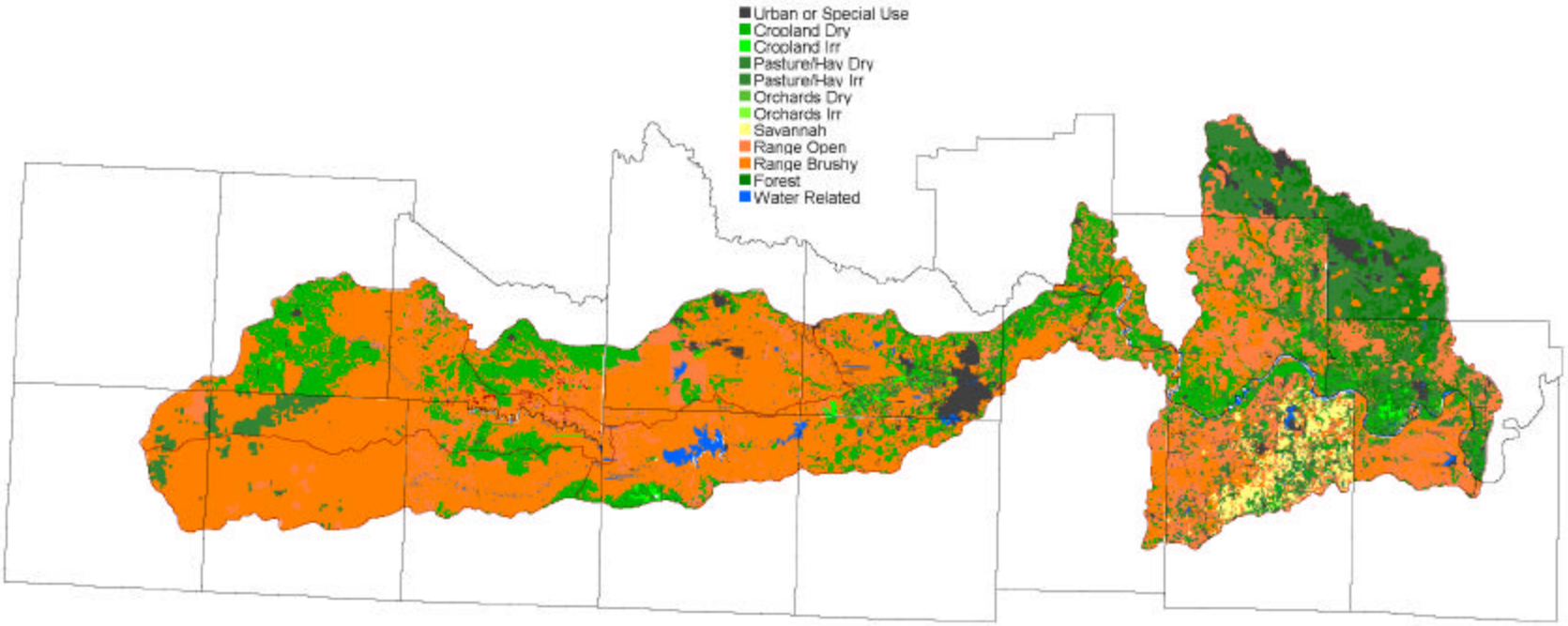
Since there are no CBMS data for King and Dickens counties in Texas and since no MIADS data were obtained for Stephens and Carter counties in Oklahoma, land use data for these counties were obtained from the LC/LU maps available from the U.S. Geological Survey (USGS). The LC/LU data were obtained in the late 1970's from interpretations of satellite imagery and high altitude aerial photography. Chart 4 is a map of the major land uses in the study area as derived from the CBMS, MIADS, and LC/LU data.

Table 5-11 lists the major land uses in the study area that are shown in the colored portion of Chart 4. This table reveals that only 25% of the total area is being used for cropland, pasture, and orchards. About 20% of the area is savannah and open range. Nearly 50% of the area is brushy rangeland. Less than 7% of the area is irrigated cropland, pasture, or orchards.

Table 5-12 lists the acres of irrigated land in the portions of the counties that are within the basin study area. Nearly 68% of the irrigated land is in Wichita County. Nearly all this land is serviced by the Wichita County Water Improvement District No. 2 (WCWID) irrigation water delivery system.

The data on irrigated areas reported in the CBMS and MIADS data have been compared to data reported by the U.S. Bureau of Census and the Texas Water Development Board (TWDB). This comparison reveals significant differences in estimates of irrigated area. These differences occur as a result of the different methods used to obtain data. The CBMS and MIADS data were developed from interpretations of aerial photographs confirmed by on-the ground visual inspection by soil conservationists employed by the SCS and/or by Soil Conservation Districts in the area in the late 1970's and early 1980's. The TWDB data were obtained from reports by persons and agencies involved in water resources programs of State and county governments and other water resource organizations. The TWDB data are now collected annually. The Census data are obtained from responses from farmers and ranchers to the Bureau

Chart 4: Mjor Land Use Groups in the Wichita-Red River Salinity Control Project Study Area



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of Census. The Bureau conducts its Census of Agriculture at 5-year intervals in the years ending in 2 and 7, as in 1987 and 1992.

TABLE 5-11
SUMMARY OF AREAS OF MAJOR LAND USES IN THE HCU'S IN THE STUDY AREA

Major Land Use	Area (acres)
Urban or Special Use	100,768
Cropland Dry	588,301
Pasture/Hay Dry	231,809
Orchards Dry	10,906
Subtotal of Dry Crop, Pasture, and Orchards	**831,016**
Cropland Irrigation	13,205
Pasture/Hay Irrigation	10,148
Orchards Irrigation	186
Subtotal of Irrigated Lands	**23,539**
Savannah	66,814
Range Open	598,771
Range Brushy	1,662,563
Forest	65,482
Water Related	55,205
Red Badlands	4,784
Total of Land Use Areas in the Five HCU Areas	**3,408,942**

TABLE 5-12
DISTRIBUTION OF IRRIGATED LAND BY COUNTY

County	Irrigated Land (acres)
Archer	82
Baylor	2,644
Cooke	100
Cottle	826
Cotton	7
Foard	14
Jefferson	98
Knox	612
Love	2,781
Montague	186
Wichita	15,896
Wilbarger	293
Total Irrigated Area in Study Area	**23,539**

The TWDB and Census data are summarized by county. The CBMS and MIADS data may be summarized by any selected delineated portion of the area covered by the survey. Table 5-13 shows a comparison of the different reports of irrigated areas in 13 of the 16 counties in the study region. For the nine counties for which data were obtained from the TWDB, the total irrigated area reported in 1997 was about 57,000 acres. The CBMS reported about 85,000 acres of irrigated land in those counties in the late 1970's to early 1980's.

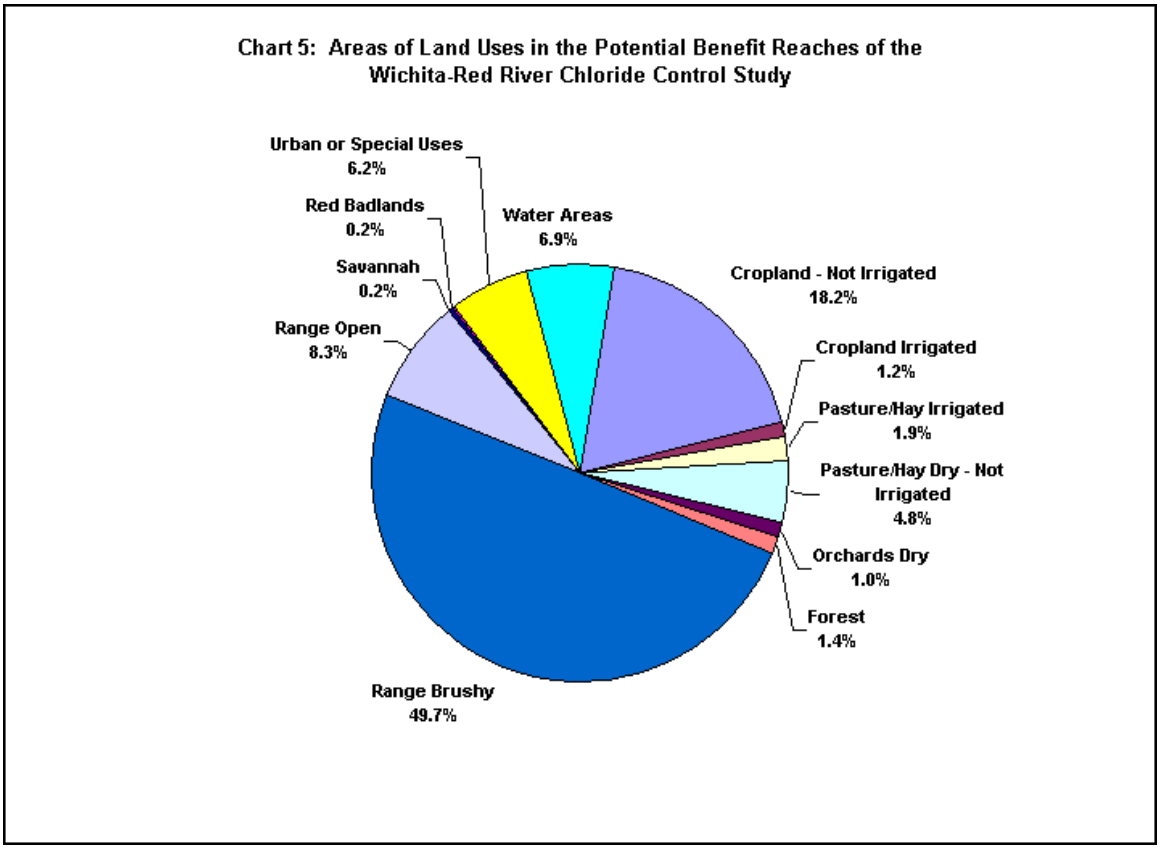
TABLE 5-13
IRRIGATED AREAS AS REPORTED BY CENSUS, TWDB, CBMS, AND MIADS

County	Irrigated Area in County as Reported in 1987 U.S. Census (acres)	Irrigated Area in County as Reported in 1992 U.S. Census (acres)	Irrigated Area Reported by Texas Water Development Board in 1997 (acres)	Irrigated Area in Counties in CBMS and MIADS Maps Circa 1980 (acres)	Portion of Irrigated Area Reported Within Wichita-Red Basin Study Area by CBMS and MIADS (acres)
Cotton	400	0	N/A	1,322	7
Jefferson	200	56	N/A	348	98
Love	3,500	3,980	N/A	3,207	2,781
Archer	300	0	0	82	82
Baylor	1,700	717	1,156	6,037	2,644
Clay	700	707	796	0	0
Cooke	1,500	91	341	242	100
Cottle	900	571	N/A	895	826
Foard	1,900	179	3,719	3,212	14
Knox	19,500	21,488	19,705	40,888	612
Montague	800	639	602	198	186
Wichita	4,400	3,956	10,340	15,955	15,896
Wilbarger	7,600	8,743	20,420	18,772	293
N/A = Not Available.					

Texas Water Development Board data from previous years support the hypothesis that a large part of this difference is due to a major decline in irrigated farmland since the 1980's. The TWDB reported about 31,000 acres of irrigation in Wichita County in 1979 but only about 11,300 acres in 1996. This apparent decline is also supported by the Census data. In spite of increases in reported areas irrigated in Knox, Wilbarger, and Love counties, total areas farmers reported as irrigated in the 13 counties declined by nearly 2,300 acres from 1987 to 1992.

This change is apparently not connected very closely to water quality because the water quality in the WCWID canal system has, if anything, slightly improved during the recent 20 years. Other factors, such as urbanization and declining farm incomes, have probably been much more significant considerations when farmers have decided how much land to irrigate. There is no reason to suppose that these other factors will change direction in the near future.

For this study, however, it is important to know what the land uses are and what land has been irrigated in the reaches described above. This information can only be obtained by examining the CBMS and MIADS data for the evaluation reaches described above. Table 5-13 and Chart 5 provide this information. The more than 16,000 acres of irrigated land comprise only about 3% of the total area in the evaluation reaches. In Reach 7, however, nearly 12% of the area is irrigated and another 31% is in non-irrigated cropland, pasture, hayland, and orchards.



Irrigating just these lands could use much more water than is potentially available for irrigation in the study area. There is no reason to include conversion of range and forestlands to irrigated croplands as an option in this study. The economic model was limited on land that could be potentially irrigated and did not include range or forestland.

Crops

The land use maps do not provide much information about the kinds of crops that have been, or that are being, produced in the study area. These data must be derived from other data sources. Detailed compilation and interpretation of crop production data is primarily the domain for the economic analyses for this study. However, some basic information about crops and cropped areas is needed in the hydrologic analysis because crop water consumption is an important factor that must be estimated. The portions of the crop water supply that would be provided by irrigation water and by natural rainfall must also be estimated as a part of the procedure for estimating the changes in salinity and chloridity that may occur in the irrigated soils if the salinity of the irrigation water is changed.

The crop area data used herein are derived by manipulating data from the 1992 Census of Agriculture. The Census data are published for counties, not for watersheds or HCU's. A Geographical Resources Analysis Support System (GRASS) program was used to derive estimates of the areas of agricultural land in each portion of each HCU in each county. These areas were then used in a spreadsheet to apportion the crop acreages reported in each county to each portion of HCU in that county. Table 5-14 provides a summary of the results of this calculation of estimates of crop acreages in each of the five HCU's in the study area. No attempt was made to further reduce these crop area estimates to the benefit evaluation reaches. It was assumed that the proportions of acreages of the major crops would be about the same in the benefit evaluation reaches as in the HCU's within which they are located. The HCU's and the benefit evaluation reaches in them are as follows:

HCU 11130201	Reaches 5 and 6
HCU 11130204	Reach 10
HCU 11130205	Reach 11
HCU 11130206	Reaches 7, 9, and 12

No reach is associated with HCU 11130207.

Chart 6 shows the areas in cropland, pasture, and orchards in the study area, and Chart 7 shows the cropland, pastureland, hayland, and orchards in the benefit evaluation reaches in the study area.

TABLE 5-14
AREAS OF MAJOR LAND USES IN THE EVALUATION REACHES

Major Land Use	Reach 5 (acres)	Reach 6 (acres)	Reach 7 (acres)	Reach 9 (acres)	Reach 10 (acres)	Reach 11 (acres)	Reach 12 (acres)	Total Land Use Area (acres)
Cropland Dry	**20,789**	**17,740**	**37,986**	**1,201**	**2,373**	**0**	**17,285**	**97,374**
Orchards Dry	5,285	186	30	0	0	0	0	5,501
Pasture/Hay Dry	16,851	5,319	2,982	136	0	0	640	25,928
Subtotal	**42,925**	**23,245**	**40,998**	**1,337**	**2,373**	**0**	**17,925**	**128,803**
Cropland Irrigated	43	75	5,700	16	329	0	30	6,193
Pasture/Hay Irrigated	0	0	9,703	0	0	0	235	9,938
Subtotal Irrigated	**43**	**75**	**15,403**	**16**	**329**	**0**	**265**	**16,131**
Forest	6,972	465	0	0	0	0	0	7,437
Range Brushy	18,980	18,225	50,017	56,670	40,100	46,752	35,936	266,680
Range Open	10,674	3,344	7,828	5,801	8,090	4,697	4,142	44,576
Red Badlands	0	0	0	0	1,139	0	0	1,139
Savannah	1,333	0	0	0	0	0	0	1,333
Urban or Special Use	1,924	315	16,597	509	274	70	13,435	33,124
Water Related	9,368	1,970	2,517	18,545	1,895	1,178	1,396	36,869
Total Area in Reaches	**92,219**	**47,639**	**133,360**	**82,878**	**54,200**	**52,697**	**73,099**	**536,092**

Chart 6: Areas in Cropland, Pasture, and Orchards in the Wichita-Red River Salinity Control Project Study Area.

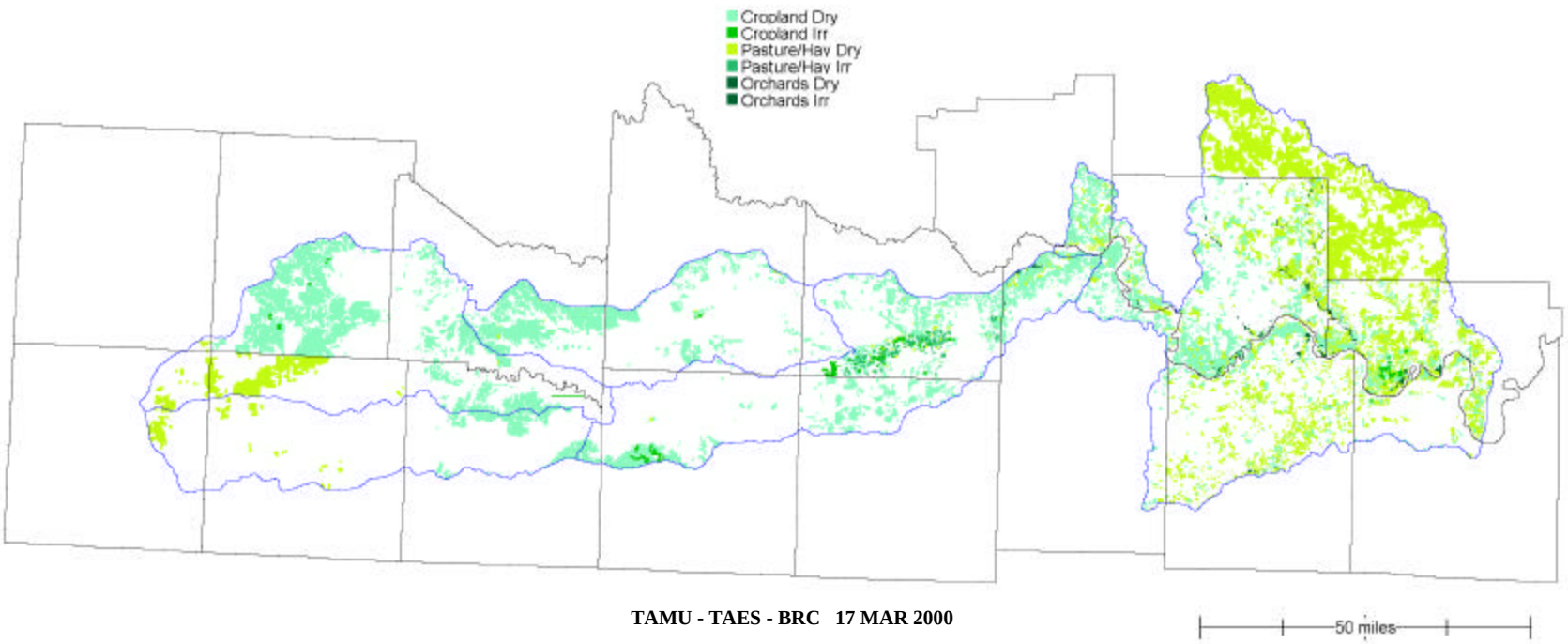


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Chart 7: Cropland, Pastureland, Hayland, and Orchards in the Benefit Evaluation Reaches in the Wichita-Red River Salinity Study

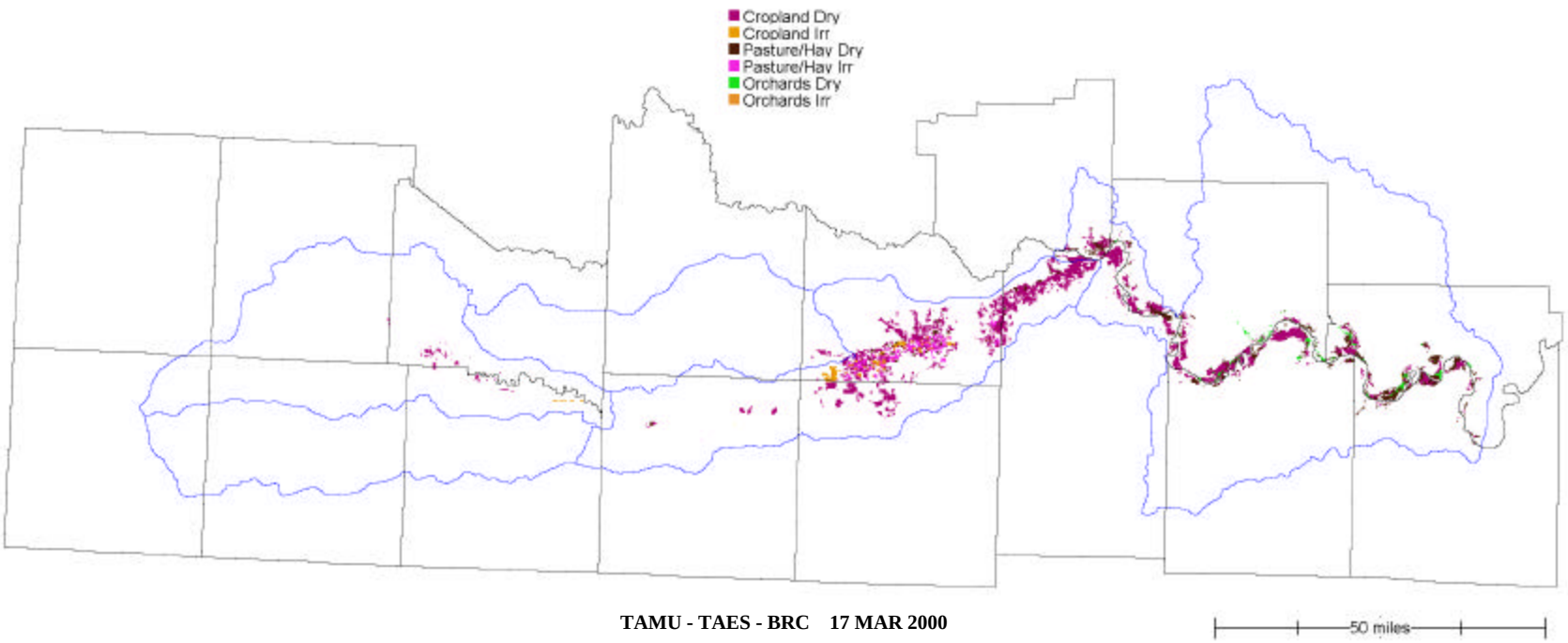

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Table 5-15 reveals that non-irrigated winter wheat was the dominant crop in 1992. Almost half the total area used for crop, hay, and pastureland was harvested in winter wheat. More than 91% of the land used for crops, hay, and pasture in the study area was used for just four crops: winter wheat, non-irrigated hay, non-irrigated pasture, and non-irrigated cotton. Personal observations in the early spring and late summer of 1999 suggest that the portion used for non-irrigated winter wheat may have increased to more than 60% while the area used to produce cotton has probably declined to just a hundred acres or so. Most of the wheat land was left open during the summer of 1999 but some of the area was sown to an annual grass, probably as a cover crop to comply with the erosion control features of government conservation programs.

TABLE 5-15

ESTIMATED AREA OF CROPS HARVESTED IN FIVE HCU AREAS IN 1992

Crops	HCU 11130201	HCU 11130204	HCU 11130205	HCU 11130206	HCU 11130207	Total Acres	Percent of Total
Irrigated Corn	151	0	0	0	0	151	0.04
Irrigated Cotton	0	1,171	970	900	170	3,211	0.78
Irrigated Potatoes	5	5	3	2	1	16	0.00
Irrigated Sorghum	0	414	348	61	0	823	0.20
Irrigated Wheat	0	924	777	599	66	2,366	0.57
Irrigated Peanuts	2,093	326	51	11	238	2,719	0.66
Irrigated Vegetables	51	0	0	5	28	84	0.02
Irrigated Orchards	199	7	6	90	17	319	0.08
Irrigated Misc. Crops	8	0	0	0	0	8	0.00
Irrigated Hay	484	125	74	608	658	1,949	0.47
Irrigated Pasture	297	89	73	458	61	978	0.24
Dry Corn	866	0	0	254	11	1,131	0.27
Dry Oats	1,475	622	117	563	169	2,946	0.71
Dry Silage	120	0	0	67	0	187	0.05
Dry Cotton	2,025	27,519	3,247	7,501	11,101	51,393	**12.43**
Dry Sorghum	2,418	1,244	679	1,151	458	5,950	1.44
Dry Soybeans	429	0	0	0	0	429	0.10
Dry Wheat	68,634	24,267	9,380	70,351	30,425	203,057	**49.12**
Dry Peanuts	2,416	70	54	10	69	2,619	0.63
Dry Vegetables	2,331	0	0	52	50	2,433	0.59
Dry Orchards	5,509	9	5	404	27	5,954	1.44
Dry Misc. Crops	1,056	100	0	4	600	1,760	0.43
Dry Hay	51,485	4,107	872	11,805	2,300	70,569	**17.07**
Dry Pasture	14,892	22,650	2,465	2,186	10,184	52,377	**12.67**
Total Crops & Pasture	156,944	83,649	19,121	97,082	56,633	413,429	
Census by counties as apportioned by C.H. Walker.							

Most of the winter wheat appears to be used for grazing cattle rather than for producing grain, but it is a common practice to use winter wheat for both limited grazing and grain harvest in the same season. Most of the land in permanent hay and pasture appears to be bermuda. Other crops that could be grown in the area, with sufficient controls on irrigation water salinity, might be grain sorghum and alfalfa.

Due to similar plant characteristics and the relatively small areas of land they may occupy, the analyses for these crops might be extended to apply to a few other crops with similar characteristics. Oats and rye are quite similar in characteristics to winter wheat, and corn grain and silage would be similar to sorghum.

Soils

As with the land use data, most of the soil map information has been assembled from the CBMS and MIADS database. CBMS and MIADS data were not available for King and Dickens counties in Texas and for Stephens and Carter counties in Oklahoma. The STATSGO soils map[1], also published by the NRCS, was used for these county areas. Chart 8 displays the combined soil map for the study area. As the map shows, the STATSGO map is less detailed than the CBMS and MIADS maps. Each colored area in the STATSGO map represents as many as 21 different soils as defined in the CBMS and MIADS maps. The dominant soil in each STATSGO map area has been selected to represent the characteristics of all the soils in that area.

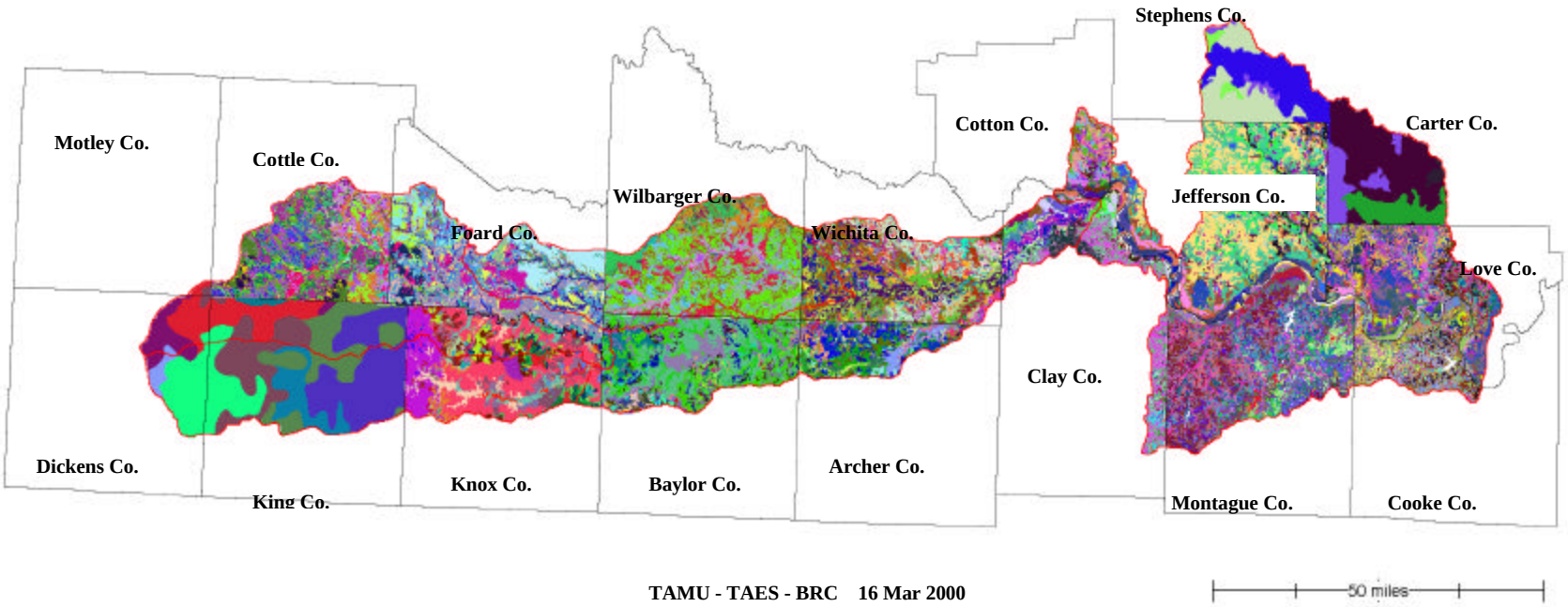
The soil map is very complex. There are 630 different soil areas shown on the map. This is simply too many soils to be used for economic or hydrologic evaluations because the possible combinations of soils, land uses, and crops with and without irrigation would make a very large array. The challenge was to decide which few soils could be used as typical soils to represent all the other soils in the area. The discussion in this section will be limited to describing how a few soils were selected to represent all the potentially irrigable soils in the benefit evaluation reaches for the economic analysis.

The first step was to find and eliminate from consideration all the soils having characteristics that restrict their potential use in irrigated and non-irrigated agriculture. The NRCS has developed databases of all the soils that have been surveyed. These databases list each of the soils and phases of soils with their identification codes and names. The data on the physical properties that have been measured or estimated in order to characterize each soil phase included. Access to these databases makes it possible to identify, classify, and map those soils in the area that have characteristics that impose limitations on their use for agriculture. The soil limitations considered most important for this study were:

- Depth of soil to bedrock or other restricting layer: Shallow soils hold less water and nutrients and restrain root growth for most agricultural crops.
- Steepness of slope: Soils with steep slopes tend to have broken slopes as well. Development and management of irrigation water and irrigation systems are more difficult and expensive on steep and broken slopes than on gentle slopes.

[1] State Soil Geographic (STATSGO) Data Base, Data Use Information. Misc. Pub. Number 1492. USDA, Soil Conservation Service. Revised May 1994.

Chart 8: Soil Map For the Wichita-Red River Salinity Control Project Study Area.



TAMU - TAES - BRC 16 Mar 2000

- Rockiness of soil: Rockiness makes tillage, harvesting and irrigation difficult and also restricts root growth and soil water holding capacities.
- Salinity and alkalinity: Soils that are naturally saline, alkaline, or both should not generally be considered for development of agriculture because their chemical characteristics tend to indicate that soil water drainage is limited. Irrigating these soils can further decrease their usefulness for agriculture.
- Other factors: Often the names of soils themselves indicate problems that are not directly determined by measurements of their chemical or physical characteristics. Soil names that include terms such as "shallow phase", "severely eroded", "rock outcrop", "urban complex", etc., have been included in the list of limited soils.

Chart 9 is a map showing where the soils in the study area have one or more of these kinds of limitations. The soil areas colored on this map have been defined as not being available for irrigated agriculture now or in the future.

The second step in the process of selecting representative soils was to remove those soils that are not already being used for irrigated or non-irrigated cropland, pasture, or orchards. The reasons for making this decision are: 1) it will be much easier and less expensive to develop or maintain irrigation on lands that have already been used for cropland and pasture than to convert range, savannah, forest, or urbanized lands to irrigated agriculture, and 2) there is more than enough cropland and pastureland in the benefit evaluation reaches to use all the irrigation water that can be made available to that land from the Wichita River and its riparian aquifers. This latter point is discussed in more detail below. As stated above, Chart 7 displays where cropland, pastureland, and orchards are found in the benefit evaluation reach areas.

The third step was to reduce the range of selectable soils to those that are found in the benefit evaluation reaches.

The fourth step was to reduce the number of selectable soils by grouping the soils having the same first names and choosing only one soil to represent the characteristics of the other soils in that group. This process introduces a significant potential for error into the selection process because individual soils in the same general name group often have characteristics quite different than other soils in their group. This is the reason they are classified as separate soils. Nevertheless, for simplification there is a strong justification for the procedure used.

The fifth step was to make a list of the total land areas occupied by the soil groups defined in step 4 (including only those soils which do not have significant limitations for agriculture), to sort that list in descending order of the group area sums; to find which few of the soil groups represented a majority part of the areas of cropland, hayland, pastureland, and orchards; and to decide which soil in each of the majority group could be used as being representative of all the soil areas under those land uses.

Chart 9: Properties of Some Soils Which Limit Their Potential For Producing Crops

- sloped
- shallow slope
- shallow saline-alkali
- shallow saline-alkali slope
- shallow saline slope
- shallow saline
- shallow nonsaline-alkali slop
- shallow
- saline-alkali slope
- saline slope
- saline
- rocky slope
- rocky shallow slope
- rocky shallow saline slope
- rocky shlw nsal-alk slope
- rocky shallow

Explanations:

Slope or Sloped: Land slopes typically too steep for safe sprinkler or surface irrigation.

Shallow: Shallow depth to bedrock or other restrictive layer will limit crop production.

Rocky: Percentage of rocks in soil will affect ability to till soil and produce field crops.

Saline: Soils are saline but not alkali; salinity of soil water may limit crop production and Increase irrigation leaching requirements.

Saline-Alkali: Soils contain both salty and alkali; crop production may be limited and And irrigation and leaching may turn the soil into a nonsaline alkali soil.

Nonsaline-Alkali: Soils generally require very expensive treatment if used for crop production.

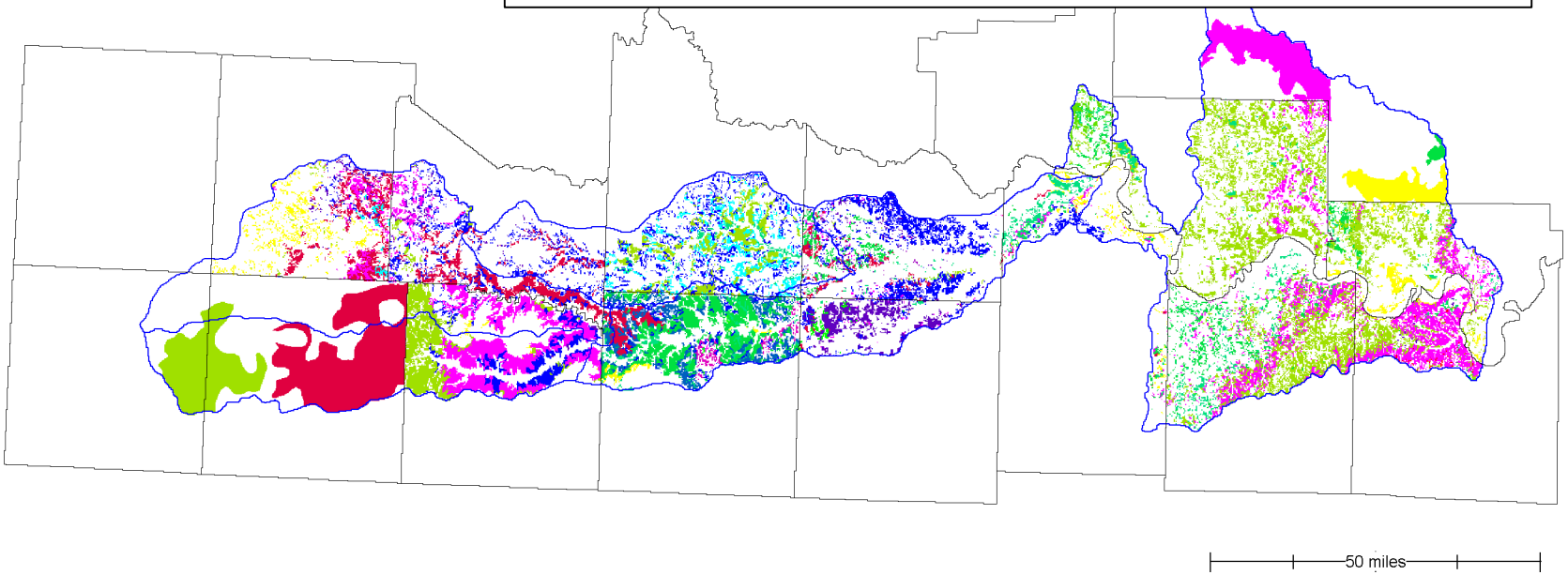


Table 5-16 is a summary of the results of following the five steps described above. Areas of cropland, pastureland, and hayland in good and limited soils in each of the major soil groups are listed. The shaded cells in the table contain the estimates for the economic analysis. They represent about 80% of the total acres of the selected land uses on good soils. The small acreages of Slaughterville fine sandy loam and Hollister clay loam were included to represent currently irrigated soils in Reaches 5 and 12. Including Gaddy fine sandy loam, Mangum silty clay loam, and Kamay silt loam in the analysis could have represented a significantly larger portion of the area. Including Gaddy loam and Yahola fine sandy loam could have represented even more. The data in this table were developed in late summer 1999.

TABLE 5-16

SOILS RECOMMENDED TO BE REPRESENTATIVE SOILS ON CROPLAND AND PASTURELAND IN EVALUATION REACHES

Reach	Land Use	Total Land Use Area (acres)	Quality	Good or Limited Soil Area (acres)	GIS Soil Number	Soil Name
5	Cropland dry	20,767	Good	18,667	60705	Teller loam
5	Pasture/hay dry	14,088	Good	14,088	60601	Gaddy fine sandy loam
5	orchard-specialty	5,270	Good	4,732	60767	Gaddy loam
5	cropland irrigation	43	Good	32	60838	Slaughterville fine sandy loam
5	cropland dry	20,767	Limited	2,100	60769	Goodnight loamy fine sand
5	orchard-specialty	5,270	Limited	538	60761	Eufaula soils
5	cropland irrigation	43	Limited	11	60761	Eufaula soils
5	pasture/hay dry	14,088	Limited	0	60761	Eufaula soils
6	cropland dry	20,342	Good	18,062	60805	Minco loam
6	pasture/hay dry	5,393	Good	4,443	60897	Yahola fine sandy loam
6	orchard-specialty	665	Good	499	60752	Easpur loam
6	cropland irrigation	96	Good	96	60805	Minco loam
6	cropland dry	20,342	Limited	2,280	60753	Easpur loam
6	pasture/hay dry	5,393	Limited	950	60872	Treadway oscar and masham soils
6	orchard-specialty	665	Limited	166	60753	Easpur loam
7	cropland dry	38,044	Good	30,723	60167	Weswood silt loam
7	pasture/hay irrigation	9,710	Good	9,133	60448	Deandale silt loam substratum
7	cropland irrigation	5,704	Good	5,482	60511	Winters loam
7	pasture/hay dry	2,985	Good	2,644	60441	Clairemont silt loam
7	orchard-specialty	30	Good	30	60171	Winters loam
7	cropland dry	38,044	Limited	7,321	60138	Mangum silty clay loam
7	pasture/hay irrigation	9,710	Limited	577	60480	Mangum soils wet
7	pasture/hay dry	2,985	Limited	341	60480	Mangum soils wet
7	cropland irrigation	5,704	Limited	222	60514	Winters loam wet

TABLE 5-16 (Continued)

Reach	Land Use	Total Land Use Area (acres)	Quality	Good or Limited Soil Area (acres)	GIS Soil Number	Soil Name
9	cropland dry	1,202	Good	987	60059	Clairemont silt loam
9	pasture/hay dry	24	Good	8	60075	Lincoln and yahola or westola soils
9	cropland dry	1,202	Limited	215	60081	Mangum clay
9	pasture/hay dry	24	Limited	16	60081	Mangum clay
10	cropland dry	2,319	Good	1,462	60333	Mangum clay
10	cropland irrigation	325	Good	110	60315	Clairemont silt loam
10	cropland dry	2,319	Limited	857	60352	Vernon clay
10	cropland irrigation	325	Limited	215	60353	Vernon owens knoco association
12	cropland dry	21,641	Good	15,120	60448	Deandale silt loam substratum
12	pasture/hay dry	641	Good	443	60117	Deandale silt loam
12	pasture/hay irrigation	235	Good	42	60446	Deandale silt loam
12	cropland irrigation	30	Good	21	60463	Hollister clay loam
12	cropland dry	21,641	Limited	6,521	60465	Kamay silt loam
12	pasture/hay dry	641	Limited	198	60465	Kamay silt loam
12	pasture/hay irrigation	235	Limited	193	60465	Kamay silt loam
12	cropland irrigation	30	Limited	9	60464	Kamay silt loam
Note: Shaded cells include data used in the economic analysis.						

The Wichita County Irrigation System

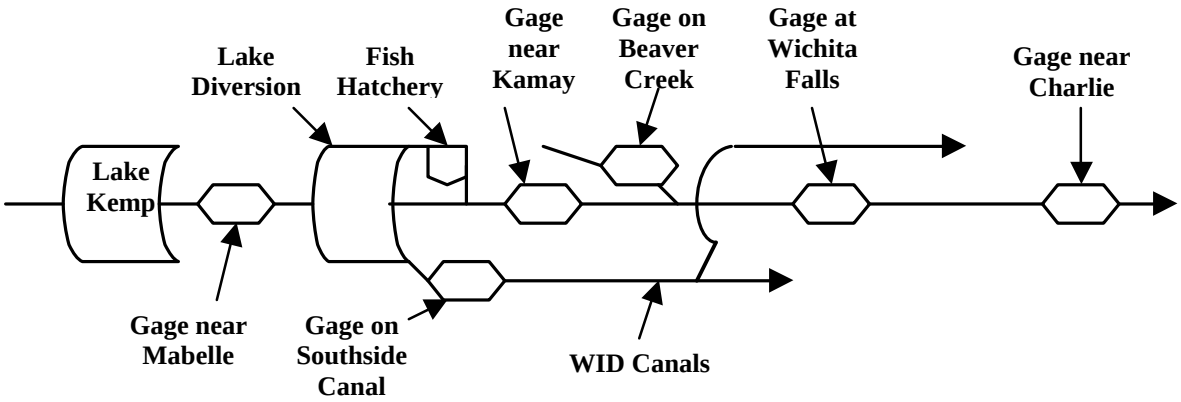
In the second and third decades of the 20th century, two non-governmental organizations were formed to develop, construct, and manage a major irrigation project in the Wichita River Valley. The major structural features of this project are Lake Kemp, Lake Diversion, and an extensive system of canals and laterals extending downstream along the valley from Lake Diversion to a short distance downstream from the Wichita-Clay County line. Wichita County Water Improvement District No. 2 now shares ownership of the entire system with the city of Wichita Falls and continues to operate the reservoirs and canal system for its customers, the landowners served by the system. The District is a political subdivision of the State of Texas organized by the Commissioner's Court by court order on December 29, 1920. The District is comprised of 41,013 irrigable acres, and the District/city of Wichita Falls has an adjudicated water right to 120,000 acre-feet of water for irrigation. Water is released from Lake Diversion into the South Side Canal to furnish irrigation needs. The District jointly owns 33.89% of the system and the city of Wichita Falls owns 66.11%, based on the percentage amount of original bonds sold to construct the system in 1923. Wichita Falls became an owner after taking over WCWID No. 1 in 1961. District No. 2 has operated the entire system since its origin. Water

rights are jointly owned and any revenue from water sold on contract is divided 50/50. The current adjudicated water rights are: irrigation 120,000 acre-feet; municipal 25,150 acre-feet; industrial 40,000 acre-feet; mining 2,000 acre-feet; and recreation (Lake Wichita replenishment), 5,850 acre-feet. West Texas Utilities (WTU) has a contractual permit for 20,000 acre-feet of industrial water to operate the Oklaunion Power Plant. Its pump station is located near the northwest end of the Lake Diversion dam and has a 23-mile pipeline to the power plant. A water conservation plan is filed with the TNRCC by the WTU. Small amounts of water used for mining (oil field uses) are either pumped or hauled directly from District canals. This use is monitored through pump capacity and tank size. The District also owns permits to pump 16,660 acre-feet of water from the Wichita River to supplement its needs in drought conditions. Cities included in the District are Valley View, Kamay, and part of Wichita Falls. There are 3,903 taxable accounts in the District. Wichita County Water Improvements District No. 2 is shown in Figure 5-7.

The WCWID now delivers irrigation water to about 15,000 acres. Some of the irrigated land has been converted to urban and suburban uses. Some has been abandoned due to contamination from oil wells and for economic reasons. Much of the original service area is now used for non-irrigated agriculture, particularly to produce non-irrigated winter wheat. Nevertheless, diversions of water from the Wichita River into the WCWID canal appear to continue to be maintained at near-capacity levels during the spring, summer, and autumn.

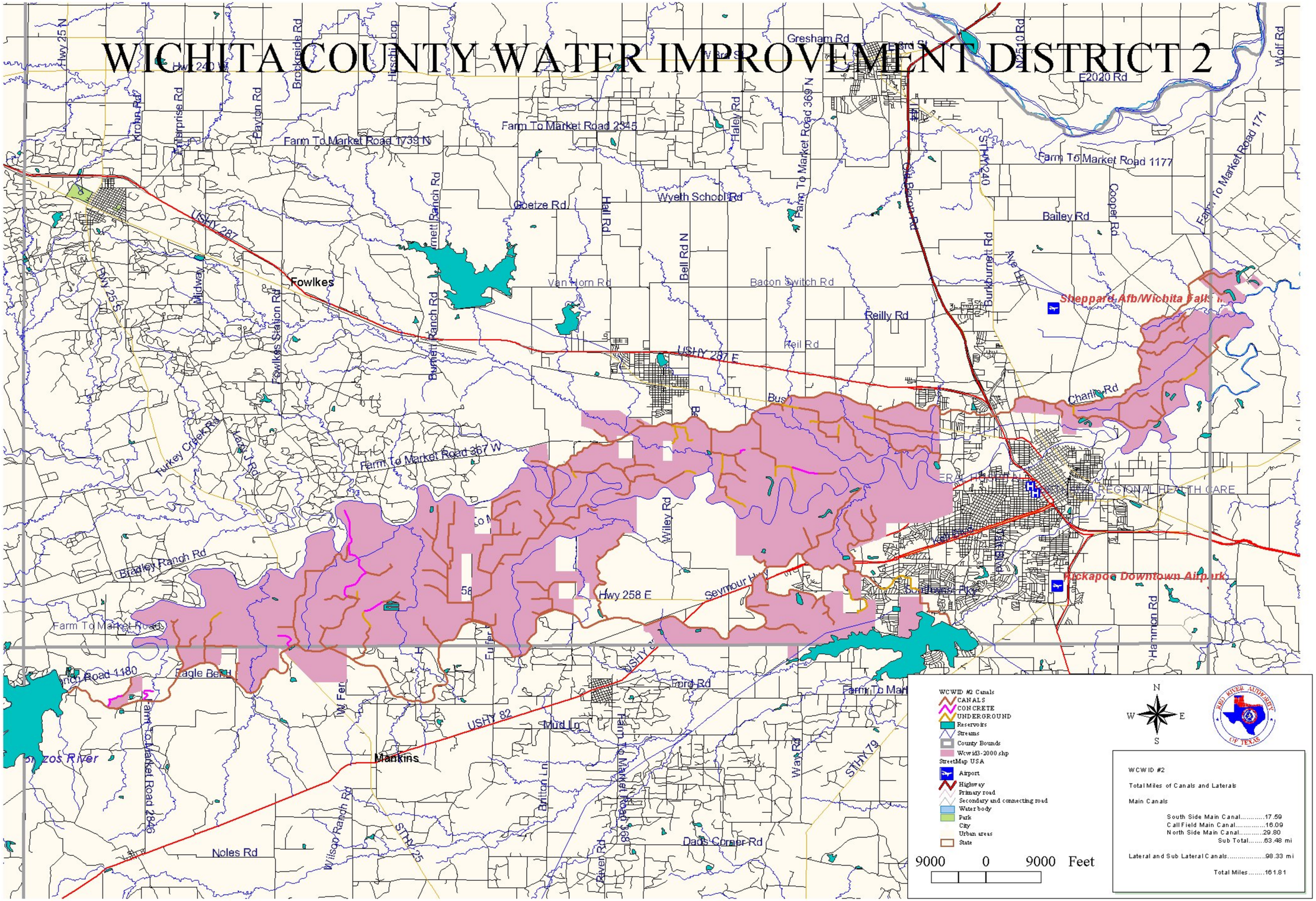
The reservoir and irrigation diversion system has a dramatic effect on Wichita River flows downstream from Lake Diversion. The following schematic is provided to help explain what this effect is and how it occurs.

Schematic for the Wichita River from Lake Kemp to the area near Charlie, Texas



This reservoir, river, and canal system is operated primarily to supply water to the WCWID canal. The U.S. Army Corps of Engineers directs operations for releases of flood control storage to reduce flooding in the lower Wichita River Basin and along the Red River downstream. The Texas Parks and Wildlife Department holds a contractual permit from the District and city for 2,200 acre-feet of water per year to operate the Texas State Fish (Dundee) Hatchery below Lake Diversion. The fish hatchery withdraws relatively small amounts of water, rarely exceeding 6 cubic feet per second (cfs). Water is diverted from Lake Diversion directly

WICHITA COUNTY WATER IMPROVEMENT DISTRICT 2



through the dam to the hatchery through a 14-inch pipe and a 30-inch siphon pipe. A water conservation plan has been submitted to the TNRCC for the Dundee Fish Hatchery. Water has been diverted in small quantities through the irrigation canal system and pumped to the Wichita Falls treatment plant for municipal and industrial use.

Metered water diverted from Lake Diversion into the South Side Canal flows by gravity for 17.5 miles to dividing head gates where the canal becomes the North Side Canal (30.5 miles to Clay County) and the Call Field Canal (18 miles to its end near Lake Wichita). From these main canals, there are 124 miles of branch laterals. Main Canal depth averages from about 8 feet below Lake Diversion to 4 feet in Clay County. The District also maintains over 75 miles of drainage canals. These canals are for subsurface drainage and also carry surface water to the Wichita River. Major drains are excavated, and improved natural drains allow smaller subsurface drains to empty into them.

Highly significant for this study is the fact that much of the time, the flow in the Wichita River at Wichita Falls is nearly independent from the flow in the river above Lake Diversion. Most of the water released from Lake Kemp is either diverted directly into the WCWID No. 2 canal or used to replenish water storage in Lake Diversion. Except for very small amounts of water released through the hatchery, nearly all the water that passes through the gage near Kamay is in occasional flood flow releases.

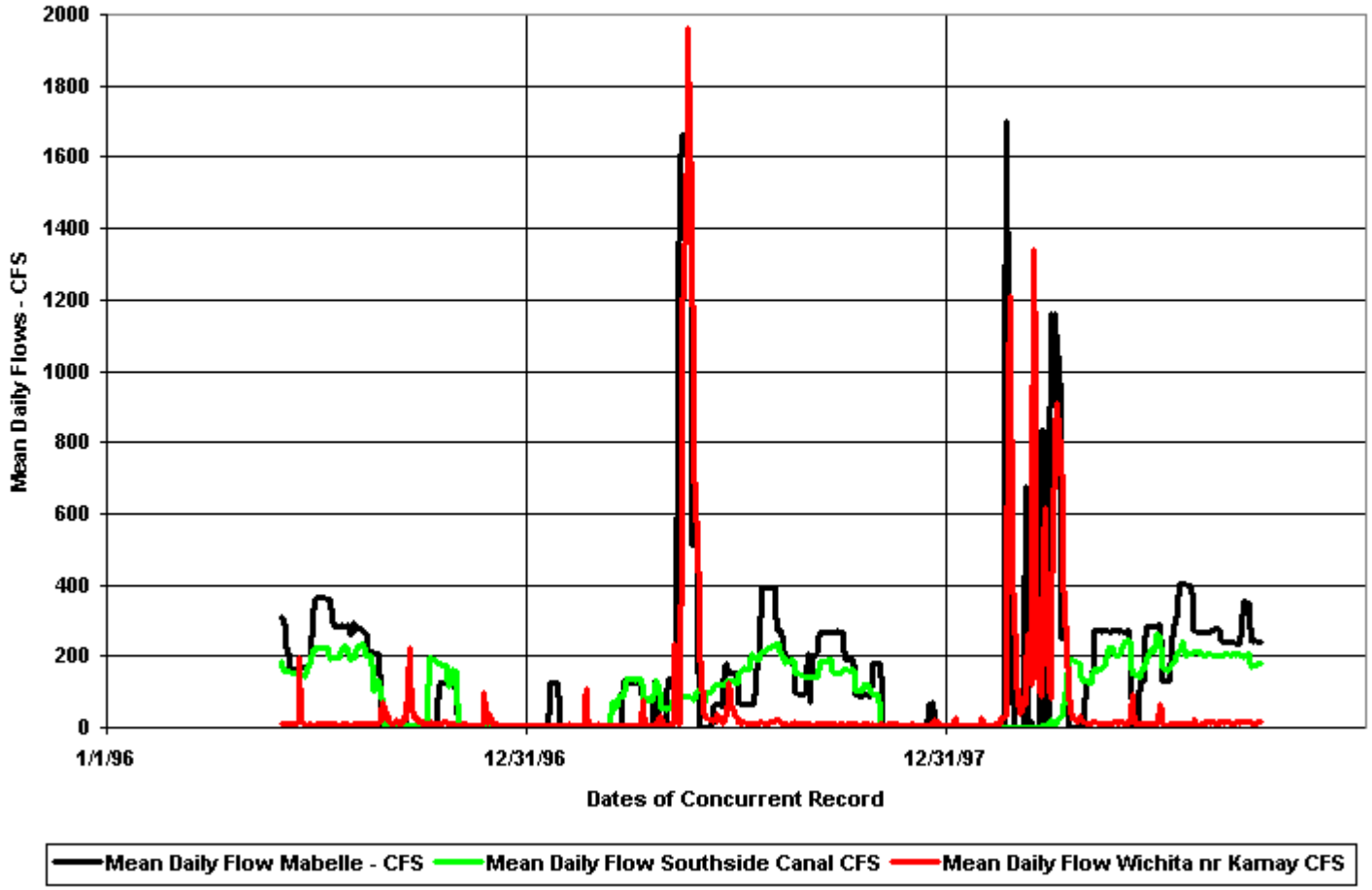
Chart 10 compares daily water flows at Mabelle, Southside Canal, and Wichita River near Kamay. Chart 11 compares probabilities of water flow at Southside Canal with flows at the Mabelle gage upstream.

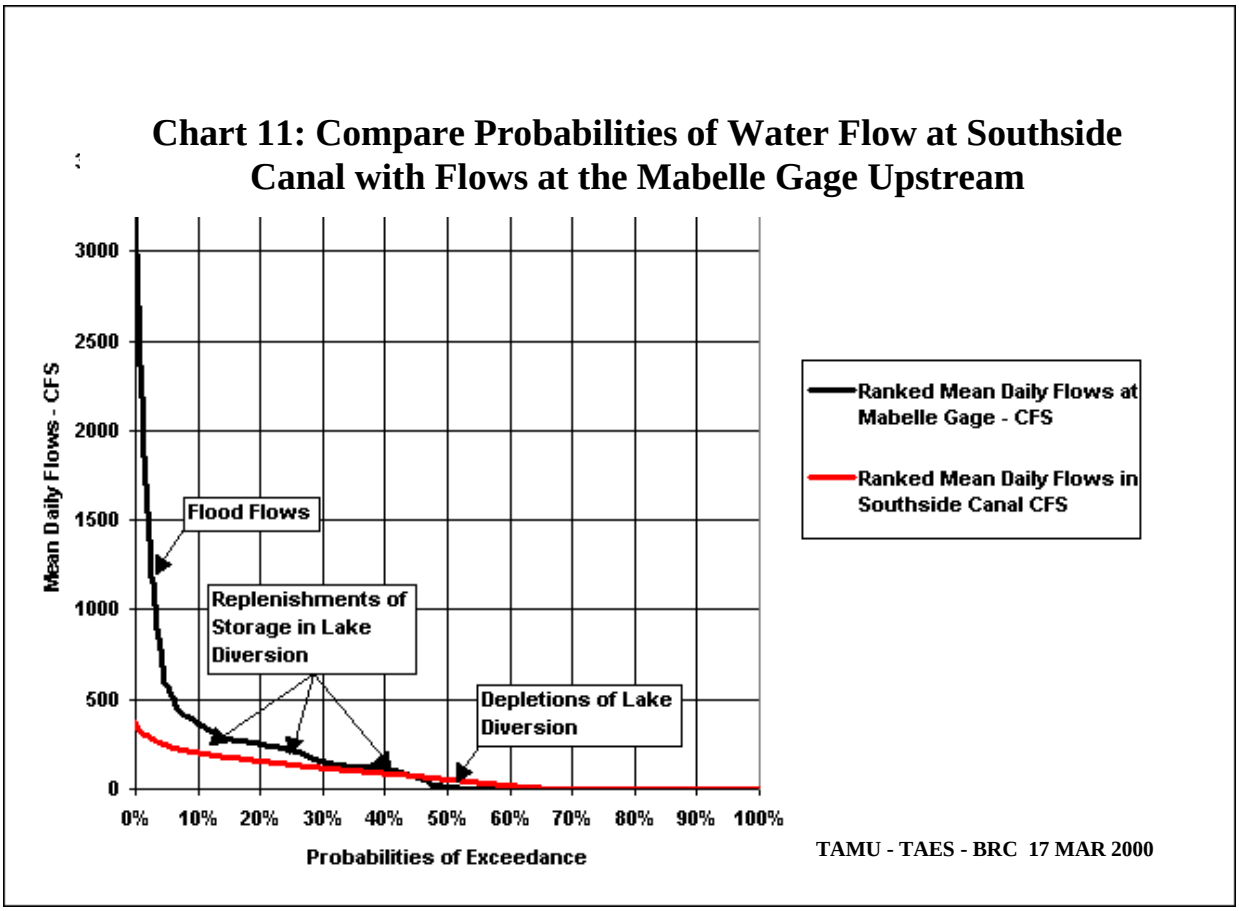
WCWID No. 2 diverts relatively large amounts of water into the irrigation canal. The average rate of diversion is about 79 cfs. The maximum recorded rate of diversion is about 370 cfs, and withdrawal rates ranging from 100 to 175 cfs are common during the summer months. The portion of this irrigation water that is not consumed by irrigated crops, evaporated from water surfaces in the system, or used by other vegetation in areas wetted by the system returns to the Wichita River below the Kamay gage. Most of this flow is surface water intentionally spilled back to the river as part of the canal management program. The remainder includes surface tailwater from the irrigated areas and groundwater that seeps through the irrigated soils to the riparian aquifers that feed into the river below the irrigated lands.

On most days, most of the water flowing in the Wichita River through the city comes from Beaver Creek, Holiday Creek, Buffalo Creek, and a number of other smaller tributary watersheds. Some return flow from the city's water supply diversions from Lake Kickapoo and Lake Arrowhead in the Little Wichita River Basin may also be entering the river in that reach.

The Wichita River Basin is essentially divided into two sub-basins at Lake Diversion. One sub-basin is the watershed above Lake Diversion and the irrigated area served by the WCWID No. 2 canal. The lower sub-basin is the Wichita River main stem and its tributaries below Lake Diversion.

Chart 10: Compare Daily Water Flows at Mabelle, Southside Canal, and Wichita River near Kamay





Implications for Project Design and Evaluation

One major implication of the bifurcation of the Wichita River Basin at Lake Diversion is that the concept of installing a system of irrigation wells along the river in Reach 7 below the WCWID canal between Lake Diversion and the eastern end of the WCWID irrigation service area in Clay County is simply not practical because all the irrigated land and nearly all the arable potentially irrigable land in this portion of the basin can be provided with irrigation water by the WCWID No. 2 canal system. The current price for water from this system is $5.00 per acre per year. This is much less than it would cost to install and operate wells in the area.

Furthermore, the potential benefits for the project will actually be more significant if the WCWID NO. 2 water is used in this area than if irrigation water was to be pumped from the riparian aquifer.

Therefore, the irrigable land area in Reaches 7 and 12 is assumed in this study to be supplied by water from Lake Kemp and Lake Diversion rather than from the main stem of the Wichita River or its riparian aquifer.

Implications for Agriculture in Reaches 10 and 11

The potential for agriculture in Reach 10, the North and Middle Forks of the Wichita River, is limited in that there would not be enough water available to irrigate any crops in this reach. On days when crops would need water the most, the amount of water in either the river or its riparian aquifer would be insufficient. Furthermore, the concentrations of total dissolved solids and chlorides with the project would require relatively large amounts of water for leaching purposes.

With Area VIII in operation, the concentrations of TDS in Reach 11, the South Wichita River, would still be so high that irrigation of most kinds of crops normally grown in the Wichita Falls area should not be attempted. Few crops can be irrigated with practical methods when typical daily TDS concentrations in the irrigation water exceed 11,000 mg/L. Furthermore, there will be so little water available from stream flow most of the time that there will not be enough to irrigate any crops in this reach.

Wichita River Above Lake Kemp

Reach 9 was intended to include all the land near the river downstream from the confluence of the North and South Wichita Rivers to the dam at Lake Diversion. That portion of Reach 9 above Lake Kemp, Reach 9A, and the reach below Lake Kemp, Reach 9B, are designated for estimating inflows of water, TDS, and chlorides into Lake Kemp. The concentrations of TDS and the electrical conductivities of the water in Reach 9B between Lake Kemp and Lake Diversion actually will be the same as for Lake Kemp and Reaches 7 and 12.

As with Reaches 10 and 11, the proposed project would diminish the opportunity for irrigated agriculture in Reach 9A because of the diminished available water supplies during low flow periods.

Lake Kemp Model

Lake Kemp was constructed nearly 80 years ago. The proposed primary purpose was to supply irrigation water to about 41,013 acres of land in the Wichita River Valley. Lake Diversion, located a few miles downstream from Lake Kemp, was also built as a part of the irrigation project. The primary purpose for Lake Diversion is to raise the water to the level required to divert water into the main irrigation canal. Except during occasional major flood events, nearly all the water released from Lake Kemp is delivered through Lake Diversion to the South Side Main Canal. The salinity and chloridity in the water in Lake Kemp, Lake Diversion, and in the upper end of the South Side Canal is approximately the same as the salinity and chloridity of the water flowing through stream gage 07312100 on the Wichita River near Mabelle. This gage is located about 0.4 mile below the Lake Kemp dam.

Since October 1970, the maximum amount of water stored in Lake Kemp has been almost 368,000 acre-feet. The average level of storage during that time has been about 204,000 acre-feet. This water storage makes a significant change in the quality of water in the Wichita River below the Seymour gage. The average concentration of TDS at the Seymour gage above

Lake Kemp is about 8,500 Mg/L. At the Mabelle gage, the TDS concentration averages only about 2,850 Mg/L. The CHL concentration in the river above Lake Kemp is about 3,750 Mg/L. At the Mabelle gage, the average CHL concentration is only about 1,100 Mg/L.

The change in TDS and CHL concentrations occurs because the lake is large enough to store much of the freshwater that comes into it during major storm events. The flood flows dilute the salinity and chloridity of the water in the lake. The mixing of water that occurs in the lake also keeps the salinity and chloridity from fluctuating very much most of the time.

Irrigation in Reaches 7 and 12

General Concepts. Reach 7 is intended to be the potentially irrigable area along the Wichita River from Lake Diversion down to the mouth of the river, which includes all irrigable land that can be served below the WCWID irrigation canals and laterals.

Reach 12 includes irrigable land located within 50 feet in elevation above the WCWID canals. This land could be supplied with irrigation water from the canal with an average pump lift of about 25 feet. Very little of this land is currently being irrigated.

Since the water to be supplied to these reaches is expected to be delivered through the WID canals, the estimates of concentrations of TDS and chlorides in Lake Kemp are also appropriate estimates for the concentrations in the irrigation water available in Regions 7 and 12.

The salinity of the soils under the irrigated areas in Reaches 7 and 12 and the changes in chloridity will not be estimated directly, but the concentrations of chlorides may be assumed to be about 39% of the concentrations of TDS, since this is the approximate ratio of chlorides to TDS concentrations found from the water quality records for the Mabelle gage.

The salinity of the water in the root zones under irrigated soils does not depend only on the salinity of the water used to irrigate the crops. It also depends on:

- the average combined salinity of the irrigation water plus the natural rain water that becomes available to the crops,
- the concentration of salts in the irrigation water,
- how much excess water is made available to leach those salts through and out of the cropland soils, and
- how effective the natural or artificial drainage system is in removing this excess water.

Irrigators control the concentrations of TDS in the water in their soils by controlling the amount of irrigation water they apply to their crops and, sometimes, by installing improved drainage systems to remove some of that water.

Where soils are naturally well drained and where rainwater comprises much or most of the needed water supply, artificial drainage systems may not be needed to control the soil water salinity. This is assumed to be the case in the soils expected to be used for irrigation in Reaches

7 and 12. Poorly drained soils with naturally high levels of salinity have been removed from the inventory of available irrigable soils.

It is assumed that the irrigators have considerable experience in using saline water to irrigate their crops and

- They will continue to manage their land to maximize use of available rainfall before applying irrigation water,
- They will use no more or less water than they need to grow their crops and to provide the leaching water needed to keep the soil salinity at concentrations low enough to minimize crop damage, and
- They will grow crops for which the leaching requirements with the available water would not cause water logging of the irrigated land.

Wichita County Water Improvement District No. 2, a political subdivision of the State of Texas, has adopted a water conservation policy that assists District personnel and water users in the diversion, delivering, and application of District irrigation water. The water conservation plan was documented most recently on November 13, 2001, by the District Board of Directors. This document describes the District's efforts to manage and conserve irrigation water by allocating revenue from water sales to improved maintenance and laying of underground lines in pipe, leak detection, repairs of canals, and direct assistance to farmers by encouraging farmers to utilize the U.S. Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) for technical irrigation advice. Three methods of irrigation occur within the District: 1) the flood method of irrigation that comprises about 82% of the total irrigated land; 2) the center pivot method comprising about 12% of the land; and 3) the furrow method that comprises about 6% of irrigated land. The NRCS, while assisting farmers, works toward an irrigation efficiency of 70% or greater. The District's goals over the next 10 years is to increase efficiency 80% or greater, eliminate unnecessary tailwater runoff, and continue to place District open canals in underground pipe to reduce water loss. As a result of the sale of 20,000 acre-feet of water to WTU in 1977, the District instituted a program to utilize its revenues to conserve water on a "pay as you go" method. Water losses were reduced by as much as 50% by cleaning canals and drains and placing worse case laterals underground in plastic pipe.

Crop Salinity Tolerances. The Agricultural Research Service of the USDA maintains a salinity laboratory at Riverside, California. Now named the George E. Brown, Jr., Salinity Laboratory, this laboratory is the best available source of information about crop responses to the salinity of water in cropland soils. Chart 59 has been derived from information obtained from that laboratory about the responses of alfalfa, sorghum, wheat, cotton, and bermuda to the electrical conductivity (EC) of water in the root zone.

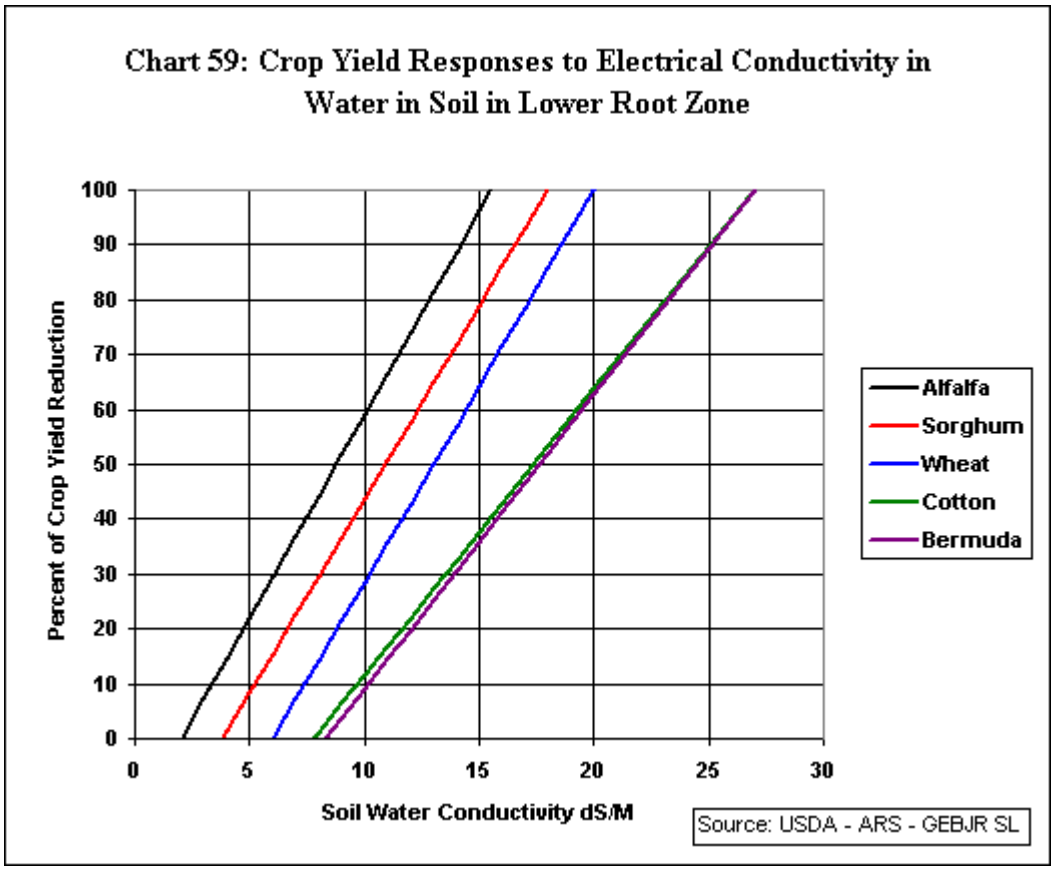


Chart 60 has been created by converting the EC values to local estimates of TDS concentrations using the formula:

TDS in mg/l = (0.617)(1000)(EC in decisiemens/meter)

The ratio 0.617 is taken from water quality data for the stream gage near Mabelle. The estimates of crop yield reduction have also been changed from estimates of yield reduction into estimates of percents of normal crop yields.

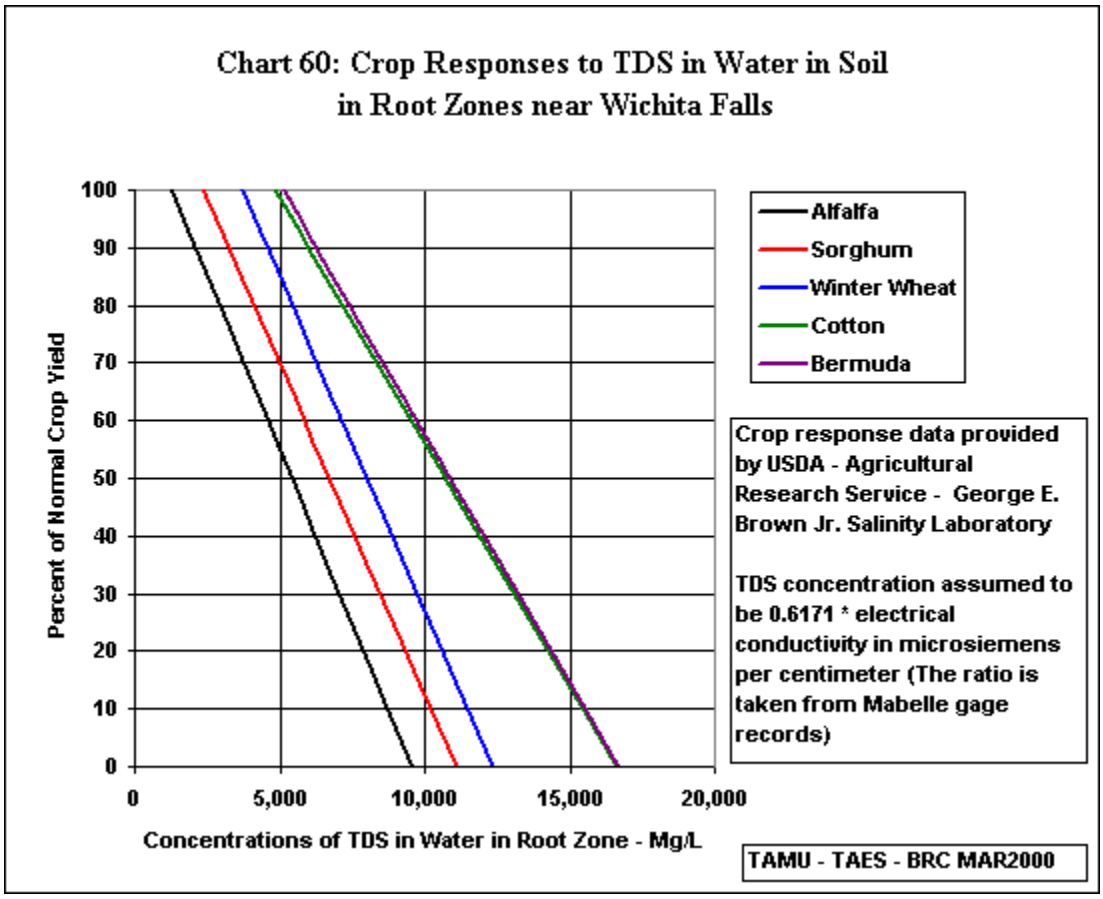


Table 5-17 provides estimates of TDS concentrations associated with 0%, 10%, 25%, and 50% reductions in crop yield for five crops grown in the area. The TDS concentrations associated with 0% yield reduction are called threshold levels.

TABLE 5-17
CROP YIELD RESPONSES TO TDS CONCENTRATIONS IN SOIL WATER

Crop	TDS Concentration for 0% Reduction in Yield (Mg/L)	TDS Concentration for 10% Reduction in Yield (Mg/L)	TDS Concentration for 25% Reduction in Yield (Mg/L)	TDS Concentration for 50% Reduction in Yield (Mg/L)
Alfalfa	1,253	2,084	3,332	5,411
Bermuda	5,118	6,272	8,001	10,885
Cotton	4,795	5,979	7,756	10,717
Sorghum	2,349	3,224	4,537	6,725
Wheat	3,704	4,568	5,865	8,026

Irrigation Water and Leaching Requirements. Irrigation and leaching water requirements were simulated for alfalfa, bermuda, cotton, sorghum, and winter wheat on a typical soil in the Wichita Falls area. The crop water requirements (evapotranspiration rates) are computed using the modified Blaney-Criddle method.[2] This is a standard method used to estimate evapotranspiration from crops. It provides daily estimates, and the required input data are readily available and easily adapted to a spreadsheet model.

The daily soil moisture storage and runoff characteristics are simulated using a generalized single soil layer version of the soil moisture and runoff accounting routine used in the EPIC model.[3]

The irrigation water applications are estimated by a formula that saturates the root zone with an irrigation application on days when the plant available water stored in the root zone is reduced to less than one-third of the total water holding capacity of the soil. The formulas for calculating leaching requirements when irrigating with saline water are taken from pages 36 to 38 of USDA Agriculture Handbook 60.[4]

The records of daily temperatures and precipitation from the Wichita Falls weather gage are used for the period January 1, 1965, through December 31, 1997.

The workbooks developed for use in the evaluation are designed to facilitate a cut and try approach that computes the portion of the total water application supplied by rainfall when the leaching water requirements are met for any combination of concentrations of TDS in the irrigation water and in the soil water under each crop.

These workbooks are also used to estimate the rate of rainwater falling on non-irrigated crops. This is done by setting the irrigation water applications to zero.

Table 5-18 summarizes the results of irrigation water and leaching requirements for the five crops under Plan I (Natural) and Plan III (Area VII) conditions of estimated median concentrations of TDS in the irrigation water for three levels of allowed crop yield reduction. Plan II (Area VIII) conditions may be considered to be reasonably close to Plan I conditions, and Plan V (Areas VII and X) conditions may be assumed to be fairly close to Plan III conditions. Plan IV (Area X) conditions would have effects somewhere between those of Plan I and Plan III.

The median level of concentrations of TDS and chlorides in the irrigation water are used because they represent the typical conditions to which the concentrations seem to respond more closely than they do to average conditions.

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[2] Irrigation Water Requirements, Technical Release No. 21. USDA, Soil Conservation Service Engineering Division, April 1967. Revised September 1970.

[3] Williams, J.R. 1995. The EPIC Model. Pp 910-913 In V. P. Singh, Computer models of watershed hydrology, Water Resources Publications, Highlands Ranch, CO.

[4] Diagnosis and Improvement of Saline and Alkali Soils. Agriculture handbook No. 60. USDA United States Salinity Laboratory, Revised 1969.

TABLE 5-18

PLAN I AND PLAN III MEDIAN VALUE IRRIGATION AND LEACHING WATER REQUIREMENTS IN REACHES 7 AND 12

Plan	Crop	Yield Reduction Allowed (%)	Average Total Crop Water Use (inches)	Water Provided By Rain (inches)	Net Irrigation Water Needed For Crop (inches)	TDS in Irrigation Water at 50% Probability (Mg/L)	Target TDS Concentration in Soil Water (Mg/L)	Total Crop Irrigation Required (inches)	Leaching Water Needed (inches)
1	Alfalfa	0	56.3	24.4	31.9	3124	1253	Inf	Inf
1	Alfalfa	10	56.3	24.4	31.9	3124	2084	Inf	Inf
1	Alfalfa	25	56.3	24.4	31.9	3124	3332	186.4	154.5
III	Alfalfa	0	57.4	24.4	33.0	2290	1253	Inf	Inf
III	Alfalfa	10	57.4	24.4	33.0	2290	2084	Inf	Inf
III	Alfalfa	25	57.4	24.4	33.0	2290	3332	66.3	33.4
I	Bermuda	0	48.8	24.6	24.2	3124	5118	44.0	19.8
I	Bermuda	10	49.3	24.4	24.8	3124	6272	38.7	13.9
I	Bermuda	25	49.3	24.5	24.8	3124	8000	34.2	9.4
III	Bermuda	0	49.3	24.5	24.8	2290	5118	36.4	11.7
III	Bermuda	10	49.3	24.6	24.8	2290	6272	33.3	8.5
III	Bermuda	25	49.4	24.6	24.8	2290	8000	30.9	6.1
I	Cotton	0	32.1	22.6	9.4	3124	4795	16.1	6.7
I	Cotton	10	32.1	22.6	9.5	3124	5979	14.0	4.5
I	Cotton	25	32.2	22.7	9.5	3124	7756	12.6	3.1
III	Cotton	0	32.1	22.6	9.5	2290	4795	13.4	3.9
III	Cotton	10	32.2	22.7	9.5	2290	5979	12.4	2.9
III	Cotton	25	32.2	22.7	9.5	2290	7756	11.5	2.0

TABLE 5-18 (Continued)

Plan	Crop	Yield Reduction Allowed (%)	Average Total Crop Water Use (inches)	Water Provided By Rain (inches)	Net Irrigation Water Needed For Crop (inches)	TDS in Irrigation Water at 50% Probability (Mg/L)	Target TDS Concentration in Soil Water (Mg/L)	Total Crop Irrigation Required (inches)	Leaching Water Needed (inches)
I	Sorghum	0	33.1	22.5	10.7	3124	2349	Inf	Inf
I	Sorghum	10	33.4	22.4	10.9	3124	3224	36.8	25.9
I	Sorghum	25	33.9	22.4	11.5	3124	4537	21.1	9.6
III	Sorghum	0	33.3	22.4	10.9	2290	2349	37.7	26.8
III	Sorghum	10	33.9	22.4	11.5	2290	3224	21.7	10.2
III	Sorghum	25	34.1	22.4	11.7	2290	4537	17.4	5.6
I	Winter Wheat	0	13.6	20.8	0	3124	0	0	0
I	Winter Wheat	10	13.6	20.8	0	3124	0	0	0
I	Winter Wheat	25	13.6	20.8	0	3124	0	0	0
III	Winter Wheat	0	13.6	20.8	0	2290	0	0	0
III	Winter Wheat	10	13.6	20.8	0	2290	0	0	0
III	Winter Wheat	25	13.6	20.8	0	2290	0	0	0

Note: "Inf" means infinite, a goal that can't be reached with the available water supply and the targeted soil water TDS concentration level.

Table 5-18 reveals that alfalfa is so sensitive to soil water salinity that it cannot be produced with normal expected yields with the irrigation water available in Reach 7 or 12 either with or without the proposed project. Sorghum production is also likely to be inhibited without the project. With Plan III, sorghum could be raised with normal expected yields with about 38 inches of irrigation per year. About 27 inches of this amount would be applied as excess water to ensure adequate leaching. Under Plan I conditions, it takes about 44 inches of irrigation water to meet crop needs and provide leaching adequate to maintain normal crop yields for bermuda. Under Plan III conditions, this requirement is reduced to about 36 inches in a typical year.

In the 33 seasons simulated with the winter wheat model, there was not a day when the soil water under winter wheat was reduced to one-third of the available water holding capacity of the Deandale soil. By the calculations in this model, the average annual amount of water needed to raise winter wheat was about 14 inches. The average annual precipitation in this area is about 30 inches. The portion of rain that infiltrates into the root zone and that is available for crop production for winter wheat is about 21 inches.

If the rainfall is presumed to be salt free, or at least nearly so, the concentration of TDS in the root zone under non-irrigated croplands on non-saline soils should be very low. Changing from non-irrigated to irrigated crops will dramatically increase the salinity of the soil water from those near zero levels at least to the threshold levels listed in Table 5-18 as target TDS in soil water for 0% reductions in yield.

Limitations of Amounts of Irrigation Water Available, Reaches 7 and 12. The water supply available to the potentially irrigable lands served by the WCWID canal is limited by the following factors:

- Water not needed by the irrigated crop is not considered to be part of the available irrigation water supply. Bermuda in the Wichita Falls area is expected to lie dormant during December, January, February, and March and to reach its peak water demand rates only in July and August.

- Lake Kemp must be operated so that the threat of major floods in the urban area is minimized. The dam itself must be protected from the threat of failure from overtopping from a major flood. Flood flow releases must be continued with a conservative policy that provides a margin of safety against these threats. Flood flow releases occur during times when the whole watershed, including the riparian aquifer downstream from Lake Diversion, is saturated from major storm events. Flood flow releases are not considered part of the available irrigation water supply. Increasing the amount of irrigation water diversions to supply a larger area of irrigated land will make more water available for irrigation by reducing the requirements for flood flow releases.

- Complete evacuation of Lake Kemp water storage during periods of drought is considered intolerable. A minimum amount of water storage needs to be maintained for environmental reasons, including salinity control purposes. It is also a very good idea to maintain a minimum amount of water storage for emergency

uses such as for municipal water reserve and for fighting potential major fires in the area downstream from the lake. The historic minimum recorded level of water storage since Lake Kemp was first filled in the 1920's has been 26,160 acre-feet in June 1953. The minimum storage level recorded since October 1959 was 31,150 acre-feet in August 1971. For this analysis, water is assumed to not be available for irrigation purposes when storage of water in Lake Kemp would be less than 30,000 acre-feet. The WCWID Drought Contingency Plan details four-stage triggering criteria to reduce water consumption by irrigators. The fourth stage or "Emergency Water Shortage Conditions" occurs when the water elevation in Lake Kemp drops below 1114 mean sea level (msl) and the content of Lake Kemp is 44,000 acre-feet. The District would allow only water use on a prorated basis by prior contract and one crop irrigation each 45 days. No irrigation would be allowed after Lake Kemp reaches 1109 msl.

- Irrigation water supplies to the lands served by the WCWID are also limited during periods of peak irrigation demand by the capacity of the WCWID canal. Water is metered when the water is diverted from Lake Diversion into the South Side Canal. Flow records indicate that the maximum canal capacity is about 300 cfs. This limitation is mitigated by the capacity of the irrigated soils to hold a reserve supply of water during short periods of peak crop water demand, but shortages of supply due to canal capacity limitations should not be expected to last longer than about 7 days. Thus, the suggested estimates of available irrigation water supplies are limited to those amounts that can be provided when the duration of maximum allowable canal flows is 7 days or less.

- Not all the water delivered to the head of the canal can be delivered to the cropland fields. Some of the diverted water is returned to the river system by seepage from the canals. Some is returned through unavoidable operational spillage. Some is used by evaporation from the canal and by the plants that line the banks of the canal. In earth-lined canal systems similar to the WCWID canal system, these "losses" are not uncommonly as much as 50% of the amounts diverted from the river sources. For this analysis, it is assumed that the delivery efficiency of the WCWID canal system from point of diversion to points of deliveries to farm fields can be as high as 80%.

- Finally, the amount of water delivered to the fields must exceed the amounts of water demanded by the crops if salinity in the cropland soils is to be controlled to levels tolerated by those crops. The excess water application required is usually referred to as the "leaching fraction". For simplicity in this analysis, this amount of required excess water is estimated with a "leaching ratio". The leaching ratio times the minimum daily crop water demand equals the amount of water that should be applied to the cropland field to supply the crop and to control the salinity levels to the crop's salinity tolerance threshold level.

Table 5-19 provides a summary of the estimates of maximum practical available water supply for conditions under the five plans.

TABLE 5-19

SUMMARY OF ESTIMATES OF WATER SUPPLIES AVAILABLE THROUGH THE WCWID CANAL WITH NO MORE THAN FOUR EVENTS IN 27 YEARS WHEN EITHER THE MAXIMUM CAPACITY OF THE WCWID CANAL IS EXCEEDED OR THE MINIMUM STORAGE OF 30,000 ACRE-FEET IS EXPERIENCED IN LAKE KEMP FOR MORE THAN 7 CONSECUTIVE DAYS

Item	Units	Plan I	Plan II	Plan III	Plan IV	Plan V
Area of Irrigated Bermuda in Average Years	acres	20000	22180	24500	21800	24000
Average Annual Field Irrigation Water Delivered	acre-feet	61334	61308	59480	60636	55376
Leaching Ratio		1.77	1.6	1.45	1.62	1.36
Average Depth of Irrigation Water Needed for Full Supply	inches	36.9	33.4	30.2	33.9	28.4
Average Depth of Irrigation Water Applied for These Conditions	inches	36.8	33.3	29.1	33.4	27.7
Depth of Irrigation Water Required in Year of Least Demand	inches	34.6	31.1	28.1	31.6	26.4
Depth of Irrigation Water Available in Year of Least Demand	inches	34.6	31.1	15.5	23.1	15.1
Total Duration of Minimum Reservoir Storage	days	0	0	157	63	124
Number of Event When Minimum Reservoir Storage > 7 Days		0	0	4	1	3
Areas of Bermuda for Full Water Supply in Year of Minimum Demand	acres	22000	24000	21200	20480	21200
Irrigation Water Delivered in Year of Least Demand	acre-feet	62827	62076	49668	53920	46714
Depth of Irrigation Water Provided in Year of Least Demand	inches	34.3	31	28.1	31.6	26.4

AGRICULTURAL IRRIGATION ECONOMIC ANALYSIS

Overview

The current economic analysis is based on a mathematical model for agriculture that includes land, water, and salinity constraints. The concept of salinity control at the source areas includes disposal of brines at the existing Truscott Brine Lake, or diversion to other stream locations as proposed by the U.S. Fish and Wildlife Service in the fall of 2001. Deep well injection was not feasible in this area due to the lack of suitable geologic formations in which to inject the brines. To estimate average annual benefits, existing conditions with Area VIII completed are compared to project alternatives with Area VII or Area X completed or with both Areas VII and X completed. This agricultural evaluation was first completed in September 2000. Revisions to crop budgets and water availability were made in September 2001, and interest rate changes were made in December 2001 to 6-1/8% for Fiscal Year 2002. The agricultural analysis in 2000 considered two optimization scenarios. First, the model limited current irrigated acres to 15,000 (current level); however, with the project, model optimization occurred. An analysis based on best management practices and optimal net returns with and without the project, known as the optimal to optimal condition scenario, was also conducted.

Previous agricultural economic analyses were conducted by Texas A&M University and others in 1980, 1992, and 1997. The economic study conducted in 1980 was an analysis of the chloride control project for the entire Red River Basin (Runkles et al.). Since then, there have been several updates using the basic soils and yields of the 1980 study, such as Lacewell et al. (1992) and McCarl et al. (1997). The updates were based on water availability and salinity with and without a project. Also, new crop enterprise budgets with updated prices were used to refine the economic model. In 1992, the economic optimization model was first expressed in the General Algebraic Modeling System (GAMS) software to make future updates more effective and efficient. This model is discussed in a later section of this report.

The crop yields, costs, and returns were based on current crop enterprise budgets for the region as developed by the farm management specialist in Vernon, Texas. The economic analysis was based on water quantity and salinity estimates developed by the U.S. Army Corps of Engineers, Tulsa District and as estimated by the Texas Agricultural Experiment Station (TAES). The economic model has been developed and applied for evaluating the agricultural implications of salinity control in the Wichita River region. This model, which includes stochastic elements, has been applied to a set of data jointly provided by the TAES Blacklands Research Center at Temple, Texas, and the U.S. Army Corps of Engineers. This report discusses some of the major differences between this analysis and previous analyses of the Red River project, including discussion of a mixture of new assumptions used, new modeling approaches, and new data used in the analysis. Most of the information and data presented is from the September 2001 TAES report with interest rate changes to 6-1/8% from 6-3/8% presented as the final benefit carried forward for cost-benefit comparisons.

ALTERNATIVE PLANS

Table 5-20 presents the alternative salinity control plans that served as the basis of the economic analysis.

TABLE 5-20
ALTERNATIVE PLANS

Plan	Plan Description
1	Pre-project Conditions (Natural)
2	Area VIII (Existing without project or Base Condition)
3	With Areas VIII and VII
4	With Areas VIII and X
5	With Areas VIII, VII, X l

Note: The TAES plan numbers 2 and 3 are reversed from the M&I analysis.

INPUT DATA AND ASSUMPTIONS

This analysis differs from previous agricultural analyses regarding:

- Reach definitions
- Soil delineation
- Land available
- Commodity prices
- Irrigation modes
- Coverage of lift zones
- Salinity data used in alternatives
- Revised leaching fraction
- Stochastic commodity prices
- Crop budgets
- Analytical structure changes
- Development of a distribution of benefits

REACH DEFINITIONS

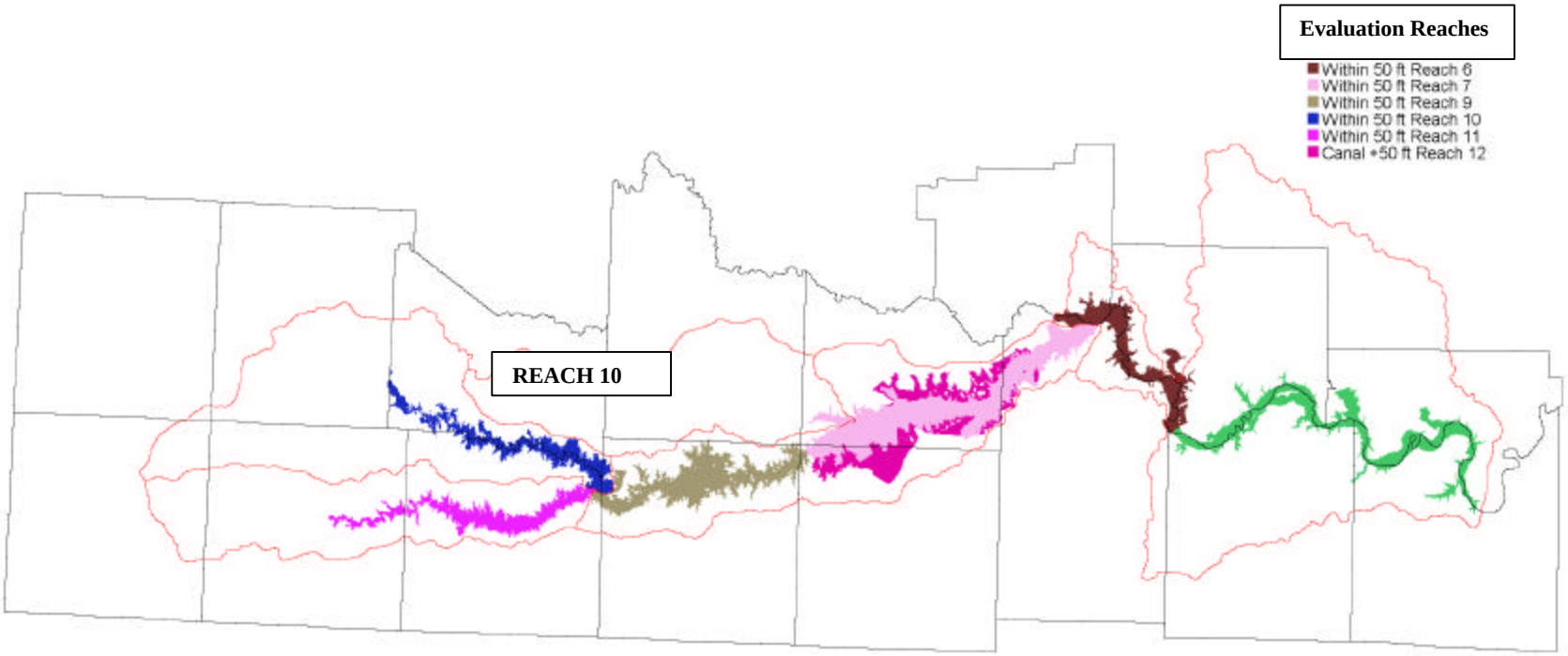
The definition of river reaches used in the agricultural economic analysis are presented in Table 5-21 and shown in Figure 5-8.

TABLE 5-21
AGRICULTURE REACH DEFINITIONS

Reach Number	Reach Characteristics and Location
5	Main stem Red River downstream from the Clay/Montague County line to the I-35 bridge north of Gainesville.
6	Main stem Red River from the Reach 5 border to a point 4 miles upstream from the mouth of the Wichita River. This does not include any of the land adjacent to the Wichita River. This includes lands that could pump from the alluvium above the mouth of the Wichita River.
7	Wichita River from Lake Diversion downstream to the mouth of the Wichita River but not above the Wichita County irrigation district canal. Most of the land is in Wichita County, while some is in Clay County.
9	Wichita River, Lakes Diversion and Kemp, upstream from the Lake Diversion Dam to the confluence of the North and South Wichita Rivers near the Knox/Baylor County line.
10	North Wichita River
11	South Wichita River
12	Adjacent to Reach 7, above the Wichita County irrigation district canal.

Note: Reach 5 in the M&I analysis is Lake Texoma.

Figure 5-8. Evaluation Reaches.



TAMU - TAES - BRC March 2000

SOIL DELINEATION

The number of soil types was greatly reduced from previous studies. These data were changed for three principal reasons.

1. Land suitable for irrigation was redefined by soil type involving a much smaller set of lands with a more narrow set of soil type characteristics.

2 The focus was narrowed to only the most important soil types, choosing those that collectively constituted more than 95% of the available irrigable land for a reach as represented in GIS data sources. The remaining lands suitable for irrigation were added to the available acreage of one of the major soil types appropriate for irrigation.

3. The yield data by soil type were revised to reflect the soil delineation developed. Data from the U.S. Department of Agriculture natural resources inventory (NRI) and Erosion Predictor Impact Calculator (EPIC) crop model simulations were used to better define crop yields for the narrower range of soil types in the region. Farm management specialists were also consulted.

LAND AVAILABLE

The available irrigable land is restricted to land currently irrigated (crops or pasture) plus dryland acres which are currently being cropped. Lands falling into this definition are sufficient to more than exhaust the available water. These lands would have moderate to low conversion costs and, thus, would be most likely candidates for irrigation. The land inventory was obtained using GIS data where lands suitable for irrigation had to meet characteristics regarding distance from river, lift, slope, and size of parcel, among other factors.

IRRIGATION MODES NARROWED TO LOW ENERGY PRECISION APPLICATION (LEPA)

Prior project analyses considered both sprinkler and flood irrigation. Current practices in the agricultural sector as influenced by equipment, energy, and labor costs strongly suggest that any irrigation systems that would be installed would be of the LEPA sprinkler system type. Thus, only that type of system was considered. The Texas High Plains is reflective of this move to LEPA as several hundred thousand acres have been converted from flood and low pressure sprinkler in the last 5 years (Wyatt 1999). Equipment purchase was amortized over 15 years when land came into irrigation. Also, costs of pumping and distribution were included on a per acre-inch basis.

CONSIDERATION OF LIFT ZONES ELIMINATED

In the earlier analyses, the land inventory involved lands disaggregated into three lift zone groupings based on distance from the river. Namely, the lands were disaggregated based on whether they were: 1) within 1/2 mile of the river; 2) between 1/2 and 1 mile from the river; and 3) greater than 1 mile from the river. In the current analysis, this distinction is eliminated. All parcels must have a specified elevation characteristic of less than a 50-foot rise. In addition, the soils, topography, and other characteristics must be applicable to irrigation.

USE OF ALTERNATIVE SALINITY LEVELS

Prior evaluations used a constant salinity level (50% chance of being equaled or exceeded) for each of the project alternatives. An estimate of the salinity of the irrigation water to be applied was made in terms of the electrical conductivity of the water associated with the selected level of salinity. Since crops respond to the salinity of the water in the soil, the salinity of the soil-water extract is always higher than the salinity in the irrigation water used. The difference depends on a complex interaction between the fraction of the total water supplied to the crop by rainwater, the fraction applied by irrigation water, the amount of water made available to leach the salts through and out of the root zone, and the effectiveness of the drainage system in removing this excess water from the soils in the root zones under the croplands. These factors vary by crop, soil, weather, salinity of the irrigation water, and by those levels of salinity in the root zones that irrigators can decide to maintain. To reflect these factors, five principal changes were made in this analysis relative to the earlier analyses.

First, the basis for the salinity estimate was changed from the salinity of the water to the salinity of the water in the soil at the point the water is taken up by the crop. This adjustment was made after discussions with the U.S. Department of Agriculture Soil Salinity Laboratory at Riverside, California.

Second, the salinity basis was converted to soil-water conductivity.

Third, calculations of salinity by crop were constructed based on the average annual portion of the crop growth water requirements that will be provided by infiltrated rainfall. This refined leaching requirements by more appropriately accounting for benefits provided through rainfall.

Fourth, the salinity estimates were treated as uncertain over time, with a seven-stream flow event distribution estimated. The actual salinity is a function of rainfall timing and amount, stream flow, deposition in arid periods of chlorides, and stochastic characteristics of nature.

Fifth, chloride level estimates were developed based on numbers provided by the Corps of Engineers. The resultant soil conductivity estimates are by reach, weather scenario (stream flow event), and crop.

METHODOLOGY FOR SOIL-WATER CONDUCTIVITY

Derivation of the estimates of soil-water conductivities by crop for each level of estimated concentration of total dissolved solids (TDS) in the irrigation water required a three-step process as follows:

1. Convert the estimates of TDS concentrations to estimates of electrical conductivity (EC) of the irrigation water. The ratios of EC to TDS vary by location and are obtained from analysis of the stream gage water quality records appropriate for each evaluation reach. Total dissolved solids are measured in milligrams per liter. Electrical conductivity is measured in microsiemens (preferred) or micromho per centimeter. The following ratios were used to estimate typical irrigation water conductivities from Corps of Engineers estimates of TDS concentrations in the irrigation water.

Evaluation Reach	**Ratio of EC to Concentrations of TDS in Irrigation Water**
5	1.647
6	1.647
7	1.621
9	1.538
10	1.502
11	1.488
12	1.621

In cases where soil-water conductivity levels suggest no feasible irrigation, a value of 99999 was used.

2. Develop models of the daily consumption of water by alfalfa, bermuda, cotton, sorghum, and winter wheat with each model having the following provisions:

   - Estimate the historic contributions of rainfall to the soil-water used by the crops. Calculate the amount of water that could be supplied to the crop by irrigation to maximize production (winter wheat did not require any irrigation); Rainfall-irrigation requirements by crop are shown in the tables below:

Gross Water Requirements by Crop and Reach (Inches)

Reach	Alfalfa	Cotton	Sorghum	Wheat	Tomatoes	Sweet Corn	Pasture
5	39.2	20.6	21.5	25.7	22.6	30.1	44.2
6	47.9	23.4	24.7	30.0	25.7	34.7	52.2
7	47.9	23.4	24.7	30.0	25.7	34.7	52.2
9	47.9	23.4	24.7	30.0	25.7	34.7	52.2
10	51.3	25.4	25.8	31.8	25.7	34.7	52.2
11	51.3	25.4	25.8	31.8	25.7	34.7	52.2
12	47.9	23.4	24.7	30.0	25.7	34.7	52.2

Rainfall by Crop and Reach (Inches)

Reach	Alfalfa	Cotton	Sorghum	Wheat	Tomatoes	Sweet Corn	Pasture
5	23.4	12.5	9.3	18.0	13.2	15.7	22.8
6	22.5	12.4	9.3	17.1	12.3	15.0	21.6
7	21.9	12.0	8.9	16.7	11.6	14.6	20.8
9	20.3	11.5	8.7	15.6	11.6	13.7	19.6
10	18.8	11.4	10.3	15.8	11.4	12.9	18.1
11	18.4	10.8	9.8	15.1	11.1	12.5	17.7
12	21.9	12.0	8.9	16.7	11.6	14.6	20.8

Irrigation Requirements for a 1.75 Leaching Fraction by Crop and Reach (Inches)

Reach	Alfalfa	Cotton	Sorghum	Wheat	Tomatoes	Sweet Corn	Pasture
5	27.650	14.175	21.350	13.475	16.450	25.200	FALSE
6	44.450	19.250	26.950	22.575	23.450	34.475	53.55
7	45.500	19.950	27.650	23.275	24.675	35.175	54.95
9	48.300	20.825	28.000	25.200	24.675	36.750	57.05
10	56.875	24.500	27.125	28.000	25.025	38.150	59.50
11	57.575	25.550	28.000	29.225	25.550	38.850	60.20
12	45.500	19.950	27.650	23.275	24.675	35.175	54.95

- Assume a constant irrigation water use efficiency of 57%, corresponding to a leaching requirement of 1.75 times the amount of irrigation applied. It was assumed for this analysis that irrigation water application efficiencies of 57% would not cause severe drainage problems in the irrigated area and that the water used for leaching would all return to the river downstream (See Appendix D).
- Calculate the expected resulting electrical conductivity of the soil-water in a Deandale soil under each crop, rainfall, and irrigation water conductivity probability condition.

3. With these crop models under these conditions, it was found that there was a unique number for each crop that could be multiplied by the estimates of irrigation water conductivity to estimate soil-water conductivity. These numbers are as follows:

Crop on Deandale Soil	**Assumed Irrigation Leach Ratio**	**Percent of Crop Water From Rain**	**Ratio of Soil-Water Conductivity to Irrigation Water Conductivity**
Alfalfa (and Tomatoes)	1.75	29.6	1.643
Bermuda	1.75	36.3	1.711
Cotton	1.75	62.6	1.479
Sorghum (and Sweet Corn)	1.75	52.7	1.526

The return flow is assumed to be 42.8% of the irrigation water applied. The values in this appendix can be converted to TDS in the root zone and in the return flow based on the following ratio of TDS to soil-water conductivity.

Reach	Ratio
5	0.607
6	0.607
7	0.617
9	0.650
10	0.666
11	0.672
12	0.617

Alternative weather events (stream flow exceedence) each have a probability of occurrence in any given year. Thus, the risk analysis incorporates this probability to estimate a distribution of potential benefits. Table 5-22 presents the probability of each event based on Corps of Engineers estimates.

TABLE 5-22
EXPECTED STREAM FLOW EVENTS AND ASSOCIATED PROBABILITY

Event Name	Individual Probability	Cumulative Probability
event0	0.10	0.10
event1	0.10	0.20
event2	0.30	0.50
event3	0.30	0.80
event4	0.10	0.90
event5	0.05	0.95
event6	0.05	1.00

REVISED LEACHING FRACTION

This analysis used a constant leaching fraction for a crop across all project-induced salinity levels, across all places, in all regions. Irrigation water requirements were developed for each crop based on rainfall during the growing season of that crop. The leaching fraction was established at a level sufficient to handle the variability in salinity across weather (stream flow) events. A leaching fraction of 1.75 was used.

STOCHASTIC COMMODITY PRICES

The agricultural model also included a component that allowed the derivation of prices with uncertainty. However, since current normalized prices are used in the evaluation, the results of the evaluation did not utilize this capability. Price uncertainty was included by using a distribution based upon FLIPSIM (a farm level policy simulation model) analyses done by the Texas A&M Agriculture and Food Policy Center for Congress in an adjacent region. The price uncertainty involved a 10-point distribution with events p1 through p10. The events are assumed equally likely or each has a 10% probability of occurrence. The percent price deviation from a base price in the September 2000 TAES report is presented in Table 5-23.

TABLE 5-23
CROP PRICE DEVIATIONS PERCENT CHANGE FROM BASE PRICE

Event	Cotton	Wheat	Sorghum	Alfalfa and Bermuda
event p1	- 20.33	- 33.72	- 30.37	- 21.55
event p2	3.52	- 27.52	- 16.74	- 14.33
event p3	- 12.32	20.00	6.82	10.80
event p4	3.32	20.00	-0.21	11.05
event p5	10.17	- 25.87	0.62	5.05
event p6	- 9.97	- 9.75	5.99	-6.70
event p7	- 16.03	0.17	- 8.88	- 2.83
event p8	- 7.43	0.99	8.47	6.30
event p9	21.11	8.84	1.03	9.30
event p10	27.76	46.86	33.26	2.86

Source: Richardson 2000

CROP BUDGET

Crop enterprise budgets that included production costs and other crop budget items were updated. Representative crop enterprise budgets for the study area for selected crops are shown from the September 2001 report.

ANALYTICAL MODEL

The current analysis required a different modeling framework due to the incorporation of uncertainty. In particular, the model that was used was stochastic programming with a recourse or discrete stochastic programming model (Dantzig 1955; Cocks 1968; Ziari et al. 1995). Within this modeling framework, acreage and irrigation installation decisions are made before the value of uncertain states like salinity and prices are known. In particular, irrigated acres are chosen before the year's cropping season, salinity, or crop prices are known. In turn, leaching water requirements, prices, and salinity affected yields become known after the cropping decisions are made. This is the same method used for analysis in the Edwards Aquifer region of Texas and in many other projects (Dillon 1991; Williams 1996; McCarl et al. 1993; and Schaible, McCarl, and Lacewell 1999). Also, the period of analysis was changed to include 2005-2105 with the same conditions assumed in place from 2055-2105.

DISTRIBUTION OF BENEFITS

The model was developed with the capability of an uncertainty or risk analysis to examine the range of benefits that would occur considering the uncertain distribution of salinity and agricultural prices. Data for the 6 salinity and the 10 equally likely price possibilities are used to distribute net income by plan. Each model run containing 60 points of price/weather combinations (as the price and salinity scenarios were assumed to be statistically independent)

was made every 5 years for use in forming net present values. Since an annual series was essential, values were interpolated for the years in between explicit model runs. For example, the model was run to estimate 2005 and 2010 values and results were interpolated for 2006-2009.

Also, in the uncertainty analysis, a distribution of final net present values was needed. That final net present value was the discounted value of the net income for 100 years. According to theory, the distributions under independence of the years could involve the 60th to the 100th points. Clearly, that distribution could not be formed as the number of points is excessive. Thus, the distribution was formed using a sampling scheme. Namely, for each year a random pair of net income outcomes was drawn from explicit model distributions for the years immediately preceding and immediately following the year at hand. This pair of net income outcomes was drawn so that the probability of each outcome matched that assumed for the salinity and price outcomes. A distribution was developed by drawing 500 sets each containing 100 years of data to form a 500-point distribution for net present value across all scenarios.

With the chloride control project in place, the time required to achieve the benefits is not known with certainty, nor can the time for Lake Kemp to reach a new equilibrium be known with certainty. These depend upon rainfall, climate, water use, and many other factors. For the base analysis, the economic model did not consider time for the reduced chlorides to have a beneficial effect. However, a time period of 5 years was assumed externally, based on TAES experiences with similar types of projects in the state. The impact on present value of benefits as well as expected affect on annual benefits was estimated.

ECONOMIC UPDATE 2001

Introduction to Year 2001 Update

Many of the assumptions and basic information used in the 2000 analysis have been adjusted and other alternatives developed for the 2001 evaluation. The basic model is the same but has been modified to address alternative irrigation allocation schemes from Lake Kemp along with probabilities of different quantities of water availability. The discount rate applied for this analysis was 6-3/8%. Final benefits are adjusted to a 6–1/8 % discount rate. Detailed descriptions have been presented earlier.

Basic Scenarios

The fundamental revision of input data for the analysis related to the allocation of irrigation water from Lake Kemp. In addition, two scenarios were run for developing benefits of the project.

Irrigation Allocation Alternatives

Three allocation schemes impacting economic Reaches 7 and 12 as provided by the Tulsa District, Corps of Engineers were as follows:

Scenario One:	71,500 acre-feet of water available 100% of the time
Scenario Two:	100,000 acre-feet of water available 89% of the time
	50,000 acre-feet of water available 11% of the time
Scenario Three:	120,000 acre-feet of water available 82% of the time
	60,000 acre-feet of water available 16% of the time
	30,000 acre-feet of water available 2% of the time

All analyses include Reaches 5 and 6 with 70,000 acre-feet of water available in each reach 100% of the time. The rationale for development of these scenarios is discussed in the hydrology appendix.

Comparisons

For the study area, there are about 15,000 acres irrigated in a base case. With improved water quality, it is expected that irrigated acres will increase. To have a set of expected benefits attributable to the project, two sets of comparisons were analyzed for the three scenarios above. The comparisons were:

Scenario One: Optimal to Optimal. The refers to running the GAMS model allowing optimal or profit maximizing acres of each crop (irrigation and dryland) to come into solution for current conditions and conditions with the salinity project.

Scenario Two: 15,000 to Optimal. This refers to running the GAMS model allowing only 15,000 irrigated acres for the current conditions situation but using the optimal (profit maximizing) acres of irrigated crops for the with project conditions.

For the Optimal to Optimal and the 15,000 to Optimal comparisons above, all three scenarios of irrigation water allocation conditions will be included. Thus, there are six runs of the GAMS model with associated results.

Input Data

Mathematical models range from simple to very sophisticated. As the analysis proceeds in the Wichita River related to salinity control, the GAMS model has become more detailed and complex. A full listing of the model as modified for this analysis is presented in Appendix A. The GAMS model represents a very powerful method for modeling using external files. For the analysis, there are data requirements related to land, water, crop yield and impact of salinity on yield, and crop enterprise budgets.

Land Availability

Land in each soil type for each reach was derived from U.S. Department of Agriculture soils maps for the study area. Table 5-24 indicates acres for soils in Reaches 5, 6, 7, 9, 10, and 12. Most of the acreage is located in Reach 7, with 30,723 dryland, 5,482 irrigated, and 9,133 in irrigated pasture. Total land available for the study is 99,827 acres.

TABLE 5-24
LAND AVAILABLE BY SOIL TYPE AND REACH

Reach	Soil Type	Text	Current Use		
			Dry	Irr	Pastirr
5	Slaughtervill	FSL	0	32	0
5	Teller	L	18,667	0	0
5	All Soils	Total	18,667	32	0
6	Minco	L	18,062	96	0
6	All Soils	Total	18,062	96	0
7	Winters	L	0	5,482	0
7	Deandale	SLS	0	0	9,133
7	Weswood	SL	30,723	0	0
7	All Soils	Total	30,723	5,482	9,133
9	Clairemont	SL	987	0	0
9	All Soils	Total	9878	0	0
10	Clairemont	SL	0	110	0
10	Mangum	CL	1,462	0	0
10	All Soils	Total	1,462	110	0
12	Hollister	CL	0	21	0
12	Deandale	SL	15,120	0	42
12	All Soils	Total	15,120	21	42

Water Availability

Basic assumptions related to water availability for the total study area are shown above. However, the analysis requires allocating water availability across reaches for the different scenarios. Table 5-25 presents water availability in acre-feet by reach for the alternative scenarios presented above - full water always; full water 89% of the time and only limited water 11% of the time; and limited water 16% of the time with no water 2% of the time and full water the rest of the time. Quantity available under alternative probabilities is presented. For reaches 7 and 12, they share water so the water given for Reach 7 is also available to Reach 12. It is just the total that is constraining.

TABLE 5-25
WATER AVAILABLE BY REACH AND ASSUMPTION

Assumption – Full Water Always Available			
Probability	1.00		
Reach 5	70000		
Reach 6	70000		
Reach 7**	71500		
Reach 9	0		
Reach 10	0		
Reach 11	0		
Reach 12**	0		
Assumption – Limited water 11% of the time, full the rest			
Probability	0.89	0.11	
Reach 5	70000	70000	
Reach 6	70000	70000	
Reach 7**	100000	50000	
Reach 9	0	0	
Reach 10	0	0	
Reach 11	0	0	
Reach 12**	0	0	
Assumption – Limited water 16% of the time, no water 2%, full the rest			
Probability	0.82	0.16	0.02
Reach 5	70000	70000	70000
Reach 6	70000	70000	70000
Reach 7**	120000	60000	30000
Reach 9	0	0	0
Reach 10	0	0	0
Reach 11	0	0	0
Reach 12**	0	0	0
** Reaches 7 and 12 share water.			

Yield Reduction Curves

A basic part of the economic analysis was to estimate the implications for irrigated agriculture comparing current conditions to with-project conditions. The reduced salinity load of the water with the project enhances yield. Therefore, the effect of salinity on crop yield represents a major component of the analysis. Table 5-26 presents the yield reduction curves used in this analysis.

TABLE 5-26
YIELD REDUCTION CURVES BY CROP

Crop	Intercept	Slope
Cotton	-40.48	5.21
Wheat	-42.86	7.14
Sorghum	-26.83	7.05
Alfalfa	-15.06	7.42
Tomatoes	-25.07	9.98
SweetCorn	-20.46	12.02
Bermuda	-44.37	5.35
Negative results are set to zero – no yield reduction.		

The intercept indicates the tolerance of a crop to salinity. For example, cotton shows a negative intercept of 40, which means there is tolerance to salt before a yield decline begins. Conversely, sweet corn has only a negative 20 and then for each unit of salinity a yield reduction that is over twice as much as for cotton. Tolerance is indicated for cotton, wheat, and Bermuda. Most sensitive to salinity are alfalfa, tomatoes, and sweet corn.

The calculations for salinity are described previously. The basis for the salinity estimate relates to the salinity of the water in the soil at the point the water is taken up by the crop. The salinity of the water in the soil is converted to soil-water conductivity. Calculations of salinity by crop were constructed based on the average annual portion of the crop growth water requirements that will be provided by infiltrated rainfall. This refined leaching requirements by more appropriately accounting for benefits provided through rainfall.

The salinity estimates were treated as uncertain over time with a seven-stream flow event distribution estimated. Actual salinity is a function of rainfall timing and amount, stream flow, deposition in arid periods of salinitys, and stochastic characteristics of nature (Walker 2000). Salinity level estimates were developed based on numbers provided by the Corps of Engineers. The resultant soil conductivity estimates are presented in Walker (2000) by reach, weather scenario (stream flow event), and crop.

Crop Enterprise Budgets

Estimating benefits to agriculture for a project such as the Wichita portion of the Red River Salinity Control project is based on increased returns to land. Therefore, the expected costs and returns for crop production under dryland and irrigated conditions is an integral part of the analysis. In this case, the Texas Cooperative Extension crop enterprise budgets for the Cross Timbers region along with budgets from Oklahoma were used to reflect the study area. Since yield is a function of salinity, the cost to harvest is incorporated on a per unit basis of crop yield. Also, the cost of water (amortized cost of a system, fuel, labor) is a function of the amount of water applied. The cost reported is for the enterprise budget yield and level of irrigation. Table 5-27 presents the crop enterprise budgets as applied in the GAMS model. The crop enterprise budgets were based on crop enterprise budgets developed for the Cross Timber region by Bevers (2001).

TABLE 5-27

CROP BUDGETS, DETAILING COSTS – YEAR 2001

		Dry	Irr
Base Budget for Bermuda Graz			
Crop Yield	(1)	5.00	
Var costs excepting water, fertilizer, and harve		50.00	
Base Budget for Cotton			
Crop Yield	(1)	226.00	440.00
Nitrogen Use	(2)	0.00	75.00
Phosphorus Use	(2)	0.00	40.00
Var costs excepting water, fertilizer, and harve		56.26	106.16
Harvest Cost	(3)	39.00	72.00
Water Cost	(4)	0.00	33.84
Base Budget for Wheat			
Crop Yield	(1)	35.00	36.00
Nitrogen Use	(2)	100.00	150.00
Phosphorus Use	(2)	0.00	45.00
Harvest Cost	(3)	16.25	18.25
Water Cost	(4)	0.00	58.55
By Product Grazing	(1)	65.00	139.50
Base Budget for Sorghum			
Crop Yield	(1)	23.00	65.00
Nitrogen Use	(2)	0.00	160.00
Phosphorus Use	(2)	0.00	60.00
Var costs excepting water, fertilizer, and harve		23.62	16.53
Harvest Cost	(3)	16.25	35.75
Water Cost	(4)	0.00	22.15
Base Budget for Alfalfa			
Crop Yield	(1)	2.50	6.00
Phosphorus Use	(2)	20.00	46.00
Var costs excepting water, fertilizer, and harve		110.40	47.93
Harvest Cost	(3)	65.00	160.00
Water Cost	(4)	0.00	66.49
Base Budget for Tomatoes			
Crop Yield	(1)		840.00
Var costs excepting water, fertilizer, and harve		3,793.67	
Harvest Cost	(3)		1,680.00
Water Cost	(4)		52.20

TABLE 5-27 (Continued)

		Dry	Irr
Base Budget for SweetCorn			
Crop Yield	(1)		180.00
Var costs excepting water, fertilizer, and harve			603.55
Harvest Cost	(3)		246.00
Water Cost	(4)		40.60
Base Budget for Pasture			
Crop Yield	(1)	1.00	
Base Budget for Bermuda			
Crop Yield	(1)		8.00
Nitrogen Use	(2)		240.00
Phosphorus Use	(2)		40.00
Harvest Cost	(3)		300.00
Water Cost	(4)		47.00

Notes:
(1) Yields are a function of water, salinity, and soil.
(2) Fertilizer use is a function of yield as altered by soil, salinity, and water available.
(3) Harvest cost is a function of yield as altered by soil, salinity, and water available.
(4) Water cost is a function of water applied.
(5) Whole budget can go to the dryland alternative if water is limited.

The base crop enterprise budgets are presented in McCarl et al. (2000) with prices updated and functions shown above incorporated.

Crop Prices

Revenue is derived from selling a crop produced or leasing grazing on small grains such as wheat. For those crops that are included in Federal farm program provisions, the USDA ERS develops normalized prices that are designed to remove the influence of the Federal farm program. Other crops are valued at the average for the region. Table 5-28 presents the crop prices used in this analysis.

TABLE 5-28
CROP PRICE AND DISCOUNT RATE ASSUMPTIONS USED

Crop	Unit	Dollars
Graze	lb/gain	0.32
BermudaGraz	aum	8.00
Cotton	pound	0.638
Wheat	bushel	3.83
Sorghum	hundredweight	4.98
Alfalfa	ton	112.98
Tomatoes	box	7.90
Sweet Corn	box	5.75
Pasture	aum	3.00
Bermuda	ton	83.98
Discount Rate		6.3750

Results

The update for the Wichita River Salinity Control Project included several scenarios and several reaches. Therefore, there is a dramatic amount of information generated. In these results, the focus will be on the implications and insight into expected benefits. Detailed results by decade and reach are presented in the Appendix to this part. The following designations are used in the summary tables in the following main body of the report.

Opt-Opt = Optimal base solution compared to optimal with project solution
15K-Opt = 15,000 acre irrigated base solution compared to optimal with project solution
Wat1 = 71,500 acre-feet of water available 100% of the time
Wat2 = 100,000 acre-feet of water available 89% of the time, 50,000 acre-feet of water available 11% of the time
Wat3 = 120,000 acre-feet of water available 82% of the time, 60,000 acre-feet of water available 16% of the time, 30,000 acre-feet of water available 2% of the time

Acres Irrigated

Six separate estimates for acres irrigated were done conforming to the three scenarios for water availability and the two scenarios on current conditions (current versus optimal). In all cases, the principal reaches irrigated are Reaches 5 and 7. Reaches 7 and 12 are related in that these two reaches share water available and the most profitable receives the water. Table 5-29 provides a summary of irrigated acres for the six scenarioes for 2005 and for 2055. This provides insight into changes over time of irrigated acreage. Details for each of the six scenarios are presented in Appendix B and show each decade, land available, dryland transformed, crop(s) irrigated, and total irrigated land. The principal crop irrigated in all cases is alfalfa, with some tomatoes and bermuda.

TABLE 5-29
ACRES IRRIGATED FOR 2005 AND 2055 ACROSS ALL REACHES BY SCENARIO

Reach	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Opt-Opt, Wat1					
2005	22,325	31,500	32,126	31,500	32,126
2055	16,822	16,822	29,292	29,292	29,562
15k-Opt, Wat1					
2005	5,482	14,615	32,126	31,500	32,126
2055	0	0	29,292	29,292	29,562
Opt-Opt, Wat2					
2005	22,325	31,500	37,003	31,500	37,003
2055	**16,822**	**16,822**	**34,262**	**31,500**	**34,533**
15k-Opt, Wat2					
2005	5,482	14,615	37,003	31,500	37,003
2055	**0**	**0**	**34,262**	**31,500**	**34,533**
Opt-Opt, Wat3					
2005	22,325	31,500	40,491	31,500	40,491
2055	16,822	22,325	37,751	31,500	38,021
15k-Opt, Wat3					
2005	**5,482**	**14,615**	**40,491**	**31,500**	**40,491**
2055	0	5,482	37,751	31,500	38,021

Table 5-29 suggests that even with some risk in water availability, the extra water brings in more irrigated acres. Wat1 is associated with full water all the time but at a lower quantity than Wat2 or Wat3. The greatest irrigated acres are for Wat3 going to over 40,000 for Plans 3 and 5. Plan 4 is relatively consistent with 31,500 acres irrigated for 2005. In 2055, there is a small decline in all cases due to costs rising slightly faster than yields.

Overall, these results suggest that irrigated acres can be expected to be from 32,000 to 40,000 for Plans 3 and 5 and about 31,000 acres with Plan 4 in 2005. Again, the detailed data for irrigated acres is presented in Appendix B.

Water Use

Irrigation is typically profitable in Reaches 7 and 12; therefore, to a large extent water use is a function of availability. Reaches 5 and 6 each had 70,000 acre-feet available with Reach 5 generally using the water in Plans 3 and 5. Plan 4 often has a reduced level of water use. The exception is under the 15,000-acre current conditions scenarios where the irrigated land went to Reaches 7 and 12. Reach 6 generally did not use all the water available. In the three scenarios for Reaches 7 and 12, Wat1 is 70,000 acre-feet compared to Wat2 with 100,000 acre-feet 89% of

the time and Wat3 with 120,000 acre-feet available 82% of the time. In each case, with more water there were more acres irrigated and more water used in Reaches 7 and 12. Reaches 7 and 12 share the quantity of water listed above, and water was allocated to the reach with the greatest economic return.

Opt-Opt, Wat1

Table 5-30 presents water use by reach and plan for 2005 and 2055 for the optimal versus optimal solution assuming full water (Opt-Opt, Wat1) assumptions. Water use declines for Plans 1 and 2 but rises in Plans 3, 4, and 5 over the 50-year planning horizon. Reach 5 uses 70,000 acre-feet in all plans and all years. Water use across the plans in 2005 in thousand acre-feet are Plan 1 - 87, Plan 2 - 115, Plan 3 - 142, Plan 4 - 115, and Plan 5 - 142. In 2055 for current conditions, water use is about 70,000 acre-feet for Plans 1 and 2 compared to 142,000 acre-feet for Plans 3, 4, and 5. Plan 4 indicates a significant increase in irrigated acres over the 50 years. The crop irrigated is primarily alfalfa with small acreage of bermuda and tomatoes. Appendix C presents detailed results of water use by reach, decade, plan, and crop.

TABLE 5-30
WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR OPTIMUM VERSUS OPTIMUM FULL WATER TO REACHES 7 AND 12

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
Opt-Opt, Wat1					
2005					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	288	288	288	288	288
Reach 7	**16,734**	**44,613**	**70,967**	**44,613**	**70,967**
Reach 12	**64**	**192**	**533**	**192**	**533**
Total	**87,086**	**115,093**	**141,788**	**115,093**	**141,788**
2055					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	545	545	545	545	545
Reach 7	0	0	71,380	71,380	70,967
Reach 12	0	0	120	120	533
Total	70,545	70,545	142,045	142,045	142,045
Based on 70,000 acre-feet to Reaches 7 and 12 full time.					

15k-Opt,Wat1

Table 5-31 follows the above format duplicating much of the information and also presenting summary water use for the solution using 15,000 current acres versus optimum with project and with full water but only 70,000 acre-feet in Reaches 7 and 12. The only difference in Tables 5-30 and 5-31 is in Plans 1 and 2 where the irrigated acres were constrained to 15,000. In these cases, water use dropped significantly, with reaches 5 and 6 dropping to zero and irrigated

land all allocated to Reach 7 for Plans 1 and 2. Water allocation for Plans 3, 4, and 5 are identical to Table 5-30 since the assumptions are exactly the same.

TABLE 5-31
WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR 15,000 ACRES CURRENT VERSUS OPTIMUM WITH FULL WATER TO REACHES 7 AND 12

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
15k-Opt, Wat1					
2005					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	288	288	288
Reach 7	**16,734**	**44,613**	**70,967**	**44,613**	**70,967**
Reach 12	**0**	**0**	**533**	**192**	**533**
Total	**16,734**	**44,613**	**141,788**	**115,093**	**141,788**
2055					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	545	545	545
Reach 7	0	0	71,380	71,380	70,967
Reach 12	0	0	120	120	533
Total	0	0	142,045	142,045	142,045
Based on 70,000 acre-feet to reaches 7 and 12 full time.					

Opt-Opt,Wat2

This scenario is for the optimal versus optimal but with more water in Reaches 7 and 12 tied to 100,000 acre-feet of water available 89% of the time and 50,000 acre-feet of water available 11% of the time. This is an increase above the 70,000 acre-feet available all the time as shown in Tables 5-30 and 5-31. Table 5-32 presents the water use where this additional water is available most of the time. In this case, Plan 1 and Plan 2 water use is the same as for Opt-Opt,Wat1 because the current conditions are the same. However, the additional water available is reflected in the water use values for Plans 3, 4, and 5. Over the 50-year planning horizon for the with-project conditions, irrigation water use increases. Water use for Plans 3 and 5 for 2005 and 2055 is approximately 170,000 acre-feet. Plan 4 goes from 115,000 to 154,000 acre-feet over the 50 years. Principal water use is in reaches 5 and 7. The principal crop irrigated was alfalfa for Plans 3, 4, and 5. In Plans 1 and 2, bermuda was irrigated. A small amount of tomatoes (1,200 acres) is in the solutions where there is strong irrigation.

TABLE 5-32

WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR OPTIMUM VERSUS OPTIMUM WITH 100,000 ACRE-FEET AVAILABLE TO REACHES 7 AND 12

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
Opt-Opt, Wat2					
2005					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	288	288	288	288	288
Reach 7	**16,734**	**44,613**	**98,933**	**44,613**	**98,933**
Reach 12	**64**	**192**	**533**	**192**	**533**
Total	**87,086**	**115,093**	**169,754**	**115,093**	**169,754**
2055					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	545	545	545	545	545
Reach 7	0	0	99,880	83,799	99,467
Reach 12	0	0	120	361	533
Total	70,545	70,545	170,545	154,705	170,545
Based on 100,000 acre-feet to Reaches 7 and 12 89% of the time and 50,000 acre-feet available 11% of the time.					

15k-Opt,Wat2

As before, this analysis is similar to Opt-Opt,Wat2 except that the current conditions are constrained to 15,000 irrigated acres. The solution for Plans 3, 4, and 5 are the same as Table 5-32. For Plans 1 and 2, all the land is allocated to Reach 7, which is where the water is used. Only 17,000 acre-feet are used for Plan 1 compared to 44,600 acre-feet for Plan 2. In 2055, irrigation water use is zero. The main crop irrigated is alfalfa in Reach 7 with limited tomatoes and bermuda. The results are presented in Table 5-33.

TABLE 5-33

WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR 15,000 IRRIGATED ACRES FOR CURRENT CONDITION VERSUS OPTIMUM WITH PROJECT ASSUMING 100,000 ACRE-FEET AVAILABLE TO REACHES 7 AND 12 89% OF THE TIME

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
15k-Opt, Wat2					
2005					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	288	288	288
Reach 7	**16,734**	**44,613**	**98,933**	**44,613**	**98,933**
Reach 12	**0**	**0**	**533**	**192**	**533**
Total	**16,734**	**44,613**	**169,754**	**115,093**	**169,754**
2055					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	545	545	545
Reach 7	0	0	99,880	83,799	99,467
Reach 12	0	0	120	361	533
Total	0	0	170,545	154,705	170,545
Based on 100,000 acre-feet to Reaches 7 and 12 89% of the time and 50,000 acre-feet available 11% of the time.					

Opt-Opt,Wat3

This is the last water availability scenario and includes 120,000 acre-feet of water available 82% of the time, 60,000 acre-feet of water available 16% of the time, and 30,000 acre-feet of water available 2% of the time. This still represents a significant increase in water availability for most of the time. Table 5-34 shows irrigation water use for reach and plan. The results are similar to Table 5-32 except for Plans 3, 4, and 5 where more water is applied. Plans 3 and 5 show 190,000 acre-feet of water applied in 2005 and 2055. As in all the cases, alfalfa is the primary crop being irrigated.

TABLE 5-34

WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR OPTIMUM VERSUS OPTIMUM WITH 120,000 ACRE-FEET AVAILABLE TO REACHES 7 AND 12 82% OF THE TIME AND OTHER LIMITS

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
Opt-Opt, Wat3					
2005					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	288	288	288	288	288
Reach 7	**16,734**	**44,613**	**118,933**	**44,613**	**118,933**
Reach 12	**64**	**192**	**533**	**192**	**533**
Total	**87,086**	**115,093**	**189,754**	**115,093**	**189,754**
2055					
Reach 5	70,000	70,000	70,000	70,000	70,000
Reach 6	545	545	545	545	545
Reach 7	0	31,433	119,880	83,799	119,467
Reach 12	0	120	120	361	533
Total	70,545	102,098	190,545	154,705	190,958
Based on 120,000 acre-feet to Reaches 7 and 12 82% of the time, 60,000 acre-feet available 16% of the time, and 30,000 acre-free available 2% of the time.					

15k-Opt,Wat3

The last scenario for water use is the same as Table 5-34 with the 15,000 irrigated acre constraint on current conditions. Table 5-35 shows water use by reach for 2005 and 2055. The results are the same in Plans 3, 4, and 5 as Table 5-34, with Plans 1 and 2 allocating the available irrigated acres to Reach 7.

Crop Yield Reductions

Crop yield reductions are incorporated into the GAMS model. The reduction that is used in a model analysis depends upon the event stochastically selected and reported in the 2001 Economic Analysis. The yield reductions were developed based on the range of expected conditions for each reach for each plan. The significance of the impact of the project conditions is reflected in yield reductions for Plans 3, 4, and 5. The equations for estimating yield reduction were presented earlier in this report. The yield reductions associated with salinity are presented in Appendix D.

TABLE 5-35

WATER USE BY REACH, PLAN, AND SCENARIO FOR 2005 AND 2055 FOR 15,000 IRRIGATED ACRES FOR CURRENT CONDITIONS VERSUS OPTIMUM WITH 12,000 ACRE-FEET AVAILABLE TO REACHES 7 AND 12 82% OF THE TIME AND OTHER LIMITS

	Plan 1	**Plan 2**	**Plan 3**	**Plan 4**	**Plan 5**
15k-Opt, Wat3					
2005					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	288	288	288
Reach 7	**16,734**	**44,613**	**118,933**	**44,613**	**118,933**
Reach 12	**0**	**0**	**533**	**192**	**533**
Total	**87,086**	**115,093**	**189,754**	**115,093**	**189,754**
2055					
Reach 5	0	0	70,000	70,000	70,000
Reach 6	0	0	545	545	545
Reach 7	0	31,433	119,880	83,799	119,467
Reach 12	0	0	120	361	533
Total	70,545	102,098	190,545	154,705	190,958
Based on 120,000 acre-feet to Reaches 7 and 12 82% of the time, 60,000 acre-feet available 16% of the time, and 30,000 acre-free available 2% of the time.					

Economic Implications

Economic benefits presented in this portion of the report are summarized values across reaches and across the 50-year planning horizon. Benefits are held constant beyond the 50-year planning horizon. The appendix provides detailed values by reach, year, and plan. Economic implications of the Wichita Salinity Control Project include the present value of total economic returns (returns to land over 100 years discounted to a present value), the total benefit of the project as compared to Plan 2 (current conditions), and average annual benefits (amortized total present value of benefits).

Total Value by Plan

Table 5-36 presents the present value of total net returns or returns to land for each plan over 50 years and across all reaches. The net present value of total net returns across the study area is near $250 million. Plan 1 is slightly less than Plan 2. Plan 2 is current conditions, and benefits over the six scenarios range from $236 million to $257 million. Basically, Plan 2 total present value of net returns is $257 million for the optimal to optimal solutions and $236 for the 15,000-acre irrigated acre constraint for current conditions. For Plans 3, 4, and 5, the present value of net returns is greater for the optimal to optimal solutions and increases as total water available is increased even with a low probability of less water being available. Plan 5 exceeds $300 million for the larger water supplies (Wat2 and Wat3). These values are useful to provide the base from which the benefits of the project can be estimated.

TABLE 5-36

TOTAL PRESENT VALUE OF NET RETURNS TO IRRIGATED AGRICULTURE FROM 2005-2055 FOR SIX SCENARIOS IN MILLION DOLLARS

	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5
Opt-Opt, Wat1 Full Water Always Available	256	257	279	260	288
15k-Opt, Wat1 Full Water Always Available	235	236	273	255	287
Opt-Opt, Wat2 Limited Water 11% of the Time, Full the Rest	256	257	284	259	300
15k-Opt, Wat 2 Limited Water 11% of the time, Full the Rest	235	236	284	259	300
Opt-Opt, Wat3 Limited Water 16% of the time, and No Water 2%	255	257	288	259	307
15k-Opt, Wat3 Limited Water 16% of the time, and No Water 2%	235	236	288	259	307

Total Net Benefits

Total net benefits are measured as the difference between Plan 2 (current conditions) and the other plans. Table 5-37 presents the total net benefits of the Wichita Salinity Control Project over the 100-year planning horizon. Some characteristics of the assumptions reveal themselves in the benefits estimates. Benefits are greater when the 15,000 irrigated acreage limitation is imposed for each water availability scenario. For Wat1, total present value of benefits go from $22 million to $36.7 million compared to Plan 5 which goes from $31 million to $51.6 million. Plan 4 is associated with less benefits than Plan 3 or Plan 5.

TABLE 5-37

TOTAL PRESENT VALUE OF NET BENEFITS TO THE WICHITA SALINITY CONTROL PROJECT FROM 2005-2055 FOR SIX SCENARIOS IN MILLION DOLLARS

	Plan 1	Plan 3	Plan 4	Plan 5
Opt-Opt, Wat1 Full Water Always Available	-0.591	22.045	3.051	31.055
15k-Opt, Wat1 Full Water Always Available	-0.953	36.699	19.554	51.599
Opt-Opt, Wat2 Limited Water 11% of the Time, Full the Rest	-1.249	26.787	2.062	42.762
15k-Opt, Wat 2 Limited Water 11% of the time, Full the Rest	-1.245	47.746	23.021	63.721
Opt-Opt, Wat3 Limited Water 16% of the time, and No Water 2%	-1.311	31.494	2.278	49.797
15k-Opt, Wat3 Limited Water 16% of the time, and No Water 2%	-1.307	52.453	23.237	70.756

With increased water availability even with a probability of less water, the benefits increase in all cases except Plan 4 for the optimal versus optimal case. Plan 3 benefits range from $26.8 to $47.7 million for the 100,000 acre-feet 89% of the time. Plan 5 is even greater, ranging from $42.8 to $63.7 million. Going to 120,000 acre-feet 82% of the time brings benefits

up to $31.5 million for Plan 3 and $49.8 million for Plan 5 comparing optimal to optimal. The values under the current conditions of 15,000 irrigated acres gives benefits of $52.5 million and $70.8 million for Plan 3 and Plan 5, respectively. Plan 4 has maximum benefits of just over $23 million. These values are useful in viewing the total benefits over 100 years and comparing to the present value of all expected costs.

Average Annual Benefits

With the present value of irrigated benefits as given in Table 5-37, it is a simple task to estimate the expected average annual benefits to the project. This involves amortizing the total benefits over the 100-year planning horizon to get expected benefits per year. Table 5-38 presents the expected average annual benefits to irrigated agriculture across all reaches for the Wichita Salinity Control Project. Naturally, the average annual benefits mirror the total present value of benefits. For Plan 3, benefits range from $1.4 to $3.34 million, for Plan 4 from $0.194 to $1.481 million, and for Plan 5 from $1.98 to $4.511 million. Clearly, based just on the agriculture component of measuring benefits to the project, Plan 5 is far superior.

TABLE 5-38
AVERAGE ANNUAL BENEFITS TO THE WICHITA SALINITY CONTROL PROJECT FOR SIX SCENARIOS IN MILLION DOLLARS

	Plan 1	**Plan 3**	**Plan 4**	**Plan 5**
Opt-Opt, Wat1 - Full Water Always Available	-0.038	1.405	0.194	1.980
15k-Opt, Wat1 - Full Water Always Available	-0.061	2.340	1.247	3.289
Opt-Opt, Wat2 - Limited Water 11% of the Time, Full the Rest	-0.080	1.708	0.131	2.726
15k-Opt, Wat 2 - Limited Water 11% of the time, Full the Rest	-0.079	3.044	1.468	4.062
Opt-Opt, Wat3 - Limited Water 16% of the time, and No Water 2%	-0.084	2.008	0.145	3.175
15k-Opt, Wat3 - Limited Water 16% of the time, and No Water 2%	-0.083	3.344	1.481	4.511

These results indicate that more water can be profitably used in the study area for as the total water available is increased, benefits increase. Also, there is support that the improved water quality is a benefit to agriculture bringing increased yields. The primary crop produced was alfalfa with some bermuda and a small acreage of tomatoes.

Appendix E contains details of benefits by reach, plan, and the beginning year of a decade. Benefits are measured as the difference between Plan 2 and the other plans. Appendix F presents the expected average annual benefits by reach and plan.

Several issues and market factors impact the economic analysis. Some major factors included in the analysis are:

a. In this analysis, the location of land available for irrigation has significantly shifted east from that in the past studies. In particular, the majority of the land available for

irrigation is located in reaches where the change in salinity is not great relative to crop tolerance for salinity. This means the yield differences in those regions for project conditions is not dramatic. In previous appraisals, there was substantially more potential irrigable acreage available in reaches that received a very large projected reduction in salinity loads and, therefore, exhibited large changes in the potential for agricultural irrigation. Our reexamination based on GIS and ownership patterns showed irrigated crop production in the uppermost reaches was not viable.

b. Over the 15 or so years that this project has been appraised, agriculture has been subjected to a cost price squeeze, and the profitability of agriculture has not been great. In the project region, the observed irrigated acres have fallen largely due to economic conditions. This occurred even though the first project works were put in place. Much of this current situation of depressed prices is resolved due to the use of normalized prices.

Reviewing the expected annual net returns for Plan 5 in Table 5-39 gives insight into the dynamics of the region. Benefits are estimated at $3.31 million in 2005 then increase slowly to $11.79 million by 2055. This is due mainly to a long-term crop yield increase that is incorporated into the model (Lacewell et al. 1992).

Table 5-40 shows the projected irrigated acres for 2005 within each reach. The principal regions for irrigated production are 5 and 7 and particularly for Plans 3, 4, and 5. Irrigated acres are projected to increase dramatically for Plans 3-5, going from 15,000 to over 50,000 acres in Plans 3 and 5 and 24,000 acres in Plan 4. This leaves about 40,000 acres available but not irrigated in Plans 3 and 5. Current irrigated acres of 15,000 were set as an upper limit in the model for Plans 1 and 2. Large irrigated acreage increases with the project (Plans 3-5) are shown for reaches 5 and 7. Reaches 9 and 11 show no irrigated acres.

For this analysis, the potential irrigated crops were cotton, wheat, sorghum, alfalfa, tomatoes, sweet corn, and bermuda. The principal crop produced is dryland alfalfa for Plans 1 and 2, with about 15,000 acres of irrigated alfalfa (See Table 5-41). However, with the project completed as defined in Plans 3-5, nearly 50,000 acres shift from dryland alfalfa to irrigated alfalfa in Plans 3 and 5. There are some minor acreages of sweet corn and tomatoes. In 2015, the solution is not dramatically different from 2005, giving stability to cropping patterns.

Table 5-42 shows acres of pasture, idle, irrigated, dryland and land converted or transformed to crop production for selected time periods. Total irrigated acreage under each plan is relatively stable. Uncertainties as far as 50 years in the future and certainly 100 years are speculation at best. Nevertheless, with the models and capabilities developed in this project, updates are efficient and easy. At this point, the benefits of the project using normalized prices and realistic assumptions suggest strong benefits through irrigated agriculture.

The land transformation cost was set at $18.11 per acre to account for extra tillage and land preparation plus an assumed cost for additional equipment to farm the cropland (Lacewell et al. 1992).

An alternative approach to estimating net benefits involves a comparison of estimated optimal cropping patterns and irrigation decisions without project (current conditions) and with project, rather than limiting irrigated acres for current conditions to 15,000. In this case, using water availability and salinity values estimated by the Corps of Engineers, the present value of total returns to land increases only $5.21 and $6.58 million for Plan 1 and Plan 2, respectively (less than 3%). Plans 3, 4, and 5, naturally, are unchanged. This is reflected in average annual net benefits of $3.17, $0.05, and $5.21 million for Plans 3, 4, and 5, respectively. This is not a major difference from the base assumption of this chapter.

References

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McCarl, Bruce A., Ronald D. Lacewell, John R. Ellis, and Michele D. Zinn. 2000. Economic Analysis. Final Completion Report on Potential Effects of the Wichita River Salinity Control Project. Texas Agricultural Experiment Station Report to U.S. Department of the Army, Corps of Engineers, Tulsa, Oklahoma.

APPENDICES

APPENDIX A

DESCRIPTION OF ECONOMIC MODEL

APPENDIX A
DESCRIPTION OF ECONOMIC MODEL

General linear optimization models within agriculture often consist of maximizing net returns to the farm or region subject to linear constraints on inputs such as land and water availability. A general sample formulation might appear as

Eq. B1.1 maximize $\sum_{i=1}^{n} NR_i * X_i$

subject to:

Eq. B1.2 $\sum_{i=1}^{n} A_{ij} * X_i \leq b_j$ for all j

Eq. B1.3 $X_i \geq 0$ for all j

with the following definitions:

NR_i = net returns per acre for crop i,
X_i = acres of crop i grown,
A_{ij} = use per acre of resource j used in production of crop i,
b_j = total availability of resource j.

Equation B1.1 represents the objective function to be maximized, while equation B1.2 depicts the technical use constraints reflecting limited resource availability, and equation B1.3 limits the decision variables X_i to be non-negative. Optimization problems such as the one depicted above assume known coefficients for the NR_i and A_{ij}, and in practice, mean values are generally used for such coefficients.

Discrete Stochastic Sequential Programming

The true decision environment faced by the agricultural producer, however, is somewhat more complex, and the uncertainty of events beyond the farmer's control affects his/her planting decisions. Risk related factors include weather impacts on yield and input use as well as output prices. In such cases, producer behavior may more accurately be predicted employing techniques such as discrete stochastic sequential programming, or DSSP (Cocks, 1968). Such techniques allow for explicit consideration of the a priori known probabilities of uncertain events. Potential stages might include, as is the case for the current modeling effort, the stages of:

1) Planting, and
2) harvesting and sale after realization of uncertain yields and prices due to market conditions weather and salinity

A general formulation for a three-stage DSSP model, similar to the one actually employed, appears below.

Eq. B2.1 maximize $\sum_{i=1} P_k \cdot NR_{ki} \cdot X_i$

subject to:

Eq. B2.2 $A_1 X \leq b_j$

Eq. B2.3 $A_{k2} Z_k \leq b_{k2}$ for all k;

Eq. B2.4 $-D_{k2} X + E_{k2} Z_k \leq 0$ for all k;

Eq. B2.5 $NR_k - C_1 X - F_k Z_k = 0$ for all k;

Eq. B2.6 $X, Z_k \geq 0$ for all k and i;

Eq. B2.7 NR_{k1} *unrestricted* for all k;

Variable definitions for the formulation are as follows:

k	denotes occurrence of state of nature k in stage 2, k=1,2,…K;
P_k	is the probability of state of nature k occurring in stage 2;
NR_k	is the expected income resulting from the occurrence of event k in stage 2;
A_1	are the technical coefficients associated with stage 1;
X	is the vector of decision variables associated with stage 1;
b_1	is the set of resource endowments associated with stage 1;
A_{k2}	are the technical coefficients associated with stage 2 given state of nature k occurs;
Z_k	is the vector of decision variables associated with stage 2 given state of nature k occurs;
b_{k2}	is the set of resource endowments associated with stage 2 given state of nature k occurs;
D_{k2}, E_{k2}	links the information resulting from decisions in stage 1 to stage 2 given state of nature k occurs in stage 2;
C_1	is the vector of returns resulting from decision variables X in stage 1;
F_k	is the vector of returns resulting from decision variables Z_k when state of nature k occurs in stage 2;

An alternative formulation also includes risk aversion applied to a variance term for the applicable expected net returns in the objective function. Such a formulation was not implemented here.

Several advantages accrue to the approach embodied within this type of formulation. First, activities and constraints are defined for each state of nature. Decisions in early stages therefore take into account potential resource use and availability for later periods. Second, the formulation explicitly considers a feasible solution *under all states of nature* considered by the decision-maker. This is not a feature of the formulation expressed in Equations B1.1-B1.3. In addition, the optimal solution at each decision node takes into consideration all the information available at that node. A third important facet is that the decision made in earlier stages is irreversible, which in this case is choice of crop mix, thereby reflecting reality more accurately. Fourth, all the risks in the constraint set are collapsed into the objective function. This allows use of a single decision rule. Additional plusses are that the framework directly incorporates the risk associated with each plan, as well as the fact that the formulation may be solved by numerous commercial software packages.

Within the current application, stage 1 corresponds to the planting decision. The second stage calculates expected net returns by combining the stochastic output price elements and the stochastic yield (due to salinity and weather conditions).

Input Data and Model Linkages

As noted in the main text and the remainder of the appendices, many facets of the physical and economic environment were included in the current formulation.

Stochastic components such as water quality, yields, and output prices are portrayed by the hexagonal figures while the static components appear as circles. Stochastic water quality (salinity adjusted for the various scenarios and mitigation plans considered) are combined with the expected crop production costs and the stochastic crop output prices to generate stochastic expected net returns for the 60 possible combinations of the 6 salinity levels and the 10 possible prices. Stochastic weather events that affect salinity also impact rainfall and the required water for leaching. These, therefore, affect the technical use coefficients for irrigation water. The resulting expected net returns and expected water use were then used within a model formulation similar to that shown in Equations B2.1 through B2.7. Soils (texture and class), irrigable land available, and the irrigation technology assumed (LEPA or low-energy precision application) comprise the remainder of the major components of the model.

Additional Temporal and Stochastic Considerations

The model is also devised to reflect temporal aspects, allowing optimization of a yearly planting decision for numerous years within some future scenarios. The Prices Paid and Prices Received Indices (developed by the USDA) were used to reflect changing price levels over time. Normalized output prices provided by the USACE for crops included served as a base to which the output price indices were applied, and current crop enterprise budget data from the Texas Agricultural Extension Service served a similar purpose for the prices paid (cost) aspect. Thus, two optimizations were performed (at 5-year intervals) for the period 2005 to 2105 utilizing the indexed output prices and costs. Optimal planting plans were therefore generated for the twenty 5-year periods and expected net returns for intermediate years obtained by interpolation.

The process described above generated a set of 100 yearly optimal planting plans (20 actually optimized and 80 obtained via interpolation) for the upcoming 100-year period. These plans were devised using DSSP and expected values based upon estimated probability distributions for salinity levels and potential output price levels.

When comparing alternative investment alternatives that have multiple-year time horizons, the concept of present-value is often employed to determine which alternative is more attractive when considering the time value of the costs and returns. The stream of net returns predicted by the model under the various investment plans lend themselves to such an analysis, and a simulation model was also devised to randomly generate a series of 500 one-hundred year streams of net returns. Statistical random deviates from both the salinity and output price probability distributions were drawn using statistical techniques and the corresponding net returns calculated for the planting plans generated by the optimization model. Present values were then calculated for each resulting revenue stream, resulting in a probability distribution of expected present values. Comparison of the resulting distribution of present values is then possible for the various investment alternatives.

GAMS File Summary

GAMS (Generalized Algebraic Modeling System) is a powerful modeling/optimization tool for which various elements may be programmed in pieces and then combined within a larger context. Such is the approach taken here, with some files serving solely as data files, others as batch type execution files, and other actually specifying the relationship among the various actual optimization model itself. Table A-1 summarizes the name and purpose of the eight GAMS files employed within the study.

TABLE A-1
GAMS FILE SUMMARY FOR OPTIMIZATION MODEL

No.	File Name	Purpose
1	RUNME.GMS	Integrates all the other files and results in execution of the complete GAMS Program
2	SALTDAT.GMS	Basic data for the agricultural model including identification of reaches, basic cropping data, and water and land availability
3	PROB.GMS	Salinity data by project alternative (included during execution in SALTDAT)
4	SALTMODE.GMS	Describes the optimization model used in the analysis
5	SALTFIN.GMS	A module which runs all the optimization model solutions and saves the data
6	SALTRPT.GMS	A procedure which summarizes model solutions into tables which in turn are used in final reporting
7	SAMP.GMS	A procedure which constructs the sample probability distribution of net present value project returns
8	GRAPH.GMS	A procedure which constructs the final tables for inclusion in the report and graphs the data

APPENDIX B

IRRIGATED ACRES

By Reach and Decade with Dryland Transformed,
Crop Irrigated, and Total Land Irrigated

Table Output-B 5 Acres Irrigated by crop, reach, plan, and decade
Land use report for COE dat under assumption - Opt-Opt - Limited water 16% of the time and no water 2%

Reach 5 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	16694	16694	16694	16694	16694
Alfalfa	16726	16726	16726	16726	16726
Total Irrigated Land Used	16726	16726	16726	16726	16726

Reach 6 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Bermuda	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Bermuda	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	96	96	96	96	96
Total Irrigated Land Used	96	96	96	96	96

Reach 7 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	9133	18014	9133	18014
Alfalfa	0	0	17602	0	17602
Tomatoes	0	0	413	0	413
Bermuda	5482	14615	5482	14615	5482
Total Irrigated Land Used	5482	14615	23496	14615	23496

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	17821	0	15451
Alfalfa	0	0	17821	0	20520
Tomatoes	0	0	413	0	413
Bermuda	5482	5482	5069	5482	0
Total Irrigated Land Used	5482	5482	23303	5482	20933

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	548
Total Dryland Transformed	0	0	15451	9133	1545
Alfalfa	0	0	20520	14615	20520
Tomatoes	0	0	413	0	413
Bermuda	5482	5482	0	0	0
Total Irrigated Land Used	5482	5482	20933	14615	20933

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15544	9133	15451
Alfalfa	0	5482	20613	14615	20520
Tomatoes	0	0	413	0	413
Total Irrigated Land Used	0	5482	21026	14615	20933

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15544	9133	15451
Alfalfa	0	5482	20613	14615	20520
Tomatoes	0	0	413	0	413
Total Irrigated Land Used	0	5482	21026	14615	20933

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15426	9133	15544
Alfalfa	0	5482	20908	14615	20613
Tomatoes	0	0	0	0	413
Total Irrigated Land Used	0	5482	20908	14615	21026

Reach 12 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	42	152	42	152
Tomatoes	0	0	173	0	173
Bermuda	21	63	0	63	0
Total Irrigated Land Used	21	63	173	63	173

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	0	152
Tomatoes	0	0	173	0	173
Bermuda	21	21	0	21	0
Total Irrigated Land Used	21	21	173	21	173

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	0	152
Alfalfa	0	0	0	21	0
Tomatoes	0	0	173	0	173
Bermuda	21	21	0	0	0
Total Irrigated Land Used	21	21	173	21	173

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	42	152
Alfalfa	0	21	0	63	0
Tomatoes	0	0	173	0	173
Total Irrigated Land Used	0	21	173	63	173

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	42	152
Alfalfa	0	21	0	63	0
Tomatoes	0	0	173	0	173
Total Irrigated Land Used	0	21	173	63	173

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	0	42	152
Alfalfa	0	21	21	63	0
Tomatoes	0	0	0	0	173
Total Irrigated Land Used	0	21	21	63	173

Table Output-B 6 Acres Irrigated by crop, reach, plan, and decade
Land use report for COE data under assumption -15K-Opt - Limited water 16% of the time and no water 2%

Reach 5 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	32	32	32	32	32
Total Dryland Transformed	0	0	16694	16694	16694
Alfalfa	0	0	16726	16726	16726
Total Irrigated Land Used	0	0	16726	16726	16726

Reach 6 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Bermuda	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Bermuda	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	96	96	96	96	96
Total Dryland Transformed	0	0	0	0	0
Alfalfa	0	0	96	96	96
Total Irrigated Land Used	0	0	96	96	96

Reach 7 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	9133	18014	9133	18014
Alfalfa	0	0	17602	0	17602
Tomatoes	0	0	413	0	413
Bermuda	5482	14615	5482	14615	5482
Total Irrigated Land Used	5482	14615	23496	14615	23496

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	17821	0	15451
Alfalfa	0	0	17821	0	20520
Tomatoes	0	0	413	0	413
Bermuda	5482	5482	5069	5482	0
Total Irrigated Land Used	5482	5482	23303	5482	20933

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15451	9133	15451
Alfalfa	0	0	20520	14615	20520
Tomatoes	0	0	413	0	413
Bermuda	5482	5482	0	0	0
Total Irrigated Land Used	5482	5482	20933	14615	20933

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15544	9133	15451
Alfalfa	0	5482	20613	14615	20520
Tomatoes	0	0	413	0	413
Total Irrigated Land Used	0	5482	21026	14615	20933

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15544	9133	15451
Alfalfa	0	5482	20613	14615	20520
Tomatoes	0	0	413	0	413
Total Irrigated Land Used	0	5482	21026	14615	20933

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	5482	5482	5482	5482	5482
Total Dryland Transformed	0	0	15426	9133	15544
Alfalfa	0	5482	20908	14615	20613
Tomatoes	0	0	0	0	413
Total Irrigated Land Used	0	5482	20908	14615	21026

Reach 12 Irrigated Acreage

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	42	152
Tomatoes	0	0	173	0	173
Bermuda	0	0	0	63	0
Total Irrigated Land Used	0	0	173	63	173

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	0	152
Tomatoes	0	0	173	0	173
Bermuda	0	0	0	21	0
Total Irrigated Land Used	0	0	173	21	173

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	0	152
Alfalfa	0	0	0	21	0
Tomatoes	0	0	173	0	173
Total Irrigated Land Used	0	0	173	21	173

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	42	152
Alfalfa	0	0	0	63	0
Tomatoes	0	0	173	0	173
Total Irrigated Land Used	0	0	173	63	173

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	152	42	152
Alfalfa	0	0	0	63	0
Tomatoes	0	0	173	0	173
Total Irrigated Land Used	0	0	173	63	173

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Irr Land Available	21	21	21	21	21
Total Dryland Transformed	0	0	0	42	152
Alfalfa	0	0	21	63	0
Tomatoes	0	0	0	0	173
Total Irrigated Land Used	0	0	21	63	173

APPENDIX C

IRRIGATION WATER USED

WATER USE BY CROP, REACH, PLAN, AND DECADE

Table Output-C 5 Water use by crop, reach, plan, and decade

Water use report for coe data under assumption Opt-Opt Limited water 16% of the time and no water 2%

Reach 5 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	70000	70000	70000	70000	70000
Peak Total Irrigation Water Used	70000	70000	70000	70000	70000

Reach 6 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Bermuda	288	288	288	288	288
Peak Total Irrigation Water Used	288	288	288	288	288

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Bermuda	288	288	288	288	288
Peak Total Irrigation Water Used	288	288	288	288	288

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	545	545	545	545	545
Peak Total Irrigation Water Used	545	545	545	545	545

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	545	545	545	545	545
Peak Total Irrigation Water Used	545	545	545	545	545

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	545	545	545	545	545
Peak Total Irrigation Water Used	545	545	545	545	545

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	545	545	545	545	545
Peak Total Irrigation Water Used	545	545	545	545	545

Reach 7 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	100924	0	100924
Tomatoes	0	0	1275	0	1275
Bermuda	16734	44613	16734	44613	16734
Peak Total Irrigation Water Used	16734	44613	118933	44613	118933
Water Used in Reach 12	64	192	533	192	533
Water Used in Reach 7 & 12	16798	44805	119467	44805	119467

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	102184	0	117658
Tomatoes	0	0	1275	0	1275
Bermuda	16734	16734	15474	16734	0
Peak Total Irrigation Water Used	16734	16734	118933	16734	118933
Water Used in Reach 12	64	64	533	64	533
Water Used in Reach 7 & 12	16798	16798	119467	16798	119467

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	117658	83799	117658
Tomatoes	0	0	1275	0	1275
Bermuda	16734	16734	0	0	0
Peak Total Irrigation Water Used	16734	16734	118933	83799	118933
Water Used in Reach 12	64	64	533	120	533
Water Used in Reach 7 & 12	16798	16798	119467	83920	119467

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	118191	83799	117658
Tomatoes	0	0	1275	0	1275
Peak Total Irrigation Water Used	0	31433	119467	83799	118933
Water Used in Reach 12	0	120	533	361	533
Water Used in Reach 7 & 12	0	31553	120000	84161	119467

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	118191	83799	117658
Tomatoes	0	0	1275	0	1275
Peak Total Irrigation Water Used	0	31433	119467	83799	118933
Water Used in Reach 12	0	120	533	361	533
Water Used in Reach 7 & 12	0	31553	120000	84161	119467

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	119880	83799	118191
Tomatoes	0	0	0	0	1275
Peak Total Irrigation Water Used	0	31433	119880	83799	119467
Water Used in Reach 12	0	120	120	361	533
Water Used in Reach 7 & 12	0	31553	120000	84161	120000

Reach 12 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Tomatoes	0	0	533	0	533
Bermuda	64	192	0	192	0
Peak Total Irrigation Water Used	64	192	533	192	533
Water Used in Reach 7	16734	44613	118933	44613	118933
Water Used in Reach 7 & 12	16798	44805	119467	44805	119467

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Tomatoes	0	0	533	0	533
Bermuda	64	64	0	64	0
Peak Total Irrigation Water Used	64	64	533	64	533
Water Used in Reach 7	16734	16734	118933	16734	118933
Water Used in Reach 7 & 12	16798	16798	119467	16798	119467

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	0	120	0
Tomatoes	0	0	533	0	533
Bermuda	64	64	0	0	0
Peak Total Irrigation Water Used	64	64	533	120	533
Water Used in Reach 7	16734	16734	118933	83799	118933
Water Used in Reach 7 & 12	16798	16798	119467	83920	119467

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	120	0	361	0
Tomatoes	0	0	533	0	533
Peak Total Irrigation Water Used	0	120	533	361	533
Water Used in Reach 7	0	31433	119467	83799	118933
Water Used in Reach 7 & 12	0	31553	120000	84161	119467

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	120	0	361	0
Tomatoes	0	0	533	0	533
Peak Total Irrigation Water Used	0	120	533	361	533
Water Used in Reach 7	0	31433	119467	83799	118933
Water Used in Reach 7 & 12	0	31553	120000	84161	119467

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	120	120	361	0
Tomatoes	0	0	0	0	533
Peak Total Irrigation Water Used	0	120	120	361	533
Water Used in Reach 7	0	31433	119880	83799	119467
Water Used in Reach 7 & 12	0	31553	120000	84161	120000

Table Output-C 6 Water use by crop, reach, plan, and decade

Water use report for coe data under assumption 15K-Opt Limited water 16% of the time and no water 2%

Reach 5 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	70000	70000	70000
Peak Total Irrigation Water Used	0	0	70000	70000	70000

Reach 6 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Bermuda	0	0	288	288	288
Peak Total Irrigation Water Used	0	0	288	288	288

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Bermuda	0	0	288	288	288
Peak Total Irrigation Water Used	0	0	288	288	288

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	545	545	545
Peak Total Irrigation Water Used	0	0	545	545	545

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	545	545	545
Peak Total Irrigation Water Used	0	0	545	545	545

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	545	545	545
Peak Total Irrigation Water Used	0	0	545	545	545

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	70000	70000	70000	70000	70000
Alfalfa	0	0	545	545	545
Peak Total Irrigation Water Used	0	0	545	545	545

Reach 7 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	100924	0	100924
Tomatoes	0	0	1275	0	1275
Bermuda	16734	44613	16734	44613	16734
Peak Total Irrigation Water Used	16734	44613	118933	44613	118933
Water Used in Reach 12	0	0	533	192	533
Water Used in Reach 7 & 12	16734	44613	119467	44805	119467

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	102184	0	117658
Tomatoes	0	0	1275	0	1275
Bermuda	16734	16734	15474	16734	0
Peak Total Irrigation Water Used	16734	16734	118933	16734	118933
Water Used in Reach 12	0	0	533	64	533
Water Used in Reach 7 & 12	16734	16734	119467	16798	119467

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	117658	83799	117658
Tomatoes	0	0	1275	0	1275
Bermuda	16734	16734	0	0	0
Peak Total Irrigation Water Used	16734	16734	118933	83799	118933
Water Used in Reach 12	0	0	533	120	533
Water Used in Reach 7 & 12	16734	16734	119467	83920	119467

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	118191	83799	117658
Tomatoes	0	0	1275	0	1275
Peak Total Irrigation Water Used	0	31433	119467	83799	118933
Water Used in Reach 12	0	0	533	361	533
Water Used in Reach 7 & 12	0	31433	120000	84161	119467

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	118191	83799	117658
Tomatoes	0	0	1275	0	1275
Peak Total Irrigation Water Used	0	31433	119467	83799	118933
Water Used in Reach 12	0	0	533	361	533
Water Used in Reach 7 & 12	0	31433	120000	84161	119467

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	120000	120000	120000	120000	120000
Addition from reach 12	0	0	0	0	0
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	31433	119880	83799	118191
Tomatoes	0	0	0	0	1275
Peak Total Irrigation Water Used	0	31433	119880	83799	119467
Water Used in Reach 12	0	0	120	361	533
Water Used in Reach 7 & 12	0	31433	120000	84161	120000

Reach 12 Peak Water Availability and use

Year 2005

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Tomatoes	0	0	533	0	533
Bermuda	0	0	0	192	0
Peak Total Irrigation Water Used	0	0	533	192	533
Water Used in Reach 7	16734	44613	118933	44613	118933
Water Used in Reach 7 & 12	16734	44613	119467	44805	119467

Year 2015

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Tomatoes	0	0	533	0	533
Bermuda	0	0	0	64	0
Peak Total Irrigation Water Used	0	0	533	64	533
Water Used in Reach 7	16734	16734	118933	16734	118933
Water Used in Reach 7 & 12	16734	16734	119467	16798	119467

Year 2025

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	0	120	0
Tomatoes	0	0	533	0	533
Peak Total Irrigation Water Used	0	0	533	120	533
Water Used in Reach 7	16734	16734	118933	83799	118933
Water Used in Reach 7 & 12	16734	16734	119467	83920	119467

Year 2035

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	0	361	0
Tomatoes	0	0	533	0	533
Peak Total Irrigation Water Used	0	0	533	361	533
Water Used in Reach 7	0	31433	119467	83799	118933
Water Used in Reach 7 & 12	0	31433	120000	84161	119467

Year 2045

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	0	361	0
Tomatoes	0	0	533	0	533
Peak Total Irrigation Water Used	0	0	533	361	533
Water Used in Reach 7	0	31433	119467	83799	118933
Water Used in Reach 7 & 12	0	31433	120000	84161	119467

Year 2055

	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Total Current Water Available	0	0	0	0	0
Addition from reach 7	10000	10000	10000	10000	10000
Gross Avail reaches 7 and 12	10000	10000	10000	10000	10000
Alfalfa	0	0	120	361	0
Tomatoes	0	0	0	0	533
Peak Total Irrigation Water Used	0	0	120	361	533
Water Used in Reach 7	0	31433	119880	83799	119467
Water Used in Reach 7 & 12	0	31433	120000	84161	120000

APPENDIX D

SALINITY YIELD REDUCTIONS
BY CROP, REACH, PLAN, AND STOCHASTIC EVENT

Table Output-D Yield reductions, by crop, reach, and plan

Report of Yield Reduction in percentage using coe salinity data

Note the same percent change applies for all years

Reach 5 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	0.00	0.00	0.00	0.00	0.00
Cotton	event2	0.00	0.00	0.00	0.00	0.00
Cotton	event3	0.00	0.00	0.00	0.00	0.00
Cotton	event4	1.36	1.36	1.36	1.36	1.36
Cotton	event5	6.11	6.11	6.11	6.11	6.11
Cotton	Event6	9.88	9.88	9.88	9.88	9.88
Cotton	Average	0.94	0.94	0.94	0.94	0.94
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	0.00	0.00	0.00	0.00	0.00
Sorghum	event2	0.00	0.00	0.00	0.00	0.00
Sorghum	event3	16.74	16.74	16.74	16.74	16.74
Sorghum	event4	31.54	31.54	31.54	31.54	31.54
Sorghum	event5	38.17	38.17	38.17	38.17	38.17
Sorghum	Event6	43.46	43.46	43.46	43.46	43.46
Sorghum	Average	12.26	12.26	12.26	12.26	12.26
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	3.68	3.68	3.68	3.68	3.68
Alfalfa	event2	13.36	13.36	13.36	13.36	13.36
Alfalfa	event3	34.28	34.28	34.28	34.28	34.28
Alfalfa	event4	50.98	50.98	50.98	50.98	50.98
Alfalfa	event5	58.69	58.69	58.69	58.69	58.69
Alfalfa	Event6	64.71	64.71	64.71	64.71	64.71
Alfalfa	Average	25.93	25.93	25.93	25.93	25.93
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	0.13	0.13	0.13	0.13	0.13
Tomatoes	event2	13.15	13.15	13.15	13.15	13.15
Tomatoes	event3	41.30	41.30	41.30	41.30	41.30
Tomatoes	event4	63.75	63.75	63.75	63.75	63.75
Tomatoes	event5	74.13	74.13	74.13	74.13	74.13
Tomatoes	Event6	82.22	82.22	82.22	82.22	82.22
Tomatoes	Average	30.54	30.54	30.54	30.54	30.54
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	7.79	7.79	7.79	7.79	7.79
SweetCorn	event2	22.33	22.33	22.33	22.33	22.33
SweetCorn	event3	53.82	53.82	53.82	53.82	53.82
SweetCorn	event4	79.07	79.07	79.07	79.07	79.07
SweetCorn	event5	90.36	90.36	90.36	90.36	90.36
SweetCorn	Event6	99.38	99.38	99.38	99.38	99.38
SweetCorn	Average	41.02	41.02	41.02	41.02	41.02
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	0.00	0.00	0.00	0.00	0.00
Bermuda	event2	0.00	0.00	0.00	0.00	0.00
Bermuda	event3	0.00	0.00	0.00	0.00	0.00
Bermuda	event4	5.30	5.30	5.30	5.30	5.30
Bermuda	event5	11.00	11.00	11.00	11.00	11.00
Bermuda	Event6	15.50	15.50	15.50	15.50	15.50
Bermuda	Average	1.86	1.86	1.86	1.86	1.86

Reach 6 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	0.00	0.00	0.00	0.00	0.00
Cotton	event2	0.00	0.00	0.00	0.00	0.00
Cotton	event3	0.00	0.00	0.00	0.00	0.00
Cotton	event4	8.12	8.12	8.12	8.12	8.12
Cotton	event5	11.90	11.90	11.90	11.90	11.90
Cotton	Event6	15.21	15.21	15.21	15.21	15.21
Cotton	Average	2.17	2.17	2.17	2.17	2.17
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	0.00	0.00	0.00	0.00	0.00
Sorghum	event2	5.31	5.31	5.31	5.31	5.31
Sorghum	event3	25.09	25.09	25.09	25.09	25.09
Sorghum	event4	41.01	41.01	41.01	41.01	41.01
Sorghum	event5	46.27	46.27	46.27	46.27	46.27
Sorghum	Event6	50.90	50.90	50.90	50.90	50.90
Sorghum	Average	18.08	18.08	18.08	18.08	18.08
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	9.30	9.30	9.30	9.30	9.30
Alfalfa	event2	21.37	21.37	21.37	21.37	21.37
Alfalfa	event3	43.80	43.80	43.80	43.80	43.80
Alfalfa	event4	61.83	61.83	61.83	61.83	61.83
Alfalfa	event5	67.81	67.81	67.81	67.81	67.81
Alfalfa	Event6	73.05	73.05	73.05	73.05	73.05
Alfalfa	Average	33.71	33.71	33.71	33.71	33.71
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	7.69	7.69	7.69	7.69	7.69
Tomatoes	event2	23.93	23.93	23.93	23.93	23.93
Tomatoes	event3	54.09	54.09	54.09	54.09	54.09
Tomatoes	event4	78.35	78.35	78.35	78.35	78.35
Tomatoes	event5	86.39	86.39	86.39	86.39	86.39
Tomatoes	Event6	93.43	93.43	93.43	93.43	93.43
Tomatoes	Average	41.00	41.00	41.00	41.00	41.00
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	16.19	16.19	16.19	16.19	16.19
SweetCorn	event2	34.34	34.34	34.34	34.34	34.34
SweetCorn	event3	68.07	68.07	68.07	68.07	68.07
SweetCorn	event4	95.20	95.20	95.20	95.20	95.20
SweetCorn	event5	100.00	100.00	100.00	100.00	100.00
SweetCorn	Event6	100.00	100.00	100.00	100.00	100.00
SweetCorn	Average	51.86	51.86	51.86	51.86	51.86
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	0.00	0.00	0.00	0.00	0.00
Bermuda	event2	0.00	0.00	0.00	0.00	0.00
Bermuda	event3	0.00	0.00	0.00	0.00	0.00
Bermuda	event4	13.37	13.37	13.37	13.37	13.37
Bermuda	event5	17.86	17.86	17.86	17.86	17.86
Bermuda	Event6	21.79	21.79	21.79	21.79	21.79
Bermuda	Average	3.32	3.32	3.32	3.32	3.32

Reach 7 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	0.00	0.00	0.00	0.00	0.00
Cotton	event2	0.00	0.00	0.00	0.00	0.00
Cotton	event3	1.55	0.00	0.00	0.00	0.00
Cotton	event4	9.93	0.00	0.00	0.00	0.00
Cotton	event5	15.10	0.24	0.00	0.00	0.00
Cotton	Event6	17.60	1.82	0.00	0.00	0.00
Cotton	Average	3.09	0.10	0.00	0.00	0.00
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	18.61	6.93	0.00	1.74	0.00
Sorghum	event2	23.35	10.47	0.00	4.35	0.00
Sorghum	event3	31.84	16.23	0.00	9.79	0.00
Sorghum	event4	43.53	24.62	1.22	15.63	0.00
Sorghum	event5	50.75	30.01	2.94	23.36	0.00
Sorghum	Event6	54.23	32.21	4.76	22.20	0.00
Sorghum	Average	28.02	14.28	0.51	8.25	0.00
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	36.44	23.21	5.85	17.33	0.22
Alfalfa	event2	41.82	27.23	7.90	20.27	1.75
Alfalfa	event3	51.45	33.75	12.92	26.45	5.79
Alfalfa	event4	64.70	43.26	16.74	33.07	9.46
Alfalfa	event5	72.87	49.37	18.68	41.84	10.92
Alfalfa	Event6	76.83	51.87	20.75	40.52	12.01
Alfalfa	Average	45.58	30.00	10.48	23.17	4.38
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	44.20	26.41	3.05	18.49	0.00
Tomatoes	event2	51.44	31.81	5.81	22.45	0.00
Tomatoes	event3	64.38	40.58	12.56	30.76	2.97
Tomatoes	event4	82.21	53.37	17.70	39.66	7.91
Tomatoes	event5	93.20	61.59	20.31	51.46	9.88
Tomatoes	Event6	98.52	64.95	23.09	49.68	11.34
Tomatoes	Average	56.97	36.02	9.76	26.84	2.74
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	57.01	37.10	11.00	28.26	2.52
SweetCorn	event2	65.10	43.14	14.07	32.69	4.83
SweetCorn	event3	79.57	52.96	21.63	41.97	10.90
SweetCorn	event4	99.50	67.26	27.37	51.92	16.42
SweetCorn	event5	100.00	76.45	30.29	65.11	18.62
SweetCorn	Event6	100.00	80.21	33.40	63.14	20.25
SweetCorn	Average	69.05	47.10	17.73	36.83	8.56
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	0.00	0.00	0.00	0.00	0.00
Bermuda	event2	0.00	0.00	0.00	0.00	0.00
Bermuda	event3	5.57	0.00	0.00	0.00	0.00
Bermuda	event4	15.52	0.00	0.00	0.00	0.00
Bermuda	event5	21.67	4.01	0.00	0.00	0.00
Bermuda	Event6	24.63	5.89	0.00	0.00	0.00
Bermuda	Average	5.54	0.49	0.00	0.00	0.00

Reach 9 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	0.00	0.00	0.00	0.00	0.00
Cotton	event2	24.25	15.10	0.00	11.79	0.00
Cotton	event3	75.07	53.81	9.04	51.52	6.26
Cotton	event4	100.00	71.69	31.55	72.79	30.49
Cotton	event5	100.00	81.94	43.89	84.57	43.10
Cotton	Event6	100.00	93.84	55.53	99.18	56.45
Cotton	Average	49.80	36.63	10.84	35.46	9.90
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	29.13	21.86	0.00	17.90	0.00
Sorghum	event2	63.53	50.74	9.61	46.14	4.39
Sorghum	event3	100.00	100.00	42.28	100.00	38.41
Sorghum	event4	100.00	100.00	73.70	100.00	72.23
Sorghum	event5	100.00	100.00	90.93	100.00	89.84
Sorghum	Event6	100.00	100.00	100.00	100.00	100.00
Sorghum	Average	71.97	67.41	32.48	65.63	29.56
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	48.37	40.13	10.06	35.64	7.73
Alfalfa	event2	87.37	72.87	26.25	67.65	20.33
Alfalfa	event3	100.00	100.00	63.28	100.00	58.90
Alfalfa	event4	100.00	100.00	98.90	100.00	97.23
Alfalfa	event5	100.00	100.00	100.00	100.00	100.00
Alfalfa	Event6	100.00	100.00	100.00	100.00	100.00
Alfalfa	Average	81.05	75.87	47.76	73.86	44.26
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	60.24	49.16	8.71	43.12	5.58
Tomatoes	event2	100.00	93.19	30.50	86.18	22.53
Tomatoes	event3	100.00	100.00	80.30	100.00	74.40
Tomatoes	event4	100.00	100.00	100.00	100.00	100.00
Tomatoes	event5	100.00	100.00	100.00	100.00	100.00
Tomatoes	Event6	100.00	100.00	100.00	100.00	100.00
Tomatoes	Average	86.02	82.87	54.11	80.17	49.64
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	74.94	62.55	17.32	55.79	13.82
SweetCorn	event2	100.00	100.00	41.67	100.00	32.78
SweetCorn	event3	100.00	100.00	97.37	100.00	90.77
SweetCorn	event4	100.00	100.00	100.00	100.00	100.00
SweetCorn	event5	100.00	100.00	100.00	100.00	100.00
SweetCorn	Event6	100.00	100.00	100.00	100.00	100.00
SweetCorn	Average	87.49	86.26	63.44	85.58	58.45
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	3.26	0.00	0.00	0.00	0.00
Bermuda	event2	32.54	21.65	0.00	17.73	0.00
Bermuda	event3	92.92	67.65	14.46	64.94	11.16
Bermuda	event4	100.00	88.89	41.20	90.20	39.95
Bermuda	event5	100.00	100.00	55.87	100.00	54.94
Bermuda	Event6	100.00	100.00	69.70	100.00	70.79
Bermuda	Average	57.96	45.68	14.74	43.82	13.63

Reach 10 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	25.47	25.47	10.34	27.39	6.14
Cotton	event2	49.97	49.97	28.31	52.86	18.68
Cotton	event3	77.04	77.04	43.56	84.98	31.58
Cotton	event4	96.30	96.30	55.23	100.00	42.43
Cotton	event5	100.00	100.00	63.33	100.00	50.46
Cotton	Event6	100.00	100.00	75.40	100.00	60.70
Cotton	Average	60.28	60.28	35.05	64.09	25.50
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	65.21	65.21	44.11	67.89	38.25
Sorghum	event2	99.41	99.41	69.18	100.00	55.75
Sorghum	event3	100.00	100.00	90.47	100.00	73.76
Sorghum	event4	100.00	100.00	100.00	100.00	88.90
Sorghum	event5	100.00	100.00	100.00	100.00	100.00
Sorghum	Event6	100.00	100.00	100.00	100.00	100.00
Sorghum	Average	86.35	86.35	72.31	86.79	61.57
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	89.28	89.28	65.36	92.31	58.71
Alfalfa	event2	100.00	100.00	93.78	100.00	78.55
Alfalfa	event3	100.00	100.00	100.00	100.00	98.96
Alfalfa	event4	100.00	100.00	100.00	100.00	100.00
Alfalfa	event5	100.00	100.00	100.00	100.00	100.00
Alfalfa	Event6	100.00	100.00	100.00	100.00	100.00
Alfalfa	Average	88.93	88.93	84.67	89.23	79.12
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	100.00	100.00	83.09	100.00	74.15
Tomatoes	event2	100.00	100.00	100.00	100.00	100.00
Tomatoes	event3	100.00	100.00	100.00	100.00	100.00
Tomatoes	event4	100.00	100.00	100.00	100.00	100.00
Tomatoes	event5	100.00	100.00	100.00	100.00	100.00
Tomatoes	Event6	100.00	100.00	100.00	100.00	100.00
Tomatoes	Average	90.00	90.00	88.31	90.00	87.42
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	100.00	100.00	100.00	100.00	90.50
SweetCorn	event2	100.00	100.00	100.00	100.00	100.00
SweetCorn	event3	100.00	100.00	100.00	100.00	100.00
SweetCorn	event4	100.00	100.00	100.00	100.00	100.00
SweetCorn	event5	100.00	100.00	100.00	100.00	100.00
SweetCorn	Event6	100.00	100.00	100.00	100.00	100.00
SweetCorn	Average	90.00	90.00	90.00	90.00	89.05
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	33.98	33.98	16.02	36.26	11.02
Bermuda	event2	63.08	63.08	37.36	66.52	25.92
Bermuda	event3	95.25	95.25	55.48	100.00	41.25
Bermuda	event4	100.00	100.00	69.34	100.00	54.13
Bermuda	event5	100.00	100.00	78.96	100.00	63.67
Bermuda	Event6	100.00	100.00	93.30	100.00	75.84
Bermuda	Average	70.90	70.90	45.00	73.58	33.64

Reach 11 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	12.59	0.00	0.00	0.00	0.00
Cotton	event2	51.36	14.90	14.90	14.90	14.90
Cotton	event3	100.00	75.86	75.86	75.86	75.86
Cotton	event4	100.00	100.00	100.00	100.00	100.00
Cotton	event5	100.00	100.00	100.00	100.00	100.00
Cotton	Event6	100.00	100.00	100.00	100.00	100.00
Cotton	Average	66.67	47.23	47.23	47.23	47.23
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	47.32	21.49	21.49	21.49	21.49
Sorghum	event2	100.00	50.54	50.54	50.54	50.54
Sorghum	event3	100.00	100.00	100.00	100.00	100.00
Sorghum	event4	100.00	100.00	100.00	100.00	100.00
Sorghum	event5	100.00	100.00	100.00	100.00	100.00
Sorghum	Event6	100.00	100.00	100.00	100.00	100.00
Sorghum	Average	84.73	67.31	67.31	67.31	67.31
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	68.91	39.66	39.66	39.66	39.66
Alfalfa	event2	100.00	72.56	72.56	72.56	72.56
Alfalfa	event3	100.00	100.00	100.00	100.00	100.00
Alfalfa	event4	100.00	100.00	100.00	100.00	100.00
Alfalfa	event5	100.00	100.00	100.00	100.00	100.00
Alfalfa	Event6	100.00	100.00	100.00	100.00	100.00
Alfalfa	Average	86.89	75.74	75.74	75.74	75.74
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	87.87	48.53	48.53	48.53	48.53
Tomatoes	event2	100.00	92.78	92.78	92.78	92.78
Tomatoes	event3	100.00	100.00	100.00	100.00	100.00
Tomatoes	event4	100.00	100.00	100.00	100.00	100.00
Tomatoes	event5	100.00	100.00	100.00	100.00	100.00
Tomatoes	Event6	100.00	100.00	100.00	100.00	100.00
Tomatoes	Average	88.79	82.69	82.69	82.69	82.69
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	100.00	61.93	61.93	61.93	61.93
SweetCorn	event2	100.00	100.00	100.00	100.00	100.00
SweetCorn	event3	100.00	100.00	100.00	100.00	100.00
SweetCorn	event4	100.00	100.00	100.00	100.00	100.00
SweetCorn	event5	100.00	100.00	100.00	100.00	100.00
SweetCorn	Event6	100.00	100.00	100.00	100.00	100.00
SweetCorn	Average	90.00	86.19	86.19	86.19	86.19
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	18.69	0.00	0.00	0.00	0.00
Bermuda	event2	64.74	21.42	21.42	21.42	21.42
Bermuda	event3	100.00	93.86	93.86	93.86	93.86
Bermuda	event4	100.00	100.00	100.00	100.00	100.00
Bermuda	event5	100.00	100.00	100.00	100.00	100.00
Bermuda	Event6	100.00	100.00	100.00	100.00	100.00
Bermuda	Average	71.29	54.58	54.58	54.58	54.58

Reach 12 yield reduction

Crop	Event	PLAN1	PLAN2	PLAN3	PLAN4	PLAN5
Cotton	event0	0.00	0.00	0.00	0.00	0.00
Cotton	event1	0.00	0.00	0.00	0.00	0.00
Cotton	event2	0.00	0.00	0.00	0.00	0.00
Cotton	event3	1.55	0.00	0.00	0.00	0.00
Cotton	event4	9.93	0.00	0.00	0.00	0.00
Cotton	event5	15.10	0.24	0.00	0.00	0.00
Cotton	Event6	17.60	1.82	0.00	0.00	0.00
Cotton	Average	3.09	0.10	0.00	0.00	0.00
Sorghum	event0	0.00	0.00	0.00	0.00	0.00
Sorghum	event1	18.61	6.93	0.00	1.74	0.00
Sorghum	event2	23.35	10.47	0.00	4.35	0.00
Sorghum	event3	31.84	16.23	0.00	9.79	0.00
Sorghum	event4	43.53	24.62	1.22	15.63	0.00
Sorghum	event5	50.75	30.01	2.94	23.36	0.00
Sorghum	Event6	54.23	32.21	4.76	22.20	0.00
Sorghum	Average	28.02	14.28	0.51	8.25	0.00
Alfalfa	event0	0.00	0.00	0.00	0.00	0.00
Alfalfa	event1	36.44	23.21	5.85	17.33	0.22
Alfalfa	event2	41.82	27.23	7.90	20.27	1.75
Alfalfa	event3	51.45	33.75	12.92	26.45	5.79
Alfalfa	event4	64.70	43.26	16.74	33.07	9.46
Alfalfa	event5	72.87	49.37	18.68	41.84	10.92
Alfalfa	Event6	76.83	51.87	20.75	40.52	12.01
Alfalfa	Average	45.58	30.00	10.48	23.17	4.38
Tomatoes	event0	0.00	0.00	0.00	0.00	0.00
Tomatoes	event1	44.20	26.41	3.05	18.49	0.00
Tomatoes	event2	51.44	31.81	5.81	22.45	0.00
Tomatoes	event3	64.38	40.58	12.56	30.76	2.97
Tomatoes	event4	82.21	53.37	17.70	39.66	7.91
Tomatoes	event5	93.20	61.59	20.31	51.46	9.88
Tomatoes	Event6	98.52	64.95	23.09	49.68	11.34
Tomatoes	Average	56.97	36.02	9.76	26.84	2.74
SweetCorn	event0	0.00	0.00	0.00	0.00	0.00
SweetCorn	event1	57.01	37.10	11.00	28.26	2.52
SweetCorn	event2	65.10	43.14	14.07	32.69	4.83
SweetCorn	event3	79.57	52.96	21.63	41.97	10.90
SweetCorn	event4	99.50	67.26	27.37	51.92	16.42
SweetCorn	event5	100.00	76.45	30.29	65.11	18.62
SweetCorn	Event6	100.00	80.21	33.40	63.14	20.25
SweetCorn	Average	69.05	47.10	17.73	36.83	8.56
Bermuda	event0	0.00	0.00	0.00	0.00	0.00
Bermuda	event1	0.00	0.00	0.00	0.00	0.00
Bermuda	event2	0.00	0.00	0.00	0.00	0.00
Bermuda	event3	5.57	0.00	0.00	0.00	0.00
Bermuda	event4	15.52	0.00	0.00	0.00	0.00
Bermuda	event5	21.67	4.01	0.00	0.00	0.00
Bermuda	Event6	24.63	5.89	0.00	0.00	0.00
Bermuda	Average	5.54	0.49	0.00	0.00	0.00

APPENDIX E

YEARLY BENEFITS BY DECADE
BY REACH AND PLAN

Table Output-E 5 Annual Benefits above plan 2 by reach, during a decade and under a plan

Reach Benefits for COE data under assumption - Opt-Opt - Limited water 16% of the time and no water 2%

$million

Reach 7

	PLAN1	PLAN3	PLAN4	PLAN5
2005	-155546	946340	12579	1519165
2015	-64656	1431920	5812	2257673
2025	-55722	2177798	145486	3338381
2035	-11124	3045558	429219	4597576
2045	-27973	3792593	607655	5874846
2055	-30511	4740495	822942	7361449

Reach 12

	PLAN1	PLAN3	PLAN4	PLAN5
2005	-290	79436	54	138230
2015	-245	95495	24	175811
2025	-228	105166	421	214655
2035	-43	87062	1158	245975
2045	-107	44544	1723	253610
2055	-117	5867	2323	187501

All Reaches

	PLAN1	PLAN3	PLAN4	PLAN5
2005	-155836	1025776	12634	1657395
2015	-64901	1527416	5836	2433484
2025	-55950	2282964	145907	3553036
2035	-11167	3132619	430377	4843551
2045	-28080	3837137	609378	6128455
2055	-30628	4746363	825265	7548950

Table Output-E 6 Annual Benefits above plan 2 by reach, during a decade, and under a plan

Reach Benefits for COE data under assumption - 15K-Opt - Limited water 16% of the time and no water 2%

$million

Reach 5

	PLAN1	PLAN3	PLAN4	PLAN5
2005	0	764736	764736	764736
2015	0	1055483	1055483	1055483
2025	0	1415045	1415045	1415045
2035	0	1874760	1874760	1874760
2045	0	2450785	2450785	2450785
2055	0	3148435	3148435	3148435

Reach 6

	PLAN1	PLAN3	PLAN4	PLAN5
2005	0	7174	7174	7174
2015	0	6504	6504	6504
2025	0	8236	8236	8236
2035	0	11547	11547	11547
2045	0	15834	15834	15834
2055	0	21231	21231	21231

Reach 7

	PLAN1	PLAN3	PLAN4	PLAN5
2005	-155546	946340	12579	1519165
2015	-64656	1431920	5812	2257673
2025	-55722	2177798	145486	3338381
2035	-11124	3045558	429219	4597576
2045	-27973	3792593	607655	5874846
2055	-30511	4740495	822942	7361449

Reach 12

	PLAN1	PLAN3	PLAN4	PLAN5
2005	0	80582	1201	139376
2015	0	96433	962	176748
2025	0	105520	775	215008
2035	0	87104	1201	246018
2045	0	44651	1830	253717
2055	0	5984	2440	187618

All Reaches

	PLAN1	PLAN3	PLAN4	PLAN5
2005	-155546	1798832	785690	2430450
2015	-64656	2590341	1068761	3496409
2025	-55722	3706598	1569541	4976670
2035	-11124	5018969	2316727	6729900
2045	-27973	6303863	3076104	8595182
2055	-30511	7916145	3995048	10718733

APPENDIX F

TOTAL PRESENT VALUE OF BENEFITS
BY REACH AND PLAN

Table Output-F 5 NPV Benefits above plan 2 by reach, during a decade and under a plan

Reach Benefits for coe data under assumption - Opt-Opt - Limited water 16% of the time and no water 2%

$million

	PLAN1	PLAN3	PLAN4	PLAN5
Reach 5	0.000	0.000	0.000	0.000
Reach 6	0.000	0.000	0.000	0.000
Reach 7	-1.307	30.097	2.271	46.800
Reach 9	0.000	0.000	0.000	0.000
Reach 10	0.000	0.000	0.000	0.000
Reach 11	0.000	0.000	0.000	0.000
Reach 12	-0.004	1.397	0.006	2.997
All Reaches	-1.311	31.494	2.278	49.797

Table Output-F 6 NPV Benefits above plan 2 by reach, during a decade and under a plan

Reach Benefits for coe data under assumption - 15K-Opt - Limited water 16% of the time and no water 2%

$million

	PLAN1	PLAN3	PLAN4	PLAN5
Reach 5	0.000	20.807	20.807	20.807
Reach 6	0.000	0.140	0.140	0.140
Reach 7	-1.307	30.097	2.271	46.800
Reach 9	0.000	0.000	0.000	0.000
Reach 10	0.000	0.000	0.000	0.000
Reach 11	0.000	0.000	0.000	0.000
Reach 12	0.000	1.409	0.018	3.009
All Reaches	-1.307	52.453	23.237	70.756

PART VI - SUMMARY OF BENEFITS AND COSTS BY ALTERNATIVE

INTRODUCTION

Control and disposal plans were developed for 14 alternatives (includes Plans 7A an 8A) in formulation of the NED plan. Net benefits and benefit-to-cost ratios were developed for each alternative to determine the plan with the greatest net benefits that would become the recommended NED plan. In some cases, modifications to the completed Area VIII and Truscott Brine Lake project are required and are included in the total costs of the alternative. Although facilities to control chlorides at Area VIII with disposal at Truscott Brine Lake were completed in 1987, enhancements to Area VIII control have included spray fields at the pipeline outflow to reduce inflows of brine into Truscott Brine Lake, extending its useful life. Other environmental enhancements since 1987 are the construction of small freshwater ponds adjacent to Truscott to attract migrating waterfowl. Some facilities for control at Area X were completed in 1988, including a low flow dam and a building to house pumps. Remaining construction at Area X includes pipelines to convey brines to Truscott Brine Lake and their associated costs, such as installing pumps and spray fields at the control site. For this evaluation, the costs and benefits associated with Area VIII control and disposal are considered sunk costs and benefits and are not included in the economic evaluation. Completed facilities at Area X are also considered sunk costs although no benefits have been realized since chloride removal has not occurred. The purpose of this evaluation is to determine the potential average annual benefits and economic feasibility for completing control and disposal facilities at Areas VII and X, the remaining salt emission areas in the Wichita Basin without control. This evaluation will also briefly describe the alternatives that were formulated and their expected costs in order to estimate net benefits and develop a benefit-to-cost ratio. More complete descriptions of alternatives evaluated and their respective costs are described elsewhere in this report.

After completion of project formulation by Tulsa District, the USFWS proposed an additional 12 alternatives that were evaluated in December 2001. Those alternatives are discussed in detail in the Main Report and Project Formulation appendix. Their costs and benefits are summarized in the last section of this appendix.

PLAN EFFECTIVENESS

Summary

Congress has directed that the goal of the Wichita River Chloride Control Project is to improve water quality to acceptable levels within the Wichita River and Red River basins. To assess the effectiveness of the project, concentration-duration curves were calculated for chloride, sulfate, and total dissolved solids (TDS) for each reach and alternative considered. Concentration-duration curves are presented in the Low Flow Analysis Appendix as Plates 1-22 in Exhibit B. Concentration-duration data are also presented in Tables 1-15 in Exhibit C of that appendix. Of particular interest within the study is the effect of the project on water quality at Lake Kemp and Lake Texoma. Discussion of the results of the concentration-duration study will concentrate on hydrologic reaches 5 (Lake Texoma) and 9 (Lake Kemp).

Plan Effectiveness at the Source Areas and by Alternative Plan

Based on the period of record, 1962-1998, the 1,080 tons/day of TDS and 491 tons/day of chlorides emits from the three salt source areas in the Wichita River Basin. The selected plan will remove 409 tons/day of chlorides and 888 tons/day of TDS, including Area VIII, which has been constructed (Table 6-2). Sulfates are also shown but control of sulfates is not a goal of the project. Table 6-1 presents the daily loads for each source area and the percent removal. These data are also included in Table C-1 in Appendix C of the Low Flow Appendix for all hydrologic reaches. Table 6-2 presents the effectiveness as percent removal or control for each plan.

TABLE 6-1
PLAN EFFECTIVENESS
PERCENT CONTROL AT SOURCE AREAS

Location		Loads (tons per day)		
		Chlorides	Sulfates	Total Dissolved Solids
Area VII	Natural	244	87	539
	Controlled	195	63	419
	% Control	80%	72%	78%
Area VIII	Natural	189	49	380
	Controlled	165	42	332
	% Control	87%	86%	87%
Area X	Natural	58	43	161
	Control	49	36	137
	% Control	84%	84%	85%

TABLE 6-2
PLAN EFFECTIVENESS
PERCENT CONTROL BY PLAN

Location		Loads (tons per day)		
		Chlorides	Sulfates	Total Dissolved Solids
Plan 1	Natural	491	209	1,080
Plan 2	Controlled	165	42	332
Area VIII	% Control	34%	20%	31%
Plan 3	Controlled	360	105	751
Areas VIII & VII	% Control	73%	50%	70%
Plan 4	Controlled	214	78	469
Areas VIII & X	% Control	44%	37%	43%
Plan 5	Controlled	409	141	888
Areas VIII, VII, & X	% Control	83%	67%	82%

Plan Effectiveness at Lake Kemp

Lake Kemp, owned and operated by the Wichita Improvement District and the City of Wichita Falls, currently supplies irrigation, industrial, and recreation water to Wichita County. The lake has not been utilized as a source of municipal drinking water due to poor water quality.

As Table 6-2 illustrates, the Wichita River Chloride Control Project has the potential to remove 31% to 82% of the TDS load and 34% to 83% of the chloride load from the Wichita River Basin. Of particular interest in the upper Wichita River Basin is the project's impact on Lake Kemp. Under natural conditions (Table 6-3), the chloride concentrations at Lake Kemp equal or exceed 696 mg/l 99% of the time and are greater than 1,312 mg/l 50% of the time. With implementation of the selected plan, chloride concentrations will equal or exceed 166 mg/l 99% of the time and will be equal to or greater than 318 mg/l 50% of the time. This represents a 76% reduction in chloride concentration at Lake Kemp. One of the milestones for chloride concentration reduction is the Environmental Protection Agency's secondary drinking water standard for chloride of 250 mg/l. The selected plan is expected to meet this secondary standard only 15% of the time. Another milestone is the Texas Natural Resource Conservation Commission's (TNRCC) secondary drinking water standard for chloride of 300 mg/l. The selected plan is expected to meet the TNRCC secondary standard greater than 40% of the time. Lake Kemp concentration-duration data are presented in Table 6-3.

TABLE 6-3
LAKE KEMP CONCENTRATION-DURATION DATA

	Natural Conditions								
	Percent of Time Equaled or Exceeded								
	1%	**5%**	**10%**	**20%**	**50%**	**80%**	**90%**	**95%**	**99%**
Chlorides (mg/l)	1,985	1,843	1,751	1,628	1,312	1,106	1,016	934	696
Sulfates (mg/l)	953	890	869	835	755	631	575	523	386
Total Dissolved Solids (mg/l)	4,650	4,305	4,115	3,838	3,254	2,762	3,515	2,325	1,745
	Plan 5 (w/Areas VII, VIII, & X)								
	Percent of Time Equaled or Exceeded								
	1%	**5%**	**10%**	**20%**	**50%**	**80%**	**90%**	**95%**	**99%**
Chlorides (mg/l)	489	434	409	377	318	257	233	212	166
Sulfates (mg/l)	540	510	494	456	395	323	294	268	202
Total Dissolved Solids (mg/l)	1,580	1,430	1,343	1,275	1,108	897	815	742	541

Wichita Falls is expected to begin utilizing Lake Kemp as a municipal drinking water source within the next 3 years. The current Lake Kemp water quality will require the city to treat the water using reverse osmosis to meet secondary drinking water requirements. Implementation of the selected plan will improve water quality at Lake Kemp but treatment will still be required. Implementation of the selected plan is expected to result in reduced treatment cost for the city of Wichita Falls.

Some members of the public and agencies have expressed concern about the changes in water quality in the Wichita River and its impact on water-based recreation. Changes in water quality may result in changes in the clarity, or turbidity, of bodies of water popular with recreation users. Lake Kemp is a resource accessible only through private property; however, visitors use the lake for recreation. In response to concerns about recreation at the lake, the Corps contracted with Texas Tech University Department of Range, Wildlife, and Fisheries Management to assess the economic value of recreation at Lake Kemp and potential impacts to the value of recreation because of projected related changes. The study estimated the impacts of Lake Kemp recreation expenditures in the areas surrounding the lake.

It is well known that water clarity affects the value of water-based recreation. Chizinski et al. (2001) used the contingent value method to quantify current recreation value and expected changes in value with changes in water clarity. According to the Chizinski et al. (2001) report, survey respondents were asked a series of questions concerning how their valuation of recreation would change with changes of water clarity at the lake. Based on this data, an increase in turbidity from 10 to 100 nephelometric turbidity units (NTU) would result in an annual loss in consumer surplus (benefits) of $208,780. The Lake Kemp recreation study discusses the impact of the project on recreation in more detail. During the course of the Chizinski research, recreation users were unable to differentiate preferences for turbidity levels between 100 and 1000 NTU.

Subsequent research (Schroeder et al. 2000) has shown the nature of turbidity levels at Lake Kemp. Further analysis of this research indicates that the changes in turbidity at Lake Kemp between pre- and post-project may not be discernable to most recreation users. Predicted changes in turbidity associated with the project are relatively minor for a highly turbid lake, with variable pre-project turbidity levels. Under various scenarios, the highest difference between pre- and post-project levels of turbidity is less than 3 NTU. Such a difference is unlikely to have an effect on the aesthetics or the productivity of the Lake Kemp resource which recreationists use. Based on projected differences between pre- and post- project turbidity, the impact to recreation use and the value of recreation under the with-project condition is below a level that can be identified by recreation users.

The study found that expenditures related to use of Lake Kemp for recreation accounted for $425,269 of expenditures in Baylor County, $983,664 of expenditures in a 10-county region surrounding Lake Kemp, and $1,508,471 of expenditures in the State of Texas. These are expenditures related to Lake Kemp use. These expenditures are not solely attributable to the availability of Lake Kemp as a recreation resource. There are a number of substitutes for Lake Kemp recreation, including other forms of recreation and expenditures.

Plan Effectiveness at Lake Texoma

The Red River Basin has an estimated total chloride load of 3,300 tons/day. The selected plan will remove 409 tons/day resulting in a 12% reduction in total chloride load for the Red River Basin. The concentration-duration study revealed that under natural conditions, the chloride concentrations at Lake Texoma equal or exceed 165 mg/l 99% of the time and is greater than 345 mg/l 50% of the time (Table 6-4). With implementation of the selected plan, chloride

concentrations will equal or exceed 147 mg/l 99% of the time and will be greater than 309 mg/l 50% of the time. This represents a 10% reduction in chloride concentration at Lake Texoma. Table 6-4 presents Lake Texoma concentration data.

TABLE 6-4
LAKE TEXOMA CONCENTRATION-DURATION DATA

	Natural Conditions								
	Percent of Time Equaled or Exceeded								
	1%	**5%**	**10%**	**20%**	**50%**	**80%**	**90%**	**95%**	**99%**
Chlorides (mg/l)	469	436	423	409	345	271	241	216	165
Sulfates (mg/l)	315	301	289	273	228	164	146	129	91
Total Dissolved Solids (mg/l)	1,294	1,234	1,207	1,166	995	791	722	634	474
	Plan 5 (w/Areas VII, VIII, & X								
	Percent of Time Equaled or Exceeded								
	1%	**5%**	**10%**	**20%**	**50%**	**80%**	**90%**	**95%**	**99%**
Chlorides (mg/l)	417	391	376	365	309	245	215	192	147
Sulfates (mg/l)	296	283	273	257	217	155	138	123	87
Total Dissolved Solids (mg/l)	1,190	1,136	1,109	1,075	921	730	665	582	435

SUMMARY OF AVERAGE ANNUAL BENEFITS BY PLAN

During project formulation, control of chlorides at Areas X and VII were evaluated for Area VII alone (Plan 3), Area X alone(Plan 4), and for Areas X and VII (Plan 5) together. Plan 2 refers to the existing condition in the economic evaluation, with Area VIII completed. The municipal and industrial average annual benefits are shown by reach and control plan in Table 4-28 and in Table 6-5 below. Agricultural benefits are shown in the agricultural section in Table 5-38 by control plan. The agricultural benefits are shown based on both an “optimal to optimal” solution (Table 6-5)and an “existing to optimal” agricultural benefit solution as shown in Table 6-6. The “optimal to optimal” solution assumes an optimal optimization management solution for both the existing and future condition, while the “existing to optimal” scenario is premised on use of existing condition acreages with optimization based on the best management practices in the optimal future solution. All costs are at October 2001 price levels and are annualized at the current Federal discount rate for FY 2002 of 6-1/8%. Refinement in benefits has occurred throughout the formulation process with the last update in December 2001 for agriculture and in May 2002 for municipal and industrial benefits.

TABLE 6-5

SUMMARY OF AVERAGE ANNUAL BENEFITS BY PLAN
Optimal to Optimal Agricultural Benefits
($1,000)

Category	Plan 3 Area X	Plan 4 Area VII	Plan 5 Areas VII and X
Municipal & Industrial	$439.4	$1,551.9	$2,144.0
Agriculture	$145.0	$2,008.0	$3,175.0
Recreation	$ 0.0	$ 0.0	$ 0.0
Total Benefits	$584.4	$3559.9	$5319.0

Note: Part V, the agricultural evaluation, shows Plan 3 as Area VII and Plan 4 as Area X.

TABLE 6-6

SUMMARY OF AVERAGE ANNUAL BENEFITS BY PLAN
Existing to Optimal Agricultural Benefits
($1,000)

Category	Plan 3 Area X	Plan 4 Area VII	Plan 5 Areas VII and X
Municipal & Industrial	$ 439.4	$1,551.9	$2,144.0
Agriculture	$1,481.0	$3,344.0	$4,511.0
Recreation	$ 0.0	$ 0.0	$ 0.0
Total Benefits	$1,920.4	$4,895.9	$6,655.0

Note: Part V, the agricultural evaluation, shows Plan 3 as Area VII and Plan 4 as Area X.

SUMMARY OF AVERAGE ANNUAL COSTS BY ALTERNATIVE

A total of 14 Corps alternatives are evaluated in project formulation, which leads to determination of the NED plan. These alternatives were described previously. Table 6-7 displays project costs and average annual costs by alternative. Derivation of interest during construction is shown for the alternative with the greatest net benefits, or NED plan, only. All costs are at October 2001 price levels and are annualized at the current Federal discount rate for FY 2002 of 6-1/8%. Refinements in project costs have occurred throughout the plan formulation period for alternatives 7A and 8A with the most recent in April 2002.

TABLE 6-7

WICHITA RIVER BASIN CHLORIDE CONTROL
TOTAL PROJECT AND ANNUAL COSTS BY PLAN, FY 2002
CURRENT ESTIMATE OCTOBER 2001, 6-1/8%
($1,000)

	Total Project Costs By Plan **Alternative 1** **Area VII Deep Well, VIII As Is, X Deep Well**			**Total Project Costs By Plan** **Alternative 2** **Area VII Deep Well, VIII As Is, Area X Pump to Truscott**	
	Item	Total		Item	Total
01	Land & Damages	$153	01	Land & Damages	$336
04	Dams	$969	04	Dams	$969
08	Road, Railroads, & Bridges	$610	08	Road, Railroads, & Bridges	$8,648
13	Chloride Removal, pumps, plant	$85,310	13	Chloride Removal, pumps, plant	$55,513
30	Plan, Eng & Design	$7041	30	Plan, Eng & Design	$5,000
31	Construction Manage, S&I	$4,286	31	Construction Manage, S&I	$4,286
	Total Project Cost	**$98,369**		**Total Project Cost**	**$74,751**

	FY 2002 Investment & Annual Costs By Plan **Alternative 1** **Area VII Deep Well, VIII As Is, X Deep Well**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 2** **Area VII Deep Well, VIII As Is, Area X Pump to Truscott**	
	Item	Total		Item	Total
	Total Project Cost	$98,369		Total Project Cost	$74,751
	Interest During Construction	$16,165		Interest During Construction	$12,284
	Total Gross Invest	$114,535		Total Gross Invest	$87,036
	Annual Charges			Annual Charges	
	Interest & Amortization	$7,034		Interest & Amortization	$5,345
	Operation & Maintenance	$15,205		Operation & Maintenance	$10,511
	Total Annual Charges	**$22,239**		**Total Annual Charges**	**$15,856**

TABLE 6-7 (Continued)

	Total Project Costs By Plan **Alternative 3** **Area VII Pump to Truscott (Raise 17.2 feet), VIII As Is, X Deep Well**			**Total Project Costs By Plan** **Alternative 4** **Area VII Deep Well, VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$468	01	Land & Damages	$112
04	Dams	$13,770	04	Dams	$969
08	Road, Railroads, & Bridges	$600	08	Road, Railroads, & Bridges	$600
13	Chloride Removal, pumps, plant	$45,737	13	Chloride Removal, pumps, plant	$55,462
30	Plan, Eng & Design	$6,000	30	Plan, Eng & Design	$4,694
31	Construction Manage, S&I	$3,745	31	Construction Manage, S&I	$2,857
	Total Project Cost	**$70,593**		**Total Project Cost**	**$64,694**

	FY 2002 Investment & Annual Costs By Plan **Alternative 3** **Area VII Pump to Truscott (Raise 17.2 feet), VIII As Is, X Deep Well**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 4** **Area VII Deep Well, VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$70,593		Total Project Cost	$64,694
	Interest During Construction	$11,601		Interest During Construction	$8,329
	Total Gross Invest	$82,194		Total Gross Invest	$73,023
	Annual Charges			Annual Charges	
	Interest & Amortization	$5, 048		Interest & Amortization	$4,484
	Operation & Maintenance	$5,613		Operation & Maintenance	$10,205
	Total Annual Charges	**$10,661**		**Total Annual Charges**	**$14,689**

TABLE 6-7 (Continued)

	Total Project Costs By Plan **Alternative 5** **Area VII Pump to Truscott (Raise 33.2 feet),** **VIII As Is, X Pump to Truscott**			**Total Project Costs By Plan** **Alternative 6** **Area VII Pump to Truscott (Raise dam 17.2 feet),** **VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$621	01	Land & Damages	$417
04	Dams	$26,096	04	Dams	$14,083
08	Road, Railroads, & Bridges	$610	08	Road, Railroads, & Bridges	$610
13	Chloride Removal, pumps, plant	$23,879	13	Chloride Removal, pumps, plant	$15,817
30	Plan, Eng & Design	$5,204	30	Plan, Eng & Design	$3,653
31	Construction Manage, S&I	$4,592	31	Construction Manage, S&I	$2,286
	Total Project Cost	**$61,002**		**Total Project Cost**	**$36,867**

	FY 2002 Investment & Annual Costs By Plan **Alternative 5** **Area VII Pump to Truscott (Raise 33.2 feet),** **VIII As Is, X Pump to Truscott**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 6** **Area VII Pump to Truscott (Raise dam 17.2 feet),** **VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$61,002		Total Project Cost	$36,867
	Interest During Construction	$7,853		Interest During Construction	$3,486
	Total Gross Invest	$68,855		Total Gross Invest	$40,353
	Annual Charges			Annual Charges	
	Interest & Amortization	$4,228		Interest & Amortization	$2,478
	Operation & Maintenance	$918		Operation & Maintenance	$612
	Total Annual Charges	**$5,147**		**Total Annual Charges**	$3,090

TABLE 6-7 (Continued)

	Total Project Costs By Plan **Alternative 7** **Area VII Pump to Truscott (Raise dam 16.5 feet),** **VIII As Is, X Pump to Truscott**			**Total Project Costs By Plan** **Alternative 8** **Area VII Pump to Truscott (Raise dam 2.4 feet wall),** **VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$682	01	Land & Damages	$468
04	Dams	$12,737	04	Dams	$1,907
08	Road, Railroads, & Bridges	$610	08	Road, Railroads, & Bridges	$610
13	Chloride Removal, pumps, plant	$26,542	13	Chloride Removal, pumps, plant	$17,889
30	Plan, Eng & Design	$4,439	30	Plan, Eng & Design	$2,755
31	Construction Manage, S&I	$4,082	31	Construction Manage, S&I	$1,735
	Total Project Cost	**$49,092**		**Total Project Cost**	**$25,364**

	FY 2002 Investment & Annual Costs By Plan **Alternative 7** **Area VII Pump to Truscott (Raise dam 16.5 feet),** **VIII As Is, X Pump to Truscott**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 8** **Area VII Pump to Truscott (Raise dam 2.4 feet wall),** **VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$49,092		Total Project Cost	$25,364
	Interest During Construction	$6,320		Interest During Construction	$2,398
	Total Gross Invest	$55,412		Total Gross Invest	$27,762
	Annual Charges			Annual Charges	
	Interest & Amortization	$3,403		Interest & Amortization	$1,705
	Operation & Maintenance	$1,225		Operation & Maintenance	$816
	Total Annual Charges	**$4,628**		**Total Annual Charges**	**$2,521**

TABLE 6-7 (Continued)

	Total Project Costs By Plan **Alternative 9** **Area VII Pump to Truscott (Raise dam 4.4 feet earth), VIII As Is, X Abandon**			**Total Project Costs By Plan** **Alternative 10** **Area VII Pump to Truscott (Raise dam 4.4 feet wall), VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$519	01	Land & Damages	$519
04	Dams	$5,925	04	Dams	$2,957
08	Road, Railroads, & Bridges	$610	08	Road, Railroads, & Bridges	$610
13	Chloride Removal, pumps, plant	$17,868	13	Chloride Removal, pumps, plant	$17,868
30	Plan, Eng & Design	$3,174	30	Plan, Eng & Design	$2,755
31	Construction Manage, S&I	$2,143	31	Construction Manage, S&I	$1,765
	Total Project Cost	**$30,239**		**Total Project Cost**	**$26,475**

	FY 2002 Investment & Annual Costs By Plan **Alternative 9** **Area VII Pump to Truscott (Raise dam 4.4 feet earth), VIII As Is, X Abandon**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 10** **Area VII Pump to Truscott (Raise dam 4.4 feet wall), VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$30,239		Total Project Cost	$26,475
	Interest During Construction	$2,859		Interest During Construction	$2,503
	Total Gross Invest	$33,098		Total Gross Invest	$28,978
	Annual Charges			Annual Charges	
	Interest & Amortization	$2,033		Interest & Amortization	$1,780
	Operation & Maintenance	$816		Operation & Maintenance	$816
	Total Annual Charges	**$2,849**		**Total Annual Charges**	**$2,596**

TABLE 6-7 (Continued)

	Total Project Costs By Plan **Alternative 11** **Area VII Pump to Truscott (Raise dam 19.2 feet earth), VIII As Is, X Abandon**			**Total Project Costs By Plan** **Alternative 12** **Area VII Pump to Truscott, VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$417	01	Land & Damages	$203
04	Dams	$15,592	04	Dams	
08	Road, Railroads, & Bridges	$610	08	Road, Railroads, & Bridges	$0
13	Chloride Removal, pumps, plant	$15,817	13	Chloride Removal, pumps, plant	$8,062
30	Plan, Eng & Design	$3,817	30	Plan, Eng & Design	$306
31	Construction Manage, S&I	$2,408	31	Construction Manage, S&I	$1,531
	Total Project Cost	**$38,662**		**Total Project Cost**	**$10,102**

	FY 2002 Investment & Annual Costs By Plan **Alternative 11** **Area VII Pump to Truscott (Raise dam 19.2 feet earth), VIII As Is, X Abandon**			**FY 2002 Investment & Annual Costs By Plan** **Alternative 12** **Area VII Pump to Truscott, VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$38,662		Total Project Cost	$10,102
	Interest During Construction	$3,656		Interest During Construction	$955
	Total Gross Invest	$42,318		Total Gross Invest	$11,057
	Annual Charges			Annual Charges	
	Interest & Amortization	$2,599		Interest & Amortization	$679
	Operation & Maintenance	$714		Operation & Maintenance	$612
	Total Annual Charges	**$3,313**		**Total Annual Charges**	**$1,291**

TABLE 6-7 (Continued)

	Total Project Costs By Plan Final Formulation Alternative 7A Area VII Pump to Truscott (Future Dam Raise in 75 Years), VIII As Is, X Pump to Truscott			**Total Project Costs By Plan Final Formulation Alternative 8A Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon**	
	Item	Total		Item	Total
01	Land & Damages	$1,174	01	Land & Damages	$739
04	Dams	$788	04	Dams	$788
08	Road, Railroads, & Bridges	$498	08	Road, Railroads, & Bridges	$498
13	Chloride Removal, pumps, plant	$43,372	13	Chloride Removal, pumps, plant	$30,452
30	Plan, Eng & Design	$2,200	30	Plan, Eng & Design	$1,600
31	Construction Manage, S&I	$2,000	31	Construction Manage, S&I	$1,300
	Total Project Cost	**$50,032**		**Total Project Cost**	**$35,377**

	FY 2002 Investment & Annual Costs By Plan Final Formulation Alternative 7A Area VII Pump to Truscott (Future Dam Raise), VIII As Is, X Pump to Truscott			**FY 2002 Investment & Annual Costs By Plan Final Formulation Alternative 8A (formerly 13) Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon**	
	Item	Total		Item	Total
	Total Project Cost	$50,032		Total Project Cost	$35,377
	Interest During Construction	$6,441		Interest During Construction	$3,345
	Total Gross Invest	$56,473		Total Gross Invest	$38,722
	Annual Charges			Annual Charges	
	Interest & Amortization	$3,468		Interest & Amortization	$2,378
	Operation & Maintenance	$781		Operation & Maintenance	$484
	EOP Monitoring	$560		EOP Monitoring	$503
	Total Annual Charges	**$4,809**		**Total Annual Charges**	**$3,365**

Interest during construction was derived for each alternative based on its construction period, which ranged from 3 to 5 years. Interest during construction for Alternative 7A is shown below.

Interest During Construction					
Applicable Rate					
6. 125% Interest Rate Compounded Annually					
Construction Period		4 Year			
Construction Cost		$50,032			
Interest Rate		6.125%			
Number of Periods		4			
Single Payment Compound Amount Factor (SPCAF)					
Project costs expended uniformly each year over 4 years, with yearly average costs expended mid-year.					
IDC Computation					
n					
IDC = Pm[(1+i)^n-.5 - 1]					
m=1					
where:					
n = number of periods, in years					
i = annual interest rate					
Alternative 7A					
Federal Costs					
Interest During Construction					
Applicable Rate					
Periods	Payment	Rate	Factor	Interest	N
1	$12,508	1.06125	0.231	$2,893	3.5
2	$12,508	1.06125	0.160	$2,004	2.5
3	$12,508	1.06125	0.093	$1,167	1.5
4	$12,508	1.06125	0.030	$ 377	0.5
Total	$50,031			$6,441	
	Amortization Factor			0.061411	

Average annual costs by alternative are shown in Table 6-8. The salt areas affected by the control alternative are shown in the last column of the table. Although earlier formulation of alternatives was completed at different price levels and interest rates, this table has revised the interest rate to 6-1/8 % and October 2001 price levels. Alternative 7A reflects revisions that include no immediate dam raise for Truscott; however, a dam raise will be considered if necessary approximately 75 years into the project life.

TABLE 6-8
AVERAGE ANNUAL COSTS BY PLAN
($1,000)

	Collect/Disposal Alternatives	Average Annual Costs		
		Annual Cost	Benefit Plan	Plan Area Affected
1	Areas VII & X, deep well	$22,239	5	VII & X
2	Area VII deep well, Area X pump to Truscott	$15, 856	5	VII & X
3	Area VII pump to Truscott (17.2 feet), Area X deep well	$10,661	5	VII & X
4	Area VII deep well, Area X abandon	$14,689	4	VII
5	Areas VII & X pump to Truscott (raise dam 33.2 feet)	$ 5,146	5	VII & X
6	Area VII pump to Truscott (17.2 feet), Area X abandon	$ 3,090	4	VII
7	Areas VII & X pump to Truscott (raise dam 16.5 feet)	$ 4,628	5	VII & X
8	Area VII pump to Truscott (2.4 feet), Area X abandon	$ 2,521	4	VII
9	Area VII pump to Truscott (4.4 feet), Area X abandon	$ 2,849	4	VII
10	Area VII pump to Truscott (4.4 feet wall), Area X abandon	$ 2,596	4	VII
11	Area VII pump to Truscott (raise 19.2 feet), Area X abandon	$ 3,313	4	VII
12	Area X pump to Truscott, Area VII abandon	$ 1,291	3	X
7A	Areas VII & X, pump to Truscott, Future dam raise	$ 4809	5	VII & X
8A	Area VII pump to Truscott, no raise, Area X abandon	$ 3,365	4	VII
Note: Area VIII as is, except for flow change for alternatives 9, 10, and 11.				

Average annual net benefits and the benefit-to-cost ratio is shown for each alternative in Table 6-9. Project formulation occurred throughout the planning process. Project benefits and costs were revised and refined as new data and information became available. The initial plan formulation included 14 Corps alternatives. Plans 7 and 8 were further revised and named 7A and 8A at which time those plans had the greatest net NED benefits. Final formulation included revision of costs and benefits to develop those costs and benefits displayed in Table 6-10 and 6-12. All costs and benefits were revised to current price levels and interest rates as shown in Table 6-9 and 6-11.

TABLE 6-9

AVERAGE ANNUAL COSTS, BENEFITS, NET BENEFITS AND BCR
OPTIMAL TO OPTIMAL AGRICULTURAL BENEFITS
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits M&I ($1,000)	Annual Benefits AG ($1,000)	Total Benefits ($1,000)	Net Benefits ($1,000)	BCR
Area VII Deep Well, VIII As Is, X Deep Well					opt-opt			
1	$98,369.0	$15,205.0	$22,239.0	$2,144.0	$3,175.0	$5,319.0	-$16,920.0	0.24
Area VII Deep Well, VIII As Is, X Pump to Truscott								
2	$74,751.0	$10,511.0	$15,856.0	$2,144.0	$3,175.0	$5,319.0	-$10,537.0	0.34
Area VII Pump to Truscott (Raise 17.2 feet), VIII As Is, X Deep Well								
3	$70,593.0	$5,613.0	$10,661.0	$2,144.0	$3,175.0	$5,319.0	-$5,342.0	0.50
Area VII Deep Well, VIII As Is, X Abandon								
4	$64,694.0	$10,205.0	$14,689.0	$1,551.9	$2,008.0	$3,559.9	-$11,129.1	0.24
Area VII Pump to Truscott (Raise dam 33.2 feet), VIII As Is, X Pump to Truscott								
5	$61,002.0	$918.0	$5,146.0	$2,144.0	$3,175.0	$5,319.0	$173.0	1.03
Area VII Pump to Truscott (Raise dam 17.2 feet), VIII As Is, X Abandon								
6	$36,867.0	$612.0	$3,090.0	$1,551.9	$2,008.0	$3,559.9	$469.9	1.15
Area VII Pump to Truscott (Raise dam 16.5 feet), VIII As Is, X Pump to Truscott								
7	$49,092.0	$1,225.0	$4,628.0	$2,144.0	$3,175.0	$5,319.0	$691.0	1.15
Area VII Pump to Truscott (Raise dam 2.4 feet wall), VIII As Is, X Abandon								
8	$25,364.0	$816.0	$2,521.0	$1,551.9	$2,008.0	$3,559.9	$1,038.9	1.41

TABLE 6-9 (Continued)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits		Total Benefits ($1,000)	Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG ($1,000)			
Area VII Pump to Truscott (Raise dam 4.4 feet earth), VIII As Is, X Abandon								
9	$30,239.0	$816.0	$2,849.0	$1,551.9	$2,008.0	$3,559.9	$710.9	1.25
Area VII Pump to Truscott (Raise dam 4.4 feet wall), VIII As Is, X Abandon								
10	$26,475.0	$816.0	$2,596.0	$1,551.9	$2,008.0	$3,559.9	$963.9	1.37
Area VII Pump to Truscott (Raise dam 19.2 feet earth), VIII As Is, X Abandon								
11	$38,662.0	$714.0	$3,313.0	$1,551.9	$2,008.0	$3,559.9	$246.9	1.07
Area X Pump to Truscott, VIII As Is, VII Abandon								
12	$10,102.0	$612.0	$1,291.0	$439.4	$145.0	$584.4	-$706.6	0.45
Area VII Pump to Truscott (Raise dam 2.4 feet), VIII As Is, X Pump to Truscott								
7A	$37,343.0	$779.1	$3,316.0	$2,144.0	$3,175.0	$5,319.0	$2,003.0	1.60
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$25,303.0	$483.7	$2,151.0	$1,551.9	$2,008.0	$3,559.9	$1,408.9	1.65

TABLE 6-10

FINAL FORMULATION COSTS
OPTIMAL TO OPTIMAL AGRICULTURE
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M & EOP ($1,000)	Total Annual Cost ($1,000)	Annual Benefits		Total Benefits ($1,000)	Net Benefits ($1,000)	BCR
				M&I ($1,000)	Ag ($1,000)			
Area VII Pump to Truscott (Future Dam Raise), VIII As Is, X Pump to Truscott								
7A	$50,032.0	$1,341.0	$4,809.0	$2,144.0	$3,175.0	$5,319.0	$510.0	1.11
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$35,377.0	$987.0	$3,365.0	$1,552.0	$2,008.0	$3,560.0	$195.0	1. 06

TABLE 6-11

AVERAGE ANNUAL COSTS, BENEFITS, NET BENEFITS AND BCR
EXISTING TO OPTIMAL AGRICULTURAL BENEFITS
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits M&I ($1,000)	Annual Benefits AG ($1,000)	Total ($1,000)	Net Benefits ($1,000)	BCR
Area VII Deep Well, VIII As Is, X Deep Well								
1	$98,369.0	$15,205.0	$22,239.0	$2,144.0	$4,511.0	$6,655.0	-$15,584.0	0.30
Area VII Deep Well, VIII As Is, X Pump to Truscott								
2	$74,751.0	$10,511.0	$15,856.0	$2,144.0	$4,511.0	$6,655.0	-$9,201.0	0.42
Area VII Pump to Truscott (Raise 17.2 feet), VIII As Is, X Deep Well								
3	$70,593.0	$5,613.0	$10,661.0	$2,144.0	$4,511.0	$6,655.0	-$4,006.0	0.62
Area VII Deep Well, VIII As Is, X Abandon								
4	$64,694.0	$10,205.0	$14,689.0	$1,551.9	$3,344.0	$4,895.9	-$9,793.1	0.33
Area VII Pump to Truscott (Raise dam 33.2 feet), VIII As Is, X Pump to Truscott								
5	$61,002.0	$918.0	$5,146.0	$2,144.0	$4,511.0	$6,655.0	$1,509.0	1.29
Area VII Pump to Truscott(Raise dam 17.2 feet), VIII As Is, X Abandon								
6	$36,867.0	$612.0	$3,090.0	$1,551.9	$3,344.0	$4,895.9	$1,805.9	1.58
Area VII Pump to Truscott(Raise dam 16.5 feet), VIII As Is, X Pump to Truscott								
7	$49,092.0	$1,225.0	$4,628.0	$2,144.0	$4,511.0	$6,655.0	$2,027.0	1.44
Area VII Pump to Truscott (Raise dam 2.4 feet wall), VIII As Is, X Abandon								
8	$25,364.0	$816.0	$2,521.0	$1,551.9	$3,344.0	$4,895.9	$2,374.9	1.94

TABLE 6-11 (Continued)

Alternative	Total Project Cost ($1,000)	O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits		Total ($1,000)	Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG ($1,000)			
Area VII Pump to Truscott (Raise dam 4.4 feet earth), VIII As Is, X Abandon								
9	$30,239.0	$816.0	$2,849.0	$1,551.9	$3,344.0	$4,895.9	$2,046.9	1.72
Area VII Pump to Truscott (Raise dam 4.4 feet wall), VIII As Is, X Abandon								
10	$26,475.0	$816.0	$2,596.0	$1,551.9	$3,344.0	$4,895.9	$2,299.9	1.89
Area VII Pump to Truscott (Raise dam 19.2 feet earth), VIII As Is, X Abandon								
11	$38,662.0	$714.0	$3,313.0	$1,551.9	$3,344.0	$4,895.9	$1,582.9	1.48
Area X Pump to Truscott, VIII As Is, VII Abandon								
12	$10,102.0	$612.0	$1,291.0	$439.4	$1,481.0	$1,920.4	$629.4	1.49
Area VII Pump to Truscott (Raise dam 2.4 feet), VIII As Is, X Pump to Truscott								
7A	$37,343.0	$779.1	$3,316.0	$2,144.0	$4,511.0	$6,655.0	$3,339.0	2.01
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$25,303.0	$483.7	$2,151.0	$1,551.9	$3,344.0	$4,895.9	$2,744.9	2.28

TABLE 6-12

FINAL FORMULATION
EXISTING TO OPTIMAL AGRICULTURE
(October 2001)

Alternative	Total Project Cost ($1,000)	O&M & EOP ($1,000)	Total Annual Cost ($1,000)	Annual Benefits		Total ($1,000)	Net Benefits ($1,000)	BCR
				M&I ($1,000)	Ag ($1,000)			
Area VII Pump to Truscott (Future Dam Raise), VIII As Is, X Pump to Truscott								
7A	$50,032.0	$1,341.0	$4,809.0	$2,144.0	$4,511.0	$6,655.0	$1846.0	1.38
Area VII Pump to Truscott (No Raise), VIII As Is, X Abandon								
8A	$35,377.0	$987.0	$3,365.0	$1,552.0	$3,344.0	$4,896.0	$1,531	1. 46

SUMMARY OF USFWS/TPWD ECONOMIC FEASIBILITY

Costs were developed for the USFWS/TPWD alternatives based on detailed costs for elements of the Corps alternatives. Pumping plants were based on the same design and cost as those features included in the Corps alternatives. Pipeline costs were prorated by length based on detailed estimates (and actual costs) for pipelines. Outfall structures on potential receiving streams were estimated at reconnaissance level detail and are relatively low cost features. Conservation easement areas were estimated using a 100-foot buffer along the receiving streams from the proposed outfall location to the confluence with the Pease River. The width of the easement was underestimated, and if implemented, the easement would need to be somewhat wider to be effective as a buffer and for access and management purposes. Table 6-13 shows the average annual municipal and industrial benefits by plan for use of Lake Kemp water in the Wichita Falls area. No benefits would accrue below that reach. Agricultural benefits are shown in Table 6-14 for the two scenarios and would accrue only to the impact area that is served by Lake Kemp water and not downstream along the Red River. Table 6-14 shows the initial implementation costs and estimated annual OMRR&R (with exclusions noted later); an economic annual cost; and M&I, agricultural (optimal to optimal), and total estimated average annual benefits; and net benefits. Two of the USFWS/TPWD alternatives, 4A1 and 4B1, were found to be economically justified. Two levels of implementation were found to be economically justified for Alternative 4A1. The maximum net benefits were associated with USFWS/TPWD Alternative 4A1, with just under $500,000 annually.

TABLE 6-13
SUMMARY OF MUNICIPAL AND INDUSTRIAL BENEFITS BY PLAN
(October 2001 Price Levels and 6-1/8 % Interest)

Economic Reach	Demand Center	Quantity Demanded (mgd)	Plan 3 Area X ($1,000)	Quantity Demanded (mgd)	Plan 4 Area VII ($1,000)	Quantity Demanded (mgd)	Plan 5 Area X & VII ($1,000)
9-WICHFALL	Wichita Falls						
	10 mgd RO w/dam	10	107.3	10	523.5	10	842.1
9-OKLAUNION	Steam-electric power	0.3	2.8	0.3	10.9	0.3	19.2
Total M & I		10.3	110.1	10.3	534.4	10.3	861.3

TABLE 6-14

USFWS/TPWD ALTERNATIVE ECONOMICS
OPTIMAL TO OPTIMAL

Alternative	Total Project Cost ($1,000)	Annual O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits			Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG* ($1,000)	Total ($1,000)		
Alternative 4A1—Pump Area VII to Raggedy Creek, Area VIII as is, Area X abandon	$27,000.00	$259.10	$2,073.98	$534.40	$1,383.00	$1,917.40	-$ 156.58	0.92
					$1,711.00	$2,245.40	$ 171.42	1.08
					$2,012.00	$2,546.40	$ 472.42	1.23
Alternative 4A2—Pump Area VII to Paradise Creek, Area VIII as is, Area X abandon	$43,300.00	$374.37	$3,284.90	$534.40	$1,383.00	$1,917.40	-$1,367.50	0.58
					$1,711.00	$2,245.40	-$1,039.50	0.68
					$2,012.00	$2,546.40	-$ 738.50	0.78
Alternative 4B1—Pump Areas VII and X to Raggedy Creek, Area VIII as is	$50,500.00	$620.44	$4,014.90	$861.30	$1,986.00	$2,847.30	-$1,167.60	0.71
					$2,733.00	$3,594.30	-$ 420.60	0.90
					$3,181.00	$4,042.30	$ 27.40	1.01
Alternative 4B2—Pump Areas VII and X to Paradise Creek, Area VIII as is	$75,100.00	$849.60	$5,897.66	$861.30	$1,986.00	$2,847.30	-$3,050.36	0.48
					$2,733.00	$3,594.30	-$2,303.36	0.61
					$3,181.00	$4,042.30	-$1,855.36	0.69
Alternative 4C1—Pump Areas VII and VIII to Raggedy Creek, drain Truscott Brine Lake, Abandon Area X	$58,200.00	$413.84	$4,325.92	$534.40	$1,383.00	$1,917.40	-$2,408.52	0.44
					$1,711.00	$2,245.40	-$2,080.52	0.52
					$2,012.00	$2,546.40	-$1,779.52	0.59
Alternative 4C2—Pump Areas VII and VIII to Paradise Creek, drain Truscott Brine Lake, Abandon Area X	$80,500.00	$561.79	$5,972.82	$534.40	$1,383.00	$1,917.40	-$4,055.42	0.32
					$1,711.00	$2,245.40	-$3,727.42	0.38
					$2,012.00	$2,546.40	-$3,426.42	0.43
Alternative 4D1—Pump Areas VII, VIII, and X to Raggedy Creek, drain Truscott Brine Lake	$81,100.00	$775.17	$6,226.53	$861.30	$1,986.00	$2,847.30	-$3,379.23	0.46
					$2,733.00	$3,594.30	-$2,632.23	0.58
					$3,181.00	$4,042.30	-$2,184.23	0.65
Alternative 4D2—Pump Areas VII, VIII, and X to Paradise Creek, drain Truscott Brine Lake	$112,000.00	$1,037.02	$8,565.41	$861.30	$1,986.00	$2,847.30	-$5,718.11	0.33
					$2,733.00	$3,594.30	-$4,971.11	0.42
					$3,181.00	$4,042.30	-$4,523.11	0.47

* Modeled Water Availability: 1st line @ 71,500 acre-feet; 2nd line @ 100,000 acre-feet; and 3rd line @ 120,000 acre-feet.

TABLE 6-15

USFWS/TPWD ALTERNATIVE ECONOMICS
EXISTING TO OPTIMAL

Alternative	Total Project Cost ($1,000)	Annual O&M ($1,000)	Total Annual Cost ($1,000)	Annual Benefits			Net Benefits ($1,000)	BCR
				M&I ($1,000)	AG* ($1,000)	Total ($1,000)		
Alternative 4A1—Pump Area VII to Raggedy Creek, Area VIII as is, Area X abandon	$27,000.00	$259.10	$2,073.98	$534.40	$1,217.00	$1,751.40	-$ 322.58	0.84
					$1,648.00	$2,182.40	$ 108.42	1.05
					$2,037.00	$2,571.40	$ 497.42	1.24
Alternative 4A2—Pump Area VII to Paradise Creek, Area VIII as is, Area X abandon	$43,300.00	$374.37	$3,284.90	$534.40	$1,217.00	$1,751.40	-$1,533.50	0.53
					$1,648.00	$2,182.40	-$1,102.50	0.66
					$2,037.00	$2,571.40	-$ 713.50	0.78
Alternative 4B1—Pump Areas VII and X to Raggedy Creek, Area VIII as is	$50,500.00	$620.44	$4,014.90	$861.30	$2,186.00	$3,047.30	-$ 967.60	0.76
					$2,634.00	$3,495.30	-$ 519.60	0.87
					$3,221.00	$4,082.30	$ 67.40	1.02
Alternative 4B2—Pump Areas VII and X to Paradise Creek, Area VIII as is	$75,100.00	$849.60	$5,897.66	$861.30	$2,186.00	$3,047.30	-$2,850.36	0.52
					$2,634.00	$3,495.30	-$2,402.36	0.59
					$3,221.00	$4,082.30	-$1,815.36	0.69
Alternative 4C1—Pump Areas VII and VIII to Raggedy Creek, drain Truscott Brine Lake, Abandon Area X	$58,200.00	$413.84	$4,325.92	$534.40	$1,217.00	$1,751.40	-$2,574.52	0.40
					$1,648.00	$2,182.40	-$2,143.52	0.50
					$2,037.00	$2,571.40	-$1,754.52	0.59
Alternative 4C2—Pump Areas VII and VIII to Paradise Creek, drain Truscott Brine Lake, Abandon Area X	$80,500.00	$561.79	$5,972.82	$534.40	$1,217.00	$1,751.40	-$4,221.42	0.29
					$1,648.00	$2,182.40	-$3,790.42	0.37
					$2,037.00	$2,571.40	-$3,401.42	0.43
Alternative 4D1—Pump Areas VII, VIII, and X to Raggedy Creek, drain Truscott Brine Lake	$81,100.00	$775.17	$6,226.53	$861.30	$2,186.00	$3,047.30	-$3,179.23	0.49
					$2,634.00	$3,495.30	-$2,731.23	0.56
					$3,221.00	$4,082.30	-$2,144.23	0.66
Alternative 4D2—Pump Areas VII, VIII, and X to Paradise Creek, drain Truscott Brine Lake	$112,000.00	$1,037.02	$8,565.41	$861.30	$2,186.00	$3,047.30	-$5,518.11	0.36
					$2,634.00	$3,495.30	-$5,070.11	0.41
					$3,221.00	$4,082.30	-$4,483.11	0.48

* Modeled Water Availability: 1st line @ 71,500 acre-feet; 2nd line @ 100,000 acre-feet; and 3rd line @ 120,000 acre-feet.

SUMMARY OF BENEFITS, COSTS, AND BCR BY PLAN: INCREMENTAL EVALUATION

Plan 7A for control of chlorides at Area VII and X, and Plan 8A for control of chlorides at Area VII were formulated as two separate alternatives that should be carried forward to final formulation. Control of chlorides at Area X alone was not economically justified in the early plan formulation phase of the study. Plan 7A has the greatest net NED benefits and is the selected plan. The difference between the two plans indicates Area X is justified based on a last added basis. Table 6-16 summarizes the evaluation.

TABLE 6-16

SUMMARY OF COSTS, BENEFITS, AND BCR BY PLAN

		Plan 7A	**Plan 8A**	**Area X Last Added**
First Cost		$50,032,000	$35,377,000	$14,655,000
O&M		$1,341,000	$986,500	$354,500
Total annual Cost		$4,808,901	$3,364,462	$1,444,400
Benefits	Existing to Optimal	$6,655,000	$4,895,900	$1,759,100
	Optimal to Optimal	$5,319,000	$3,559,900	$1,759,100
Net Benefits	Existing to Optimal	$1,846,100	$1,531,400	$314,700
	Optimal to Optimal	$510,100	$195,400	$314,700
BCR	Existing to Optimal	1.38	1.46	1.22
	Optimal to Optimal	1.11	1.06	1.22