ASSESSMENT OF BRUSH MANAGEMENT/ WATER YIELD FEASIBILITY FOR THE WICHITA RIVER WATERSHED ABOVE LAKE KEMP

HYDROLOGIC EVALUATION AND FEASIBILITY STUDY

Prepared for the

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

By the

RED RIVER AUTHORITY OF TEXAS

In Cooperation with

USDA-Natural Resource Conservation Service
Texas Agriculture Experiment Station, Blackland Research & Experiment Station
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ASSESSMENT OF BRUSH MANAGEMENT/ WATER YIELD FEASIBILITY FOR THE WICHITA RIVER WATERSHED

ACRONYMS AND ABBREVIATIONS

7Q2	7 Day Average of a 2-Year Flow Period
AMSL	Above Mean Sea Level
Authority	Red River Authority of Texas
C	Celsius
cfs	Cubic Feet Per Second
CCP	Chloride Control Project
CRP	Conservation Reserve Program
ET	Evapotranspiration
F	Fahrenheit
GIS	Geographic Information System
HRU	Hydrologic Response Unit
mg/L	Milligrams Per Liter
MLRA	Major Land Resource Area
NCDC	National Climatic Data Center
NRCS	Natural Resource Conservation Service
SWAT	Soil and Water Assessment Tool
SWCD	Soil and Water Conservation District
TAMU	Texas A & M University
TAES	Texas Agriculture Experiment Station
TAEX	Texas Agriculture Extension Service
TDS	Total Dissolved Solids
TNRCC	Texas Natural Resource Conservation Commission
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
USDA	United States Department of Agriculture
USGS	United States Geological Survey

1.0 INTRODUCTION

The Red River Authority of Texas (Authority) in cooperation with the Texas State Soil and Water Conservation Board (TSSWCB) is charged with delineating the Wichita River watershed above Lake Kemp to establish baseline criteria for determining the feasibility of implementing a brush control and management program to increase watershed yield.

The Texas Legislature designated the TSSWCB as the lead agency to conduct comprehensive watershed studies in conjunction with the Texas Agriculture Experiment Station and Extension Service, river authorities, other local entities, and the public to determine the benefits of implementing brush control programs in priority watersheds selected throughout the state.

Water is one of the major issues that Texans must face if future economic development and growth are to be maintained throughout the state, and the Wichita River Basin is certainly no exception. The limited availability of this natural resource has brought about numerous innovative measures aimed at improving watershed management to restore and increase the productivity of the resources. One such measure is that of brush control and management to increase watershed runoff. The United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) estimates that brush in Texas uses approximately 10 million acre-feet of water per year as compared to the 15 million acre-feet per year currently consumed for all other purposes.

Increasing watershed runoff and aquifer recharge, as demonstrated in other brush control studies, is believed to be an effective means of improving natural resource management, but the extent of the overall economic benefit and long-term impacts to the environment need to be further evaluated in order to determine accurate cost versus benefits for program implementation and possible alterations to sensitive ecosystems.

The Wichita River watershed above Lake Kemp in North Texas was selected as one of several sites in Texas to evaluate the long-term effectiveness of implementing brush control as an alternative water management strategy, thereby increasing watershed yield and improving resource management practices. Refer to **Figure 1 A, Vicinity Map** of the study area. The results of this study will provide historical and current hydrological information to assist in determining the feasibility of implementing a watershed specific brush control program. The scope of the study will focus on:

- Delineation of general hydrology and geology of the watershed,
- Description of the changes in general land use and cover characteristics,
- Quantifying the availability of surface and groundwater,
- Identifying possible impacts to the environment and ecosystem, and
- Identifying benefits that may be received as a result of implementation.

2.0 EXECUTIVE SUMMARY

2.1 ABSTRACT

The Wichita River watershed above Lake Kemp covers parts of eight counties in the North Central Texas portion of the Rolling Plains region of the State and contains 1,335,040 acres. In FY 2000 the watershed area, sparsely populated with 6,208 persons, is predominately rural in nature. The economy is supported primarily by ranching activities with some farming and the production of oil and gas. Refer to **Figure 1A** for general location of the study area.

The study was accomplished under the direction of the Texas State Soil and Water Conservation Board in partnership with the Red River Authority of Texas, Texas Agriculture Experiment Station and Texas Agriculture Extension Service, the USDA Natural Resource Conservation Service, Blackland Research Center, local Soil and Water Conservation Districts, and of course, participating landowners within the watershed study area.

Overgrazing by livestock production, range fire suppression and droughts have promoted the spread of noxious brush to the extent that over 825,000 acres (62%) of the watershed area have been infested with mesquite, cedar and mixed brushes. This noxious brush utilizes much of the available water resources without any beneficial return to the watershed and inhibits production capabilities of the region.

Based on the historical average annual rainfall and runoff measurements, the watershed receives an average of over 335,000 acre-feet per year with only 119,100 acre-feet resulting in actual runoff. This represents a net loss of over 216,000 acre-feet of water per year (64.5%) that is attributed to evapotranspiration. The total surface water and groundwater uses within the watershed area are 111,929 acre-feet per year. Much of the water resources contain excessive amounts of dissolved solids and other contaminants which further limit water use and retards economic development of the watershed area.

The results of the study revealed that implementation of the proposed brush control program may be expected to provide a net increase in overall watershed yield at Lake Kemp between a minimum of 27.6% (about 32,900 acre-feet per year) to a maximum of 38.9% (about 46,330 acre-feet per year) over the measured long-term average. The estimated average cost per acre for implementation of the proposed brush control program would be $70.37 per acre of removed brush with the state funding $52.78 per acre. Participating landowners would be required to provide an average cost share of $17.59 per acre.

Components of the Wichita River Basin Chloride Control Project have been implemented on the Wichita River that includes a 3,090 surface acre reservoir in Knox County and two low-flow diversion facilities in the headwaters of the South and the Middle Forks of the Wichita River in King County. A similar diversion structure is planned for construction on the North Fork in Cottle County in the near future. The low-flow diversion facilities will divert the highly concentrated brine to the Truscott Reservoir for disposal. When completed, the Chloride Control Project will effectively reduce the dissolved solids level to the point that water impounded in Lake Kemp would meet drinking water standards 98% of the time. Refer to **Figure 1A** for location of the chloride control diversion facilities.

By selectively implementing the proposed brush control program in a manner so as to leave brush above and remove brush below each of the three diversion structures, the two programs would complement each other by replacing the highly concentrated water diverted from the river's base flow by the chloride project with a good quality water added to the runoff of the watershed by the brush control program. Additional benefits can be realized in reducing the time-frame for meeting drinking water standards up to 26% and preventing an increase in operating cost to divert the additional runoff above the diversion facilities.

In light of the present need for Lake Kemp to supplement other surface water supplies, the combination of brush control and chloride control jointly implemented should be considered a high priority for the region. It should also be noted that both brush control and chloride control projects have been recommended for immediate implementation in the Regional Water Plan for Area B. Therefore, the proposed brush control program appears to be economically feasible for the Wichita River watershed above Lake Kemp and exhibits a total public benefit-to-cost ratio of 1.33:1. It is subsequently recommended for state funding and implementation as described in the report.

2.2 WATERSHED DELINEATION AND MODELING

A Geographic Information System (GIS) was utilized to assimilate, manage and analyze hydrological, climatological, land use and cover, and general topography data and prepare a comprehensive simulation model of the Wichita River watershed. The GIS provides spatial display and analysis of relevant watershed data to determine an accurate prediction of results from implementation of the brush control program over the watershed area throughout the planned ten year life. The present brush cover, by type and category, was determined utilizing satellite imagery from the 1999 Landsat-7 Survey and ground verified for positional accuracy and densities.

The watershed was then hydrologically divided into 48 sub-watersheds or sub-basins to accurately identify and select areas for removal of brush that would provide the greatest benefit to land uses and watershed yield. Brush cover was classified in categories of heavy, heavy mixed, moderate, moderate mixed and light. The noxious brushes having the highest uptake of the water resources were identified as cedar, mesquite and mixed brushes. Data layers were developed by the GIS for spatial analysis and integration with the hydrological modeling tool that include soils, topography, climate, and vegetative cover. The GIS will provide long-term assessment of the results and assist both the state and landowners with maintaining the implemented brush control program to achieve optimum benefits. Refer to **Figure 1B** for details of moderate and heavy brush densities.

The amount of additional water expected from the implementation of the brush control program was estimated by using the Soil and Water Assessment Tool (SWAT) model, a simulation model that predicts the impact of watershed management activities on watershed yield and sedimentation of large unmeasured watersheds. The SWAT model then quantifies the impact of climate and vegetation changes, reservoir management activities, groundwater and surface water uses, channel hydrology, water quality conditions, and water transfers. The model was employed and calibrated by the USDA-Natural Resource Conservation Service, Blackland Research Center to predict watershed yield using historical climatology and streamflow data assembled from stations located throughout the watershed. Calibration of the model was accomplished by adjusting input parameters so that simulated output track measured streamflows as closely as possible. Data utilized for calibration purposes were from the period 1960 through1998.

Since quantitative rainfall, evaporation and streamflow data were not consistent throughout the study area prior to 1959, brush cover was systematically reduced by categorizing the heavy mesquite areas (determined by satellite imagery) as moderate mesquite. All areas with natural vegetative cover were classified as open rangeland in poor condition with respect to the erosive nature of the soils. The natural channel loss coefficients for streams were adjusted to correlate with the noted reductions in water table conditions resulting from groundwater withdrawals for irrigation and diversion of highly concentrated brine water in the upper reaches of the watershed by the Chloride Control Project. The overall hydrologic condition of the watershed is in fair condition, but the highly erosive soil structure may warrant further attention if sufficient grass cover is not provided as brush is removed.

The simulation model was applied on the different brush management techniques with the assumption that identified brush would be removed by the selected means leaving no more than a 5% canopy and would be maintained at this level for a minimum period of ten years.

Following recharge of the aquifers, reduction of brush cover on all eligible acreage would increase streamflow as measured at the Mabelle stream gage up to 38.9% or about 46,330 acre-feet per year above the current long-term average of 119,100 acre-feet per year.

2.3 ECONOMIC ANALYSIS

The total estimated cost to implement the brush control program as described for the Wichita River watershed above Lake Kemp is $58,097,472 or about $70.37 per controlled acre. However, the costs will vary with brush type and density categories. Present values of control costs are used for estimation purposes since some of the treatments will be required in the first and second years of the program, while others will not be needed until year six or seven. Present values of total control costs per acre range from $159.45 for mechanical control of heavy mesquite to $33.75 for moderate mesquite that can be initially controlled with herbicide treatments.

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher cost. Present values of the state cost share per acre of the brush control range from $140.75 for mechanical control of heavy mesquite to $21.70 for control of moderate mesquite with herbicides. Total treatment area, rancher cost, state cost share and program cost per acre for the brush types and density categories are shown in the following table.

Brush (Type and Density)	Acreage Impacted	Rancher Cost Share	Rancher Percent	State Cost Share	State Percent	Present Value Total Cost
Heavy Mesquite	139,520	18.70	35.87 – 11.60	33.43 – 140.75	64.13 – 88.40	52.13 – 159.45
Heavy Cedar	83,840	18.79	40.53 – 14.58	27.57 – 110.07	59.47 – 85.42	46.36 – 128.86
Heavy Mixed	179,840	21.80	47.02 – 16.92	24.56 – 107.06	52.98 – 83.08	46.36 – 128.86
Moderate Mesquite	144,640	12.05	35.70	21.70	64.30	33.75
Moderate Cedar	122,880	15.13	28.15	38.62	71.85	53.75
Moderate Mixed	154,880	19.09	35.53	34.65	64.47	53.75
Total / Average	**825,600**	**$17.59**	**30.44%**	**$52.78**	**69.56%**	**$70.37**

The estimated cost of increased watershed yield averages $36.59 per acre foot for the entire Wichita River watershed above Lake Kemp. The estimated cost per sub-watershed ranged from $17.56 to $91.76 per increased acre-foot over the ten year program life through the removal of brush.

2.0 EXECUTIVE SUMMARY (continued)

Program benefits are defined as the total benefits that will accrue to the rancher as a result of implementing the brush control program. In order for the rancher to receive maximum benefit from the program, he is expected to invest or incur costs for an amount equal to his total cost share based on the acreage, brush type and density categories to be removed. Therefore, his total benefits are equal to the maximum amount that a profit maximizing rancher could be expected to spend on a brush control program (for a specific brush density category) based on the present value of the improved net returns to the ranching operation through typical livestock, wildlife and farming enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, most of the improved net returns would result from increased amounts of usable forage produced by eliminating much of the competition for water and nutrients.

Present values of these benefits will vary with brush type-density categories. The total projected direct benefits to the landowner would be $19,314,450 or about $23.40 return per enrolled acre. Additional public benefits are expected to result from the increased watershed yield and improved quality. These benefits may also be indirectly attributed to expanding the water uses out of Lake Kemp. The following table represents the total benefits to be gained, directly and indirectly, within and without the watershed area.

Projected Program Benefits	Units	Unit Value	Annual Benfits
Net Increase in Return for Livestock Production	64,000 head	$136/head	$ 8,704,000
Value of Enhanced Wildlife Habitat for Hunting	403,200 acres	$0.50/ac	201,600
Value of Additional Watershed Yield to Region	46,330 ac-ft	$68/ac-ft	3,150,440
Net Reduction of Advanced Treatment Costs	17,922 ac-ft	$405/ac-ft	7,258,410
Total Value of Benefits to be Gained			**$ 19,314,450**

Assuming that 100% of the landowners participate in the program and the state funds its share of the cost, the benefit-to-cost ratio for the proposed brush control program is 1.33:1. That is, for each dollar the landowner invests into the program, he could expect to receive $1.33 in return as total program benefits.

Therefore, it is recommended that the Texas Legislature commit to appropriate $43,395,225 over the next three biennia for funding the proposed brush control program within the Wichita River watershed above Lake Kemp. It is further recommended that at least $10,000,000 be provided in FY 2001 for initial program start-up cost with the remaining balance to be funded over the next three biennia.

2.4 PROGRAM IMPLEMENTATION

It is recommended that implementation of the Wichita Basin Brush Control and Management Program be accomplished over the next four to six years with follow-up maintenance throughout the next ten year period to receive optimum benefits from the program.

It is further recommended that the program be administered through the Texas State Soil and Water Conservation Board (TSSWCB) in accordance with Chapter 203 of the Agriculture Code with certain exceptions to permit a greater cost share flexibility to accommodate the participants in the program. Cost share funds should be administered at the local level by the Soil and Water Conservation Districts (SWCD) participating in the program based on allocations from the TSSWCB. The SWCD's should contract with individual landowners for developing and implementing individual brush control plans.

The TSSWCB should be designated to initiate quality control measures to ensure proper herbicide mix and application, and followup monitoring be accomplished under the direction of the TSSWCB with the SWCD's as the primary contact with the participating landowners to ensure the successful implementation and maintenance of the brush control program throughout its design life.

Should consideration be given to coordination of brush control and chloride control projects for optimum benefits to the region, then it is recommended that up to 16,000 acres of light to moderate mixed brush be excluded out of the proposed brush removal plan in support of the chloride control objectives. Refer to **Figure 8, Chloride Control Project Area** for details of the restricted brush removal zone. Restricting up to 16,000 acres from brush removal would result in a reduction of about $215,529 to both the state and landowners without significant impact to the benefits to be derived from brush control.

3.0 HYDROLOGIC EVALUATION

3.1 DESCRIPTION OF THE WATERSHED

The Wichita River watershed is located in the north central Texas portion of the Rolling Plains land resource area of the southern central lowlands within parts of Baylor, Knox, King, Dickens, Motley, Cottle, Foard, and Wilbarger Counties. Refer to **Figure 1, Vicinity Map** for geographical representation of the Wichita River watershed.

This multi-county watershed area is presently sparsely populated and predominately rural in nature with only two urbanized areas S Guthrie and Paducah S located within the watershed boundary. For the purpose of this study, county population data were extrapolated from the U. S. Census data from 1900 through 1990 to demonstrate the region's development period and subsequent decline. From 1990 through 2050, the Texas Water Development Board's (TWDB) 1997 Consensus Water Plan population projection data were utilized to show the expected change in population over the next fifty years. According to the TWDB's 1997 Consensus Water Plan, the watershed population is expected to decline from a present population of 6,208 to approximately 5,693 by 2050. Refer to **Chart 1**, for population of the watershed. The largest cities located just outside of the watershed study area are Vernon to the north in Wilbarger County and Seymour to the south in Baylor County.

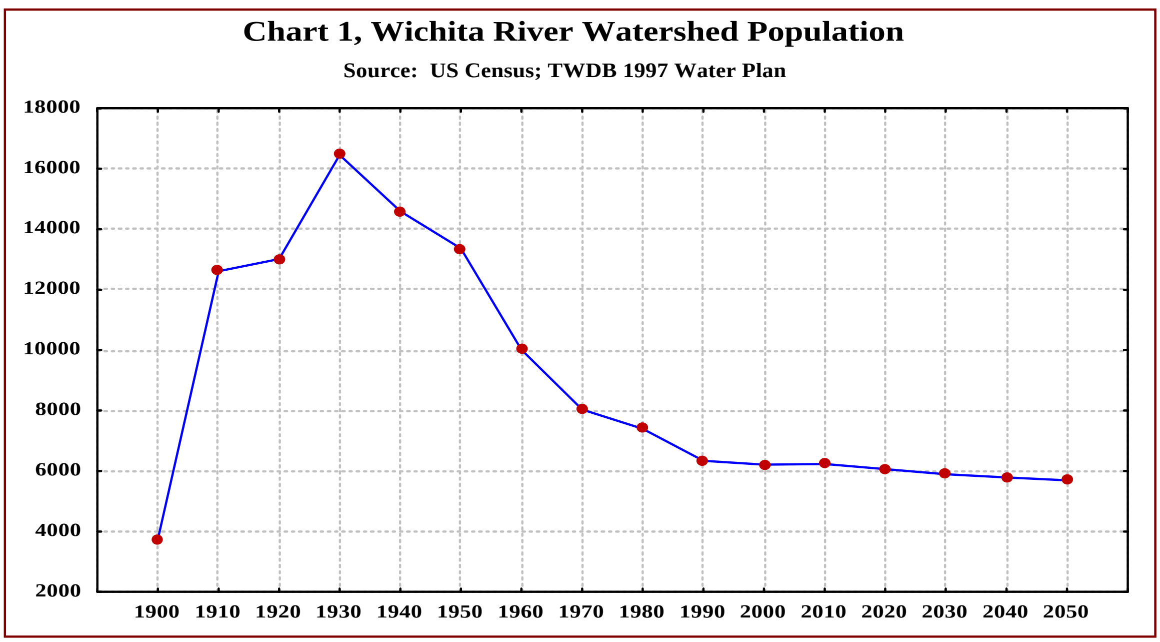

Chart 1, Wichita River Watershed Population

Source: US Census; TWDB 1997 Water Plan

The watershed was settled in the mid 1800's and was utilized as ranch rangeland for livestock production and dryland farming in support of ranching activities. By 1940, both dry and irrigated farmland for the production of cotton, sorghum, small grain and forages were found to be prevalent throughout the area, as is the case today. Other than sporadic exploration and production of oil and gas introduced in the mid 1950's, no major industries are located within the study area.

The study area is subdivided into three hydrologic unit areas or sub-watersheds associated with the major hydrologic features of the watershed that include the North and South Forks of the Wichita River and Lake Kemp. The North Fork (11130204) contains 1,068 square miles or about 683,220 acres, the South Fork (11130205) contains 731 square miles or about 467,887 acres, and Lake Kemp (11130207) contains 230 square miles or about 146,902 acres. Together the three hydrologic unit areas make up the Wichita River watershed above Lake Kemp and contain 2,029 square miles of contributing drainage area or about 1,298,000 acres. The watershed area is composed of 1,045,788 acres of rangeland (80.6%), 251,273 acres of cropland (19.4%) and 948 acres of urbanized areas.[1]

Two of the three tributaries originate in the eastern part of Dickens County. The North and Middle Forks converge in the southwestern part of Foard County and form the county boundary between Foard and Knox Counties where they join the South Fork to form the Wichita River in the northwest part of Knox County, making up the watershed above Lake Kemp. Refer to **Figure 2, Surface Hydrology** for details of the study area.

Topography of the watershed generally consists of gently rolling prairies with broad valleys and rough wet-weather drainages of the recent terrace geological deposits sloping to the east from an average elevation of 2,356 feet above mean sea level (AMSL) in the western part of Dickens County to 1,150 feet AMSL at the Baylor – Archer County line. The watershed above Lake Kemp is drained by the Wichita River and its three main tributaries, which produce a moderate to rapid surface drainage during rainfall events. The long-term (40-year) average annual runoff of the watershed is 119,100 acre-feet per year or about 61 acre-feet per square mile of the contributing drainage area.

[1] Texas Department of Water Resources, Report 268, 1982.

3.0 HYDROLOGIC EVALUATION (continued)

3.2 HISTORICAL CONSIDERATIONS

The Wichita River watershed was occupied by Apache Indians until the early 1800's when the Comanches moved into the region. In the 1870's the U.S. Army pushed the Indians out of the area and opened the region to white settlement. Counties were formed by the Texas Legislature between the period 1876 – 1895 and ranching with some farming became the major economy which spurred the inflow of population to the region. Many of the large ranches were established during the 1880's through 1900's. Early ranchers began conserving water by damming canyons and draws to hold heavy spring rains for use during the long dry periods. In the early 1890's some of the first wells were drilled and windmills employed to lift water to the surface from aquifers as deep as 300 feet. Very little land was devoted to crop production during this period. In the early 1900's, there were less than 500 farms and corn was reported to have been planted on approximately 800 acres with cotton following with less than 200 acres. Ranching continued to dominate the economy with over 150,000 head of beef cattle being reported in the region in 1920. Population of the watershed peaked to 16,250 in 1930 when a series of events that included the Great Depression, World War II, the Dust Bowl, and the drought of record prompted the collapse of the economy forcing the decline in population. However, ranching remained as the leading enterprise, but coupled with overgrazing, range fire suppression and droughts, a gradual ecological change was brought about promoting the spread of noxious bush into the once natural prairie landscape.

The watershed had a major modification from its natural prairie stream with the addition of Lake Kemp, a reservoir constructed on the main-stem of the Wichita River in Baylor County in 1923. The installation of low-flow inflatable weirs on the South Fork in 1981 and on the Middle Fork in 1994, components of the Wichita River Basin Chloride Control Project, have further segmented the river’s natural hydrologic system. Numerous stock ponds, small earthen reservoirs and controlled drainages encompassing about 44,000 acres have been constructed throughout the watershed area that have further modified the natural hydrology.

3.2.1 ECOLOGICAL

Most of the watershed study area is located in the Mesquite Plains subregion which typifies the Rolling Plans region of Texas. The region is gently rolling plains of mesquite-short grass savanna. Documentation of early European settlers described Texas rangelands as grasslands with the only hardwoods located in and along river banks. Prior to settlement by the Europeans in the late 1800's and associated livestock grazing, significant brush growth was inhibited due to naturally occurring factors.

Tree seeds commonly die following germination in grass cover because they cannot compete with grasses for sunlight and moisture. Additionally, any surviving seedlings are typically destroyed in periodic wildfires that occur in natural grasslands.

With the influence of heavy grazing, the competitiveness of grass relative to brush was lessened and thus removed the fuel (grass) from rangeland wildfires. The result of heavy grazing is the increased dominance of trees and brush in grassland areas. Accounts as early as the 1880's reported mesquites and other noxious brush spreading from the river bottom lands into the rangelands. Livestock avoid grazing noxious seedlings such as juniper (cedar) and mesquite, thus providing these brushes a competitive advantage over the common grasses of the rangeland.[2]

Soils of the uplands are pale to reddish brown to dark grayish brown, neutral to calcareous sandy loams, clay sandy loams and clays. Saline soils are common, as are shallow and stony soils with pockets of deep sand. Bottomlands have only minor areas of reddish brown, loam to clay, calcareous alluvial soils. Refer to **Figure 3, Land Resource Classifications** for details.

Whereas today, mesquite, prickly-pear, shinnery oak, salt cedar, juniper, and sagebrush have populated more than 60% the watershed area with dense stands of noxious brush choking out much of the common grasses, such as little bluestem, big bluestem, indiangrass, switchgrass, hairy gama, buffalograss and broomweed. The landscape reflects a history of overgrazing, soil erosion, lowered water tables in some areas where irrigated farm lands exist, declining native grasslands, and altered river ecosystems.[3] **Refer to Figure 4, Vegetation/Brush Cover** for types and density and **Tables 1-A and 1-B, Land Use/Type/Cover Classifications** listing.

Compared with other river basins in Texas, the Wichita River watershed is highly erosive, which is predominately attributed to sheet and rill and gully and stream erosion associated with overland runoff following rainfall events.[4] In 1977, gross sheet and rill erosion averaged about 2,388,978 tons annually, which was an average annual rate of 2.10 tons per acre of land area.

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[2] Seimens, Fuhlendorf and Tayor, Jr., TAES, Sonora, 1997

[3] Evaluation of Selected Natural Resources in Parts of the Rolling Plains, TPWD, 1998

[4] Greiner, 1982

Gross gully and streambank erosion averaged about 2,281,429 tons, which was an average rate of 1.58 tons per acre of land area.

Total average annual gross erosion from these sources was 3.68 tons per acre in 1977, which was 1.89 tons per acre higher that the state average.[5] During this period, only 43,313 acres were designated as controlled drainage within the watershed.

By contrast, a sediment yield assessment of the watershed in 1994 revealed that the gross annual erosion has been significantly reduced to1.74 tons per acre for sheet and rill and 0.98 tons per acre for gully and streambank. This may be primarily attributed to improved farming and ranching practices and erosion control throughout the watershed area over the past 20 years. Most of which is attributed to the USDA Conservation Reserve Program being implemented and practiced within the watershed area. Refer to **Table 1-C, Soil Erosion and Sedimentation Characteristics** in the Appendix for details.

[5] TDWR, Report 288, 1982

The watershed provides a healthy habitat for over 654 different species of mammals, amphibians, reptiles, birds and fishes that have been considered native to the region. In 1998, there were eleven birds, three fishes, five mammals and three reptiles among the species native to this area that have been listed as endangered or threatened.[6] The intermixing of rangeland and cropland has provided an excellent habitat for most common game wildlife such as deer, quail, dove, pheasant and turkey. Refer to **Table 2, Summarized Fish and Wildlife Inventory** located in the Appendix for details.

3.2.2 HYDROLOGICAL

For the purpose of this study, the Wichita River watershed is presumed to terminate at the Lake Kemp dam in Baylor County and consists of 2,086 square miles of drainage area; 2029 square miles are contributing. The total drainage area contains 1,335,040 acres, of which approximately 44,000 acres are currently controlled by earthen stock ponds and reservoirs and considered non-contributing. Daily streamflow data from four USGS stream gaging stations were collected and analyzed to establish baseline and trend surface hydrologic conditions and watershed runoff characteristics from 1960 to present. The four stream gaging stations used include:

- 07312100 – Wichita River near Mabelle, Texas
- 07311900 – Wichita River near Seymour, Texas
- 07311800 – South Fork Wichita River near Benjamin, Texas
- 07311700 – North Fork Wichita River near Truscott, Texas

The Wichita River has exhibited several major hydrological changes since its early settlement, with the most significant changes occurring during 1923 with the construction of Lake Kemp in Baylor County. The changes in hydrologic conditions have affected the frequency, duration, and yield of flood events, which in turn has altered the base flow of the river itself below the impoundment. However, the purpose of Lake Kemp was to control flooding and to provide surface water for irrigation. Lake Kemp also provides an artificial habitat that has aided in the proliferation of aquatic wildlife and game within the region. Lake Kemp is operated by the Wichita County Water Improvement District #2 and the flood control pool is managed by the U.S. Army Corps of Engineers. Releases from the reservoir closely proximate the normal base flow of the river, except during flood stages.

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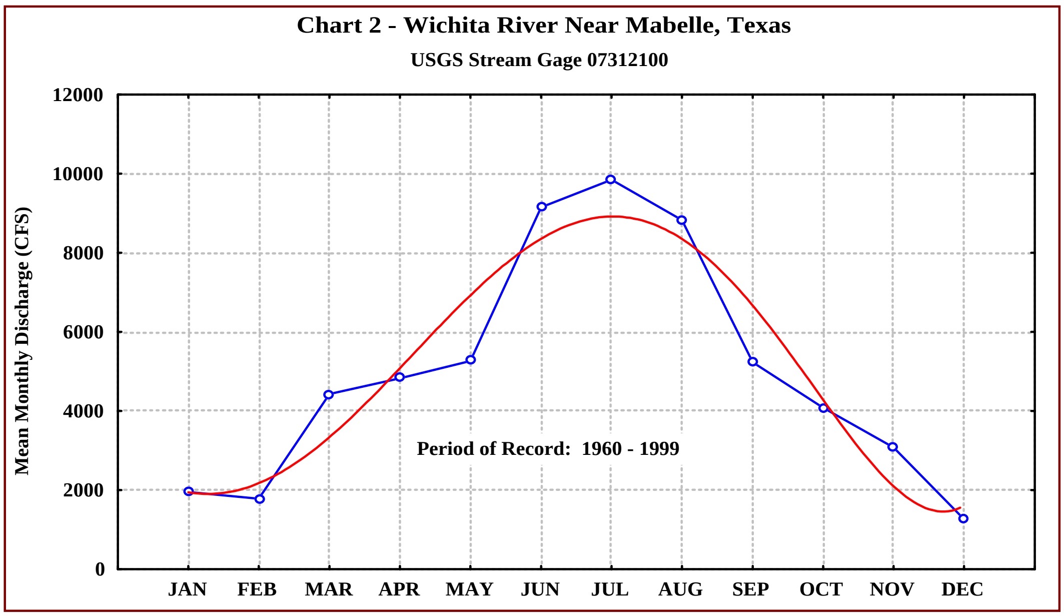
[6] Species of Special Concern, TPWD, Moulton and Baird, 1998

Lake Kemp impounds water of the Wichita River and had a total capacity of 268,000 acre-feet of storage at elevation 1,144 feet when it was constructed in 1923. The lake is permitted to yield 193,000 acre-feet. However, only about 70,000 acre-feet are used for irrigation, 20,000 acre-feet for industrial (power generation) and 5,850 acre-feet for recreation (Lake Wichita) due to the high concentrations of dissolved solids.

A hydrograph was prepared from daily historical data assembled by month of the USGS Stream Gage 07312100 near Mabelle, Texas for the period of 1960 – 1999 and presented in the following **Chart 2** to depict the control feature of Lake Kemp.



The mean annual daily streamflow is 165.2 cubic feet per second (cfs) and ranges from a high in 1987 of 522 cfs to a low in 1981 of 59.9 cfs. The highest instantaneous peak flow was 4,290 cfs on March 24, 1976 and the lowest mean daily flow was 0.09 cfs on May 8, 1989. The long-term average annual watershed runoff is 119,100 acre-feet or about 58.7 acre-feet per square mile. In 1998, the total annual runoff was 131,000 acre-feet or about 65 acre-feet per square mile of drainage area. This represents an increase of approximately 10.4% (17.4 cfs) over the historical long-term flow.

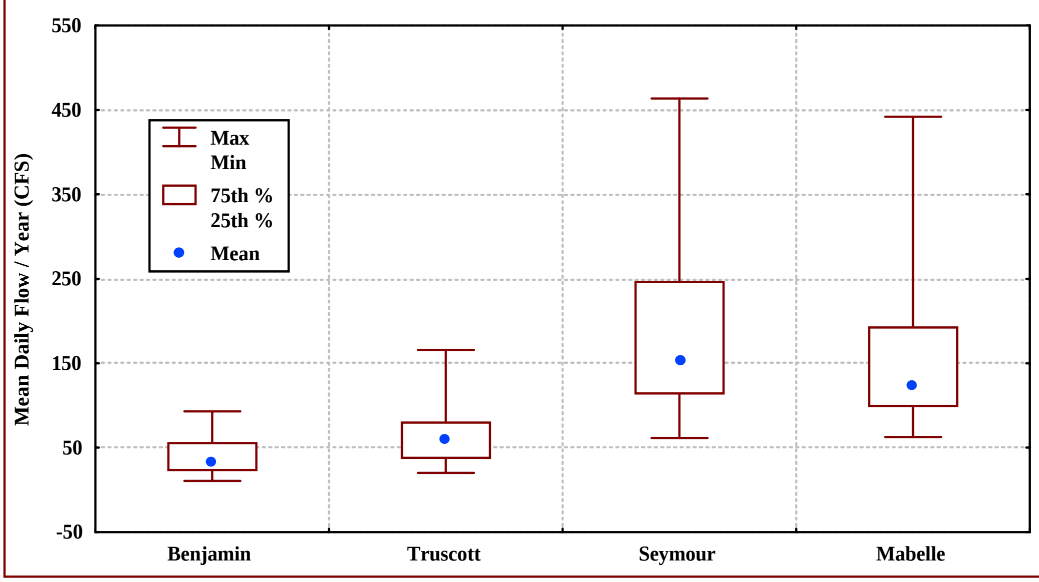
Daily streamflow data were compiled from the USGS stream gages in tabular form by calendar year and by station for comparison with graphic plots presented herein. Refer to **Table 3, USGS Stream Gages** located in the Appendix for details.

Streamflow data from the four USGS Stream Gages were plotted together to show a correlation between the strategic control points within the hydrologic system of the Wichita River using the long-term weighted average daily flow records. Refer to **Chart 3, Historical Streamflows** for details.

The USGS stream gage near Seymour did not have a complete record for the 40-year period, but by extrapolating the flow data from the North Fork (Truscott gage) and the South Fork (Benjamin gage) a profile of the watershed above Lake Kemp may be obtained. The results of this extrapolation revealed that the mean annual streamflow above Lake Kemp was 186.8 cfs or 66.7 acre-feet per square mile, which correlates well with the overall average annual runoff per square mile of uncontrolled drainage of the watershed.

Chart 3 - Wichita River Watershed, Historical Streamflows

Source: USGS Stream Gages 1960 - 1999



The Wichita River near Seymour receives about 68,883 acre-feet per year from the North and Middle Forks (62.2%) and about 41,861 acre-feet from the South Fork (37.8%). The total extrapolated volume to pass the Seymour gage is 110,744 acre-feet per year. In an effort to validate the estimate, a mathematical model was prepared based on the average annual rainfall of 23.1 inches, average evaporation rate of 67.5 inches, average rainfall days of 39.2 per year, a rainfall to runoff ratio of 9.2 inches per year and a slope index of 0.087 over the 1,874 square mile watershed. The computed runoff volume of the watershed was predicted to reach 113,793 acre-feet per year under these conditions with a 97.4% confidence level.

Further analysis of the streamflow data obtained from the USGS gaging stations over the period of record revealed distinct variations for two similar hydrologic periods between 1960 – 1980 and 1981 – 1999. Both periods exhibited similar rainfall characteristics and runoff conditions. However, from the period of 1960 – 1980, the average annual streamflow measured 38.3 cfs (Benjamin), 58.4 cfs (Truscott), 158.3 cfs (Seymour) and 144.4 cfs (Mabelle). Whereas, the period between 1981 – 1999 for each of the gages measured 48.5 cfs, 76.6 cfs, 218.3 cfs, and 184.6 cfs. This indicates that the overall average annual streamflow has shown a significant increase (about 24.3% average) between these two periods of record, which correlates with an increase in rainfall of 14.5% between the same two periods.

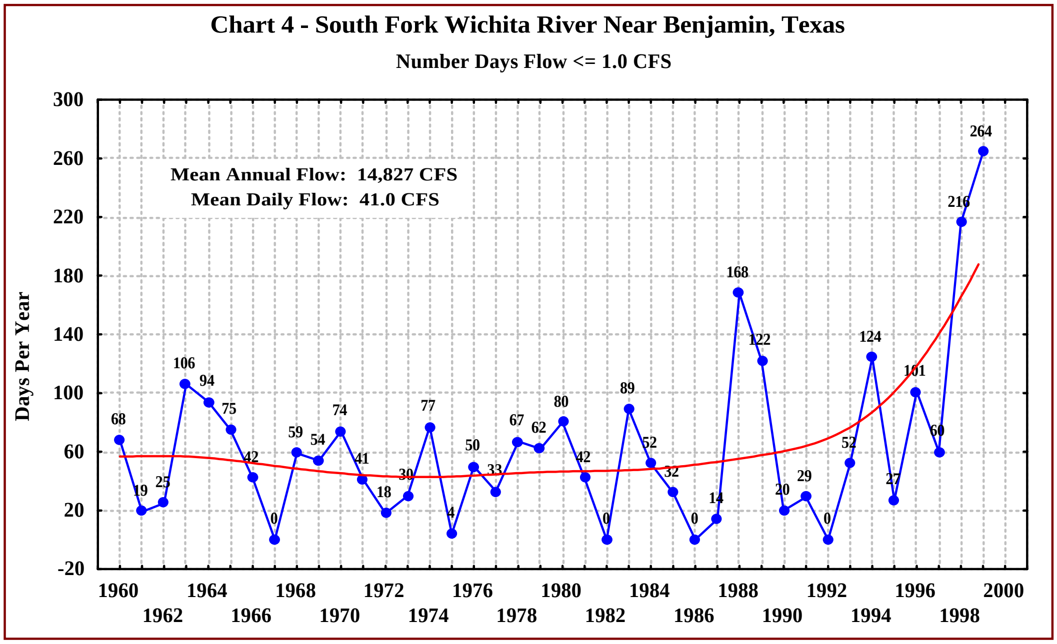
A cursory low-flow assessment was conducted of the streamflow data for the Wichita River near Benjamin, Truscott and Seymour USGS gaging stations. Daily low-flow data obtained from the three USGS stream gages were utilized to determine the number of days flow was less than or equal to 1.0 cfs and what percent of time the river channel was below normal base flow. Normal base flow was established from the median annual low-flow over the 40-year period of record. This should not be confused with the 7Q2 protocol for low-flow analysis.

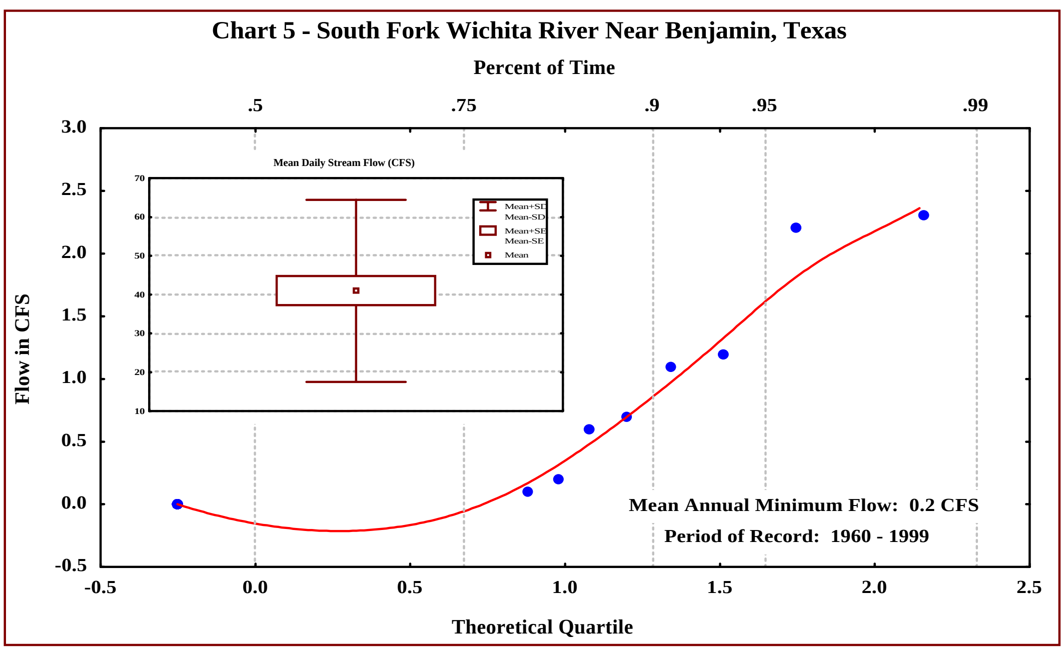
It's interesting to note that the Bateman Pump Station, located in the headwaters of the South Fork Wichita River near Guthrie, Texas in King County, has diverted an average of 4.13 million gallons per day at approximately 6.39 cfs for the period 1987 – 1999. This represents 63.7% of the base flow at the diversion point with only minimal effect on streamflow as observed downstream at the Benjamin stream gage. Diversion of water at the Bateman Pump Station only occurs during lower flow conditions when the brine is at the highest concentrations. During rainfall events producing higher-than-normal flow, the inflatable weir collapses allowing the diluted brine to pass and contribute to streamflow.

Water quality downstream of the diversion facilities has shown a significant improvement. The average chloride concentrations have shown a decrease from 2,965 (milligrams per liter) (1968 – 1979) to 2,150 mg/L (1997 – 1999) as measured at the USGS gage near Seymour. Since 1996, livestock and wildlife have returned to utilizing the South Fork as a watering source. However, the dissolved chloride concentrations continue to average 1,028 mg/L and limit use of the water for most purposes as measured at the Mabelle stream gage. When all three chloride control features are complete and operational, Lake Kemp water is projected to meet the drinking water standard of 300 mg/L for chloride at least 98% of the time.

3.0 HYDROLOGIC EVALUATION (continued)

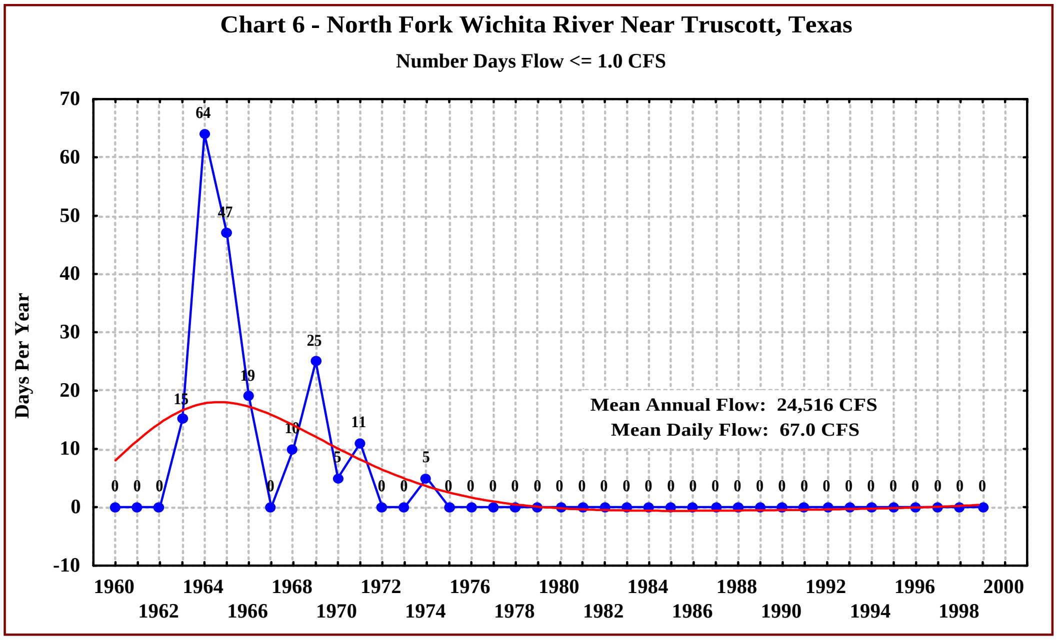
The following **Chart 4** shows the results of the assessment for the South Fork of the Wichita River near Benjamin, Texas in Knox County in terms of the number of days per year that flow was 1.0 cfs or less. **Chart 5** shows the duration as a percent of time the low-flow conditions occurred.

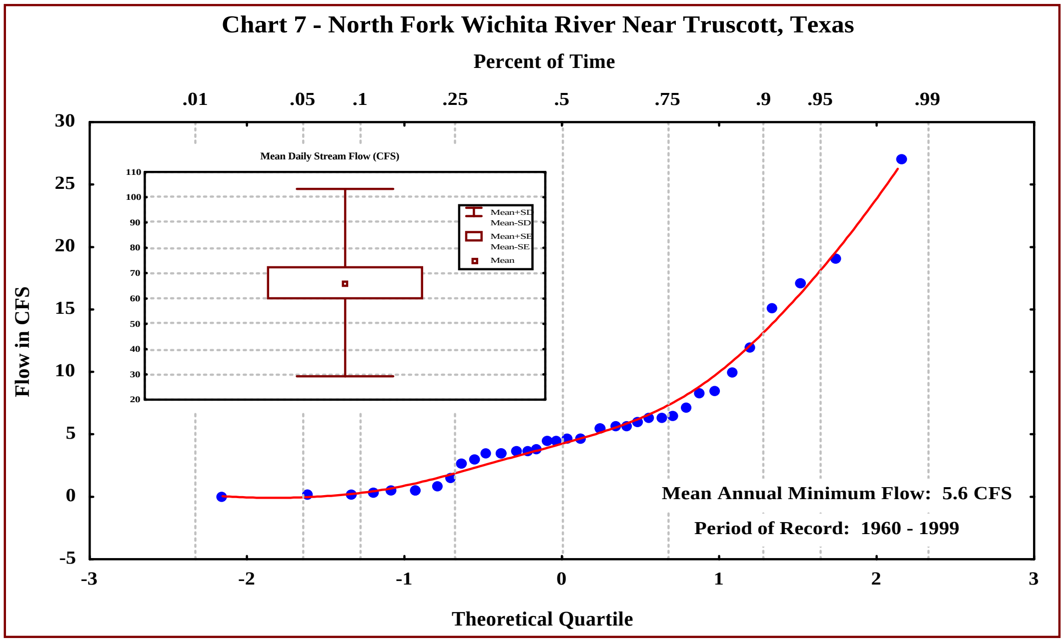




3.0 HYDROLOGIC EVALUATION (continued)

The following **Chart 6** shows the results of the assessment for the North Fork of the Wichita River near Truscott, Texas in Knox County in terms of the number of days per year that flow was 1.0 cfs or less. **Chart 7** shows the duration as a percent of time the low-flow conditions occurred.





3.0 HYDROLOGIC EVALUATION (continued)

The following **Chart 8** shows the results of the assessment for the Wichita River near Seymour, Texas in Baylor County in terms of the number of days per year that flow was 1.0 cfs or less. **Chart 9** shows the duration as a percent of time the low-flow conditions occurred.

Chart 8 - Wichita River Near Seymour, Texas

Number Days Flow <= 1.0 CFS

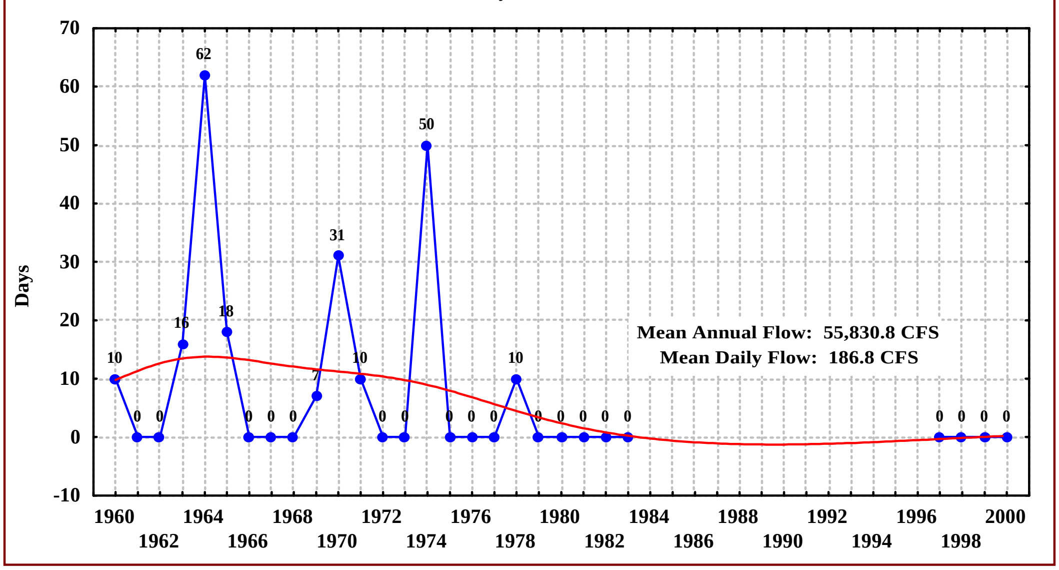
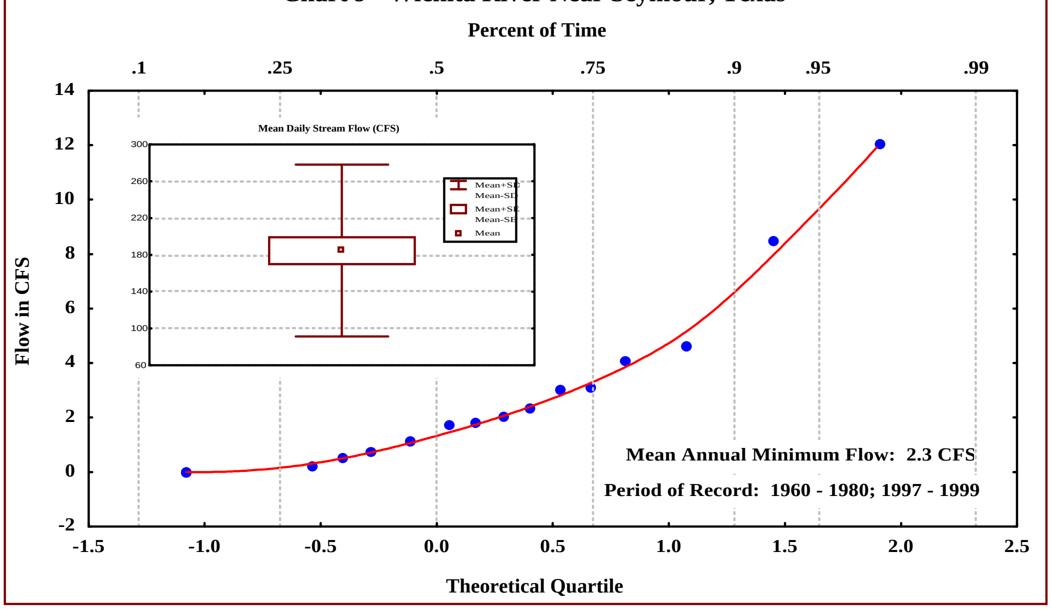


Chart 9 - Wichita River Near Seymour, Texas



The general climate conditions of the region for the period from 1940 to 1997 were considered sub-humid to arid with an average growing season of 214 frost free days. The mean annual air temperature was 62.7°F and ranged from a high of 99.4°F in July to a low of 27.9°F in January. Winds were highly variable and prevail out of the south in spring and summer, and out of the north during winter.

Average annual rainfall for the watershed was 23.1 inches and ranged from 26.3 inches in the eastern portion to 20.7 inches in the western portion of the watershed. The average annual evaporation rate was 67.4 inches per year and ranged from 69.9 inches in the east to 77.5 inches in the west.[7] Both annual rainfall and evaporation rates have shown a nominal increase over the past decade. Refer to **Table 4, Regional Climatology Data** located in the Appendix for details.

Drought in the Rolling Plains of Texas is a frequently recurring event that residents and wildlife have come to live with. Droughts are a natural part of the hydrologic cycle, but the effects tend to accumulate more slowly and last over long periods. The watershed has experienced eight drought years during the past 50-year period consisting of six 1-year droughts and one 2-year drought for a total of seven droughts. The drought of record in the1950's has been the baseline for comparing the severity and intensity of other less severe drought periods that seem to occur almost every decade. While droughts may not include dramatic natural disasters like that of a flood or tornado, they can produce far-reaching consequences of social and economic hardships, destruction of property, vegetation, crops, livestock, environmental distress, wildlife habitats and shifts in population comparable to a natural disaster. Because of today's increased demand for water resources, the duration and severity of current droughts reach a critical level much faster than before and the recovery process is more slower than in the past. Droughts occurring within this region of the state have an adverse impact on both surface water and groundwater resources.

Streamflow measurements have long been a good indicator of the intensity and eventually the severity of drought conditions. It is important to note the normal or base flow measurements of a particular stream segment are most useful in predicting the impacts on all water uses including the environment and aquatic habitat areas. Climate changes such as temperature and rainfall tend to pose a greater risk to the environmental uses than any other water use in the Wichita River watershed primarily due to the high concentrations of dissolved solids.

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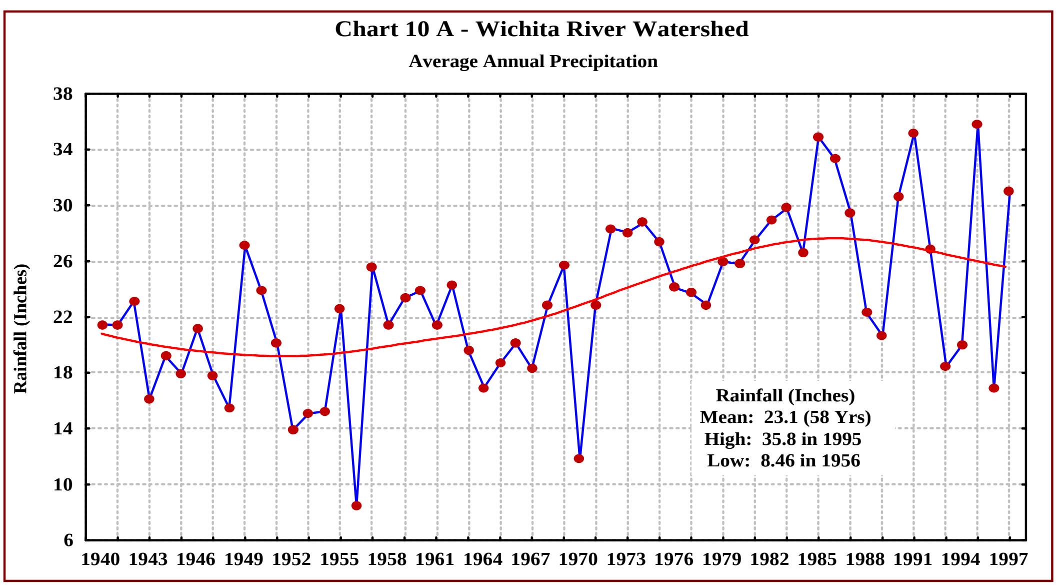
[7] TWDB, Climatic Atlas of Texas, 1951 – 1980; 1940 – 1997; NCDA, NOAA Climatology

3.0 HYDROLOGIC EVALUATION (continued)

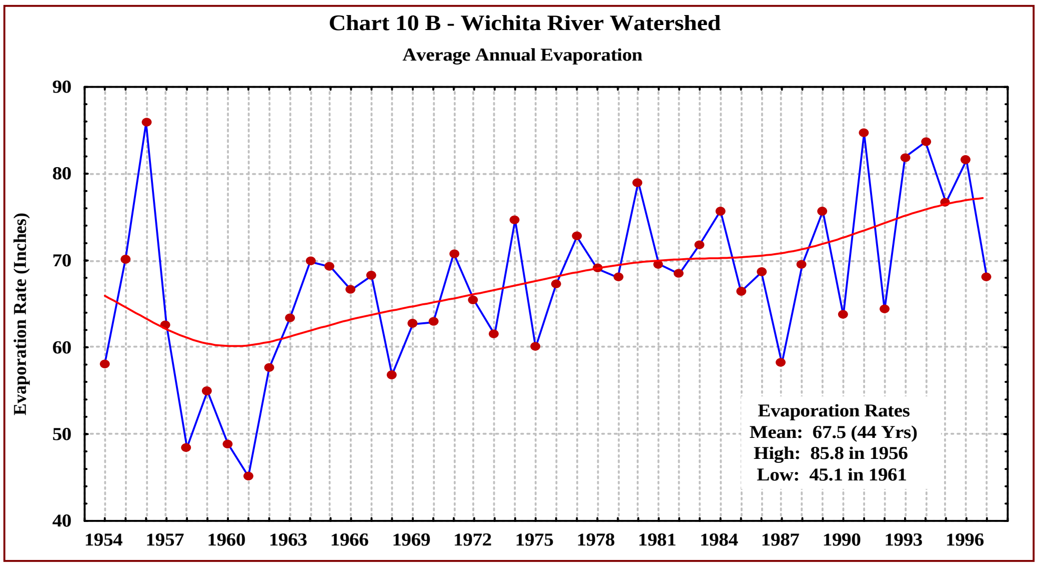
During extended low-flow periods, the dissolved solids concentrations reach highs from 7,000 – 15,000 mg/L as TDS near Seymour, Texas. In the upper reaches of the Wichita River, TDS concentrations prohibit the waters use for most purposes and salt deposits form along the banks of the stream with levels reaching 24,000 mg/L TDS.

Monthly precipitation and evaporation data was obtained from the TWDB and the National Climatology Data Center (NCDC). These data were evaluated in conjunction with streamflow data from the USGS for correlation with the observed increase in streamflow. The results showed the average annual rainfall did increase approximately 12.5% over the period of 1981 – 1997, which probably explains the increase in streamflow. However, research conducted by Ward (1992) concerning non-linear predictions of precipitation change to streamflow, appears to be significant when applied to the Wichita River watershed. By this theory, one may conclude that a 12.5% increase in average rainfall over the watershed will produce a 51.4% increase in streamflow as shown between the two periods. Several comparisons were made to low-flow periods as shown in **Chart 8** (Seymour gage) between 1968 – 1978 that show a direct correlation with below normal rainfall and streamflow. Therefore, a 15% reduction in the normal annual rainfall over the watershed will reduce streamflow by about 62% and constitutes a severe drought condition.

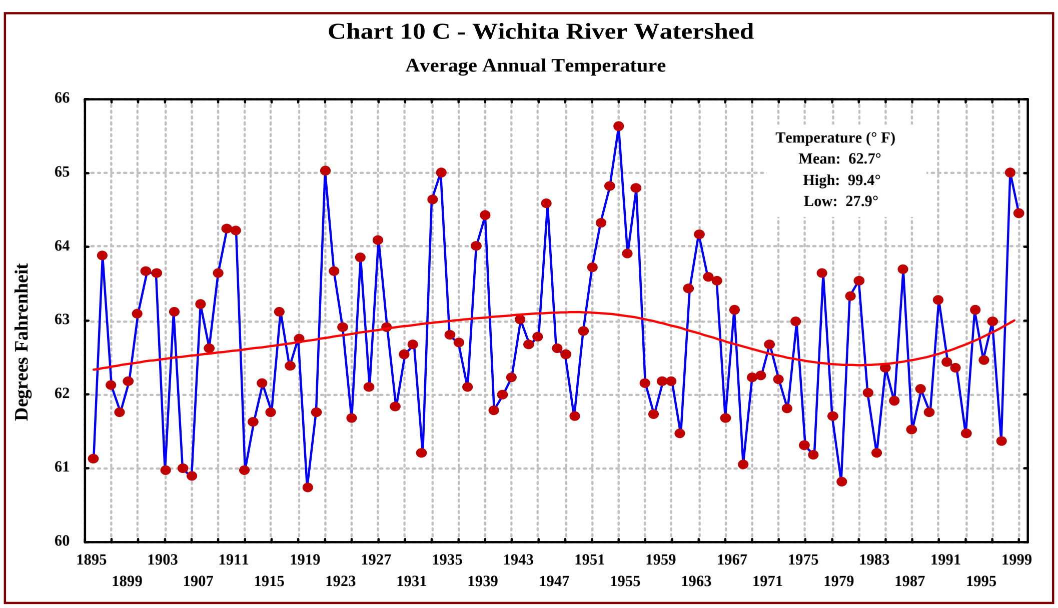
The following **Chart 10 – A** shows the trend for precipitation data from the TWDB dataset for the watershed area including Lake Kemp. The last ten years shows an increase of about 12.5% over previous periods with the rainfall duration increased from 31.2 to 42.6 days per year rain fell.



Evaporation rates over the watershed have shown a moderate decrease from the previous average of 73.1 inches per year to the current average rate of 67.5 inches per year. However, during the past two decades, another high of 84.6 inches was reached in 1991, which closely matches the record high of 85.8 inches in1956. Refer to **Chart 10 – B** for details of the trend changes over the watershed.



Temperatures within the region have remained fairly constant over the long-term with the extreme highs almost matching those of the drought during the 1950's. Refer to the following **Chart 10 – C** for details of the long-term trend.



3.3 GEOLOGICAL CONSIDERATIONS

The watershed study area includes several prominent geologic structures as shown in **Figure 5, Geologic Map**. Stratigraphic units that supply fresh to saline water from springs and wells located throughout the watershed area range in geologic ages from the Permian to the Quaternary. The Permian and Quaternary Formations contain the largest and most prolific aquifers within the study area. These geologic units include the Blaine Formation of the Permian Pease River Group, the Clear Fork of the Permian, the Quaternary Seymour Formation and the Alluvium. The Blaine and the Seymour Formations are the aquifers utilized primarily for private, municipal, and agricultural uses because of the acceptable quality. **Refer to Table 5, Geologic Units and their Water-Bearing Characteristics** located in the Appendix.

The total acreage irrigated within the watershed area for the period of 1958 – 1994 ranged from a high in 1964 of 11,510 acres to a low in 1994 of 4,262 acres.[8] Total water use for irrigation was12,002 acre-feet in 1958, of which 97 acre-feet was with surface water and 11,905 was from groundwater. Water use per irrigated acre averaged 1.25 acre-feet per acre for the same period of time and ranged from a low of 0.78 in 1958 to 1.89 in 1979. Refer to **Table 6 – A, Summary of Water Uses** located in the Appendix for details. Water use within the region showed to be down significantly since 1979 when the total water use for all purposes was 5,548 acre-feet and has only slightly increased to 6,419 acre-feet in 1999. Refer to **Table 6 – B, Summary of Water Uses** for details.

In 1980, there was a total of 115 artesian springs within the watershed ranging from 40 small seeps of less than 0.028 cubic feet per second (cfs) to six medium-to-large size springs discharging upwards of 35 cfs.[9] Most of the springs are artesian during wet years and originate from the Seymour Sand and Blaine Aquifers located in Cottle, King, Knox and Baylor Counties. Nine of the 115 springs inventoried within the watershed during this time have ceased to flow to the surface.

Several springs included in the TWDB's observation well database exhibited a modest increase in flow, especially in the Seymour Sand in Knox County during the period 1989 – 1994. **Refer to Table 7, Artesian Springs Inventory** located in the Appendix for details.

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[8] TWDB Report 347, 1996

[9] Brune, G.; Springs of Texas, 1981, PGMA, 1998

3.0 HYDROLOGIC EVALUATION (continued)

3.4 EXISTING SURFACE WATER HYDROLOGY

Of the 2,086 square miles of drainage within the study area, about 68 square miles are controlled by earthen stock ponds and reservoir impoundments. There are approximately 134 earthen stock ponds utilized for livestock watering, erosion control and recreation, and two lakes that contain about 44,000 surface acres within the study area. Refer to **Figure 2, Surface Hydrology** for details.

There are three significant impoundments within the watershed study area that influence the surface hydrology of the area. They are Lake Kemp in Baylor County, Truscott Brine Reservoir in Knox County and Bateman Brine Collection Facility on the South Fork of the Wichita River near Guthrie, Texas in King County. Another reservoir, Lake Diversion, is located in parts of Baylor and Archer Counties and is an integral part of the Lake Kemp hydrologic system, but is not included in the watershed study area. Lake Kemp discharges water into Lake Diversion through a 12.5 mile stretch of the Wichita River and is used for surface irrigation purposes within the Wichita River valley area.

Lake Kemp is an on-channel multi-purpose reservoir that impounds water from the Wichita River in northern Baylor County and serves as the eastern boundary of the study area. Lake Kemp was constructed in August 1923 for the purpose of flood control and irrigation, and covers a surface area of 15,590 acres. The lake is operated by the Wichita County Water Improvement District Number #2. Flood storage is managed by the U.S. Army Corps of Engineers, Tulsa District. Water is allocated for municipal, industrial, mining and irrigation uses. However, due to the generally high concentrations of dissolved solids, only a portion of the reservoir's yield is utilized for these purposes.

Another significant hydrological feature is the Truscott Brine Reservoir located in Knox County on the Bluff Creek watershed, a tributary of the South Fork of the Wichita River. The Truscott Brine Reservoir is a component of the Wichita River Basin Chloride Control Project designed to improve water quality. It impounds highly saline waters diverted from the South Fork of the Wichita River. This reservoir controls 64 square miles of Bluff Creek drainage area, a tributary to the North Wichita River watershed with a maximum surface area of 3,090 acres. The Wichita River Basin Chloride Project, when completed, will divert highly saline water from all three forks of the Wichita River for final storage and evaporation at the Truscott Brine Reservoir.[10]

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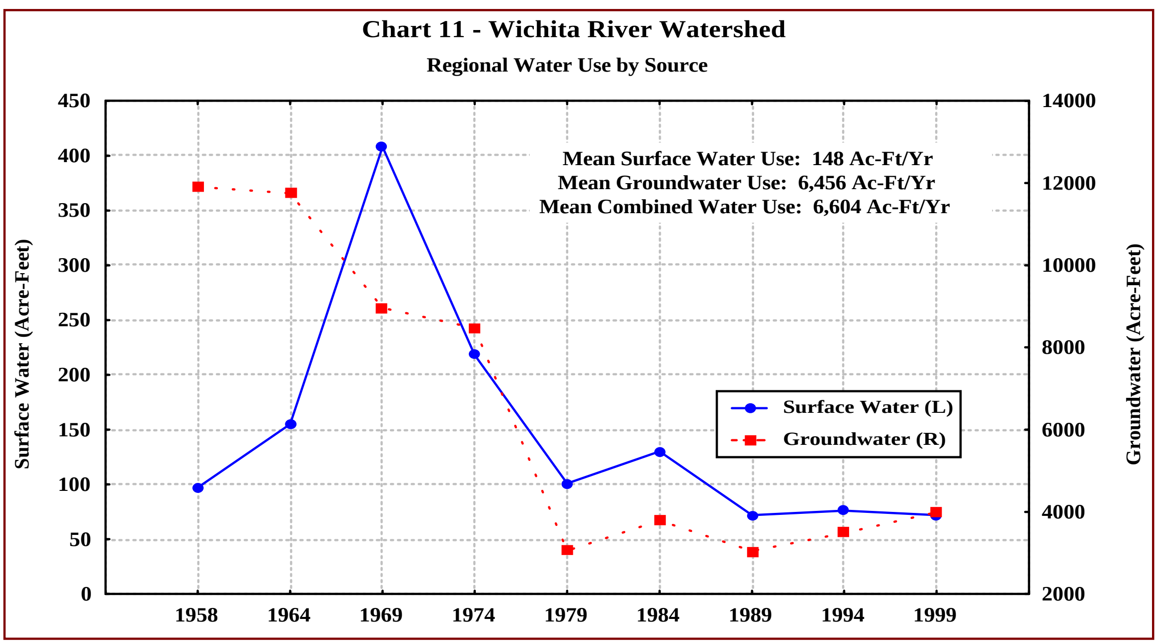
[10] RRA, Wichita River Basin Chloride Control Project, Summary Report, 2000

The Bateman chloride diversion facilities consist of an inflatable fabric weir, pump station and 22 mile pipeline where highly saline waters are impounded behind the inflatable weir during low-flow periods and pumped to the Truscott Brine Reservoir in Knox County for disposal. During high flows, the inflatable weir collapses, permitting the diluted water to pass into the river system. Two other similar features are planned for construction on the Middle and North Forks of the Wichita River in the near future. The process has already demonstrated its effectiveness in reducing the chloride and sulfate levels of Lake Kemp as a direct benefit to municipal, industrial, agricultural and irrigation uses.[11]

Surface water use has been severely limited due to the high dissolved solids concentrations within the watershed except for livestock and some irrigation uses from earthen stock ponds and accounts for about 2.2% of the total water use. Groundwater has been relied upon for all purposes including municipal, domestic, livestock and irrigation uses and accounts for about 97.8% of the total water use within the watershed. Total water use averaged 6,604 acre-feet per year over the period 1958 – 1999. The record high was reached in 1958 of 12,002 acre-feet with the record low in 1989 of 3,114 acre-feet. Total water use has shown a steady decline as compared to the overall average historical use for the watershed area. Total water use by source is illustrated below in the following **Chart 11**. These data were compiled from the TWDB Water Plan database and extrapolated to the watershed area based on population and use characteristics of the counties represented.



[11] Wichita River Basin Chloride Monitoring Data Review, Alan Plummer & Associates, Inc., RRA, 1998

3.5 EXISTING GROUNDWATER HYDROGEOLOGY

The Permian and Quaternary Formations contain the largest and most prolific aquifers within the study area. These are the Blaine Formation of the Permian Pease River Group, the Clear Fork of the Permian, the Quaternary Seymour Formation and the Alluvium. However, the Blaine and the Seymour Formations are predominately utilized for domestic, municipal and agricultural uses because of their acceptable quality and dependable yield characteristics. **Refer to Table 5, Geologic Units and their Water-Bearing Characteristics** located in the Appendix for details.

The **Blaine Formation of the Pease River Group** is the most prolific aquifer within the group and consists mostly of gypsum and anhydrite. The Blaine is designated as a minor aquifer in the state and is located in parts of King, Cottle, Knox and Foard Counties. Water recharged to the aquifer moves along solution channels in the formation dissolving evaporite deposits of anhydrite and halite, which, in turn, contribute to its overall poor quality. The primary source of groundwater in the Blaine is precipitation that falls on the outcrop area. Solution openings and fractures in the gypsum offer ready access for water to percolate downward. The Blaine may also receive some of its recharge from overlying Dog Creek Shale. Groundwater occurs primarily in solution channels and caverns in beds of anhydrite and gypsum and is utilized for irrigation of highly salt-tolerant crops.

Well yields vary from a few gallons per minute to more than 1,500 gallons per minute with average saturated thickness ranging from 30 – 150 feet. Seasonal water level declines are limited to those areas dependent on groundwater for irrigation.

The aquifer becomes artesian where overlain by the Dog Creek Shale and discharges saline waters in the western part of the watershed area with concentrations of dissolved solids as high as 10,000 milligrams per liter (mg/L).

The following **Chart 12** shows the overall variance and trend over time of the Blaine Gypsum Aquifer as it occurs in parts of King, Cottle, Foard and Knox Counties during the period of 1956 – 1998.

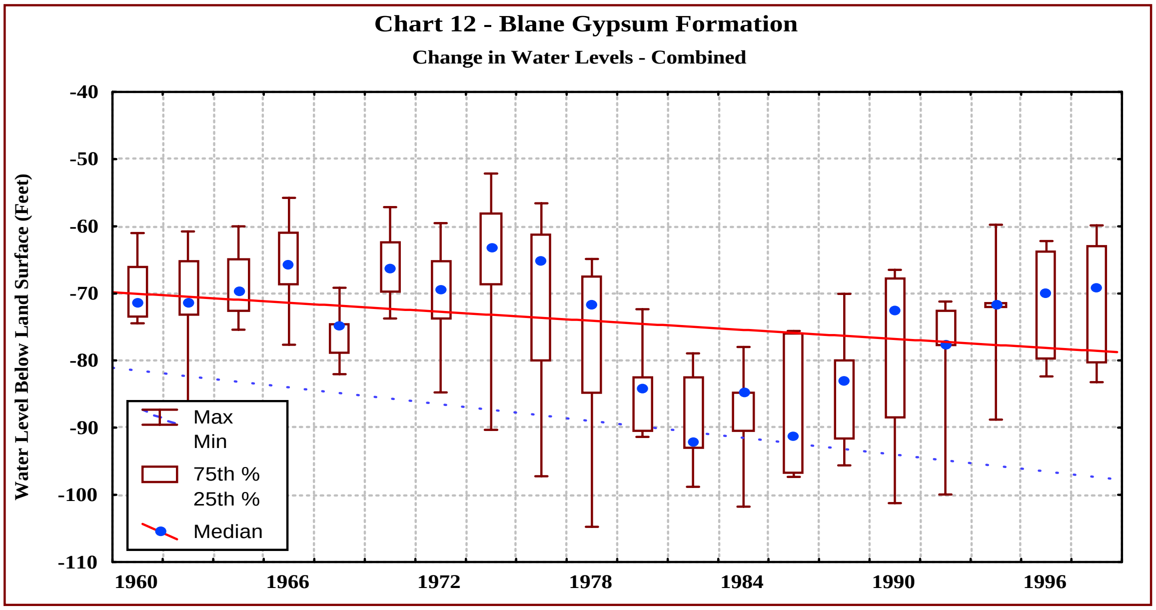


Chart 12 - Blane Gypsum Formation
Change in Water Levels - Combined

Most of the decline in the water level is due to seasonal usage for irrigation of cultivated crop lands. Although the Blaine Formation is present in other parts of the watershed, high dissolved solids prohibit its use for most purposes. The Blaine becomes artesian in the eastern parts of King and Cottle Counties where it discharges to the surface through seeps and springs in the headwaters of the three forks of the Wichita River. The following **Chart 13** shows the trend change in water levels over time of the selected well data.

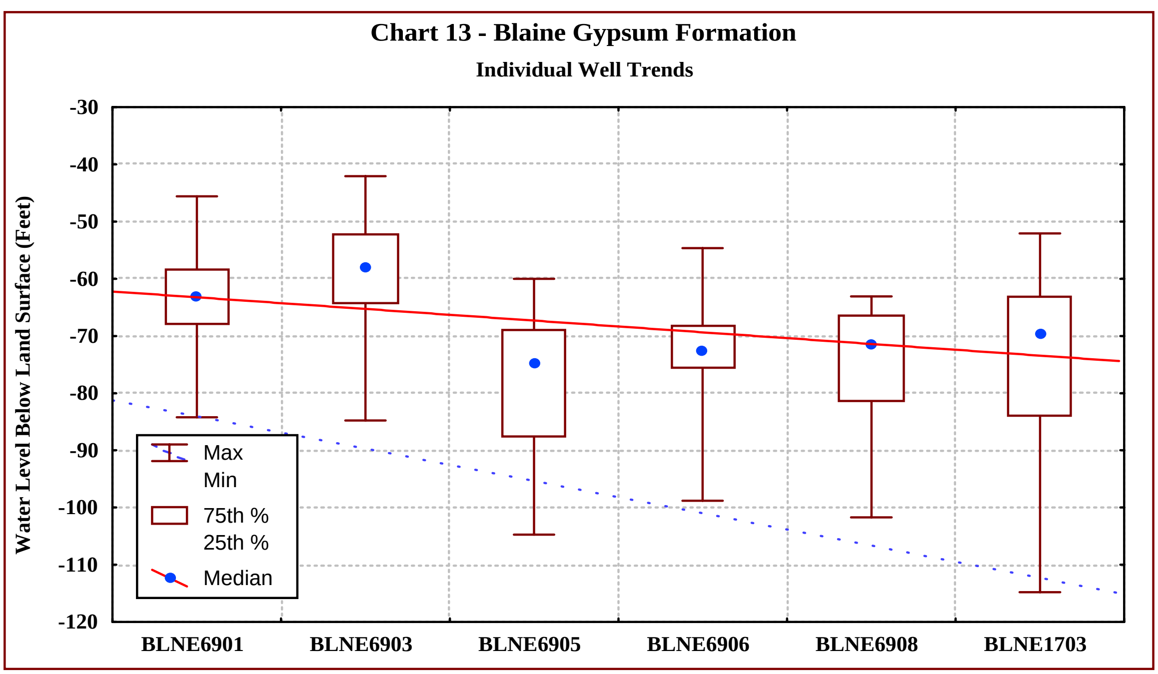


Chart 13 - Blaine Gypsum Formation
Individual Well Trends

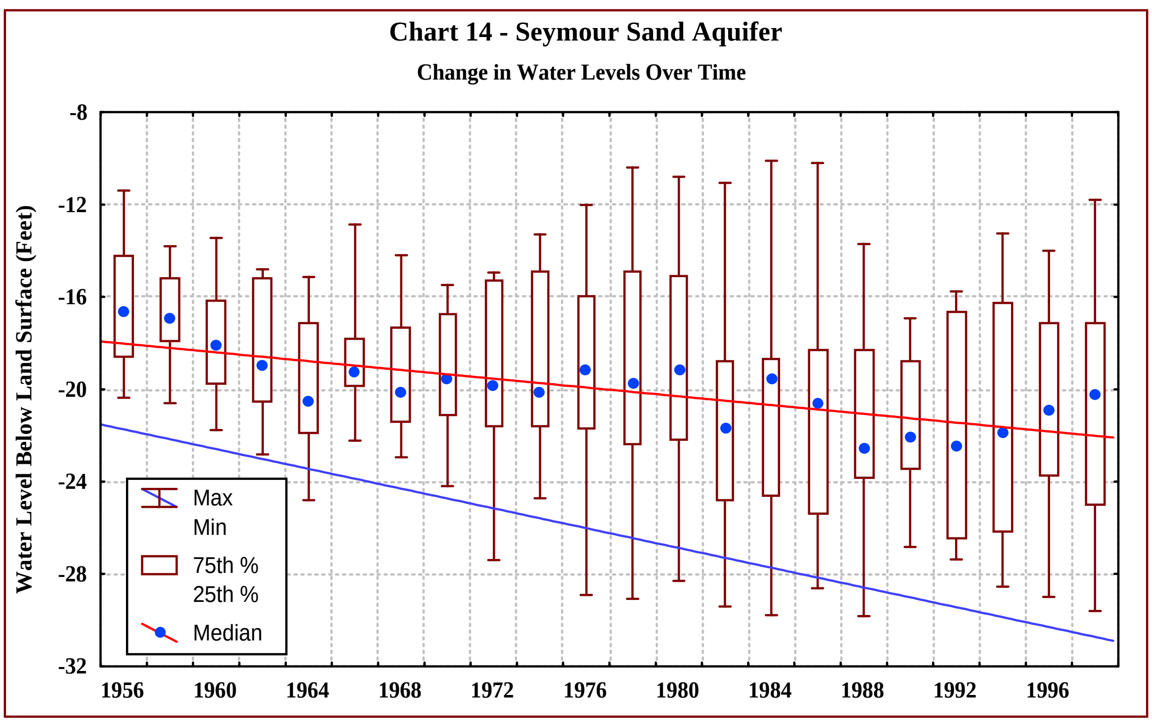
As a result of the hydrodynamics of the upper aquifer and the lower Permian evaporite deposits, numerous natural springs and seeps occur throughout the Pease River and Clear Fork Groups in a north-south trend of the western-most part of the Wichita River watershed. A study by Richter and Kreitler (1986) indicated that most salt-emission areas occur within the Blaine Formation outcrop. They attributed the occurrence to highly mineralized groundwater with the Blaine Aquifer as originating from two possible sources, halite (salt beds) dissolution by upper aquifer groundwater flow through the Blaine and brine discharge from deep-basin saline aquifers which underlie the High Plains often referred to as the Permian Formation.

The hydraulic head of the deeper aquifer is the same as or greater than the shallow aquifer, which probably forces the saline water to move vertically toward the surface if a pathway exists. Salt springs in King, Cottle and Motley Counties contribute highly concentrated brine to the watershed and enter the Wichita River and its tributaries in the western part of the study area.

These springs are believed to be emitting from the Permian Formation and provide a constant discharge to the watershed, even under extreme drought conditions. Chloride concentrations have been measured that are comparable to that of sea water and prohibit the use of much of the land and water resources within the watershed. The salt contaminates the alluvial deposits and promotes the growth of salt cedars and other noxious brush.

The **Seymour Formation of the Quaternary** is designated as a major aquifer and consists of isolated alluvium remnants which occur in parts of Cottle, Foard, Knox, Baylor and Wilbarger Counties. Groundwater in the Seymour Aquifer occurs in unconsolidated sediments consisting principally of discontinuous beds of poorly sorted gravel, conglomerate, sand, silty clay and caliche. The sediments were deposited by streams flowing generally eastward and mostly represent material eroded from the High Plains. Individual areas vary greatly in thickness, with total saturated thickness reaching upwards of 100 feet. Typical saturated thickness throughout the study area is less than 40 feet. Most of the aquifer is unconfined under water-table conditions and typically yields small to moderate quantities of water. Recharge is predominately from direct infiltration of precipitation and provides a reliable source of fresh water for municipal, domestic and irrigation uses within the watershed study area. Water in the aquifer moves from southwest to northeast.

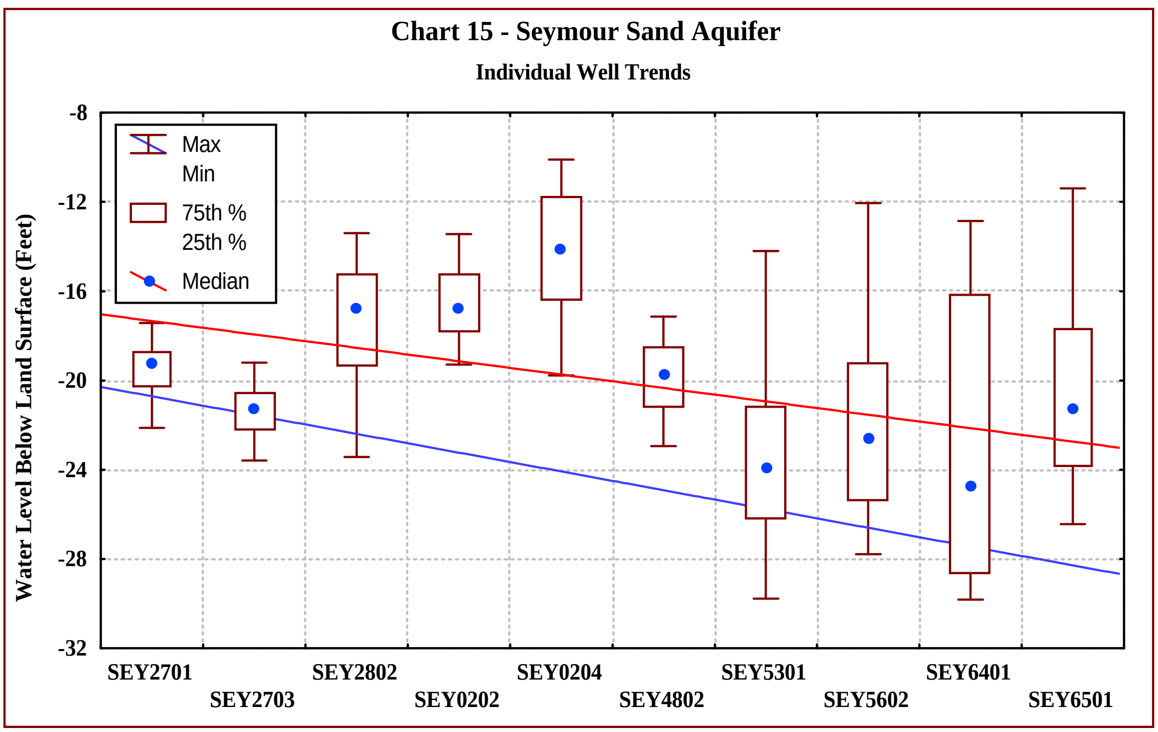
Ten wells were selected across the watershed from the TWDB's state observation wells to ascertain the general nomenclature of the Seymour Sand and the observed variance of measured water levels over a period from 1956 through 1998. Refer to the following **Chart 14,** for details of the observed changes in static water levels within the aquifer over time.



Also refer to **Table 8, TWDB Observation Well Inventory** located in the Appendix for general specifications of the wells utilized in the course of this evaluation together with other wells and springs having specific nomenclature relevant to the study.

The selected well data were combined to determine the extent of change in water levels over the period 1956 through 1998 and as they relate to use. Again, the trend shows a slight decline in water level of the Seymour Sand Aquifer. However, the interquartile range shows the greatest deviation during the 1970's, 1980's and 1990's, which correlates well with historical periods of drought and subsequent higher seasonal use for irrigation.

The following **Chart 15** shows the trend change in water levels over time of the selected individual well data during the period of record.



The **Alluvium of the Quaternary** age consists of floodplain and channel deposits composed of fine sand, silt, clay and gravel. Small amounts of alluvium are found along almost all streams and creeks within the study area. The channel deposits of alluvium are of hydrologic significance within the valley of the Wichita River and its tributaries where the deposits may reach up to 50 feet in thickness. The most favorable sediments for development may be found within the oxbows of former streambeds where the permeability is greater. These terrace deposits are an important source of fresh water for municipal, domestic and irrigation uses within isolated parts of the watershed study area. Floodplain deposits are derived, for the most part, from the Seymour Formation and were transported to their present positions by existing streams. These sediments were erratically deposited and are very discontinuous. Recent alluvium deposits lie unconformably on the Seymour formation resulting in hydrologic communication between the two. Locally, there may be drainage from these deposits into the more porous Permian beds below. Saturated thickness varies from about 10 feet to 60 feet and water produced from the recent alluvium deposits is typically from shallow wells in small quantities with water quality ranging from fresh to moderately saline. Much of the water contains large concentrations of sulfate associated with dissolved gypsum formations in the western part of the study area.

The **Clear Fork of the Permian** consists of shale and thin layers of limestone, dolomite, gypsum, marl and sandstone. The Clear Fork Group is located in parts of Knox, Baylor, Foard and Wilbarger Counties. The Clear Fork Group typically yields small quantities of poor quality water and are predominately used for livestock and some domestic uses. The Clear Fork Group is only utilized where the Seymour or Alluvium is not available due to its poor quality, low yield and greater depth to the aquifer. There were no wells with sufficient data available for analysis within the study area.[12]

A common component to all of the described aquifers is that of aquifer recharge. Recharge occurs in each of the aquifers through direct infiltration of precipitation on the land surface. The Wichita River and its tributaries adjoining the aquifers outcrop areas are typically at elevations lower than water levels in the aquifers. The only other possible sources for aquifer recharge is upward leakage from the lower Permian Formations. The annual effective recharge for the Blaine Aquifer is estimated to be 142,600 acre-feet and the Seymour Sand is 207,200 acre-feet per year.[13]

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[12] TNRCC, PGMA File Report, 1998

[13] TWDB, Report 337, 1992

3.0 HYDROLOGIC EVALUATION (continued)

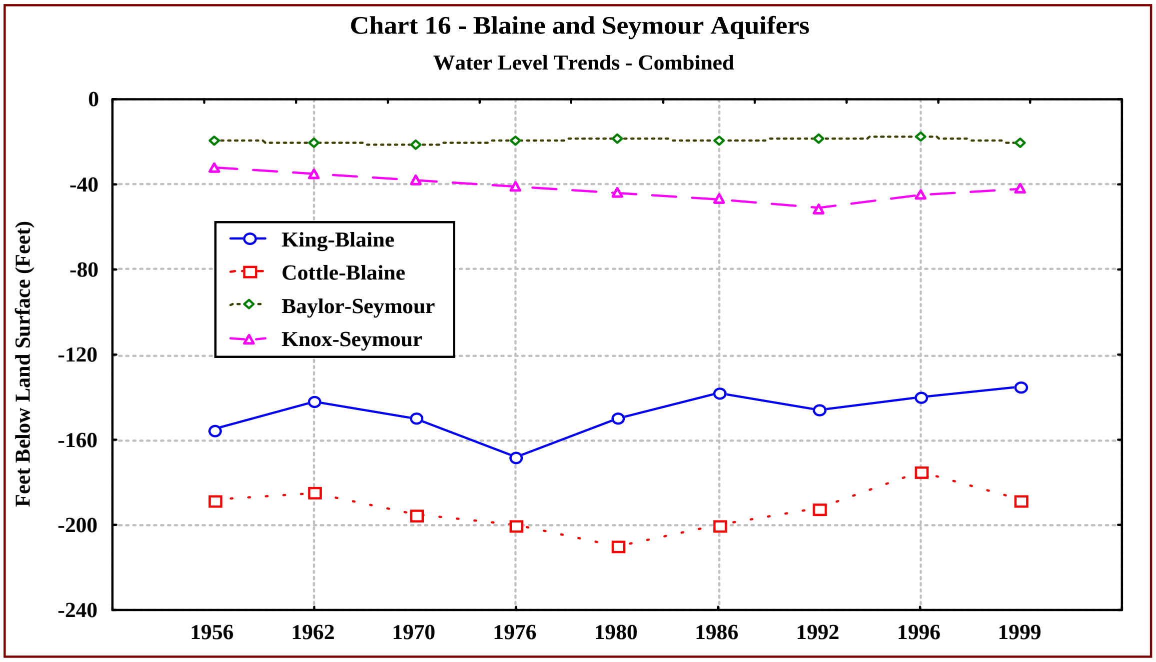
Discharge from the aquifers occurs from natural and artificial means. Natural discharge occurs as water moves eastward along solution channels and caverns dissolving the evaporitic deposits and discharging into topographically low areas through salt seeps and springs. This occurs in parts of Knox, Baylor and Wilbarger Counties and is typical of the Blaine and Seymour Formations. There were 115 artesian springs varying from small seeps to medium sized discharges (0.028 cfs – 6.8 cfs) located within the study area. The natural springs identified within this study area have not shown any major change in flow patterns over the past ten years, except for the normal seasonal fluctuations. However, some springs located in Knox, Foard and Cottle Counties that had previously ceased to flow, have begun to flow again. This is believed to be the result of improved land management practices implemented in the areas. Most of the springs are directly related to the Blaine or Seymour Aquifers with the exception of salt springs located in King and Cottle Counties. These artesian salt springs originate from the Permian with salinity levels comparable to that of sea water. **Refer to Table 7, Artesian Springs Inventory** located in the Appendix for details.

Artificial discharge is from wells in the heavily irrigated areas and predominately occurs throughout the study area where the aquifers are present. Wells located within the study area are utilized primarily for irrigation, domestic and private uses. Approximately 25 wells were selected within the watershed area to provide the general groundwater background hydrogeology for the most widely used aquifers, the Blaine and the Seymour.

Data collected from the wells were evaluated to determine aquifer trend changes in water levels over a period from 1953 to 1998. Although a wide range of water levels has occurred annually, the overall weighted average trend of the aquifer water level shows a slight decline over the period of record. This may be attributed to heavy pumping for irrigation use during dry periods. Some of the individual observation wells showed a slight rise in water levels from 12 to 36 feet with ranges from 0.5 – 1.0 foot per year from 1954 to 1990.

The following **Figure 6, TWDB Observation Well Locations**, depicts the geographical positions of the wells utilized in this evaluation with respect to the Wichita River watershed above Lake Kemp. This is not a complete representation of all the wells within the watershed, rather only the wells having sufficient data available for use in support of the discussions presented herein. Of the 287 well records evaluated, only 25 were selected for use in this study.

The following **Chart 16** depicts the overall weighted average water level trends with respect to time for the Seymour and Blaine Aquifers within the Wichita River watershed area.



The Blaine Aquifer, as it occurs in the Wichita River watershed**,** shows the most dramatic decrease in water level in the periods of 1976 and1980 in King and Dickens Counties. This is believed to be caused by heavy pumping for the irrigation of cultivated farm lands in the area during corresponding drought periods and seasonal uses. The more widely used aquifer, the Seymour Sand, shows a more subtle variance in water levels with the most decrease occurring during the periods 1992 and 1999 and probably for the same reasons. It should be noted that neither of the aquifers within the study area have shown to be exceeding the recharge rates through over pumping and some of the individual well data evaluated actually showed an increase in water level trends in the later period of record.[14] Refer to **Table 8, TWDB Observation Well Inventory** located in the Appendix for details. Each of the aquifers evaluated within the study area are non-uniform or unconfined and vary greatly in hydraulic character, making it difficult to represent descriptive properties of the water bearing formations without field reconnaissance. Each well has shown unique operational characteristics and level fluctuations under localized stress conditions brought on by drought or extended use during seasonally dry periods.

[14] TWDB, Report 337, 1992

3.6 DESCRIPTION OF WATERSHED HYDROLOGIC SYSTEM

The Wichita River watershed above Lake Kemp represents 2,086 square miles of surface drainage area (1,335,040 acres) is reflective of a highly modified hydrologic system since about 1923. The watershed exhibits a long-term yield of 119,100 acre-feet of water per year or about 58.7 acre-feet per square mile of contributing drainage area. The North Fork and Middle Fork of the Wichita River make up 61.2% of the total annual streamflow impounded in Lake Kemp. From the Wichita River's headwater tributaries exhibit normal streamflow characteristics with a gradual increase in velocity as the river proceeds downstream to Lake Kemp. The long-term average streamflow near Seymour, Texas is 186.8 cfs or about 135,243 acre-feet per year and the median of the inner quartile range (normal base flow) may be expected to be equal to or greater than 152.1 cfs under normal rainfall conditions. Accordingly, it may be assumed that a 15% decline in average annual rainfall over the watershed will reduce the base flow at the Seymour gaging station to approximately 41.4 cfs.

Land use patterns have changed since the mid 1800's from predominately open range land to a combination of range and cropland . Since 1950, much of the cultivated cropland has been converted to range or pasture land through the USDA, Farm Service Agency's Conservation Reserve Program (CRP). The acreage within the watershed may be allocated in two categories with 80.6% to range land and 19.4% for cropland. Irrigated croplands have decreased from 11,510 acres in 1964 to 4,110 in 1999 and groundwater used for irrigation has decreased from 12,002 acre-feet in 1964 to 3,717 acre-feet in 1999. The CRP has also been instrumental in reducing soil erosion, sedimentation rates in streams and lakes, improving water quality, wildlife habitat areas and enhancing wetland resources. Since implementation of the CRP, about 7,390 (64.2%) acres of the 11,500 acres of highly erodible cropland have been removed from cultivation and returned to native grasslands. The change in land use from crops like cotton to permanent grass cover may be attribute to rising water tables in parts of Cottle County. Historically, there have been very little irrigated cropland in Cottle County, which indicates the rising water tables are not simply the result of decrease pumping of groundwater for irrigation. The rising water levels appear to be related to the land with permanent grass cover holding rainfall and allowing it to percolate into the ground. Additionally, nitrogen fertilizer application has been reduced from 18 pounds per acre to about 2 pounds per acre. This effort has resulted in a net reduction of nitrogen runoff of 1.0 pounds per acre and phosphorus runoff by 1.5 pounds per acre. Leached nitrogen has reportedly been reduced by 2.8 pounds per acre.[15]

[15] TNRCC, PGMA File Report, 1998

3.0 HYDROLOGIC EVALUATION (continued)

Total annual water use within the watershed for all purposes has shown a minor increase from 5,548 acre-feet in 1979 to 6,419 acre-feet in 1999 with the most significant increase being experienced in the municipal category from 1,206 acre-feet to 1,337 acre-feet while regional population showed a decline over the same period. About 98% of the total water use is from groundwater and primarily from two aquifers, the Seymour Sand (76%) and the Blaine Gypsum (12%). The remaining portion (2%) is drawn from the Paleozoic formations within the watershed. Refer to **Figure 5** for geographic locations of the aquifers with respect to the watershed. [16] The TWDB estimates that these aquifers have an effective recharge rate of 142,600 acre-feet per year for the Blaine and 207,200 acre-feet per year for the Seymour.

Overall, static groundwater levels have remained fairly constant over the past 50 years with only a slight decline being evident since 1996. Some individual wells have shown significant water level increases due to the reduction in irrigation uses. The Blaine in Cottle County exhibited the greatest decline from 1996 to present probably due to increased irrigation use in the area during drought conditions. However, the noted decline fell within the normal fluctuation range for the aquifer. Neither of the aquifers evaluated appear to have a greater total withdrawal rate than their recharge rates.

A number of small springs located on the Matador Wildlife Management Area in Motley County that did not have a recorded flow in several years are now flowing again primarily due to improved land management practices employed through the USDA Conservation Reserve Program (CRP). This is also typical of other springs located in parts of Cottle, King and Foard Counties where the CRP has been successfully implemented. The rejuvenated spring flow to the watershed provides additional aquatic and wetland habitats at or near the springs' discharge points and contributes to the volume and reliability of stream base flow.[17]

The Wichita River is a typical prairie stream ecosystem characterized by extreme fluctuations in environmental conditions and streamflow regimes. Native fish faunas are well adapted to the variable flows, broader extremes in water temperatures, lower turbidity and higher salinity levels. However, the more common species found in similar prairie streams within the region are unable to propagate in this type of stream primarily due to the high concentrations of dissolved solids and their abundance is severely limited in the upper reaches of the river system.

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[16] TWDB Consensus Water Plan, 1997

[17] Moulton, D.W. and Baird, A.L. 1998

The smalleye and sharpnose shiners and the shovelnose sturgeon have been listed on the TPWD threatened and/or endangered species list. Refer to **Table 2** in the Appendix for a listing of fish and wildlife common to this watershed.

The watershed is also important to both migratory and wintering waterfowl. Corridors of riparian habitat are exceptionally valuable wildlife habitats for these type birds. Several of the birds listed as threatened or endangered by the TPWD and/or the USFWS occur within the watershed area only as migrants or as wanderers normally found along the Gulf coast. The Wichita River watershed provides some of the essential habitat for the interior least tern. Although its primary nesting ground in Texas is restricted to the Prairie Dog Town Fork of the Red River, they have been identified in the reaches of the Wichita River watershed above Lake Kemp.

Water quality for both surface water and groundwater is impaired for many uses and by a number of influencing factors. The chemical character of groundwater mirrors the mineral composition of the rocks through which it has passed. Groundwater chemical composition changes over time as it moves through its environment and dissolves some of the minerals from the surrounding rocks. Concentrations of the various dissolved mineral constituents depend upon the solubility of the minerals in the formation, the length of time the water is in contact with the rock, and the concentration of carbon dioxide present with the water.

The TWDB evaluated the chemical concentrations of total dissolved solids, chloride, sulfate and nitrate from its observations wells within the Seymour and Blaine aquifers to determine if any significant changes have occurred over the period 1988 – 1998.[18] As it relates to the Wichita River watershed study area, the analysis showed a slight increase in chemical concentrations for each of the constituents over the previous period of assessment (1988) to the current study period (1998).

The Seymour Aquifer in Baylor, Knox, Foard and Cottle Counties for TDS averaged 1,637 mg/L and ranged from a low of 215 mg/L to a high of 5,932 mg/L out of 77 samples; chloride averaged 313 mg/L and ranged from a low of 3 mg/L to a high of 2,965 mg/L out of 188 samples; sulfate averaged 284 mg/L and ranged from a low of 14 mg/L to a high of 3,024 mg/L out of 188 samples; nitrate (as N) averaged 74 mg/L and ranged from a low of 0.2 mg/L to a high of 1,484 mg/L out of 74 samples.

[18] TWDB, File Report 98-03, PGMA-16 Update,1998

The Blaine Aquifer in King, Cottle and Foard Counties for TDS averaged 3,042 mg/L and ranged from a low of 1,395 mg/L to a high of 4,959 mg/L out of 20 samples; chloride averaged 372 mg/L with a low of 12 mg/L to a high of 2,248 mg/L out of 42 samples; sulfate averaged 1,603 mg/L and ranged from a low of 119 mg/L to a high of 2,529 mg/L out of 42 samples; nitrate (as N) averaged 20 mg/L and ranged from a low of <0.04 mg/L to a high of 85.8 mg/L out of 40 samples.

Surface water quality of the Wichita River, its tributaries and Lake Kemp contain high concentrations of total dissolved solids, chloride and sulfate. Because of the natural salt spring in the upper reaches, the water is unsuitable for most uses the majority of the time. However, water impounded in Lake Kemp is utilized in part, for irrigation downstream and for power plant cooling operations. Due to the current drought conditions experienced within the region, water from Lake Kemp is blended with Lakes Kickapoo and Arrowhead to supplement existing supplies in the Wichita Falls and surrounding area.

For the period 1968 – 1999 the USGS stream gage 07312100 measured total dissolved solids (TDS) by regression of conductivity as collected daily from the gage. TDS concentrations in Lake Kemp averaged 2,959 mg/L and ranged from a low of 1,200 mg/L to a high of 4,420 mg/L; chloride concentrations averaged 1,137 mg/L and ranged from a low of 450 mg/L to a high of 1,700 mg/L; sulfate concentrations averaged 590 mg/L and ranged from a low of 410 mg/L to a high of 730 mg/L.

The Wichita River Basin Chloride Control Project is designed to reduce chloride and sulfate levels of water impounded in Lake Kemp by diverting highly concentrated brine originating from natural springs located in the upper reaches of the watershed out of the base flow. Refer to Section 3.4 of this report for additional information on the project. The brush stands located in the drainage area above each of the diversion facilities including the Truscott Brine Reservoir should not be removed. Doing so would increase the quantity of water being diverted, thereby increasing operating cost significantly. It is estimated that this would impact a maximum of 16,000 acres (less than 2%) of the less densely populated brush areas above all four of the chloride control facilities. By selectively implementing the proposed brush control program in a manner so as to leave brush above and remove brush below each of the three diversion structures and the reservoir, the two programs would complement each other by replacing the highly concentrated water diverted from the river's base flow with a good quality water added to the runoff of the watershed by the brush control program. Additional benefits can be realized in reducing the chloride project's time-frame for meeting drinking water standards up to 26% and preventing an increase in operating cost to divert the additional runoff above the diversion facilities. Refer to **Figure 8, Chloride Project Area**.

3.0 HYDROLOGIC EVALUATION (continued)

3.7 SUMMARY AND CONCLUSIONS

Following is a summary of the conclusions developed as a result of the review and analysis of available information pertaining to the general hydrologic, hydrogeologic, geologic, climate and ecological condition of the Wichita River watershed above Lake Kemp. The conclusions with respect to implementation of a brush control program for the purpose of increasing watershed yield are as follows:

- There have been significant changes in the hydrological system that have impacted streamflow, spring flow and groundwater levels since about 1923. Most changes appear to be for the better in terms of resource management. Steamflow has shown an increase of 10.4% or 6.1 acre-feet per square mile over the historical average. Several springs that were once dormant have return to surface flow. Both are believed to be due to improved land resource management practices and reduced groundwater use for irrigation purposes since1980. This would further demonstrate that removal of noxious brush would prove feasible and substantially increase overall watershed yield with a higher quality of water.

- The annual watershed runoff was 130,875 acre-feet in 1998. This is 11,775 acre-feet greater (about 9%) than the historical long-term average of 119,100 acre-feet. The historical high annual watershed runoff was 318,473 acre-feet or 162.1 acre-feet per acre of contributing drainage area in 1992 when annual rainfall reached 35.21 inches.

- The Wichita River watershed above Lake Kemp is dependent upon groundwater (97.8%) for most uses, which is supplied primarily from the Seymour Sand and Blaine Aquifers. The TWDB estimates that these aquifers have an effective recharge rate of 142,600 acre-feet per year for the Blaine and 207,200 acre-feet per year for the Seymour Sand. The total withdrawal from these aquifers has reduced significantly over the past 40 years to 6,419 acre-feet in 1999. With the exception of seasonal fluctuations, water levels have remained fairly constant showing only minor reductions in the last few years. This could be due to the drier climate conditions and rapid spread of noxious brush within the aquifer recharge zones. However, including Lake Kemp, the total surface and groundwater utilized out of the watershed study area averages about 112,000 acre-feet per year. Most of the water is discharged out of Lake Kemp and utilized for irrigation, industrial and some municipal uses. Considering the long-term average annual streamflow of 119,100 acre-feet per year, the additional watershed yield provided by the brush control program would benefit the entire regional area through increased water supply available to the region.

- Climate conditions appear to be changing with annual rainfall rates showing a 12.5% increase due in part to extended durations over the last ten years where the average rainfall-days increased from 31.2 days per year to 42.6 days per year over the watershed. Long-term evaporation rates (30-year) have decreased from the average 73.1 inches per year to 67.5 inches per year with a matching record high of 85.5 inches being set in 1996. The last decade shows the evaporation trend reversing with a defined increase pattern of about 1.3 inches increase per year. Average annual temperatures have remained relatively constant over the past 100 years with a slight increase in the long-term average from 62.1° F to 62.7° F over the last 20 years.

- The aquatic habitat appears to be stable and supports an abundance of aquatic life even with the high dissolved solids found throughout the Wichita River system. The added quantity of higher quality water through removal of noxious brush would greatly enhance the health of the aquatic habitats within the watershed area and increase their abundance. The improved habitat areas would further promote the proliferation of popular game for hunting such as quail, dove, pheasant and turkey that would add a direct economical benefit to landowners for leased hunting.

- In 1998, there were eleven birds, three fishes, five mammals and three reptiles among the species native to this area that have been listed as endangered or threatened. They include the following:

Birds:	Golden-Cheeked Warbler, Reddish Egret, Peregrine Falcon, American Peregrine Falcon, Arctic Peregrine Falcon, Whooping Crane, Bald Eagle, Brown Pelican, White-Faced Ibis, Black-Capped Vireo, Interior Least Tern
Fish:	Smalleye and Sharpnose Shiners, Shovelnose Sturgeon
Mammals:	Texas Kangaroo Rat, Black-Footed Ferret, Cave Myotis Bat, Long-Legged Myotis Bat, Plains Spotted Skunk
Reptiles:	Texas Horned Lizard, Texas Garter Snake, Brazos Water Snake

- The ecological transformation was a gradual process that began with early settlement in the late 1800's and the onset of major ranching activities to the point where the watershed population peaked at 16,250 in 1930. The economy collapsed with the Great Depression and area population stabilized around 6,000 by 1990. However, ranching continued to prevail as the leading enterprise with overgrazing, numerous droughts and range fire suppression becoming the principle cause for the spread of noxious brush to the extent that the once open prairie range is now populated with over 62% of brush covering the landscape (about 825,000 acres).

Although early records do not reflect the density of brush in the area, accounts of long-time residents agree that mesquite and juniper (cedar) covered an estimated 20% of the open range areas (about 267,000 acres) after 1930 and began rapidly spreading throughout the watershed area, limiting land uses, livestock production and utilizing much of the water resources.

- Soil erosion has been reduced over the past 20 years due in part to returning cultivated lands to rangelands with native grass covers, construction of many earthen stock ponds and terraces, and generally improved land resource management throughout the watershed, especially in the upper reaches.

- Lake Kemp is a modification to the natural prairie stream, but with several definite advantages. The reservoir provides a healthy aquatic habitat for fish and wildlife, controls flooding during heavy rainfall events, and provides a good source of water for irrigation, municipal, industrial and agricultural uses. The reservoir is currently being used to supplement surface water supplies for Wichita Falls and surrounding areas and is identified in the State's Regional Water Plan for Area B as a regional water supply source that will greatly enhance municipal and agricultural activities within the watershed, contingent upon the continued reduction of dissolved solids. Given its reduced yield characteristics due to the 77-years of sedimentation, the brush control program in the upper watershed could greatly enhance the beneficial uses of the reservoir as a potential regional water supply and extend its useful life.

- A brush control program coupled with the Wichita River Basin Chloride Control Project will provide increased watershed yield of a higher quality for replacement of the diverted poor quality water, thereby maintaining an equitable water balance for the benefit of all water uses including the environmental needs. By selectively implementing the proposed brush control program in a manner so as to leave brush above (about 16,000 acres) and remove brush below each of the three diversion structures and the Truscott Brine Reservoir, the two programs would complement each other by replacing the highly concentrated water diverted from the river's base flow by the chloride project with a good quality water added to the runoff of the watershed by the brush control program. Additional benefits can be realized in reducing the time-frame for meeting drinking water standards up to 26% and preventing an increase in operating cost to divert the additional runoff above the diversion facilities. Refer to **Figure 8, Chloride Control Project Area** for details.

3.0 HYDROLOGIC EVALUATION (continued)

- An organized brush control program will have its greatest benefit on the hydrologic system when implemented over areas comprising the surface outcrops of the Quaternary deposits. This would provide an immediate impact on aquifer recharge through percolation into the Alluvium deposits and Seymour Sand, thereby restoring normal water table conditions of the aquifers under the prevailing use demands.

- Due to the abundance of natural springs in the upper parts of the watershed, a brush control program should provide relief from the inordinate depletion of groundwater from uncontrolled brush proliferation, thereby restoring the static head needed to cause dormant springs to once again flow.

- Due to the highly erosive nature of the soils within the watershed area, a grass cover should be replaced immediately upon removal of the brush to prevent heavy erosion and sediment loading to the water courses during heavy rainfall events.

4.0 WATERSHED DELINEATION AND MODELING

4.1 INTRODUCTION

A Geographic Information System (GIS) was utilized to assimilate, manage and analyze hydrological, climatological, land use and cover, and general topography data and prepare a comprehensive simulation model of the Wichita River watershed. The GIS provides spatial display and analysis of relevant watershed data to determine the most accurate prediction of results to be expected from implementation of the brush control program over the watershed area throughout the planned ten year life. The present brush cover, by type and category, was determined utilizing satellite imagery from the 1999 Landsat-7 Survey and ground verified for positional accuracy and densities.

The watershed was then hydrologically divided into 48 sub-watersheds or sub-basins to accurately identify and select areas for removal of brush that would provide the greatest benefit to land uses and watershed yield. Brush cover was classified in categories of heavy, heavy mixed, moderate, moderate mixed and light. The noxious brushes having the highest uptake of the water resources were identified as cedar, mesquite and mixed brushes. Data layers were developed by the GIS for spatial analysis and integration with the hydrological modeling tool that includes soils, topography, climate, and vegetative cover. The GIS will provide long-term assessment of the results and assist both the state and landowners with maintaining the implemented brush control program to achieve optimum benefits.

The amount of additional water expected from the implementation of the brush control program was estimated by using the Soil and Water Assessment Tool (SWAT) model, a simulation model that predicts the impact of watershed management activities on watershed yield and sedimentation of large unmeasured watersheds. The SWAT model then quantifies the impact of climate and vegetation changes, reservoir management activities, groundwater and surface water uses, channel hydrology, water quality conditions, and water transfers. The model was employed and calibrated by the USDA-Natural Resource Conservation Service, Blackland Research and Extension Center to predict watershed yield using historical climatology and streamflow data assembled from stations located throughout the watershed. Calibration of the model was accomplished by adjusting input parameters so that simulated output track measured streamflows as closely as possible. Data utilized for calibration purposes were from the period 1960 through 1998.

A detailed description of the hydrologic simulation and modeling of the Wichita River watershed may be found in the Technical Appendix of this report.

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.2 WATERSHED DATA

Location: The Wichita River watershed is located in north-central Texas in the Rolling Plains Major Land Resource Area (MLRA).

Topography: The outlet or "catchment" for the portion of the Wichita River simulated in this study is Lake Kemp, which is located in sub-basin number 48. The sub-basin delineation and numbers are shown in **Figure 4-9**.

Weather Data: The average annual rainfall for the Wichita River Watershed (1960 – 1998) varied from 22.1 inches in the western portion of the watershed to 25.9 inches in the eastern portion. The composite average for the entire watershed was 24.6 inches. Weather stations used for modeling are shown in **Figure 4-10**. For each sub-basin, precipitation and temperature data were retrieved by the SWAT input interface for the weather station nearest the centroid of the sub-basin.

Soils: The dominant soil series in the Wichita River watershed are Carey, Knoco, Miles, Owens, Tillman, and Vernon. These six soil series represent about 55% of the watershed area. A short description of each follows:

Carey: The Carey series consist of very deep, well drained, moderately permeable soils that formed in weakly consolidated silty or sandy sediments of Permian age. These soils are on nearly level to moderately sloping shoulders with summits of dissected terraces on uplands of the Central Rolling Red Plains (MLRA 78B, 78C). Surfaces are generally smooth to gently convex and slopes range from 0% to 8%.

Knoco: The Knoco series consist of very shallow, shallow, well drained, very slowly permeable soils that formed in residuum over dense non-cemented claystone bedrock of Permian age. These soils are on very gently sloping to very steep ridges, side slopes and erosional foot slopes on uplands of the Central Rolling Red Plains (MLRA-78B, 78C), Rolling Limestone Prairie (MLRA-78D), and North Central Prairie (MLRA-80B). Slopes range from 1% to 60%.

Miles: The Miles series consist of very deep, well drained, moderately permeable soils that formed in loamy alluvial materials. These soils are on nearly level to moderately sloping terrace pediments on uplands in the Central Rolling Red Plains (MLRA 78B, 78C). Slopes range from 0% to 8%.

Owens: The Owens series consist of soils that are moderately deep to dense, weathered shale. They are well drained, very slowly permeable soils, formed in residuum weathered from shale. These soils are on gently sloping to steep uplands. Slopes range from 1% to 40%.

Tillman: The Tillman series consist of very deep, well drained, slowly permeable soils, formed in loamy and clayey alluvium derived from redbed clays and claystone sediments of Permian age. These soils are on nearly level to gently sloping uplands of the Central Rolling Red Plains (MLRA-78C) and the Rolling Limestone Prairie (MLRA-78D). Slope ranges from 0% to 5%.

Vernon: The Vernon series consist of moderately deep, well drained, very slowly permeable soils that formed in residuum weathered from claystone. These soils are on gently sloping to steep uplands of the Central Rolling Red Plains (MLRA-78B, 78C), Central Limestone Prairies (MLRA 78D) and North Central Prairie (MLRA 80B). Slopes range from 1% to 45%.

Land Use and Land Cover: **Figure 4-11** shows the areas of heavy and moderate brush (oak not included) in the Wichita River Watershed. This is the area of brush removed or treated in the no-brush simulation.

Ponds and Reservoirs: Surface area, storage, and drainage area were obtained from the Texas Natural Resource Conservation Commission (TNRCC) for existing inventory-sized ponds and reservoirs in the watershed **(Figure 4-12)**, and input to the SWAT model. Diversions of streamflow from the low-flow dam in the South Wichita at gage 07311782 (Guthrie) were also input. This diversion was pumped to an evaporation reservoir (Truscott Brine Lake) in sub-basin 32.

Model Input Variables: Significant input variables for the SWAT model for the Wichita River Watershed are shown in **Table 4-1** below. Input variables for all sub-basins in the watershed were the same, with three exceptions:

- It was necessary to reduce soil available water capacity fraction by 0.03 (inches H_2O/inch soil) in the area below stream gages 07311700 and 07311800 **(Figure 4-12)** in order to calibrate flow at stream gage 07311900.

- Comparisons of measured and predicted flow from preliminary SWAT runs indicated that channel transmission losses may have been higher in the North Wichita River. Therefore, 0.16 inches per hour was assumed in the North Wichita River above gage 07311700 (Truscott) and 0.04 inches per hour in the remainder of the watershed.

- The re-evaporation coefficient was assumed higher for brush than for other types of cover because brush is deeper rooted, and opportunity for re-evaporation from the shallow aquifer is higher. The re-evaporation coefficient for all brush hydrologic response units (HRU – combinations of soil and land use/cover) is 0.4, and for non-brush HRU's are 0.1.

4.3 WICHITA RIVER WATERSHED RESULTS

Calibration: SWAT was calibrated for flow at stream gages 07311600 (Paducah), 07311700 (Truscott), 07311800 (Benjamin), and 07311900 (Seymour) as shown on **Figure 4-13**. The results of calibration are shown for gages 07311700 and 07311800 on **Figures 4-14 and 4-15**. Measured and predicted total monthly flows compared reasonably well with R^2 values of 0.56 for gage 07311700 and 0.54 for gage 07311800. At gage 07311700 the measured monthly mean was 4,027 acre-feet, and predicted monthly mean was 3,900 acre-feet. At gage 07311800 the measured mean was 2,493 acre-feet, and predicted mean was 2,535 acre-feet. Average base flow for the entire watershed was 47% of total flow, which is very close to measured base flow of about 45%.

At gage 07311700 predicted flow was less than measured **(Figure 4-14)**. In July and August 1966, SWAT underestimated flow by a large amount, causing the cumulative lines of measured and predicted flow to diverge significantly. It is possible that large amounts of rainfall occurred in those two months that were not measured accurately at any of the weather stations. The measured and predicted lines for the remainder of the simulated period are parallel, with the predicted line approaching and nearly catching up to the measured line near the end of the simulation.

At gage 07311800 predicted flow for the simulation period was slightly higher than measured **(Figure 4-15)**. The lines of cumulative measured and predicted flow diverge somewhat near the beginning of the simulation, but converge toward the end. Again, this may have been due to precipitation variability that was not reflected in measured data.

<u>Brush Removal Simulation</u>: Average annual evapotranspiration (ET) was 23.82 inches for the brush condition (calibration) and 21.87 inches for the no-brush condition, or 97% and 89% of precipitation for the brush and no-brush conditions, respectively.

Figure 4-16 shows the cumulative monthly flow to Lake Kemp for the brush and no-brush conditions over the period 1960 through 1998.

Total sub-basin area, area of brush treated, fraction of sub-basin treated, water yield increase per acre of brush treated, and total water yield increased for each sub-basin is given in **Table 4-2** below. The amount of annual increase varied among the sub-basins and ranged from 25,733 gallons per acre of brush removed per year in sub-basin number 1 to112,803 gallons per acre in sub-basin number 26.

Variations in the amount of increased water yield were expected and influenced by brush type, brush density, soil type, and average annual rainfall, with sub-basins receiving higher average annual rainfall generally producing higher water yield increases. The larger water yields were most likely due to greater rainfall volumes, as well as increased density and canopy of brush.

A gray-scale graph of the sub-basins in the Wichita River watershed, with water yield increases represented by varying color intensities is shown in **Figure 4-17**. Darker shading represents higher water yield increases.

For the entire simulated watershed, the average annual water yield increased by 95% or approximately 152,004 acre-feet. The average annual flow at the outlet (Lake Kemp) increased by 145,426 acre-feet. The increase in volume of flow to Lake Kemp was slightly less because of stream channel transmission losses that occurred between each sub-basin and the watershed outlet.

TABLE 4-1
SWAT INPUT VARIABLES

VARIABLE	CALIBRATION	
	WITH BRUSH	WITHOUT BRUSH
Runoff Curve Number Adjustment	-2	-2
Soil Available Water Capacity Adjustment (Inches H^2O/inch soil)	0 and -0.03	0 and -0.03
Soil Evaporation Compensation Factor	0.9	0.9
Minimum Shallow Aquifer Storage for Groundwater Flow (inches)	0	0
Shallow Aquifer Re-Evaporation Coefficient	0.4	0.1
Minimum Shallow Aquifer Storage for Re-Evaporation (inches)	0.04	0.04
POTENTIAL HEAT UNITS (°C)		
Heavy Cedar	4,036	N/A
Heavy Mesquite	3,511	N/A
Heavy Mixed Brush	3,753	N/A
Moderate Cedar	3,511	N/A
Moderate Mesquite	3,108	N/A
Moderate Mixed Brush	3,310	N/A
Heavy Oak	3,511	3,511
Moderate Oak	3,108	3,108
Light Brush and Open Range/Pasture	2,704	2,704
PRECIPITATION INTERCEPTION (INCHES)		
Heavy Cedar	0.79	N/A
Heavy Mesquite	0	N/A
Heavy Mixed Brush	0.59	N/A
Moderate Cedar	0.59	N/A
Moderate Mesquite	0	N/A
Moderate Mixed Brush	0.39	N/A
Heavy Oak	0	0
Moderate Oak	0	0
Light Brush and Open Range/Pasture	0	0
PLANT ROOTING DEPTH (FEET)		
Heavy and Moderate Brush	6.5	N/A
Light Brush and Open Range/Pasture	3.3	3.3
MAXIMUM LEAF AREA INDEX		
Heavy Cedar	6	N/A
Heavy Mesquite	4	N/A
Heavy Mixed Brush	4	N/A
Moderate Cedar	5	N/A
Moderate Mesquite	2	N/A
Moderate Mixed Brush	3	N/A
Heavy Oak	4	4
Moderate Oak	3	3
Light Brush	2	2
Open Range and Pasture	1	1
Channel Transmission Loss (inches/hour)	0.04 and 0.16	0.04 and 0.16
Sub-Basin Transmission Loss (inches/hour)	0.015	0.015
Fraction Transmission Loss Returned as Base Flow	0.8	0.8

TABLE 4 - 2
SUB-BASIN DATA AND WATERSHED YIELD

SUB-BASIN	TOTAL AREA (ACRES)	BRUSH AREA (TREATED) (ACRES)	BRUSH FRACTION (TREATED)	INCREASE IN WATER YIELD (GAL/ACRE/YEAR)	INCREASE IN WATER YIELD (GALLONS/YEAR)
1	13,284	8,397	0.63	25,733	216,078,477
2	46,661	30,680	0.66	26,291	806,618,075
3	16,465	6,444	0.39	54,483	351,071,993
4	12,540	5,379	0.43	57,122	307,249,997
5	13,218	8,466	0.64	28,865	244,374,486
6	16,045	10,190	0.64	31,556	321,550,392
7	52,577	36,449	0.69	48,479	1,767,011,514
8	63,469	36,484	0.57	53,421	1,949,006,716
9	75,950	27,853	0.37	49,033	1,365,711,107
10	38,072	10,354	0.27	42,432	439,342,078
11	16,875	6,077	0.36	28,882	175,513,199
12	25,793	8,635	0.33	39,043	337,141,059
13	14,297	5,214	0.36	33,746	175,936,804
14	15,746	6,561	0.42	49,251	323,150,848
15	10,065	6,504	0.65	56,787	369,339,822
16	9,556	4,362	0.46	52,946	230,953,724
17	3,487	1,498	0.43	59,154	88,598,722
18	27,369	9,758	0.36	67,891	662,499,876
19	6,946	2,875	0.41	48,545	139,554,585
20	20,393	5,109	0.25	56,850	290,468,358
21	48,065	45,344	0.94	36,223	1,642,475,517
22	1,740	1,740	1.00	38,843	67,570,378
23	23,426	23,426	1.00	39,538	926,201,635
24	39,149	30,253	0.77	46,765	1,414,809,041
25	30,972	17,655	0.57	56,219	992,525,495
26	26,178	16,266	0.62	112,803	1,834,812,503
27	37,728	29,769	0.79	76,963	2,291,117,650
28	38,736	32,625	0.84	51,446	1,678,437,006
29	36,312	33,632	0.93	53,234	1,790,377,239
30	78,253	73,592	0.94	49,096	3,613,105,492
31	12,973	7,682	0.59	76,732	589,436,878
32	17,945	11,119	0.62	78,029	867,629,691

TABLE 4-2
SUB-BASIN DATA AND WATERSHED YIELD
(continued)

SUB-BASIN	TOTAL AREA (ACRES)	BRUSH AREA (TREATED) (ACRES)	BRUSH FRACTION (TREATED)	INCREASE IN WATER YIELD (GAL/ACRE/YEAR)	INCREASE IN WATER YIELD (GALLONS/YEAR)
33	7,416	5,133	0.69	62,115	318,809,773
34	25,855	14,691	0.57	71,967	1,057,275,748
35	23,341	15,678	0.67	102,176	1,601,924,107
36	15,506	9,301	0.60	57,447	534,305,149
37	14,308	10,405	0.73	75,260	783,103,216
38	13,845	6,367	0.46	64,976	413,706,250
39	86,420	61,795	0.72	70,117	4,332,850,136
40	68,762	40,987	0.60	74,741	3,063,455,505
41	13,173	5,769	0.44	60,820	350,870,423
42	10,277	7,041	0.69	104,070	732,734,977
43	14,712	10,786	0.73	59,100	637,434,654
44	9,971	8,017	0.80	98,940	793,220,592
45	5,829	5,040	0.86	99,532	501,654,934
46	4,715	3,896	0.83	90,861	353,972,889
47	13,104	1,129	0.09	35,353	39,919,370
48	93,786	66,988	0.71	85,776	5,745,911,288
TOTALS	**1,311,305**	**833,413**	—	—	**49,530,819,369**
AVERAGE	—	—	**0.64**	**59,431**	—

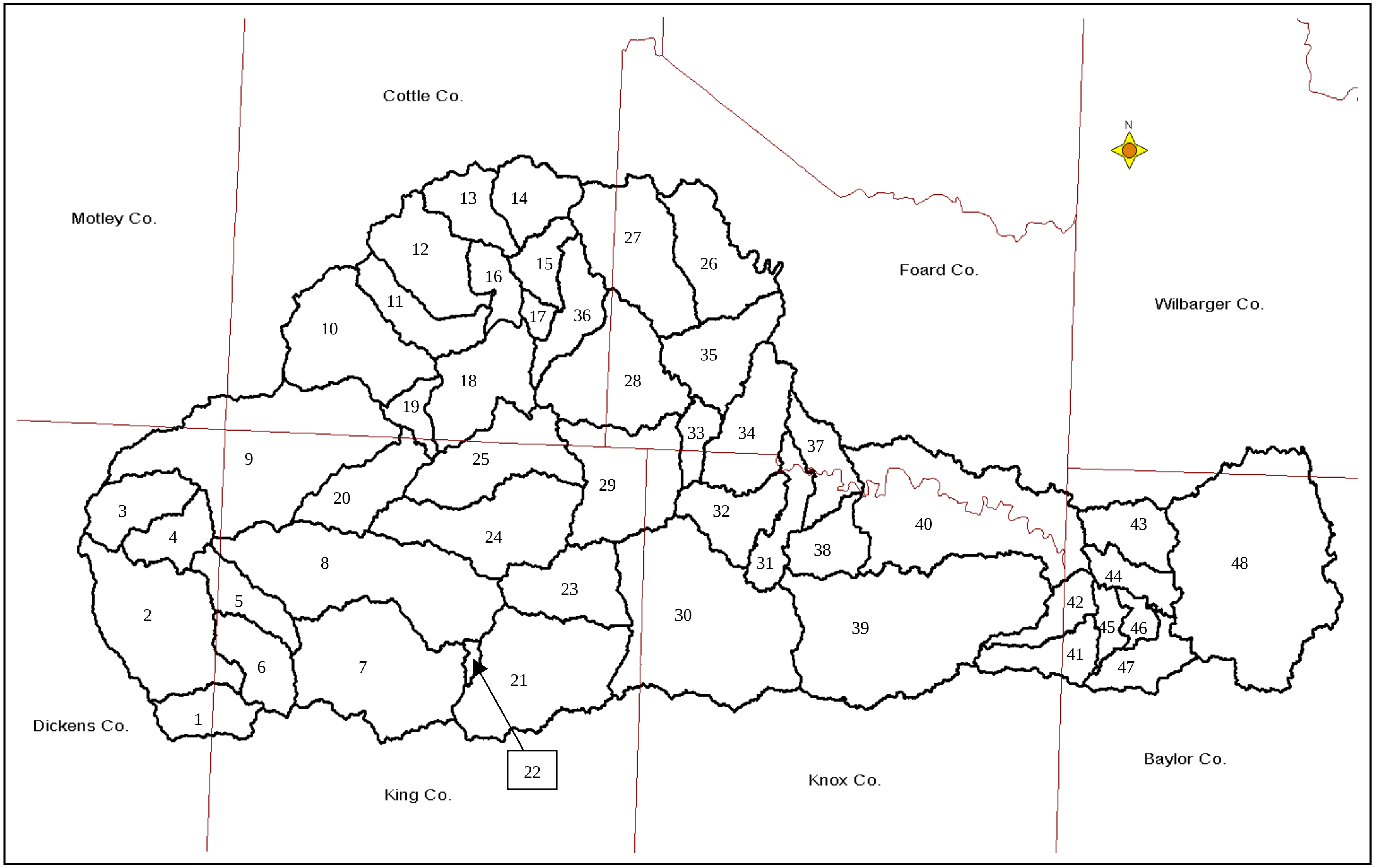

Figure 4-9 n Wichita River Watershed Sub-Basin Map

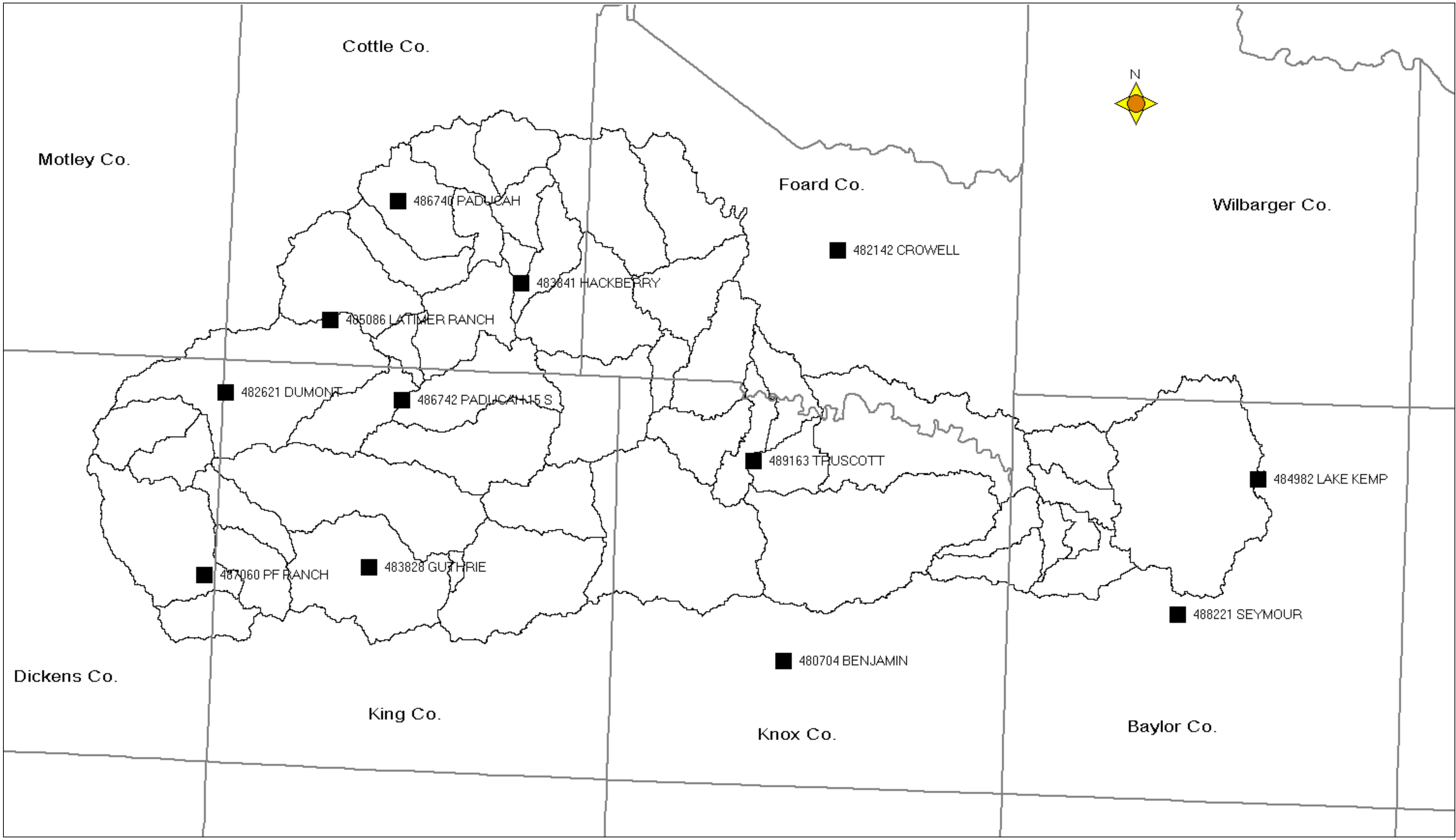

Figure 4-10 n Weather Stations in the Wichita River Watershed

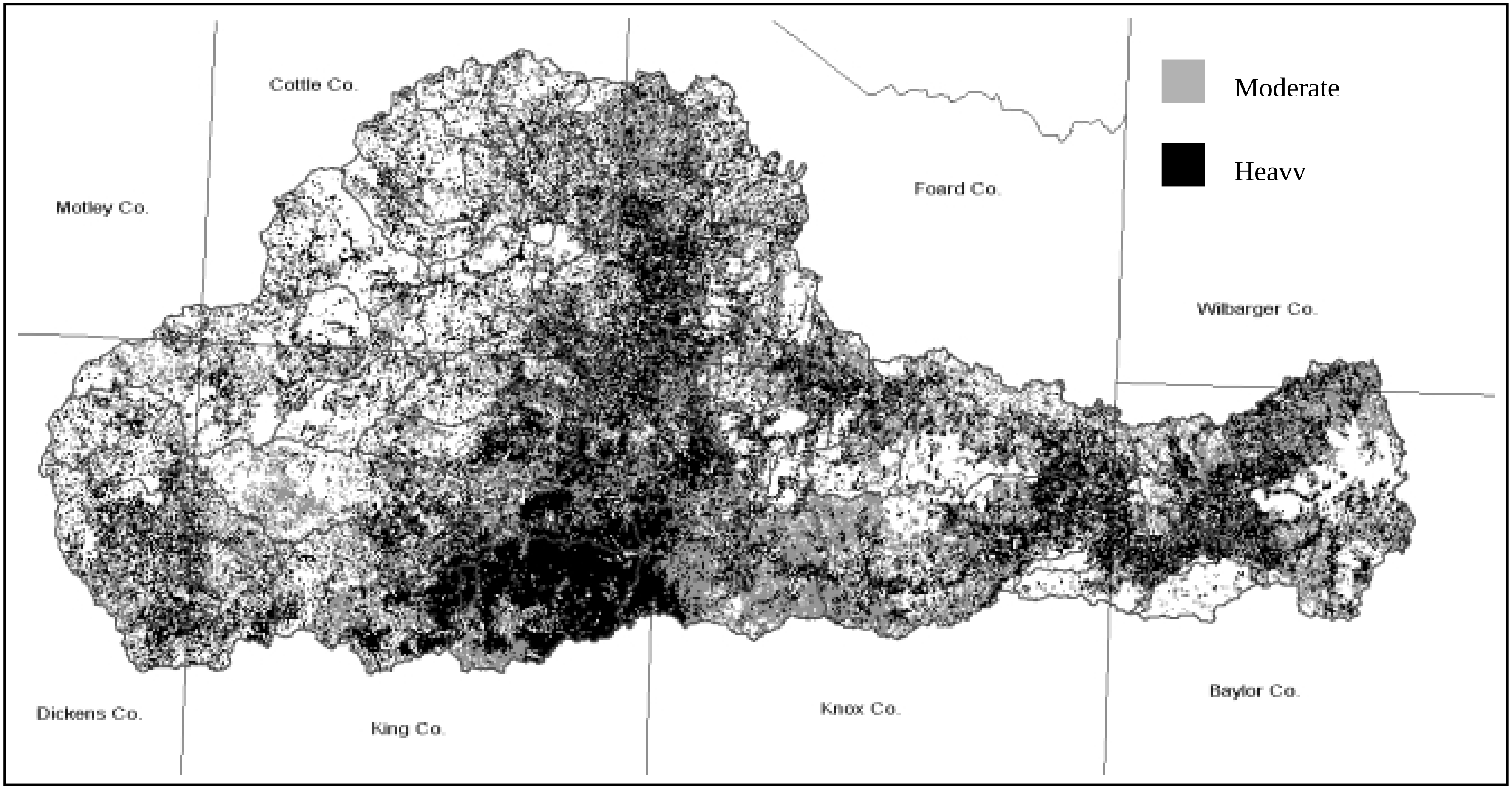

Figure 4-11 n Areas of Heavy and Moderate Brush (oak not included) in the Wichita River Watershed

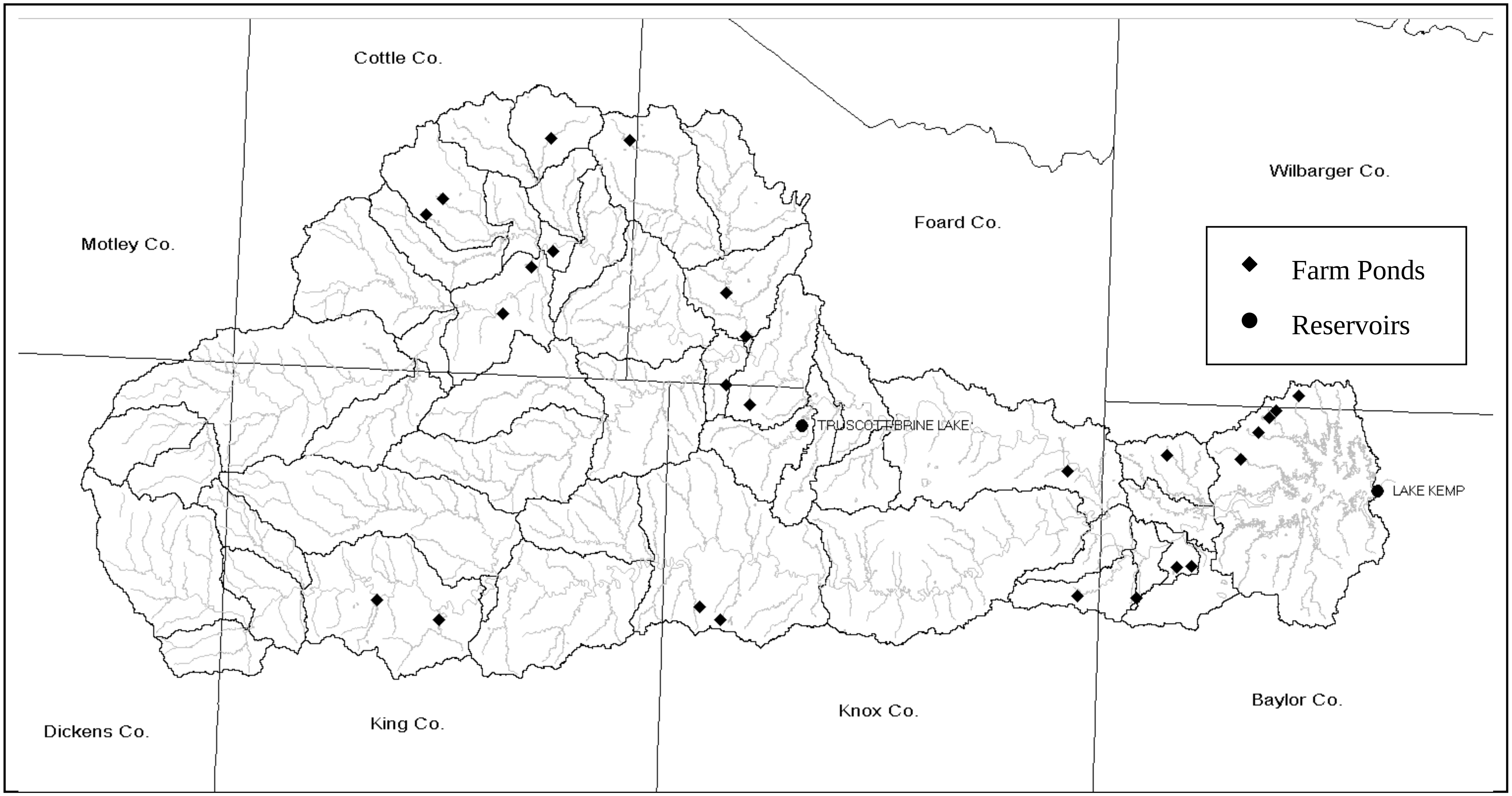

Figure 4-12 n Significant Ponds and Reservoirs in the Wichita River Watershed (from TNRCC Inventory of Dams)

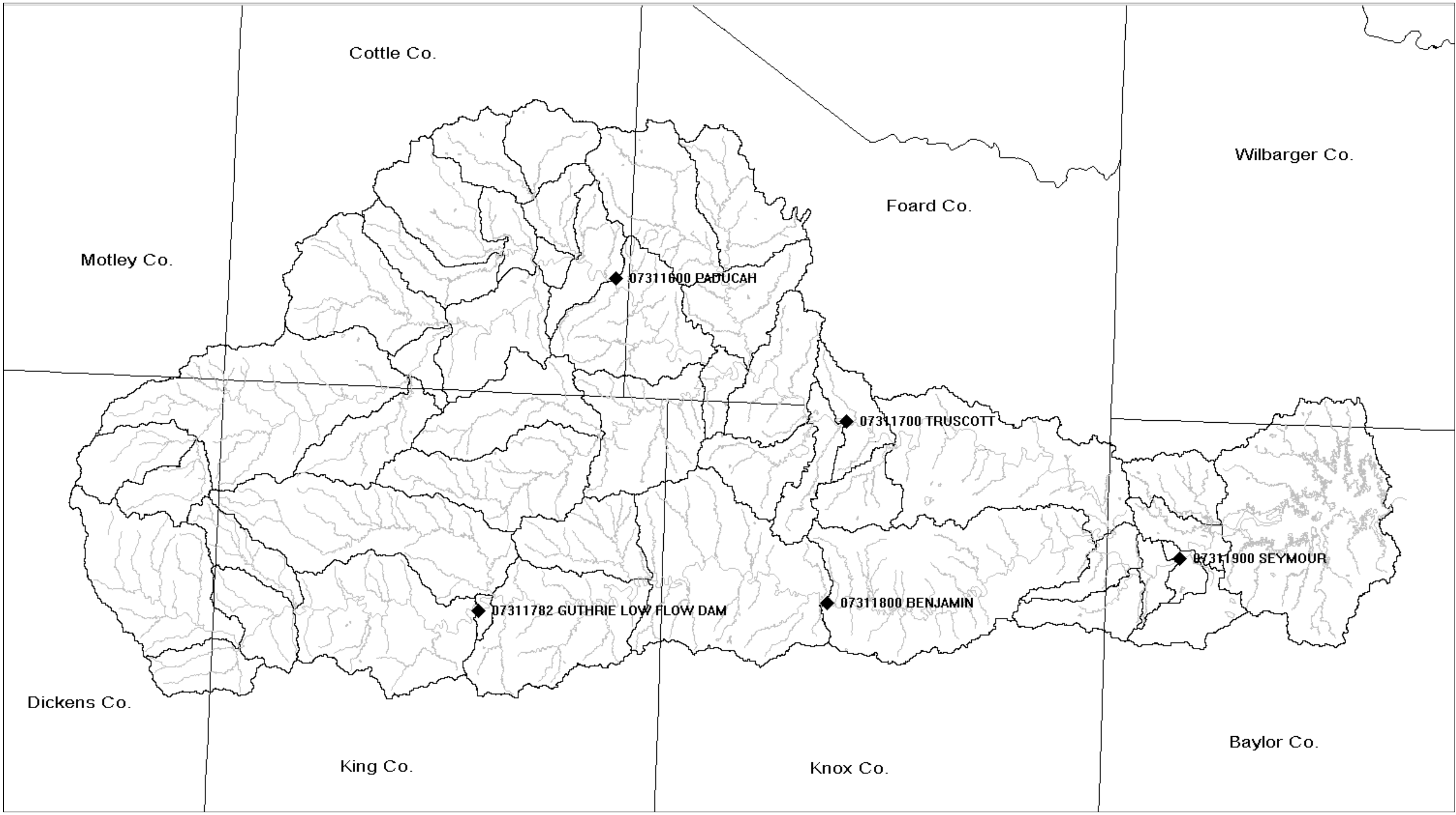

Figure 4-13 n Stream Gages used for Calibration of Flow in the Wichita River Watershed

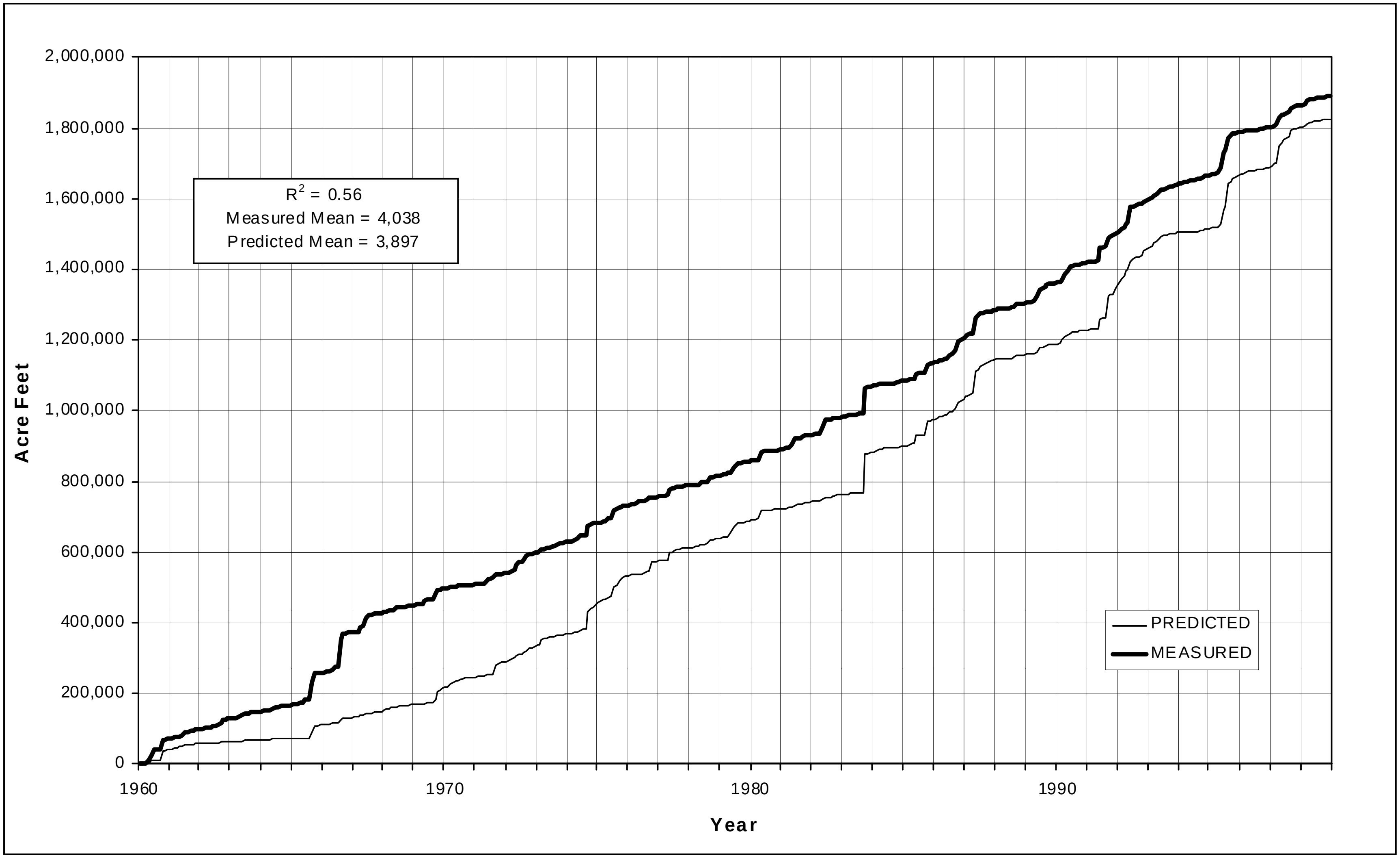

Figure 4-14 n Cumulative Monthly Measured and Predicted Streamflow at Gage 07311700 (Truscott), Wichita River Watershed, 1960 through 1998, Monthly Statistics Shown in Box.

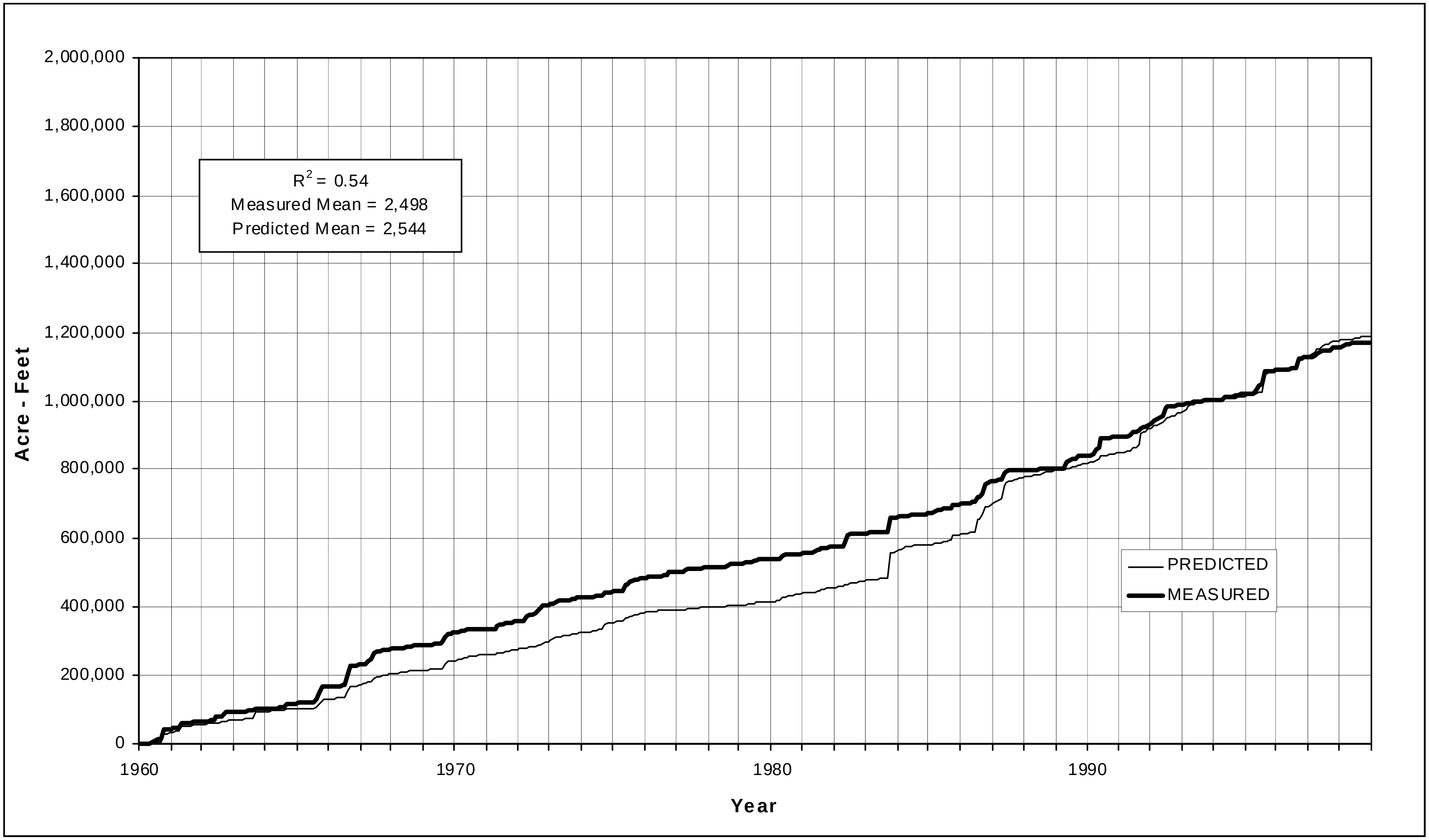

Figure 4-15 ∩ Cumulative Monthly Measured and Predicted Streamflow at Gage 07311800 (Benjamin), Wichita River Watershed, 1960 through 1998, Monthly Statistics Shown in Box

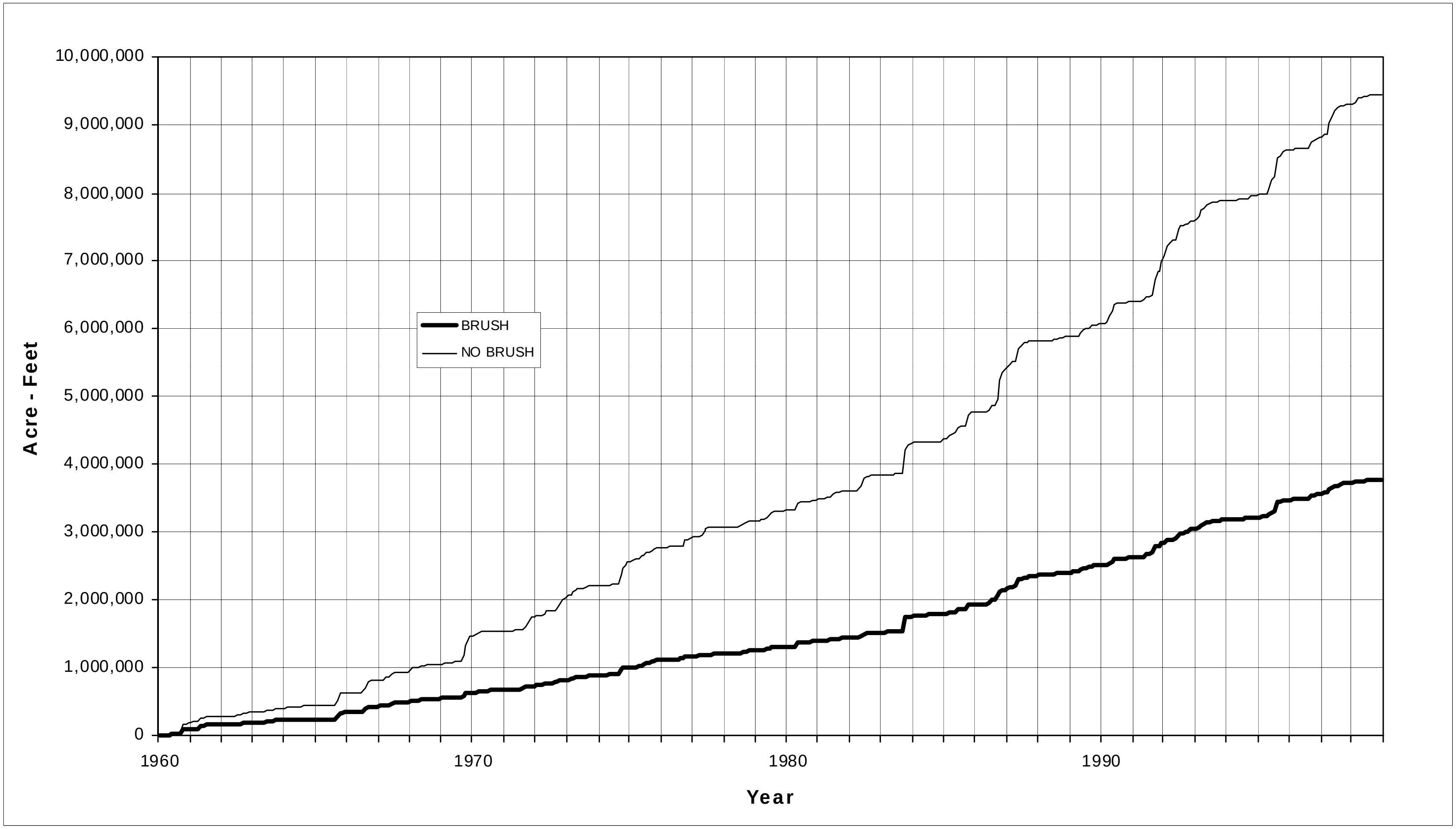

Figure 4-16 n Cumulative Monthly Predicted Flow to Lake Kemp for Brush and No-Brush Conditions, Wichita River Watershed, 1960 through 1998.

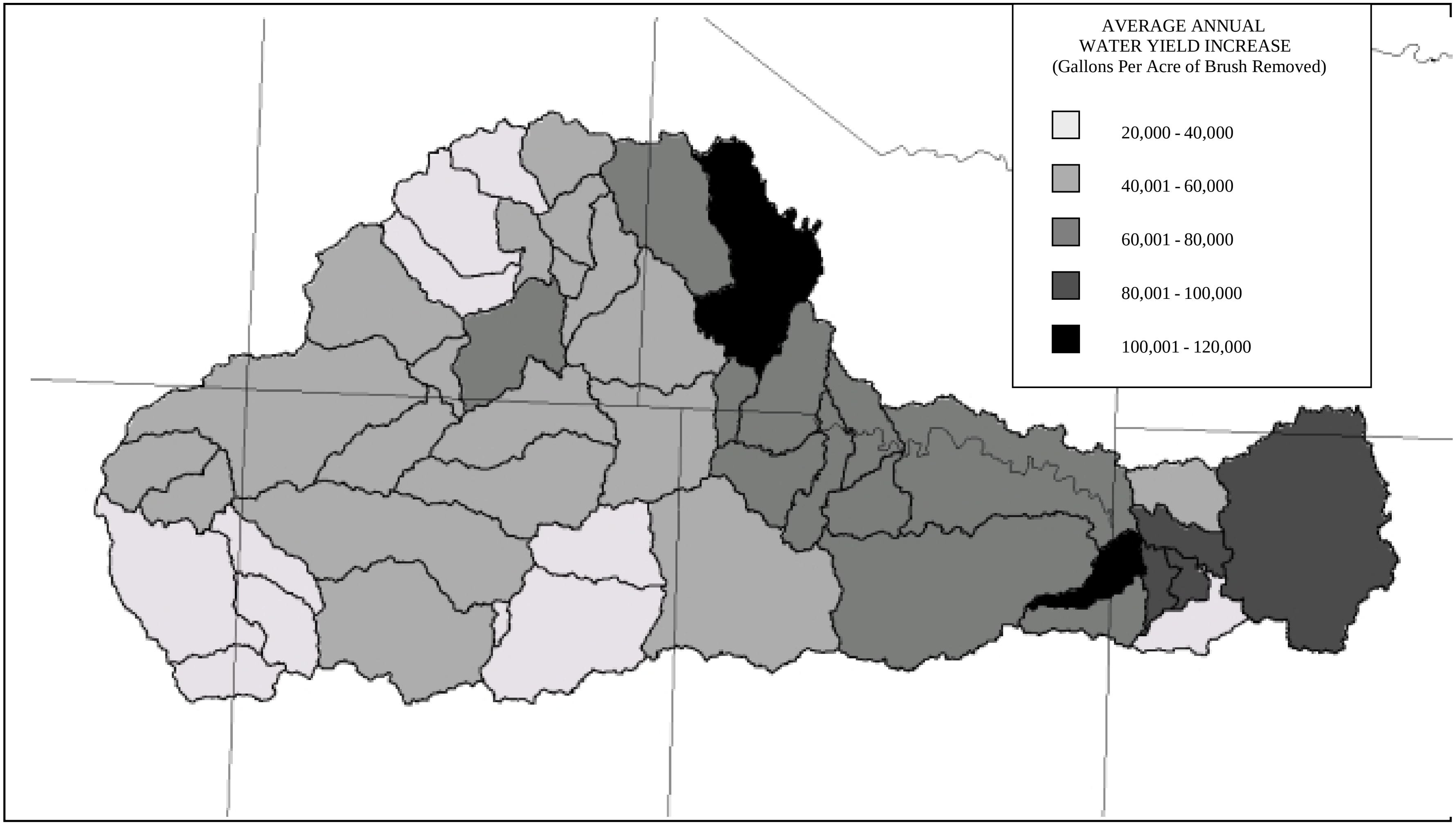

Figure 4-17 – Increase in Water Yield Per Unit Area of Brush Removed, Wichita River Watershed, 1960 through 1998

5.0 ECONOMIC ANALYSIS

5.1 INTRODUCTION

Amounts of the various types and densities of brush cover in the watershed were detailed in the previous chapter. Changes in water yield (runoff and percolation) resulting from control of specified brush type-density categories were estimated using the SWAT hydrologic model. This economic analysis utilizes brush control processes and their costs, production economics for livestock and wildlife enterprises in the watershed, and the previously described, hydrological-based water yield data to determine the per acre-foot cost of a brush control program for water yield in the Lake Kemp watershed.

5.2 BRUSH CONTROL COST

Brush control costs include initial and follow-up treatments required to reduce brush canopy to 5% or less and maintain it at the reduced level for at least ten years. Obviously, the cost will vary with brush type-density categories. Present values of control programs are used for comparison since some of the treatments will be required in the first and second years of the program, while others will not be needed until year six or seven. Present values of total control costs per acre range from $140.75 for mechanical control heavy mesquite to $21.70 for moderate mesquite that can be initially controlled with herbicide treatments. Cost of treatments, year those treatments are needed, and treatment life for each brush type density category are detailed in Table 1.

5.2 RANCHER BENEFITS VERSUS COST SHARE

Rancher benefits are the total benefits that will accrue to the rancher as a result of the brush control program. In order for the rancher to have no net benefit from the state's portion of the control cost, he is expected to invest or incur costs for an amount equal to his total net benefits. Therefore, his total benefits are equal to the maximum amount that a profit maximizing rancher could be expected to spend on a brush control program (for a specific brush density category) based on the present value of the improved net returns to the ranching operation through typical cattle, sheep and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, most of the improved net returns would result from increased amounts of usable forage produced by eliminating much of the competition for water and nutrients by controlling the brush. Present values of these benefits will vary with brush type-density categories. They range from $21.80 per acre for the control of heavy mixed brush to $12.05 per acre for control of moderate mesquite.

5.0 ECONOMIC ANALYSIS (continued)

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state cost share per acre of the brush control range from $140.75 for mechanical control of heavy mesquite to $21.70 for control of moderate mesquite with herbicides. Total treatment cost, rancher benefits, and state cost share for all brush type-density categories are shown in Table 2.

5.3 COST OF ADDITIONAL WATER

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program (after adjusting for the differences in time of water availability and time of cost share expenditures). The brush control program water yields and the estimated acreage by brush type-density category by sub-basin were supplied by the Blacklands Research Center and are not included in this preliminary report. The total state cost share for each sub-basin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the sub-basin. The cost of added water resulting from the control of the eligible brush in each sub-basin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the ten year period). The cost of added water thus determined averages of $36.59 per acre-foot for the entire Wichita Watershed (Table 3). Sub-basins range from costs per added acre foot of $17.56 to $91.76.

TABLE 5 – 1

WICHITA WATERSHED YIELD BRUSH CONTROL PROGRAMS BY TYPE-DENSITY CATEGORY

Heavy Mesquite Aerial Chemical			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
4	Aerial Spray Herbicide	$ 25.00	$ 18.35
7	Choice Type IPT or Burn	$ 15.00	$ 8.75
			$ 52.10

Heavy Mesquite Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Tree Doze or Root Plow, Rake and Burn	$ 150.00	$ 150.00
6	Choice Type IPT or Burn	$ 15.00	$ 9.45
			$ 159.45

Heavy Cedar Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Tree Doze, Stack and Burn	$ 107.50	$ 107.50
3	Choice Type IPT or Burn	$ 15.00	$ 11.91
6	Choice Type IPT or Burn	$ 15.00	$ 9.45
			$ 128.86

Heavy Cedar Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Two-way Chain and Burn	$ 25.00	$ 25.00
3	Choice Type IPT or Burn	$ 25.00	$ 11.91
6	Choice Type IPT or Burn	$ 15.00	$ 9.45
			$ 46.36

Table 5 – 1 (continued)
Wichita Watershed Yield Brush Control Programs by Type-Density Category

Heavy Mixed Brush Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Two-way Chain and Burn	$ 25.00	$ 25.00
3	Choice Type IPT or Burn	$ 15.00	$ 11.91
6	Choice Type IPT or Burn	$ 15.00	$ 9.45
			$ 46.36

Moderate Mesquite Mechanical or Chemical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
7	Choice Type IPT or Burn	$ 15.00	$ 8.75
			$ 33.75

Moderate Cedar Mechanical or Chemical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Chemical or Mechanical, Stack and Burn	$ 45.00	$ 45.00
7	Choice Type IPT or Burn	$ 15.00	$ 8.75
			$ 53.75

Moderate Mixed Brush Mechanical or Chemical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Chemical or Mechanical, Stack and Burn	$ 45.00	$ 45.00
7	Choice Type IPT or Burn	$ 15.00	$ 8.75
			$ 53.75

TABLE 5 – 2
PRESENT VALUE OF COST FOR BRUSH CONTROL IN DOLLARS PER ACRE

Brush (Type and Density)	Acreage Impacted	Rancher Cost Share	Rancher Percent	State Cost Share	State Percent	Present Value Total Cost
Heavy Mesquite	139,520	18.70	35.87 – 11.60	33.43 – 140.75	64.13 – 88.40	52.13 – 159.45
Heavy Cedar	83,840	18.79	40.53 – 14.58	27.57 – 110.07	59.47 – 85.42	46.36 – 128.86
Heavy Mixed	179,840	21.80	47.02 – 16.92	24.56 – 107.06	52.98 – 83.08	46.36 – 128.86
Moderate Mesquite	144,640	12.05	35.70	21.70	64.30	33.75
Moderate Cedar	122,640	15.13	28.15	38.62	71.85	53.75
Moderate Mixed	154,880	19.09	35.53	34.65	64.47	53.75
Total / Average	**825,360**	**$17.59**	**30.44%**	**$52.78**	**69.56%**	**$70.37**

5.0 ECONOMIC ANALYSIS (continued)

TABLE 5 – 3

COST PER ACRE-FOOT OF ADDED WATER FROM BRUSH CONTROL BY SUB-BASIN

Sub-Basin	Total State Cost	Added Gallon Per Year	Added Acre-Feet Per Year	Total Acre-Feet Per 10 Years	Cost Per Acre-Foot
1	$ 457,182.65	216,078,212.22	663.12	5,173.66	$ 88.37
2	1,772,111.33	806,617,084.67	2,475.42	19,313.20	91.76
3	344,487.78	351,071,562.48	1,077.40	8,405.86	40.98
4	270,611.17	307,249,619.41	942.91	7,356.62	36.78
5	405,303.90	244,374,185.73	749.96	5,851.16	69.27
6	551,815.58	321,549,997.08	986.80	7,699.02	71.67
7	1,829,171.16	1,767,009,344.68	5,422.75	42,308.30	43.23
8	1,620,183.78	1,949,004,323.95	5,981.27	46,665.89	34.72
9	1,338,434.24	1,365,709,430.82	4,191.21	32,699.79	40.93
10	590,024.30	439,341,539.12	1,348.29	10,519.35	56.09
11	343,140.75	175,512,983.29	538.63	4,202.39	81.65
12	440,716.10	337,140,645.01	1,034.65	8,072.31	54.60
13	262,233.00	175,936,587.60	539.93	4,212.53	62.25
14	299,909.61	323,150,451.65	991.71	7,737.34	38.76
15	354,443.07	369,339,368.84	1,133.46	8,843.26	40.08
16	187,848.00	230,953,440.19	708.77	5,529.82	33.97
17	84,634.43	88,598,612.82	271.90	2,121.36	39.90
18	522,247.77	662,499,062.28	2,033.14	15,862.51	32.92
19	124,871.50	139,554,413.54	428.28	3,341.41	37.37
20	246,020.32	290,468,000.94	891.41	6,954.81	35.37
21	2,730,475.37	1,642,473,500.85	5,040.57	39,326.48	69.43
22	110,738.33	67,570,294.84	207.37	1,617.87	68.45
23	1,369,643.80	926,200,497.94	2,842.41	22,176.44	61.76
24	1,563,106.99	1,414,807,304.26	4,341.88	33,875.37	46.14
25	971,017.42	992,524,276.72	3,045.95	23,764.46	40.86
26	771,619.10	1,834,810,250.24	5,630.83	43,931.69	17.56
27	1,478,568.35	2,291,114,837.65	7,031.17	54,857.19	26.95
28	1,801,533.32	1,678,434,945.84	5,150.93	40,187.52	44.83

Sub-Basin	Total State Cost	Added Gallon Per Year	Added Acre-Feet Per Year	Total Acre-Feet Per 10 Years	Cost Per Acre-Foot
29	$ 1,948,506.76	1,790,375,041.38	5,494.46	42,867.75	$ 45.45
30	3,769,655.99	3,613,101,057.14	11,088.20	86,510.10	43.57
31	439,757.96	589,436,154.61	1,808.91	14,113.13	31.16
32	613,063.06	867,628,625.83	2,662.65	20,774.02	29.51
33	260,808.40	318,809,382.14	978.39	7,633.40	34.17
34	722,243.11	1,057,274,449.79	3,244.66	25,314.80	28.53
35	801,913.88	1,601,922,140.98	4,916.12	38,355.54	20.91
36	472,961.33	534,304,493.17	1,639.72	12,793.09	36.97
37	522,081.31	783,102,254.46	2,403.25	18,750.17	27.84
38	293,231.45	413,705,742.62	1,269.62	9,905.54	29.60
39	3,111,539.76	4,332,844,817.46	13,297.01	103,743.25	29.99
40	2,006,939.15	3,063,451,744.60	9,401.39	73,349.60	27.36
41	307,258.55	350,869,992.59	1,076.78	8,401.04	36.57
42	424,456.46	732,734,077.37	2,248.68	17,544.18	24.19
43	493,711.42	637,433,871.96	1,956.21	15,262.37	32.35
44	452,996.05	793,219,617.91	2,434.30	18,992.41	23.85
45	272,492.79	501,654,318.26	1,539.52	12,011.33	22.69
46	243,926.57	353,972,454.43	1,086.30	8,475.32	28.78
47	24,499.30	39,919,320.98	122.51	955.81	25.63
48	3,371,088.17	5,745,904,234.60	17,633.53	137,576.77	24.50
Total	**$ 43,395,224.59**	**—**	**152,004.32**	**1,185,937.22**	**$ 36.59**

6.0 PROGRAM IMPLEMENTATION

Based on the results shown in this study, it is recommended that implementation of the Wichita Basin Brush Control and Management Program be accomplished over the next four to six years with follow-up maintenance throughout the next ten year period to receive optimum benefits from the program.

It is further recommended that the program be administered through the Texas State Soil and Water Conservation Board (TSSWCB) in accordance with Chapter 203 of the Agriculture Code with certain exceptions to permit a greater cost share flexibility to accommodate the participants in the program.

Cost share funds should be administered at the local level by the Soil and Water Conservation Districts (SWCD) participating in the program based on allocations from the TSSWCB. The SWCD's should contract directly with individual landowners for developing, implementing and monitoring the brush control program within the watershed area.

The TSSWCB should be designated to initiate quality control measures to ensure proper herbicide mix and application, and followup monitoring accomplished under the direction of the TSSWCB with the SWCD as the primary contact with the participating landowners to ensure the successful implementation and maintenance of the brush control program throughout its design life.

Consideration should be given to coordination of the Brush Control and Chloride Control Projects together for optimum benefit to the region as explained in Chapter 3.6. Therefore, it is recommended that approximately 16,000 acres of the light to moderate mixed brush be excluded out of the proposed brush removal plan within the selected area above the Chloride Control Project features. Refer to **Figure 8** for details of the restricted brush removal zone. This would result in a reduction in cost (both state and landowner) of about $215,529 for the 16,000 acres.

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APPENDICES

TABLE 1 – A
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
LAND USE, TYPE AND COVER

Land Use/Cover Classifications	Square Miles	Acres
Heavy Cedar	131	83,840
Heavy Mesquite	218	139,520
Heavy Mixed Cedar and Mesquite	281	179,840
Moderate Cedar	192	122,880
Moderate Mesquite	226	144,640
Moderate Mixed Cedar and Mesquite	242	154,880
Heavy Oak	82	52,480
Moderate Oak	0	0
Light Brush Densities	316	202,240
Open Range and Grasslands	189	120,960
Cropland	118	75,520
Cropland, Irrigated	25	16,000
Water, Barren or Other	66	42,240
Total Watershed Area	**2,086**	**1,335,040**

Source: TAMES, Classified from Landsat 7 Imagery, 1999

TABLE 1 – B
LAND USE/COVER CLASSIFICATIONS

Hydrologic Unit Area	Cropland	Range	Urban	Total	Sq Mi	Cropland	Range
North Wichita River S 11130204	197,757	484,515	948	683,220	1,068	28.90%	70.90%
South Wichita River S 11130205	33,955	433,932	S	467,887	731	7.30%	92.70%
Lake Kemp S 11130207	19,561	127,341	S	146,902	230	13.30%	86.70%
Total	**251,273**	**1,045,788**	**948**	**1,298,009**	**2,029**	**19.40%**	**80.60%**

TABLE 1 – C
SOIL EROSION AND SEDIMENTATION CHARACTERISTICS

Hydrologic Unit Area	Sheet/Rill Erosion Tons	Sheet/Rill Rate Tons/Acre	Gully/Stream Tons	Gully/Stream Erosion Rate Tons/Acre	Controlled Drainage Acres	Sediment Yield Tons/Acre	Sediment Yield AcFt/ Sq Mile
North Wichita River	953,496	1.39	1,352,775	1.98	28,121	1.46	0.71
South Wichita River	1,033,063	2.20	762,655	1.63	13,844	1.48	0.77
Lake Kemp	402,419	2.73	165,999	1.13	1,348	1.40	0.74
Totals	**2,388,978**	**6.32**	**2,281,429**	**4.74**	**43,313**	**4.34**	**2.22**

Source: TDWR, Report 268 Erosion and Sedimentation by Water in Texas, 1982

TABLE 2
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
SUMMARIZED FISH AND WILDLIFE INVENTORY

Common Name	Scientific Name	Native	Introduced	Threatened	Endangered	Extirpated
MAMMALS[19]						
Virginia Opossum	*Didelphis virginiana*	M				
Cave Myotis Bat	*Myotis velifer*			M		
Long-Legged Myotis Bat	*M. volans*			M		
Eastern Cottontail	*Sylvilagus floridanus*	M				
Black-Tailed Jackrabbit	*Lepus californicus*	M				
Deer Mouse	*Peromyscus maniculatus*	M				
Palo Duro Mouse	*Peromyscus truei comanche*			M		
Hispid Cotton Rat	*Sigmodon hispidus*	M				
Ord's Kangaroo Rat	*Dipodomys ordii*	M				
Texas Kangaroo Rat	*Dipodomys elator*			M		
Southern Plains Woodrat	*Neotoma micropus*	M				
Black-Footed Ferret	*Mustela nigripes*				M	
Nine-Banded Armadillo	*Dasypus novemcinctus*	M				
American Beaver	*Castor canadensis*	M				
Black-Tailed Prairie Dog	*Cynomys ludovicianus*	M				
Thirteen-Lined Ground Squirrel	*Spermophilus tridecemlineatus*	M				
Plains Pocket Gopher	*Geomys bursarius*	M				
Least Shrew	*Cryptotis parva*	M				
Striped Skunk	*Mephitis mephitis*	M				
Plains Spotted Skunk	*Spilogale putorium interrupta*			M		
Common Raccoon	*Procyon lotor*	M				
Coyote	*Canis latrans*	M				

[19] The Mammals of Texas, Drs. William B. Davis and David J. Schmidly and Texas Parks and Wildlife published revision in 1994

Common Name	Scientific Name	Native	Introduced	Threatened	Endangered	Extirpated
MAMMALS[20] (continued)						
White-Tailed Deer	*Odocoileus virginianus macroura*	M				
White-Tailed Deer	*Odocoileus virginianus macroura*	M				
Common Gray Fox	*Urocyon cinereoargenteus*	M				
Bobcat	*Lynx rufus*	M				
FISH[21]						
Spotted Gar	*Lepisosteus*	M				
Gizzard Shad	*Dorosoma cepedianum*	M				
Red Shiner	*Cyprinella lutrensis*	M				
Sharpnose Shiner	*Notropis oxyrhynchus*			M		
Smalleye Shiner	*Notropis buccula*			M		
Red River Shiner	*N. bairdi*	M				
Common Carp	*Cyprinus carpio*	M				
Fathead Minnow	*P. promelas*	M				
Blue Catfish	*Lctalurus furcatus*	M				
Channel Catfish	*I. Punctatus*	M				
Flathead Catfish	*Pylodictis olivaris*	M				
Red River Pupfish	*Cyprinodon rubrofluviatilis*	M				
White Bass	*Morone chrysops*	M				
Green Sunfish	*Lepomis cyanellus*	M				
Bluegill	*L. macrochirus*	M				
Largemouth Bass	*M. salmoides*	M				
White Crappie	*Pomoxis annularis*	M				
Freshwater Drum	*Aplodinotus grunniens*	M				
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*			M		

[20] The Mammals of Texas, Drs. William B. Davis and David J. Schmidly and Texas Parks and Wildlife published revision in 1994

[21] Texas Parks and Wildlife PGMA Study: North-Central Texas by Daniel W. Moulton and Alison L. Baird

Common Name	Scientific Name	Native	Introduced	Threatened	Endangered	Extirpated
AMPHIBIANS AND REPTILES[22]						
Cricket Frog	*Acris crepitans*	M				
Texas Toad	*Bufo speciosus*	M				
Woodhouse's Toad	*Bufo woodhousii*	M				
Spotted Chorus Frog	*Pseudacris clarki*	M				
Plains Leopard Frog	*Rana blairi*	M				
Bullfrog	*Rana catesbeiana*	M				
Eastern Collared Lizard	*Crotaphytus collaris*	M				
Texas Horned Lizard	*Phrynosoma cornutum*			M		
Western Diamondback Rattlesnake	*Crotalus atrox*	M				
Western Hognose Snake	*Heterodon nasicus*	M				
Diamondback Water Snake	*Nerodia rhombifer*	M				
Bullsnake	*Pituophis melanoleucus*	M				
Massasauga Snake	*Sistrurus catenatus*	M				
Checkered Garter Snake	*Thamnophis marcianus*	M				
Texas Garter Snake	*Thamnophis sirtalis annectens*			M		
Common Kingsnake	*Lampropeltis getula*	M				
Brazos Water Snake	*Nerodia harteri*			M		
Slider Turtle	*Trachemys scripta*	M				
Smooth Softshell Turtle	*Apalone (Trionyx) mutica*	M				
Snapping Turtle	*Chelydra serpentin*	M				
BIRDS[23]						
Great Blue Heron	***Ardea herodias treganzai***	M				
Little Blue Heron	*Florida caerula*	M				
Cattle Egret	*Bubulcus ibis ibis*		M			

[22] U.S. Fish and Wildlife Service Online Database

[23] U.S. Fish and Wildlife Service Online Database, Texas Parks and Wildlife PGMA Study: North-Central Texas by Daniel W. Moulton and Alison L. Baird, et al

Common Name	Scientific Name	Native	Introduced	Threatened	Endangered	Extirpated
BIRDS[5] (continued)						
Green Heron	*Butorides virescens*		M			
Turkey Vulture	*Cathartes aura*	M				
Mississippi Kite	*Ictinia misisippiensis*		M			
Red-Tailed Hawk	*Buteo jamaicensis*		M			
Wild Turkey	*Meleagris gallopavo*	M				
Northern Bobwhite	*Colinus virginianus taylori*	M				
Killdee	*Charadrius vociferus vociferus*	M				
Interior Least Tern	*Sterna antillarum athalassos*				M	
Mourning Dove	*Zenaida macroura marginella*	M				
Wood Duck	*Aix sponsa*		M			
Mallard	*Anas platyrhynchos platyrhynchos*	M				
Blue-Winged Teal	*Anas discors discors*		M			
Greater Roadrunner	*Geococcyx californianus*	M				
Bald Eagle	*Haliaeetus leucocephalus*			M		
Great Horned Owl	*Bubo virginianus pallescens*	M				
Barn Owl	*Tyto alba pratincola*	M				
Common Nighthawk	*Chordeiles minor howelli*		M			
Chimney Swift	*Chaetura pelagica*		M			
Black-Chinned Hummingbird	*Archilochus alexandri*		M			
Red-Bellied Woodpecker	*Melanerpes carolinus zebra*	M				
Western Kingbird	*Tyrannus verticalis*		M			
Scissor-Tailed Flycatcher	*Tyrannus forficatus*		M			
Blue Jay	*Cyanocitta cristata cyanotephra*	M				
American Crow	*orvus brachyrhynchos brachyrhynchos*	M				
Brown Pelican	*Pelecanus occidentalis*			M		
Whooping Crane	*Grus americana*				M	
Purple Martin	*Progne subis subis*	M				
Cliff Swallow	*Petrochelidon pyrrhonota pyrrhonota*		M			

Common Name	Scientific Name	Native	Introduced	Threatened	Endangered	Extirpated
BIRDS[5] (continued)						
Barn Swallow	*Hirundo rustica erythrogaster*		M			
American Robin	*Turdus migratorius migratorius*		M			
Northern Mockingbird	*Mimus polyglottos leucopterus*	M				
House Sparrow	*Passer domesticus domesticus*	M				
Northern Cardinal	*Cardinalis cardinalis cardinalis*	M				
Black-Capped Vireo	*Vireo atricapillus*				M	
Red-Winged Blackbird	*Agelaius phoeniceus fortis*	M				
Eastern Meadowlark	*Sturnella magna lilianae*	M				
Great-Tailed Grackle	*Quiscalus mexicanus prosopidicola*	M				
Common Grackle	*Quiscalus quiscula versicolor*		M			
House Finch	*Carpodacus mexicanus frontalis*	M				
White-Faced Ibis	*Plegadis chihi*				M	
Peregrine Falcon	*Falco peregrinus*			M		
American Peregrine Falcon	*F.p. anatum*				M	
Arctic Peregrine Falcon	*F.p. tundrius*			M		
Golden-Cheeked Warbler	*Dendroica chrysoparia*				M	
Reddish Egret	*Egretta rufescens*			M		
Brown-Headed Cowbird	*Molotrus ater ater*	M				
Bullock's Oriole	*Icterus bullockii*		M			

TABLE 3
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
USGS STREAMFLOW GAGES

	South Wichita River - 584 Square Miles Near Benjamin - 07311800				North Wichita River - 937 Square Miles Near Truscott - 07311700				Wichita River - 1,874 Square Miles Near Seymour - 07311900				Wichita River - 2,086 Square Miles Near Mabelle - 07312100			
Year	**Avg**	**Max**	**Min**	**Total**	**Avg**	**Max**	**Min**	**Total**	**Avg**	**Max**	**Min**	**Total**	**Avg**	**Max**	**Min**	**Total**
1960	58.6	7,850.0	0.0	21,726.0	96.5	5,960.0	4.7	35,578.3	263.9	15,100.0	0.2	97,532.0	148.2	729.0	2.0	54,229.0
1961	34.1	2,990.0	0.0	12,550.9	38.2	930.0	2.9	13,986.7	157.0	4,940.0	3.0	57,743.9	202.4	955.0	2.6	74,532.3
1962	34.6	1,080.0	0.0	12,524.1	42.2	1,720.0	1.5	15,372.4	167.0	4,140.0	2.0	60,445.0	112.0	654.0	2.8	41,192.8
1963	14.4	566.0	0.0	5,224.9	30.9	1,820.0	0.5	11,258.2	99.3	8,870.0	0.5	36,064.2	147.0	577.0	2.0	54,051.7
1964	20.9	1,300.0	0.0	7,527.4	22.7	1,270.0	0.1	8,249.3	117.1	6,410.0	0.0	42,261.6	135.0	929.0	2.4	49,729.9
1965	66.5	5,150.0	0.0	24,396.1	129.3	19,400.0	0.1	47,080.4	245.2	16,100.0	0.0	89,730.4	109.2	710.0	2.5	40,054.7
1966	88.2	3,710.0	0.0	32,157.7	155.6	16,600.0	0.3	57,320.7	309.5	14,600.0	1.1	113,005.6	211.9	1,800.0	2.5	77,682.8
1967	58.0	4,250.0	1.2	21,069.4	73.7	3,420.0	4.7	26,740.2	233.8	12,200.0	8.5	85,146.3	239.5	1,340.0	3.9	88,040.1
1968	23.0	922.0	0.0	8,446.4	30.7	950.0	0.5	11,230.8	127.8	3,970.0	1.1	46,859.6	215.1	1,140.0	3.6	78,854.9
1969	49.8	2,390.0	0.0	18,199.0	63.3	2,880.0	0.2	23,082.0	181.9	7,820.0	0.7	66,411.7	89.9	609.0	8.0	33,171.1
1970	14.5	821.0	0.0	5,338.2	20.3	698.0	0.8	7,438.8	61.7	3,830.0	0.0	22,638.9	201.2	1,080.0	5.8	73,712.3
1971	34.0	2,340.0	0.0	12,575.3	43.9	1,520.0	0.4	16,040.9	106.3	5,140.0	0.0	39,046.4	161.6	595.0	12.0	59,070.0
1972	63.8	3,480.0	0.0	23,329.8	76.5	3,260.0	3.4	27,891.7	264.5	6,220.0	1.8	96,654.3	193.1	1,600.0	1.9	70,433.0
1973	24.9	735.0	0.0	9,047.5	42.9	1,480.0	4.4	15,694.4	113.5	2,410.0	2.3	41,440.6	122.0	890.0	0.2	44,609.4
1974	27.7	1,150.0	0.0	10,066.5	74.9	4,530.0	0.0	27,175.6	135.4	6,300.0	0.0	49,136.6	122.8	2,010.0	0.3	44,867.5
1975	56.2	1,690.0	0.7	20,596.8	69.6	3,980.0	5.6	25,617.4	189.4	5,980.0	4.6	69,447.7	100.4	1,510.0	0.2	37,142.7
1976	21.0	973.0	0.0	7,731.8	34.0	1,520.0	5.4	12,452.2	91.4	2,880.0	3.1	33,587.0	90.4	1,500.0	0.5	33,163.9
1977	20.9	716.0	0.0	7,667.4	40.6	1,300.0	8.4	14,939.0	98.1	2,820.0	4.6	36,132.1	115.8	1,090.0	0.5	42,610.3
1978	15.0	1,280.0	0.0	5,479.7	39.4	2,600.0	3.7	14,288.8	107.2	5,890.0	0.0	39,125.1	97.5	521.0	0.6	35,829.9
1979	13.9	380.0	0.0	5,097.9	54.9	1,900.0	3.8	20,111.4	123.2	3,214.8	1.9	38,046.4	100.4	797.0	0.5	37,044.9
1980	26.8	2,560.0	0.0	9,909.9	46.7	4,430.0	4.6	17,250.7	131.6	9,855.9	2.7	36,064.2	116.4	508.0	0.4	42,841.9
1981	24.0	852.0	0.0	8,758.5	61.0	3,340.0	3.6	22,303.8	*152.2*	*5,910.7*	*2.6*	*80,426.6*	62.8	410.0	0.4	23,165.5
1982	54.4	2,070.0	2.2	19,831.5	67.8	3,580.0	6.2	24,747.6	*218.7*	*7,966.5*	*6.1*	*37,245.5*	72.5	811.0	0.4	26,687.3
1983	70.1	8,260.0	0.0	25,938.4	118.7	18,500.0	2.6	43,983.7	*338.0*	*37,731.6*	*1.9*	*39,152.7*	152.8	1,730.0	0.3	55,788.4
1984	12.9	665.0	0.0	4,718.8	22.7	470.0	6.3	8,325.2	*63.7*	*1,600.4*	*4.6*	*23,134.0*	115.6	492.0	0.4	42,626.8
1985	37.9	2,500.0	0.0	13,917.9	70.0	4,790.0	6.0	25,658.4	*193.1*	*10,278.9*	*4.4*	*22,142.6*	89.8	542.0	0.5	33,152.2
1986	86.9	3,150.0	1.1	32,001.0	97.3	2,580.0	5.4	35,848.4	*329.7*	*8,079.3*	*4.7*	*100,317.3*	332.7	2,980.0	0.7	121,375.2
1987	48.9	2,530.0	0.6	17,888.3	106.1	10,900.0	19.0	39,096.0	*277.4*	*18,936.3*	*14.3*	*125,582.9*	336.1	2,750.0	0.6	121,787.7
1988	10.9	708.0	0.0	4,008.5	30.9	1,010.0	7.1	11,280.6	*74.8*	*2,422.4*	*5.2*	*67,100.8*	100.2	364.0	0.6	36,841.9
1989	48.4	4,260.0	0.0	17,720.6	75.6	2,920.0	10.0	27,562.0	*222.0*	*10,123.8*	*7.3*	*27,616.9*	116.4	2,060.0	0.1	42,579.5
1990	75.5	6,920.0	0.1	27,368.7	80.4	4,110.0	8.3	29,267.3	*279.1*	*15,552.3*	*6.1*	*57,937.8*	332.8	3,130.0	0.3	122,036.5
1991	47.4	2,410.0	0.0	17,270.3	115.5	8,160.0	12.0	41,882.0	*291.6*	*14,903.7*	*8.8*	*17,932.5*	173.9	1,190.0	0.4	63,413.0
1992	77.8	1,860.0	2.3	28,105.5	128.2	4,370.0	27.0	46,401.0	*368.7*	*8,784.3*	*21.4*	*40,162.9*	441.9	3,530.0	0.8	160,556.0
1993	23.1	1,040.0	0.0	8,312.0	60.1	2,060.0	15.0	21,947.0	*148.9*	*4,371.0*	*11.0*	*71,889.4*	168.6	1,170.0	0.8	61,526.4
1994	25.1	1,690.0	0.0	9,144.7	38.0	1,010.0	4.5	13,859.1	*112.9*	*3,807.0*	*3.3*	*34,725.2*	103.2	760.0	1.0	37,872.5
1995	93.0	5,880.0	0.2	34,349.0	166.0	13,000.0	17.0	60,752.0	*463.6*	*26,620.8*	*12.6*	*52,269.2*	361.0	2,710.0	0.7	132,462.3
1996	52.2	5,190.0	0.0	18,835.6	23.7	246.0	6.5	8,663.6	*135.9*	*7,664.8*	*4.7*	*64,861.6*	121.7	393.0	0.1	44,841.8
1997	41.1	1,250.0	0.0	15,016.4	83.0	4,120.0	3.5	30,183.5	225.6	8,320.0	12.0	82,228.0	148.7	1,660.0	0.2	54,897.7
1998	17.3	735.0	0.0	404.7	36.9	1,430.0	5.7	13,432.2	102.3	3,570.0	1.7	36,956.4	181.5	1,700.0	0.3	65,979.9
1999	26.1	2,030.0	0.0	9,641.1	72.7	3,680.0	3.5	26,643.9	149.7	5,240.0	4.1	55,028.1	95.3	415.0	0.0	2,150.4
Avg	**41.0**	**2,508.3**	**0.2**	**14,847.4**	**67.0**	**4,311.1**	**5.6**	**24,515.9**	**186.8**	**8,764.4**	**4.3**	**55,830.8**	**163.5**	**1,258.5**	**1.6**	**59,065.2**
'60-'80	**38.3**	**2,206.3**	**0.1**	**13,364.9**	**58.4**	**3,912.8**	**2.7**	**21,371.4**	**158.3**	**7,080.5**	**1.8**	**56,977.1**	**144.4**	**1,025.9**	**2.6**	**52,993.6**
'81-'99	**48.5**	**2,842.1**	**0.3**	**16,485.9**	**76.6**	**4,751.4**	**8.9**	**27,991.4**	**218.3**	**10,625.5**	**7.3**	**54,563.7**	**184.6**	**1,515.6**	**0.5**	**65,775.9**

TABLE 4 S A
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
REGIONAL CLIMATOLOGY DATA

YEAR	TEMP °F	YEAR	TEMP °F	YEAR	TEMP °F	YEAR	TEMP °F
1895	61.12	1921	65.03	1947	62.62	1973	61.80
1896	63.88	1922	63.66	1949	62.53	1974	62.98
1897	62.12	1923	62.90	1949	61.70	1975	61.30
1898	61.76	1924	61.67	1950	62.85	1976	61.18
1899	62.18	1925	63.85	1951	63.73	1977	63.63
1900	63.10	1926	62.11	1952	64.33	1978	61.70
1901	63.66	1927	64.10	1953	64.81	1979	60.83
1902	63.63	1928	62.91	1954	65.63	1980	63.33
1903	60.97	1929	61.83	1955	63.90	1981	63.54
1904	63.12	1930	62.55	1956	64.78	1982	62.01
1905	60.99	1931	62.68	1957	62.16	1983	61.20
1906	60.88	1932	61.20	1958	61.73	1984	62.36
1907	63.22	1933	64.63	1959	62.18	1985	61.90
1908	62.63	1934	65.01	1960	62.17	1986	63.68
1909	63.64	1935	62.80	1961	61.46	1987	61.52
1910	64.25	1936	62.69	1962	63.43	1988	62.06
1911	64.23	1937	62.09	1963	64.18	1989	61.75
1912	60.98	1938	64.00	1964	63.60	1990	63.28
1913	61.63	1939	64.42	1965	63.55	1991	62.44
1914	62.14	1940	61.79	1966	61.68	1992	62.35
1915	61.77	1941	61.99	1967	63.15	1993	61.46
1916	63.13	1942	62.23	1968	61.06	1994	63.13
1917	62.38	1943	63.01	1969	62.23	1995	62.48
1918	62.76	1944	62.68	1970	62.24	1996	62.98
1919	60.74	1945	62.78	1971	62.68	1997	61.38
1920	61.77	1946	64.58	1972	62.21	1998	65.01

TABLE 4 S B
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
REGIONAL CLIMATOLOGY DATA

YEAR	RAIN ″	EVAP ″	YEAR	RAIN ″	EVAP ″	YEAR	RAIN ″	EVAP ″
1940	21.48		1960	23.89	48.89	1980	25.80	79.03
1941	21.43		1961	21.36	45.14	1981	27.48	69.58
1942	23.12		1962	24.29	57.60	1982	28.90	68.45
1943	16.12		1963	19.62	63.27	1983	29.78	71.84
1944	19.21		1964	16.95	69.83	1984	26.60	75.70
1945	17.93		1965	18.68	69.24	1985	34.90	66.41
1946	21.20		1966	20.11	66.61	1986	33.34	68.62
1947	17.82		1967	18.31	68.22	1987	29.49	58.16
1948	15.47		1968	22.87	56.83	1988	22.30	69.56
1949	27.10		1969	25.67	62.65	1989	20.65	75.68
1950	23.91		1970	11.79	62.87	1990	30.58	63.69
1951	20.09		1971	22.89	70.79	1991	35.21	84.63
1952	13.89		1972	28.35	65.37	1992	26.85	64.30
1953	15.08		1973	28.06	61.49	1993	18.45	81.91
1954	15.22	58.11	1974	28.75	74.70	1994	19.99	83.66
1955	22.61	70.23	1975	27.36	60.01	1995	35.84	76.67
1956	8.46	85.81	1976	24.09	67.22	1996	16.86	81.55
1957	25.60	62.57	1977	23.70	72.72	1997	30.98	68.00
1958	21.43	48.44	1978	22.87	69.04			
1959	23.35	54.93	1979	25.96	68.06			

Average Maximum Rainfall . . . . 35.84"
Average Minimum Rainfall . . . . 8.46"

Average Maximum Evaporation . . . . 85.81"
Average Minimum Evaporation . . . . 45.15"

TABLE 5
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

System	Group/Geologic Unit		Approximate Maximum Thickness	Character of Rock	Water-Bearing Properties *
Quaternary	Alluvium		60	Surficial flood plain and terrace alluvium along the streams consisting of gravel, sand, silt, and clay	Yields small quantities of fresh to moderately saline water to wells mainly along rivers and their major tributaries
	Seymour Formation		125	Unconsolidated sediments of fine-to coarse-grained gravel, fine-to coarse-grained sand, silt and clay	Yields small to large quantities of fresh to moderately saline water to wells and springs
Tertiary	Ogallala Formation		SSS	Tan, yellow, and reddish-brown, silty to coarse-grained sand, mixed or alternating with yellow to red silty clay and variable sized gravel	Western boundary of study area
Cretaceous	Fredericksburg-Washita Groups Undifferentiated		SSS	Fossiliferous limestone, marl, and clay; some sand near the top	Yields small quantities of water to shallow wells
	Trinity Group		SSS	Fine to coarse sand, interbedded calcareous shale, conglomerate, limestone, clay and anhydrite	Not included in study area
Triassic	Dockum Formation		400	Clay, shale, and sandy shale, cross-bedded sandstone, conglomerate, gypsum, and anhydrite	Yields small to moderate quantities of water for domestic and livestock purposes
Permian	Whitehorse/ Pease River Groups Undifferentiated	Quater-master Blaine San Angelo	1,900	Sand, sandstone, shale, gypsum, anhydrite, dolomite, and salt	Yields small to large quantities of fresh to moderately saline water for domestic, livestock, and irrigation wells
	Clear Fork Group		1,800	Chiefly shale and thin beds of limestone, marl, dolomite, anhydrite, gypsum, and sandstone	Yields small quantities of slightly to moderately saline water
	Wichita-Albany Group		1,400	Chiefly gray and red shale; minor amounts of limestone, sandstone, siltstone, conglomerate, and coal	Yields fresh to slightly saline water in small quantities to wells in the outcrop area

* **Yields of Wells**, in gallons per minute (gpm): Small S less than 100 gpm; Moderate S 100-1,000 gpm; Large S more than 1,000 gpm
Quality of Water, in milligrams per liter (mg/L) **Total Dissolved Solids (TDS)**: Fresh S less than 1,000 mg/L; Slightly Saline S 1,000-3,000 mg/L; Moderately Saline S 3,000-10,000 mg/L; Very Saline to Brine S more than 10,000 mg/L

TABLE 6 S A
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
SUMMARY OF WATER USES S IRRIGATION

Watershed	Surface Water		Groundwater		Combined		Total
Area	**Acres**	**Ac-Ft**	**Acres**	**Ac-Ft**	**Acres**	**Ac-Ft**	**Ac-Ft/Ac**
1958	194	97	9,225	11,905	9,418	12,002	0.78
1964	195	155	11,314	11,753	11,510	11,908	0.97
1969	813	408	9,843	8,964	10,656	9,372	1.14
1974	444	218	10,924	8,472	11,368	8,691	1.31
1979	205	101	5,768	3,054	5,972	3,155	1.89
1984	293	130	5,079	3,785	5,372	3,915	1.37
1989	227	72	4,468	3,042	4,695	3,114	1.51
1994	265	76	3,997	3,485	4,262	3,562	1.20
1999	231	72	3,879	3,645	4,110	3,717	1.11
Average	**319**	**148**	**7,166**	**6,456**	**7,485**	**6,604**	**1.25**

TABLE 6 S B
COMBINED WATER USES

Use Category	Acre-Feet Per Year						
	1969	**1974**	**1979**	**1984**	**1989**	**1994**	**1999**
Municipal	1,537	1,423	1,206	1,291	1,187	1,279	1,337
Manufacturing	0	0	0	0	0	0	0
Power	0	0	0	0	0	0	0
Mining	0	0	0	12	33	65	122
Irrigation	9,372	8,691	3,155	3,915	3,114	3,562	3,717
Livestock	1,306	1,222	1,187	1,327	1,197	1,289	1,243
Total	**14,184**	**13,310**	**5,548**	**6,545**	**5,531**	**6,195**	**6,419**

Source: *Texas Water Development Board, Report 337, 1992; Updated 1998*
RRA Information Repository, Regional Water Planning Data, 2000

TABLE 7
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
ARTESIAN SPRINGS INVENTORY

County	Medium to Large	Medium	Small	Very Small	Seeps	Former	Total
Baylor	0	0	7	3	9	0	19
Cottle	4	1	1	2	8	0	16
Dickens	0	1	9	4	7	2	23
Foard	0	2	10	1	1	0	14
King	2	1	3	3	4	5	18
Knox	0	3	5	4	11	2	25
Total	**6**	**8**	**35**	**17**	**40**	**9**	**115**

Discharge Rate (cfs)	**28 - 280**	**2.8 - 28**	**0.28 - 2.8**	**0.028 - 0.28**	**<0.028**	**No Flow**

Source: Evaluation on Selected Natural Resources in Rolling Plains Region, Texas Parks and Wildlife, 1998 (Brune 1981)

TABLE 8
WICHITA RIVER WATERSHED ABOVE LAKE KEMP
TEXAS WATER DEVELOPMENT BOARD OBSERVATION WELL INVENTORY

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
Seymour									
2119325	Knox	Enserch Exploration		1,488	-23.54	-23.54		N	
2119326	Knox			1,490				U	
2119327	Knox	J. Burnett		1,450				U	Spring
2119328	Knox	J. Burnett		1,450				U	Spring
2119329	Knox	E.D. Welch		1,487				U	Abandoned due to high mineral content
2119330	Knox	E.D. Welch		1,485	-13.17	-12.60	-0.57	U	Abandoned due to high mineral content
2119331	Knox	Louis Baty	31	1,480	-20.26	-20.97	0.71	U	
2120101	Knox	John Kinnibrugh		1,467	-17.29	-17.54	0.25	U	
2120102	Knox	John Kinnibrugh		1,467				U	
2120103	Knox	John Kinnibrugh		1,467	-17.98	-17.98		U	
2120104*	Knox	W.T. Waggoner Est	32	1,460	-28.73	-28.98	0.25	H S	
2120105	Knox	Rose Anne Riggs	57	1,461	-16.11	-16.80	0.69	H S	
2120106	Knox			1,447	-15.12	-15.12	0.00	U	
2120107*	Knox	Waggoner Ranch		1,450				S	Spring
2120901	Knox	A.K. Boyd	35	1,426	-18.66	-18.90	0.24	U	Water-level observation well
2121940	Baylor	Rex Howell	44	1,353	-23.35			U	
2121941	Baylor	Rex Howell	43	1,353	-23.00			U	
2121942	Baylor	G.C. Laney	27	1,353				U	

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
2122401	Baylor	Wallace L. Malone	32	1,311	-23.10			H S	
2122402	Baylor	Ruby E. Nichols	35	1,314	-21.40			H S	
2122403	Baylor	Ruby E. Nichols	29	1,319	-25.10			U	
2122404	Baylor	Ruby E. Nichols	40	1,321	-28.00			H S	
2122405	Baylor	Ruby E. Nichols	32	1,322	-31.50			U	Formerly used as livestock supply
2122406	Baylor	Wallace L. Malone		1,280				U	Spring flows about 10 gpm
2122407	Baylor	Wallace L. Malone		1,285				U	Spring flows about 15 gpm from 2 cuts in bluff
2122408	Baylor	Wallace L. Malone		1,285				U	Spring flows about 15 gpm from 2 cuts in bluff
2122501	Baylor	Glen Miller	33	1,341				U	Dug well; formerly used as domestic and livestock supply
2122701*	Baylor	J.G. Campbell	35	1,342	-19.51	-18.45	-1.06	I	Yearly observation well; reported to pump about 200 gpm; gravel packed
2122702	Baylor	Jess L. Compton	40	1,337				I	Gravel packed
2122703	Baylor	Edward Haisler	29	1,328	-21.19	-17.80	-3.39	U	Dug well; reported to pump 75 gpm; historical observation well
2122704	Baylor	Cora Morris Estate	28	1,312	-15.65	-15.30	-0.35	I	Used as monthly observation well in this study; reported tested by driller at 400 gpm; reported to pump 125 gpm
2122705	Baylor	Cora Morris Estate	31	1,313	-14.00			I	Reported tested at 400 gpm by driller; reported to pump 275 gpm; gravel packed
2122706	Baylor	Cora Morris Estate	31	1,315	-18.70			I	Reported tested at 400 gpm by driller; reported to pump 275 gpm; gravel packed
2122707	Baylor	Cora Morris Estate	20	1,330	-14.35	-14.00	-0.35	I	Reported to pump 35 gpm; used as a monthly observation well in this study; gravel packed

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
2122708	Baylor	Cora Morris Estate	20	1,330	-14.30			I	Reported to pump 35 gpm; gravel packed
2122709	Baylor	Cora Morris Estate	22	1,331	-14.30			I	Reported to pump 35 gpm; gravel packed
2122710	Baylor	Mrs. R.E. Morris	32	1,328	-14.00			H S	
2122711	Baylor	Heirs of J.E. Morris	22	1,333	-14.75	-13.50	-1.25	H S	
2122713	Baylor	Heirs of J.E. Morris	21	1,338	-16.20			U	Dug well; windmill broken; formerly used as a domestic and livestock supply; gravel packed
2122802*	Baylor	Gene/Randy Walker	41	1,300	-14.75	-12.55	-2.20	I	
2122806	Baylor	Edward J. Haisler	33	1,324	-20.81	-22.31	1.50	I	Yearly observation well; reported to pump 250 gpm; gravel packed
2122832	Baylor	T.E. Craddock	42	1,311	-16.10			I	Reported to pump 400 gpm; gravel packed
2122833	Baylor	T.E. Craddock	37	1,310	-16.30			I	Reported to pump 225 gpm; gravel packed
2122834	Baylor	T.E. Craddock	37	1,309	-16.10			I	Reported to pump 225 pgm; gravel packed
2122835	Baylor	Frank Coufal, Sr.	44	1,316	-23.30			U	Formerly used as irrigation supply; gravel packed
2122836	Baylor	Anton Fojtik	37	1,308	-15.40			I	Gravel packed
2122847	Baylor	S.E. Williamson	33	1,312	-12.80			I	Reported to pump 300 gpm; gravel packed
2122848	Baylor	S.E. Williamson	33	1,311	-12.80			I	Reported to pump 250 gpm; gravel packed
2122849	Baylor	S.E. Williamson	30	1,322				U	
2122901	Baylor	Earley W. Samsill	17	1,317	-7.80			H S	
2122904	Baylor	Earley W. Samsill	33	1,318	-5.90	-5.80	-0.10	H S	
2122905	Baylor	Earley W. Samsill	28	1,324	-21.50			S	

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
2122910	Baylor	Glen Miller		1,346				U	Spring flows about 2 gpm; water flows from Permian sandstone but source is Seymour Alluvial deposits overlying the older rocks
2130202*	Baylor	C.C. Rodden	33	1,297	-16.99	-17.10	0.11	I	Reported tested by driller at 800 gpm; reported to pump 300 gpm; yearly and monthly observation well in this study; gravel packed
2130204*	Baylor	Burrell Lee, Jr.	22	1,284	-13.25	-11.10	-2.15	I	Reported yield about 75 gpm; historical observation well
Blaine Gypsum									
1262501	Cottle	City of Paducah	271	2,021	-130.49			P	
1262502	Cottle	City of Paducah	280	2,021	-130.41			U	Owners well #14-A; cemented from 0'-100'; gravel packed from 0'-265'
1262503	Cottle	City of Paducah	238	2,019	-114.00			P	Owners well #5; gravel packed from 0'-238'
1262504	Cottle	City of Paducah	238	2,015	-114.00			P	Owners well #6; gravel packed from 0'-238'
1262505	Cottle	City of Paducah	246	2,022	-127.00			P	Owners well #7; gravel packed from 0'-246'
1262506	Cottle	City of Paducah	237	2,021	-127.00			P	Owners well #9; gravel packed from 0'-237'
1262507	Cottle	City of Paducah	234	2,011				P	Owners well #10; gravel packed from 0'-234'
1262508	Cottle	City of Paducah	268	2,024				P	Owners well #11; gravel packed from 0'-268'
1262509	Cottle	City of Paducah	268	2,013	-142.00			P	Owners well #12; gravel packed from 0'-268'

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
1262510	Cottle	City of Paducah	280	2,018				P	Owners well #13; gravel packed from 0'-265'
1262801	Cottle	City of Paducah	304	1,985	-80.00			P	Owners well #1; gravel packed from 0'-180'; plugged back to 180'
1262802	Cottle	City of Paducah	215	2,005	-100.00			P	Owners well #2; gravel packed from 0'-215'
1262803	Cottle	City of Paducah	240	2,012	-110.00			P	Owners well #3; gravel packed from 0'-240'
1263405	Cottle	R.M. Parks	167	1,774				I	Casing perforated; open interval not known; former water-level observation well
1263406	Cottle	Hoyt Russell	220	1,790				S	
1263701	Cottle	W.L. Goodwin	256	1,758	-194.00			I	Pump set a 210'; former water-level observation well
1264801	Cottle	Anne Burnett-Triangle Ranch	150	1,733	-90.00			S	Driller reported yield of 12 gpm
1264802	Cottle	Triangle Ranches of Texas	120	1,750	-82.30			S	
2206901*	Cottle	Mike and Tracye Litz	165	1,730	-64.04	-66.10	2.06	I	Water-level observation well; casing slotted; interval unknown
2206902*	Cottle	O.T. Owens	150	1,730	-63.67	-61.25	-2.42	I	Former water-level observation well; period of record 1953-1960; casing slotted
2206903*	Cottle	Clyde Perkins	160	1,731	-58.29	-65.90	7.61	I	Water-level observation well; material setting including open or screened; intervals unknown
2206905*	Cottle	Ross Thomas	197	1,751	-77.63	-75.50	-2.13	U	Water-level observation well; former irrigation well; unused since 1981
2206906*	Cottle	Don Hutchinson	157	1,745	-73.38	-75.95	2.57	I	Water-level observation well; reported yield 300 gpm

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
2206908*	Cottle	Buster Kippen	171	1,751	-73.90	-99.92	26.02	I	Former water-level observation well; period of record 1953-1970; casing slotted from 60'-171'; reported yield 1,000 gpm
2214104	Cottle	Ernest Goodwin	241	1,857	-170.01	-171.02	1.01	I	Former water-level observation well; period of record 1963-1972; reported yield 1,600 gpm
2214105	Cottle	Leon Thompson	286	1,880				S	No permission granted when well was sampled in March 1991
2213802	King	Mark Robinson	400	1,978	-60.90			I	Originally drilled to 158'; later deepened to 400'; casing perforated from 60'-158'; open hole from 158'-400'
2213902	King	Leah Quinn	325	1,932	-251.15			I	Casing perforated; interval unknown
2213904	King	Ella Foster	320	1,930	-251.85			U	Casing perforated from 200'-320'; reported yield 300 gpm
2214401	King	A.B. Northcutt	60	1,908				U	
2214501	King	T.E. Long	225	1,823	-82.45	-85.95	3.50	I	Measured yield 282 gpm in 1960; casing perforated from 75'-105' and from 193'-223'; former water-level observation well
2214504*	King	Dale Rankin	230	1,825	-144.46	-138.45	-6.01	U	Casing perforated from 170'-230'; water-level observation well
2231501*	King	S.B. Burnett Estate (6666 Ranch)	60	1,791	-31.12	-65.30	34.18	S	Water-level observation well; casing perf-orated
2232602	King	Paul Engler	60	1,689	-20.28	-17.17	-3.11	U	Water-level observation well
1357503*	Foard	Warren Haynie	40	1,670	-17.86	-9.08	-8.78	I	Former water-level observation well; reported yield 200 gpm
1357506*	Foard	Warren Haynie		1,680	-19.98	-21.70	1.72	U	Water-level observation well; drilled for oil field use
1358701*	Foard	Johnson Eckard Ranch	33	1,678	-13.74	-13.00	-0.73	U	Water-level observation well; former stock well; now unused

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
Alluvium									
2222702*	King	S.B. Burnett Estate (6666 Ranch)	60	1,760	-35.53	-33.42	-2.11	S	Roadside park mill; historical observation well
Quarternary Alluvium									
2212701*	Dickens	Unknown	55	2,377	-38.15	-50.00	11.85	U	
Quartermaster Formation and Whitehorse Group									
2219302*	Dickens	Red River Authority	260	2,506	-210.00	-214.40	4.40	P	Supplies water for Guthrie and Dumont in King County
2219303*	Dickens	Red River Authority	260	2,511	-190.00	-189.70	-0.30	P	Owners well #2; well data from TDH records
2220101*	Dickens	Red River Authority	245	2,486	-169.00	-161.40	-7.60	P	Owners well #3; well data from TDH records
2220701*	Dickens	Pitchfork Land and Cattle Company	189	2,157				S	
2228302*	Dickens	Pitchfork Land and Cattle Company	70	1,940				S	
2228401*	Dickens	Pitchfork Land and Cattle Company	165	2,139				S	
Whitehorse Group									
2212601	King	Jordan Rogers	108	2,022	-17.35			I	
2212902*	King	Lowell Smith	300	2,107	-100.36	-101.28	0.92	I	Water-level observation well; casing set to 285' and perforated from 100'-200'; open from 285'-300'
2212903	King	Lowell Smith	230	2,130				U	Casing perforated from 100'-230'
2213801	King	Mark Robinson	50	1,975				H	Casing perforated from 40'-50'

Well #	County	Owner	Well Depth (Ft)	Alt of Land Surface (Ft)	Std of Ref Measurement from LSD (Ft)	Most Recent Measurement from LSD (Ft)	Level Differential	Use of Water	Remarks
2213802	King	Mark Robinson	400	1,978				I	Originally drilled to 158'; later deepened to 400'; casing perforated from 60'-158'; open hole from 158'-400'
2213803	King	Mark Robinson	168	1,978				I	Casing perforated from 60'-168'
2213901*	King	Kirkhat and Dorsey	120	1,962	-54.25	-44.85	-9.40	U	Casing slotted; former water-level observation well
2214703	King	Pitchfork Cattle Co	151	1,924	-100.00			U	Casing torch-slotted from 144'-151'
2221701*	King	Pitchfork Ranch	120	1,947	-106.31	-116.80	10.49	S	Water-level observation well; Ogallala mill
2229101	King	Pitchfork Cattle Co	115	1,905	-64.59			S	E. vat windmill
Clear Fork Group									
2102701*	Foard	Kenton Barker	25	1,515	-10.63	-9.55	-1.08	H S	Historical observation well; old hand-dug, brick lined well; formerly used by all neighbors

Source: Texas Water Development Board, Groundwater Data System, Well Records Inventory, 1999

* Included in Analysis

Water Use: H = Domestic I = Irrigation U = Unused S = Stock P = Public Supply