ASSESSMENT OF BRUSH MANAGEMENT / WATER YIELD FEASIBILITY FOR THE LAKE ARROWHEAD WATERSHED

TEXAS STATE SOIL AND WATER CONSERVATION BOARD

Final Report

December 31, 2002

Assessment of Brush Management/ Water Yield Feasibility for the Lake Arrowhead Watershed

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 Resources Conservation Service
Texas Agriculture Experiment Station, Blackland Research and Experiment Station
Texas Cooperative Extension
Texas A&M University, Department of Agricultural Economics
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TECHNICAL APPENDIX

Acronyms and Abbreviations

AMSL	Above Mean Sea Level
Authority	Red River Authority of Texas
C	Celsius
cfs	Cubic Feet Per Second
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 Resources Conservation Service
SWAT	Soil and Water Assessment Tool
SWCD	Soil and Water Conservation District
TAMU	Texas A & M University
TAES	Texas Agriculture Experiment Station
TCE	Texas Cooperative Extension
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

Red River Authority of Texas (Authority) in cooperation with the Texas State Soil and Water Conservation Board (TSSWCB) is charged with delineating the Lake Arrowhead Watershed on the Little Wichita River 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 (TAES) and Texas Cooperative Extension (TCE), river authorities, other local entities, and the public to determine the benefits of implementing brush control programs in priority watersheds selected throughout the state. The nine previous watershed studies indicated that brush removal would result in cost effective increases in water yields throughout most of the watersheds studied. Therefore, in 2001 the Texas Legislature appropriated funds to conduct four additional watershed studies, including the Lake Arrowhead Watershed.

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 Little Wichita River Basin is certainly no exception. The limited availability of this natural resource has generated 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) and the Natural Resources Conservation Service (NRCS) estimate 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 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 benefits versus cost for program implementation and possible alterations to sensitive ecosystems.

The Lake Arrowhead watershed in North Texas was selected as one of four sites in Texas for evaluation of 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** on page 1-3 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.

1.0 INTRODUCTION (continued)

The scope of the study will focus on the following:

- 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 ground water;
- Identifying possible impacts to the environment and ecosystem; and
- Identifying benefits that may be received as a result of implementation.

Little Wichita River Watershed Vicinity Map

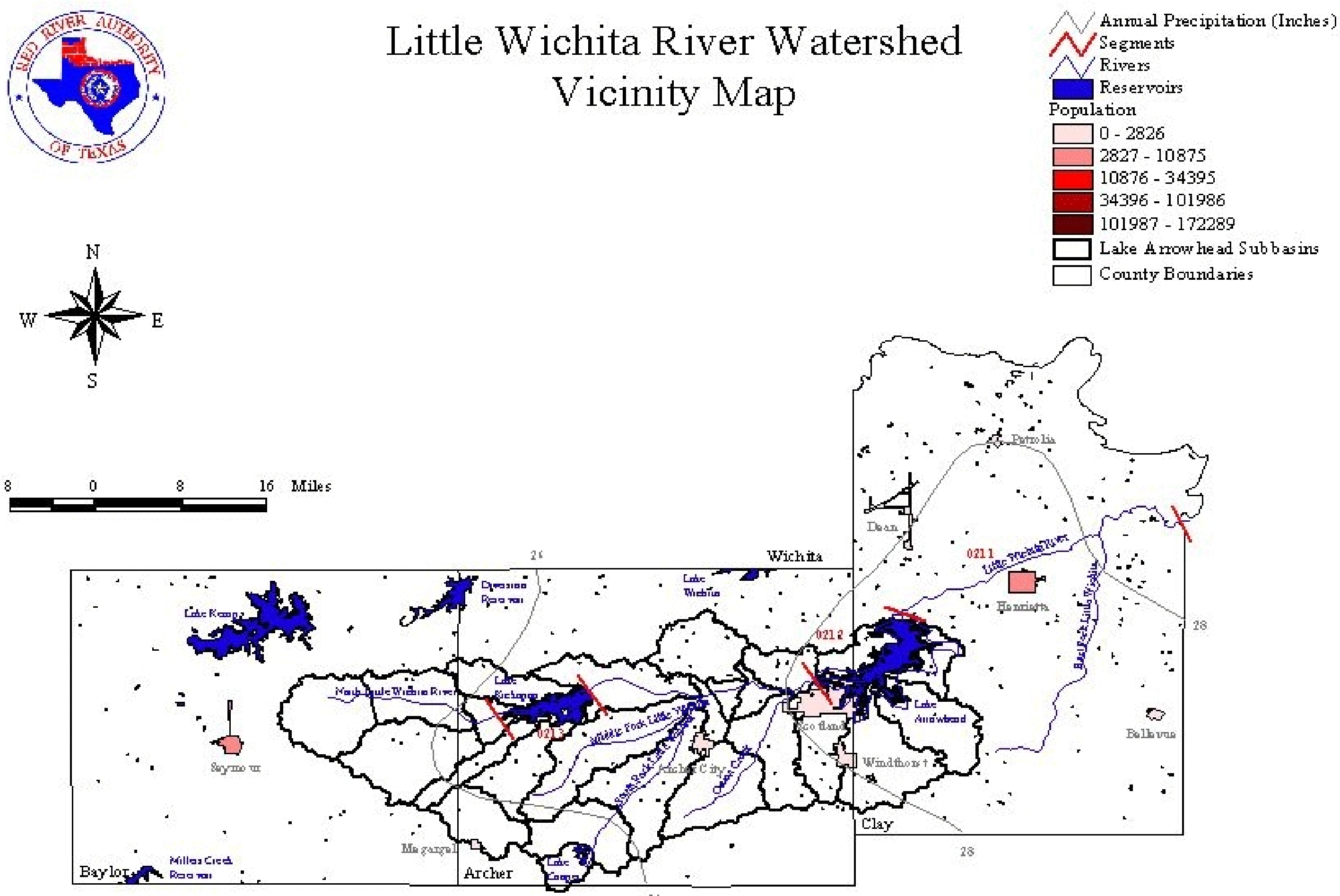


Figure 1-A

2.0 EXECUTIVE SUMMARY

2.1 Abstract

The Lake Arrowhead Watershed on the Little Wichita River covers parts of three counties in the north-central Texas portion of the Rolling Plains region of the state and encompasses 529,280 acres. Approximately 14,893 people reside within the watershed area, which is predominately rural in nature. The economy is supported primarily by ranching and dairy activities, as well as farming, oil, and gas production.

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

Overgrazing by livestock, range fire suppression, and droughts have promoted the spread of noxious brush to the extent that over 387,263 acres (73%) of the watershed area has been infested with mesquite and other mixed brush. These noxious brushes utilize much of the available water resources without any beneficial return to the watershed, and inhibit production capabilities of the region. Refer to **Figure 1-B** on page 2-6 which depicts the **Areas of Light to Heavy Brush**.

Based on historical average annual rainfall measurements, the watershed yields an average of 211,887 acre-feet per year with only 139,845 acre-feet resulting in actual runoff. This represents a net loss of more than 72,042 acre-feet of water per year (34%) that is attributed to evapotranspiration (ET). Due to the fact that the extremely limited ground water available in the watershed contains excessive amounts of dissolved solids and other contaminants, surface water is primarily utilized throughout the watershed. Both Lake Kickapoo and Lake Arrowhead are the primary water sources for the City of Wichita Falls and other smaller communities in the surrounding area.

The preliminary results of the study revealed that implementation of the proposed brush control program may be expected to provide a net increase in an overall watershed yield of approximately 151,623 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 $94.12 per acre of removed brush with the state funding $75.64 per acre. Therefore, participating landowners would be required to provide an average cost share of $18.48 per acre.

2.0 EXECUTIVE SUMMARY (continued)

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 Lake Arrowhead watershed. 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 28 sub-watersheds or sub-basins to accurately identify and select areas for removal of brush that would provide the greatest benefit to land use 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 mesquite and mixed brushes. Data layers were developed by the GIS for spatial analysis and integration with the hydrological modeling tool that included soils, topography, climate, and vegetative cover. The GIS will provide long-term assessment of the results and assist both the state and landowners with maintenance of 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, ground water and surface water uses, channel hydrology, water quality conditions, and water transfers. The model was employed and calibrated by the USDA-Natural Resources 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 through 1999.

2.0 EXECUTIVE SUMMARY (continued)

2.2 Watershed Delineation and Modeling

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. The overall hydrologic condition of the watershed is considered to be 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 3 to 8 percent canopy, and would be maintained at this level for a minimum period of ten years.

2.3 Economic Analysis

The total estimated cost to implement the brush control program as described for the Lake Arrowhead watershed is $26,132,932 or $94.12 per enrolled 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 cost per acre ranges from $175.57 for mechanical control of heavy mesquite to $35.57 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 $156.14 for mechanical control of heavy mesquite to $18.03 for control of moderate mesquite utilizing 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 table on the following page.

2.0 EXECUTIVE SUMMARY (continued)

2.3 Economic Analysis

Table 2-1 – Cost Share

Brush (Type and Density)	Acreage Impacted	Rancher Cost Share	Rancher Percent	State Cost Share	State Percent	Present Value Total Cost
Heavy Mesquite	132,602	$ 19.43	35.47%	$ 18.05–156.14	64.53–88.93%	$ 54.78–175.57
Heavy Cedar	0	0.00	0.00%	0.00	0.00%	0.00
Heavy Mixed	0	0.00	0.00%	0.00	0.00%	0.00
Moderate Mesquite	145,055	17.54	15.86%	18.03–93.03	50.69–84.14%	35.57–110.57
Moderate Cedar	0	0.00	0.00%	0.00	0.00%	0.00
Moderate Mixed	0	0.00	0.00%	0.00	0.00%	0.00
Total / Average	**277,657**	**$ 18.49**	**27.93%**	**$ 52.78**	**72.07%**	**$ 75.64**

The estimated cost of increased watershed yield averages $14.90 per acre foot for the entire Lake Arrowhead watershed. The estimated cost per sub-watershed ranged from $6.84 to $26.38 per increased acre-foot over the ten-year program life through the removal of brush.

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 reasonably be 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.

2.0 EXECUTIVE SUMMARY (continued)

2.3 Economic Analysis

Present values of these benefits will vary with brush type-density categories. Total projected direct benefits to the landowner would be $18.49 return per enrolled acre. Additional public benefits are expected to result from the increased watershed yield.

Therefore, it is recommended that the Texas Legislature commit to appropriate $17,545,832 over the next three biennia for funding the proposed brush control program within the Lake Arrowhead watershed. It is further recommended that at least $4,000,000 be provided in FY 2004 for an 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 Lake Arrowhead 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 SWCDs 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 should be accomplished under the direction of the TSSWCB with the SWCDs 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 also be given to requesting participation from beneficiary entities such as the City of Wichita Falls. Beneficiary entities could provide cost share financing in support of the program to offset landowner and/or state costs as the projected gain in water yield will increase or at least expand the firm yield of the existing reservoirs.

Little Wichita River Watershed
Areas of Light to Heavy Brush

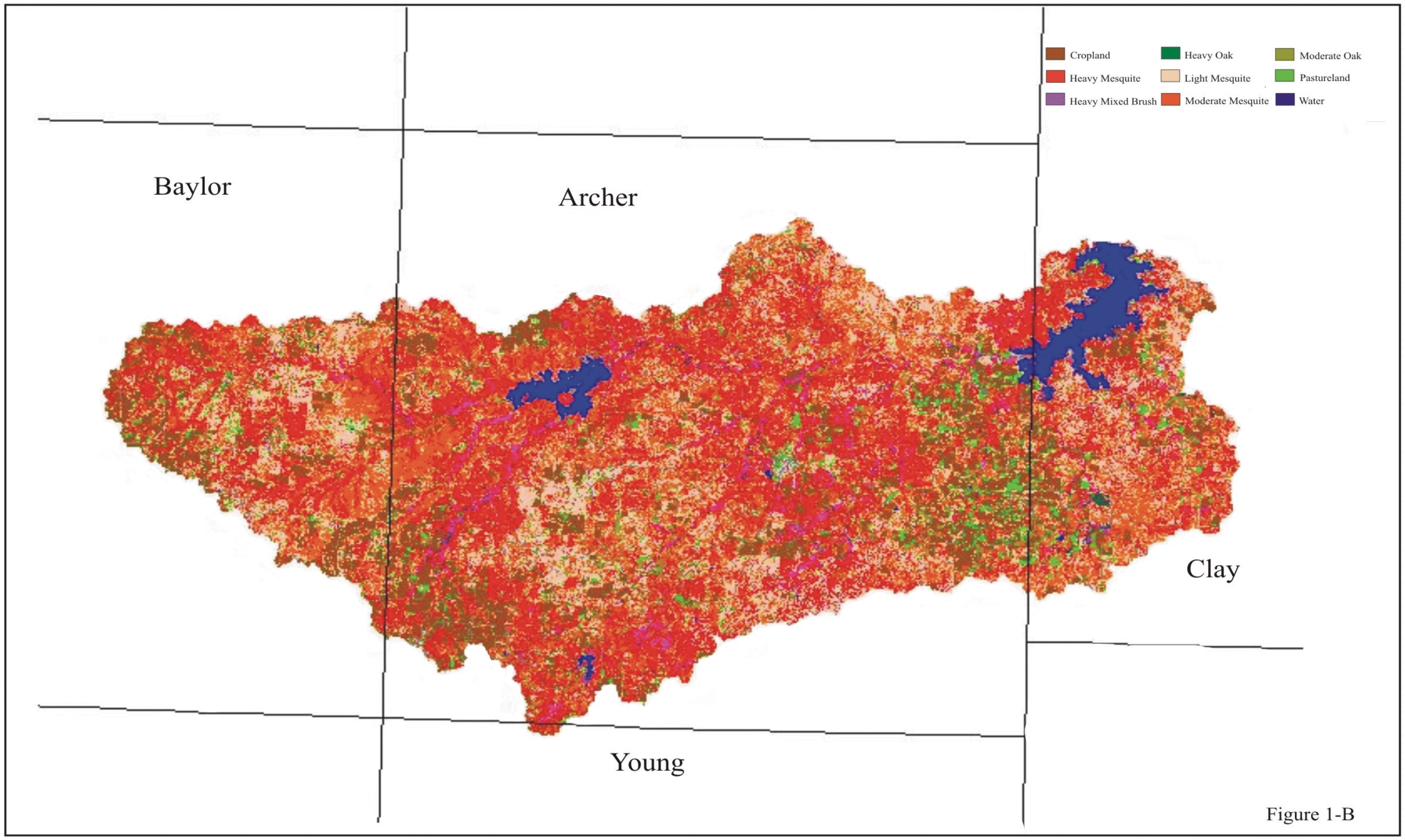


Figure 1-B

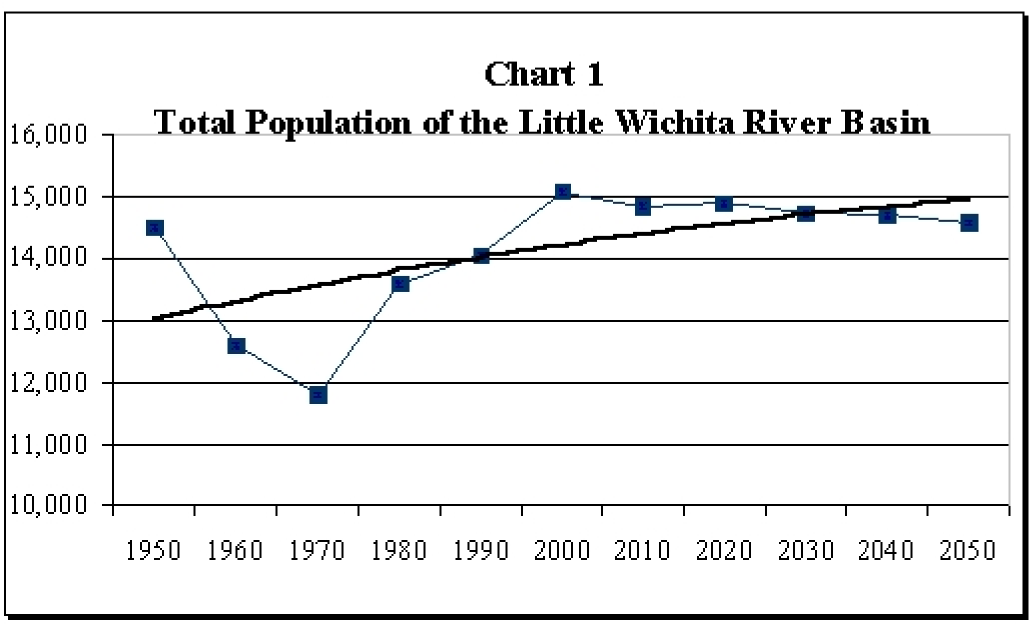
RRA of Texas GIS/CADD department, USDA-NRCS, Blackland Research Center, 1999

3.0 HYDROLOGIC EVALUATION

3.1 Description of the Watershed

The Lake Arrowhead watershed on the Little Wichita River is located in the north-central Texas portion of the Rolling Plains land resource area of the south-central lowlands within parts of Clay, Archer, and Baylor Counties. Refer to **Figure 1-A, Vicinity Map** for geographical representation of the Lake Arrowhead watershed.

This multi-county watershed area is sparsely populated and predominately rural in nature with four urbanized areas – Archer City, Scotland, Windthorst, and Megargel – located within the watershed boundary. For the purpose of this study, county population data were extrapolated from the U. S. Census data from 1950 through 2000 to demonstrate the region's general population stability. From 2000 through 2050, the Texas Water Development Board's (TWDB) 2001 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 2001 Consensus Water Plan, the watershed population is expected to decline from a present population of 14,893 to approximately 14,592 by 2050. Refer to **Chart 1** for population of the watershed. The largest cities located just outside of the watershed study area include: Wichita Falls to the northwest in Wichita County, Henrietta to the north in Clay County, and Seymour to the south in Baylor County.



3.0 HYDROLOGIC EVALUATION (continued)

3.1 Description of the Watershed

The watershed was settled in the mid to late 1800's and utilized as ranch rangeland for livestock production and dryland farming. Wheat and feed grains were the predominant crops. Between 1890 and 1915 farming became more prevalent in the watershed with the production of cotton, wheat, and cereal crops. However, by the 1920's farming began to decline, converting the land back to primarily livestock pasture land with intermittent farming. This trend has remained to the present. Other than exploration and production of oil and gas introduced in the mid 1950's, no other major industries are located within the study area.

The study area is located within a single hydrologic unit area associated with the major hydrologic features of the Red River Basin. The Little Wichita River Basin (11180209) contains 1,442 square miles or about 923,462 acres of land. Approximately 827 square miles or 529,280 acres form the Lake Arrowhead watershed. This watershed area comprises 402,344 acres of rangeland (76%), 84,685 acres of crop land (16%), and an urbanized land and water area[1] spread over 42,251 acres.

The North Little Wichita River originates just east of Seymour in Baylor County then runs eastward into Lake Kickapoo located east of the Archer County line. From Lake Kickapoo, the river continues its eastward journey through the center of Archer County where it joins the South Fork of the Little Wichita River and Onion Creek. At this point the North Fork enters the headwaters of Lake Arrowhead just north of Scotland. The dam is located northeast of the Scotland Community in Clay County, which creates the Lake Arrowhead watershed. Refer to **Figure 2, Surface Hydrology** on page 3-3 for details of the study area.

The topography of the Lake Arrowhead watershed generally consists of moderate to gently rolling prairies with shallow depressions sloping to the east from an average elevation of 1,457 feet above mean sea level (AMSL) in the eastern portion of Baylor County to 912 feet AMSL on the flood plain of Lake Arrowhead in Clay County. The watershed above Lake Arrowhead is drained by the Little Wichita River and its tributaries, which produce a moderate to rapid surface drainage during rainfall events. The long-term (53-year) average annual runoff of the watershed is 59,042 acre-feet per year or about 77.8 acre-feet per square mile of the contributing drainage area.

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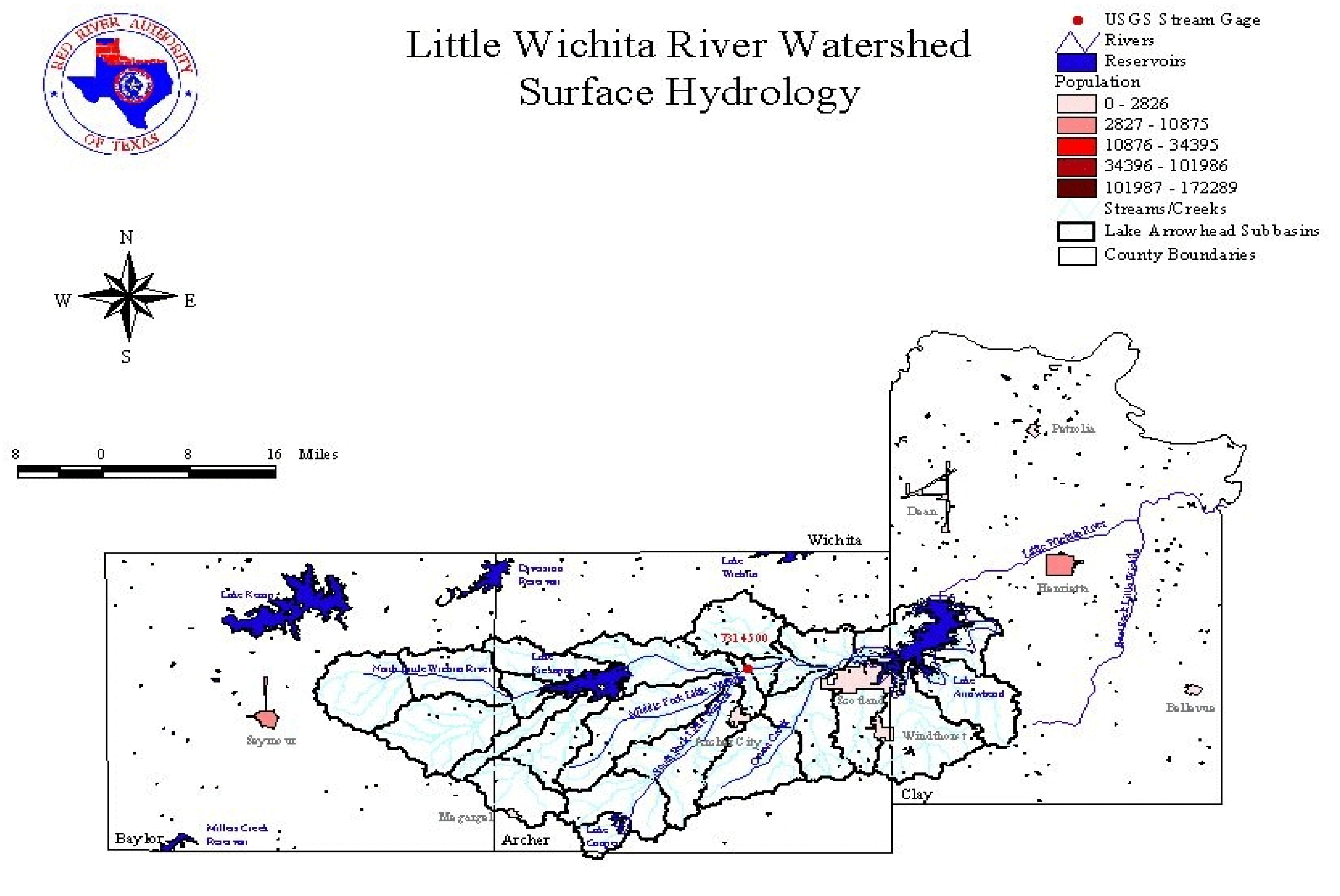
[1] Texas Department of Water Resources, Report 268, 1982.



Little Wichita River Watershed
Surface Hydrology
RED RIVER AUTHORITY OF TEXAS
USGS Stream Gage
Rivers
Reservoirs
Population
0 - 2826
2827 - 10875
10876 - 34395
34396 - 101986
101987 - 172289
Streams/Creeks
Lake Arrowhead Subbasins
County Boundaries
N
W
E
S
8
0
8
16
Miles
Wichita
Baylor
Archer
Clay
7314500
Seymour
Megargel
Archer City
Scotland
Windthorst
Henrietta
Petrolia
Dean
Bellevue
Lake Arrowhead
Little Wichita River

Figure 2

3.0 HYDROLOGIC EVALUATION (continued)

3.2 Historical Considerations

Historically, the Little Wichita River watershed was occupied by several Indian tribes including predominately the Wichita, Apache, and Comanche tribes. Sporadic settlement of the area by Europeans began in the 1850's, but because the Comanches and Apaches used the area to hunt buffalo, it was not actually settled until the 1880's when the U.S. Army removed the native Indians from the area.

Counties were formed by the Texas Legislature during the period of 1857 to 1879. It was during this time that ranching and some farming became the predominate practice of the area, and spurred the inflow of population to the region. Most of the largest ranches were established during the 1880's through 1900's.

Due to the arid climate, early ranchers began conserving water by damming canyons and draws to hold heavy spring rains for use because the availability of ground water was very limited and of poor quality. Farming also began to increase during this period with cotton, wheat, and corn being the prevailing crops. In early 1900 there were approximately 1,600 farms in the area, which increased to approximately 2,600 in 1910. Cotton was the leading farming crop, and ranching continued to expand with reportedly 164,000 heads of beef cattle in the region in 1900. Population peaked at 19,057 in 1920. Then, a series of events including the Great Depression, World War II, the Dust Bowl, and the drought of record prompted the collapse of the economy, forcing the inevitable decline in population. However, ranching remained as the leading enterprise, but overgrazing, range fire suppression, and droughts caused a gradual ecological change that promoted the spread of noxious bush into the once natural prairie landscape.

The Little Wichita River watershed was drastically modified from its natural prairie stream system with the additions of Lake Kickapoo, constructed on the North Fork of the Little Wichita River in Archer County in 1946, and Lake Arrowhead, constructed on the river's main stem in Clay County in 1966. Numerous stock ponds, small earthen reservoirs, and controlled drainage were constructed throughout the watershed area that further modified its natural hydrology.

3.0 HYDROLOGIC EVALUATION (continued)

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 its 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 and crop land being returned to pasture, the competitiveness of grass relative to brush was lessened, thus removing the fuel (grass) from rangeland wildfires. The result of heavy grazing causes an increased dominance of trees and brush in grassland areas. Accounts as early as the 1890's reported mesquites and other noxious brush spreading from the river bottom lands into the rangelands. Livestock avoid grazing on 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, neutral to calcareous clay, sandy loams, and clays. Bottom lands have only minor areas of reddish brown, loam to clay, calcareous alluvial soils. Refer to the following **Figure 3, Land Resource Classifications** for details.

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

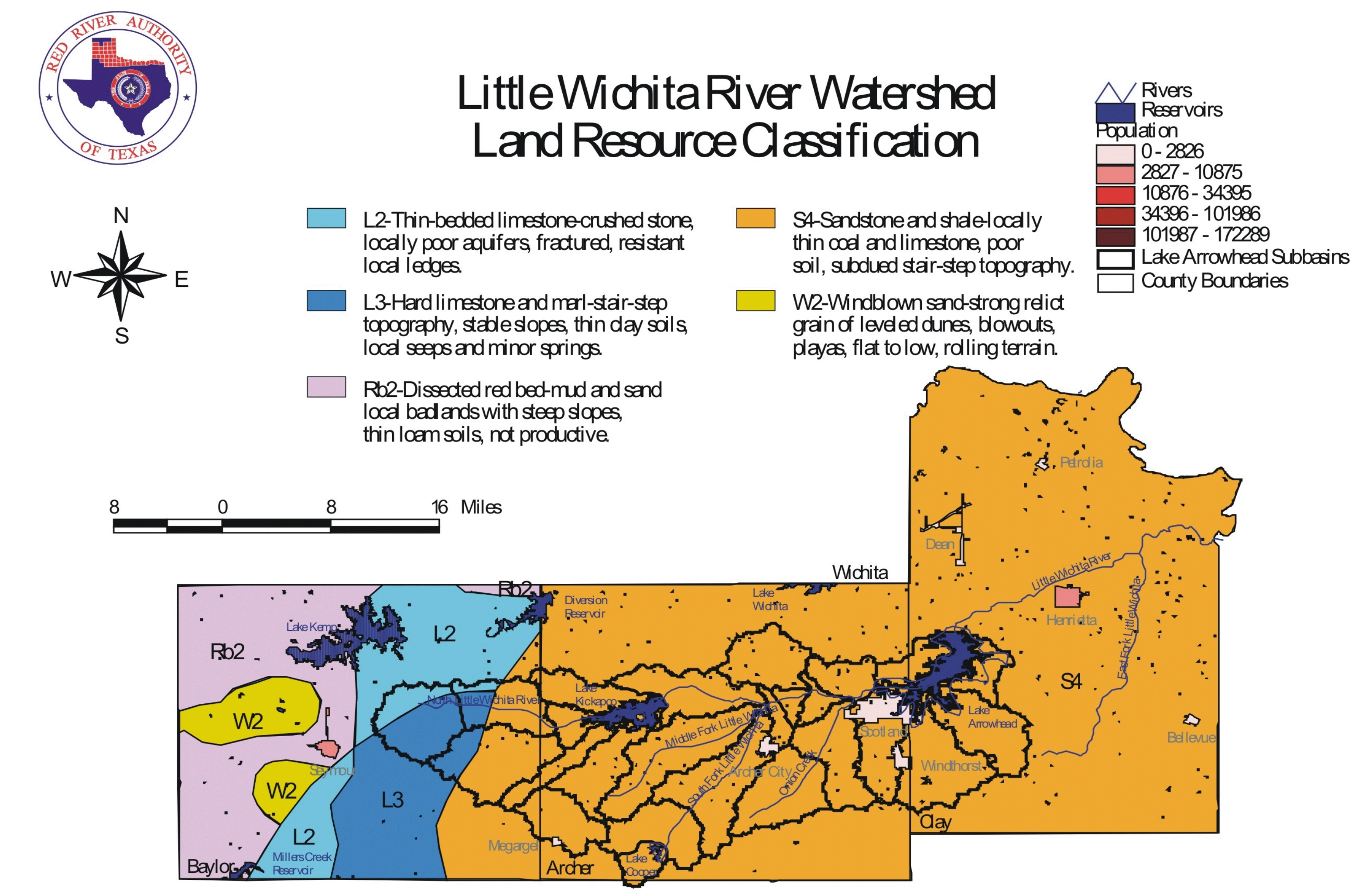


Figure 3

RRA of Texas GIS/CADD department, The Bureau of Economic Geology, University of Texas at Austin, 1999

3.0 HYDROLOGIC EVALUATION (continued)

3.2.1 Ecological

Currently, mesquite and lotebush has populated more than 73 percent the watershed area with dense stands, choking out much of the common grasses, such as little bluestem, big bluestem, indiangrass, switchgrass, hairy grama, buffalograss, and broomweed. The landscape reflects a history of over-grazing, soil erosion, declining native grasslands, and altered river ecosystems.[3] Refer to **Figure 4, Vegetation / Brush Cover** on page 3-8 for types and density, and the following **Table 3-1, Land Use, Type and Cover**.

Table 3-1 – Land Use, Type, and Cover

Land Use/Cover Classifications	Square Miles	Acres
Heavy Mesquite	207	132,480
Heavy Mixed Cedar and Mesquite	17	10,880
Moderate Mesquite	210	134,400
Light Mesquite	171	109,440
Heavy Oak	4	2,560
Moderate Oak	8	5,120
Crop Land	118	75,520
Improved Pastureland	24	15,360
Water, Barren, or Other	68	43,520
Total Watershed Area	**827**	**529,280**

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

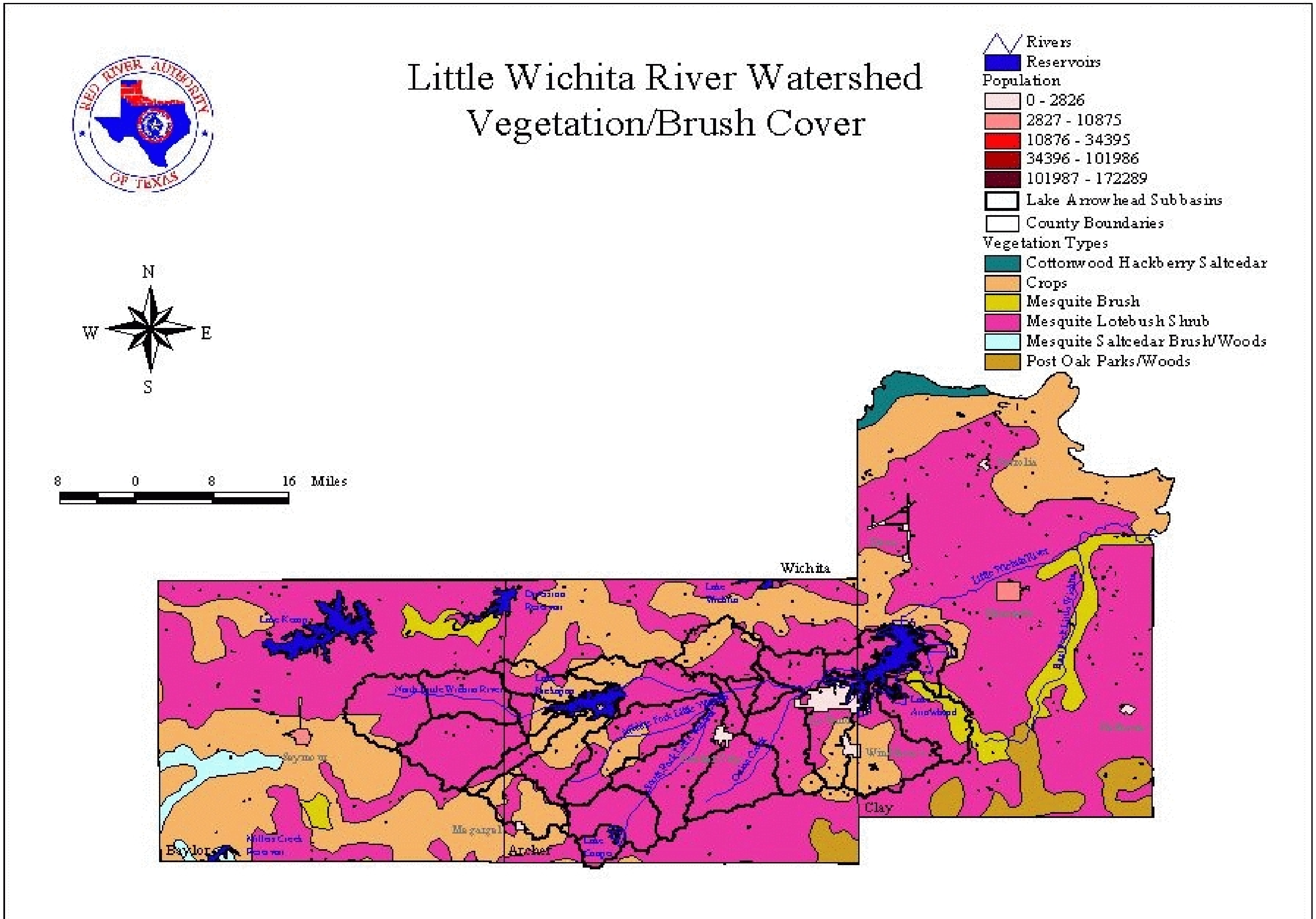

Little Wichita River Watershed
Vegetation/Brush Cover
Rivers
Reservoirs
Population
0 - 2826
2827 - 10875
10876 - 34395
34396 - 101986
101987 - 172289
Lake Arrowhead Subbasins
County Boundaries
Vegetation Types
Cottonwood Hackberry Saltcedar
Crops
Mesquite Brush
Mesquite Lotebush Shrub
Mesquite Saltcedar Brush/Woods
Post Oak Parks/Woods
N
W
E
S
8
0
8
16
Miles
Wichita
Clay
Baylor
Archer
Seymour
Megargel
Lake Kemp
Little Wichita River
Lake Arrowhead

Figure 4

3.0 HYDROLOGIC EVALUATION (continued)

3.2.1 Ecological

Erosion in the watershed is low to moderate with a sheet and rill erosion rate of 1.87 tons per acre above Lake Kickapoo and 0.76 tons per acre below the reservoir. On the other hand gully and streambank erosion measures 0.44 tons per acre above Lake Kickapoo and 0.54 tons per acre below the reservoir.[4] Although much of the watershed consists of tight, hard-packed clay and sandstone, the speed with which the runoff occurs erodes the soils creating an extremely high turbidity in the water. This high turbidity consists of a very fine clay particulate matter which is very slow to settle, leaving the water in most of the ponds and reservoirs very red in color after rainfall events or during extended windy conditions. Gullies are evident in areas where slopes converge and the runoff picks up speed. Stream flow records indicate that flows rise and fall extremely fast following rainfall events.

The watershed provides a healthy habitat for more than 525 different species of mammals, amphibians, reptiles, birds and fishes that have been considered native to the region. In 1998, there were nine birds, two fishes, five mammals, and one reptile among the species native to this area that have been listed as endangered or threatened.[5] The intermixing of rangeland and crop land has provided an excellent habitat for the most common game, such as deer, quail, dove, and turkey. Refer to **Table A-1, Fish and Wildlife Inventory** located in the Appendix beginning on page A-1 for details.

3.2.2 Hydrological

For the purpose of this study, the Little Wichita River watershed is presumed to terminate at the Lake Arrowhead dam in Clay County. It encompasses 827 square miles of drainage area, of which 802 square miles are contributing. The total drainage area contains 529,280 acres, with approximately 16,000 acres currently controlled by earthen stock ponds and reservoirs, which are considered non contributing.

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[4] TWDB Report 268

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

3.0 HYDROLOGIC EVALUATION (continued)

3.2.2 Hydrological

Daily streamflow data from one U.S. Geological Survey (USGS) stream gaging station (07314500 – Little Wichita River near Archer City) were collected and analyzed to establish baseline and trend surface hydrologic conditions and watershed runoff characteristics from 1946 to the present. Additional information is available in **Table A-2, USGS Streamflow Gage** located in the Appendix on page A-15.

The Little Wichita River has exhibited several major hydrological changes since its early settlement, with the most significant changes occurring during 1946 and 1966 with the constructions of Lakes Kickapoo in Archer County and Arrowhead in Clay County. These 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 impoundments. However, the purpose of Lake Kickapoo and Lake Arrowhead was to provide a dependable water supply for the City of Wichita Falls and its surrounding communities. The lakes also provide an artificial habitat that has aided in the proliferation of wildlife within the region. Both lakes are operated by the City of Wichita Falls. Releases from the reservoirs closely proximate the normal base flow of the river, except during flood stages.

Lake Kickapoo impounds water of the North Fork of the Little Wichita River and had a total capacity of 106,000 acre-feet of storage at an elevation of 1,045 feet when it was constructed in 1946, and permitted to yield 41,720 acre-feet.

Lake Arrowhead also impounds water of the North Fork of the Little Wichita River and had a total capacity of 228,000 acre-feet of storage at an elevation of 926 feet when it was constructed in 1966, and permitted to yield 45,000 acre-feet.

Another minor reservoir complex within the watershed consists of Lake Olney and Lake Cooper, both located on Mesquite Creek in southwestern Archer County. The lakes, which were built in 1935 and 1953 respectively, maintain a conservation storage capacity of 6,650 acre-feet with diversion rights of 1,260 acre-feet allocated to the City of Olney for their water supply.

3.0 HYDROLOGIC EVALUATION (continued)

3.2.2 Hydrological

The mean annual daily streamflow is 51.7 cubic feet per second (cfs) and ranges from a high in 1990 of 252 cfs to a low of 2.49 cfs in 1984. Streamflows of 0 cfs are common during the summer months. The highest instantaneous peak flow was 20,100 cfs on May 16, 1989, while the long-term average annual watershed runoff is 59,042 acre-feet or about 77.8 acre-feet per square mile. In 1999, the total annual runoff was 19,506 acre-feet or about 25.7 acre-feet per square mile of drainage area. This represents a decrease of approximately 66 percent of the historical long-term flow.

The general climate conditions of the region for the period from 1960 to 1999 were considered sub-humid to arid with an average growing season of 227 frost free days. Average air temperatures varied from 83° F in the summer to 44° F in the winter. Winds were highly variable and prevailed out of the south during the spring and summer, and out of the north in the winter.

Average annual rainfall for the watershed was 28.2 inches and ranged from 30.3 inches in the eastern portion to 26.2 inches in the western portion of the watershed. The average annual evaporation rate was 61.7 inches per year and ranged from 59.9 inches in the east to 63.6 inches in the west.[6] Only the evaporation rates have shown a nominal increase over the past 40 years. Refer to **Table A-3, Regional Climatology Data** located in the Appendix.

Drought in the Rolling Plains is a frequently recurring event that residents and wildlife have learned to accept. Droughts are a natural part of the hydrologic cycle, but the effects tend to accumulate more slowly and last over longer 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, seemingly occurring 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.

[6] TWDB, Climatic Atlas of Texas, 1951 – 1980; 1940 – 2001; NCDA, NOAA Climatology

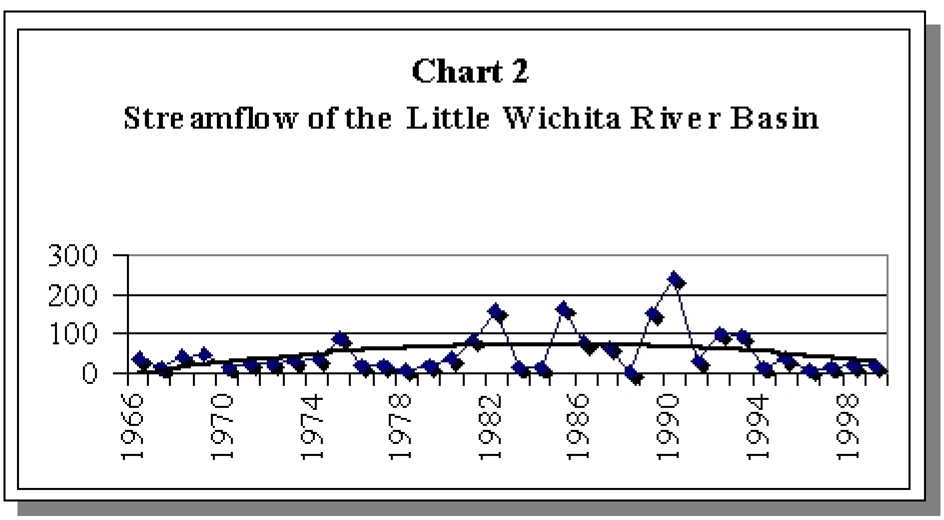
3.0 HYDROLOGIC EVALUATION (continued)

3.2.2 Hydrological

Because of today's increased demand for water resources, the duration and severity of current droughts reach a critical level much faster than previously and the recovery process is slower-paced than in the past. Droughts occurring within this region of the state have an adverse impact on both surface water and ground water 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 beneficial in predicting the impacts on all water uses, including the environment and aquatic habitat areas. **Chart 2** depicts the streamflow during the period of 1966 through 1999.

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 streamflow. The results showed the average annual rainfall has remained fairly steady throughout the period with an above average amount being received between 1981 and 1993. During this same period, streamflow, as measured at the gauge near Archer City, increased accordingly as indicated in Chart 2.

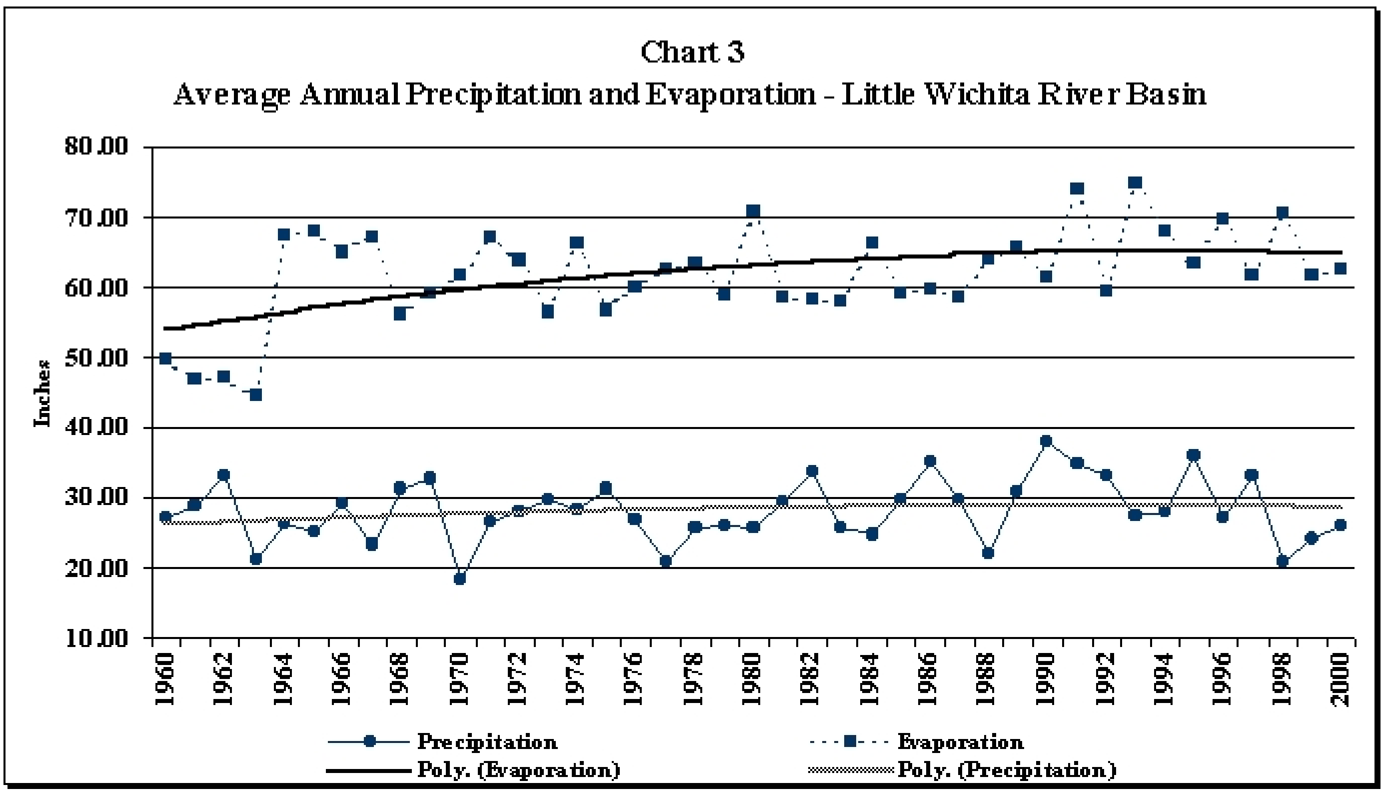


3.0 HYDROLOGIC EVALUATION (continued)

3.2.2 Hydrological

The mean annual daily streamflow is 51.7 cfs and ranges from a high of 252 cfs in 1990 to a low of 2.49 cfs in 1984. In 1999 the average daily flow was 77.1 cfs with an annual runoff of 12,380 acre-feet. The instantaneous peak on March 20, 1999 was 1,560 cfs.

The following **Chart 3** shows the trend for precipitation data from the TWDB dataset for the watershed area including Lake Arrowhead as compared to the trend for evaporation over the same period. While the precipitation trend has remained fairly constant, evaporation rates have experienced an upward trend over the study period.



3.0 HYDROLOGIC EVALUATION (continued)

3.3 Geological Considerations

The watershed study area primarily includes two prominent geologic structures as shown in **Figure 5, Geologic Map** on page 3-15. Stratigraphic units that supply fresh to saline water from wells located throughout the watershed area range in geologic ages from the Pennsylvanian to the Quaternary. The Pennsylvanian and Permian Formations contain the largest and most prolific aquifers within the study area. These geologic units include the Cisco Group of the late Pennsylvanian Formation and the Wichita – Albany Group of the early Permian Formation. Water from both groups is used for domestic and livestock purposes with some industrial use in the production of hydrocarbons. However, due to the limited amount of water available from the formations, as well as its poor quality, virtually no ground water is utilized throughout the watershed for municipal or irrigation purposes. Refer to **Table A-4, Geologic Units and their Water-Bearing Characteristics** located in the Appendix on page A-17 for details.

3.4 Existing Surface Water Hydrology

Of the 827 square miles of drainage within the study area, about 66 square miles are controlled by earthen stock ponds and reservoir impoundments. There are approximately 74 earthen stock ponds utilized for livestock watering, erosion control and recreation, and three lakes that contain about 42,342 surface acres within the study area. Refer to **Figure 2, Surface Hydrology** on page 3-3 for details.

There are three significant impoundments within the watershed study area that influence the surface hydrology of the area. They include: Lake Kickapoo in Archer County, the Lake Olney and Lake Cooper complex, also located in Archer County, and Lake Arrowhead in Clay County. All three reservoirs were developed for water supply use, primarily by entities outside the watershed. The Lake Olney/Cooper complex is maintained by the City of Olney and permitted for 1,260 acre-feet per year. Lakes Kickapoo and Arrowhead are owned and operated by the City of Wichita Falls and permitted for a combined yield of 86,720 acre-feet. Lake Kickapoo, located on the North Fork, does not have the capabilities to release flows downstream except for the emergency spillway. Although Lake Arrowhead maintains the capability to release small amounts of water, it is only released on demand to the City of Henrietta in compliance with prior water rights. All other releases are from the emergency spillway during flood events. Lake Kickapoo and Lake Arrowhead are currently the only fresh water supply sources that do not require advanced treatment available to the City of Wichita Falls and other surrounding communities.

Little Wichita River Watershed
Geologic Map

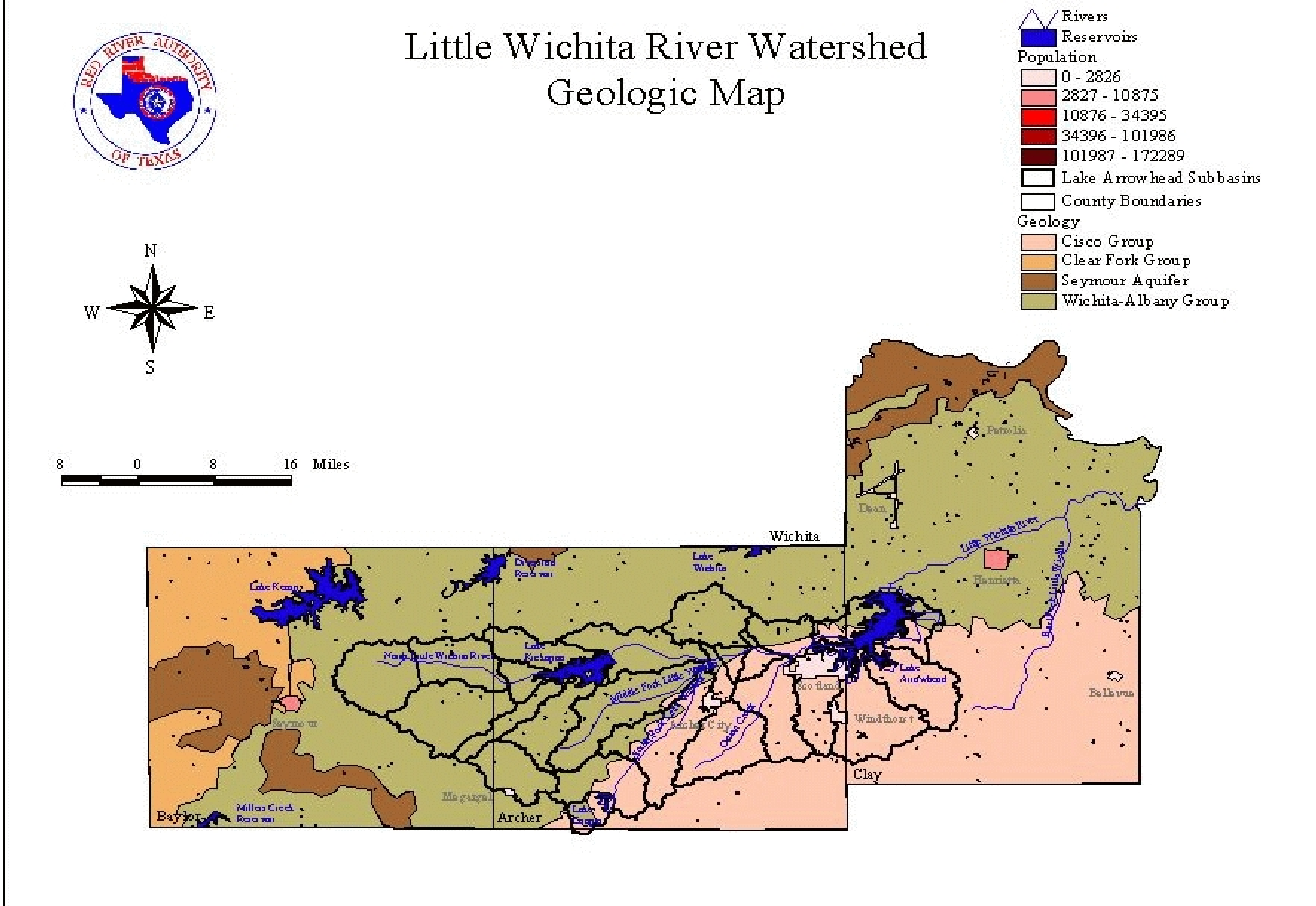
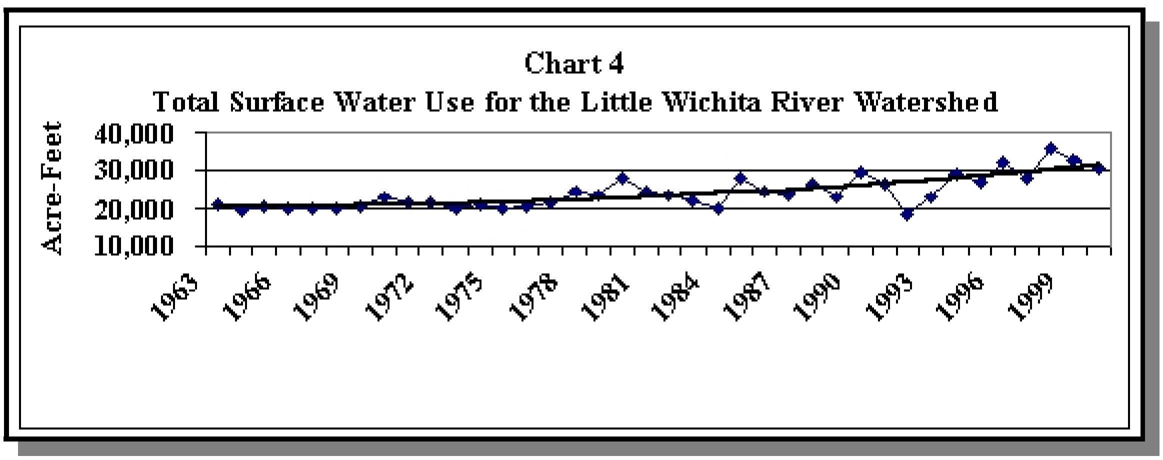


Figure 5

3.0 HYDROLOGIC EVALUATION (continued)

3.4 Existing Surface Water Hydrology

Surface water from earthen stock ponds and the three major reservoirs within the watershed account for approximately 99.2% of the total water use for all purposes within the watershed, while ground water is relied upon for minimal livestock and industrial uses. However, the majority of the surface water utilized from the watershed is actually used by entities outside of the Little Wichita River watershed. Total surface water diverted from the watershed averaged 23,856 acre-feet per year over the period of 1953 through 1999. The record high was attained in 1998 when 35,857 acre-feet was used. The record low occurred in 1992 when only 18,207 acre-feet were utilized. Total water use has shown a steady incline as compared to the overall average historical use for the watershed area. Total surface water use is illustrated below in **Chart 4**. These data were compiled from the TWDB State Water Plan database and USGS Water Resource Data, which were extrapolated to the watershed area based on population and use characteristics of the counties represented.



3.0 HYDROLOGIC EVALUATION (continued)

3.5 Existing Ground Water Hydrogeology

The Pennsylvanian and Permian Formations contain the largest and most prolific aquifers within the study area. These are the Cisco Group of the Late Pennsylvanian and early Permian Formation and the Wichita-Albany Group of the Permian. These are depicted in the **Geologic Cross-Section of Major Formations** shown in **Figure 7** on page 3-20. However, while a few wells from each of the formations are used for individual domestic, industrial, and livestock purposes, none of the formations are utilized for municipal or irrigation purposes due to their limited quantity and poor quality. **Refer to Table A-4, Geologic Units and their Water-Bearing Characteristics** located in the Appendix for details.

The **Cisco Group** outcrops primarily in the Archer and Clay County portions of the study area and consists of shale, sandstone, limestone, conglomerate, and beds of coal. Small yields of fresh to slightly saline water can be found in domestic and livestock wells throughout the watershed. Industrial wells from this formation are primarily used for water-flood in secondary recovery of hydrocarbons.

The **Wichita – Albany Group** exists throughout the watershed study area and consists of limestone, sandstone, siltstone, conglomerate, and coal formations. Water wells from this group are low yield and commonly do not provide adequate supply as most wells cannot sustain prolonged pumpage. Water produced from wells in this group is primarily used for domestic and livestock purposes. Poor water quality in some places throughout the formation preclude use for human consumption.

Although small pockets of the **Canyon Group** of the Pennsylvanian formation and of the **Alluvium** can be found within the watershed study area, no recorded wells were discovered through the course of this study.

Data collected from the wells were evaluated to determine aquifer trend changes in water levels over a period from 1963 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 incline over the period of record. This may be attributed to decreased pumping due to deteriorating quality from heavier pumping periods prior to the period of record. Some of the individual observation wells showed a slight rise in water levels from 2 feet to 33 feet during the period of 1963 to 2001.

3.0 HYDROLOGIC EVALUATION (continued)

3.5 Existing Ground Water Hydrogeology

The following **Figure 6, TWDB Observation Well Locations** on page 3-19, depicts the geographical positions of the wells utilized in this evaluation with respect to the Little Wichita River watershed above Lake Arrowhead. This is a complete representation of all the listed wells within the watershed. However, only five wells within the watershed had sufficient data available for use in support of the discussions presented herein. Also refer to **Table A-5, Texas Water Development Board Observation Well Inventory** and **Table A-6, Artesian Springs Inventory** located in the Appendix for general specifications of the wells utilized in the course of this evaluation.

3.6 Description of Watershed Hydrologic System

The Little Wichita River watershed above Lake Arrowhead represents 827 square miles of surface drainage area (529,280 acres) and is reflective of a highly modified hydrologic system since about 1946. The watershed exhibits a long-term yield of 59,042 acre-feet of water per year, or approximately 77.8 acre-feet per square mile of contributing drainage area.

The Little Wichita River's headwater tributaries exhibit normal streamflow characteristics with a gradual increase in velocity as the river progresses downstream to Lake Arrowhead. The long-term average streamflow near Archer City, Texas is 51.7 cfs or about 37,420 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 41.8 cfs under normal rainfall conditions.

Land use patterns have changed since the mid 1800's from predominately open range land to a combination of range and crop land. Since 1950, much of the cultivated crop land has been converted to range or pasture land through the U.S. Department of Agriculture (USDA), Farm Service Agency's Conservation Reserve Program (CRP). The agricultural acreage within the watershed may be allocated in two categories with 84.3 percent to range land and 15.7 percent for crop land. 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.

Little Wichita River Watershed
TWDB Observation Well Locations

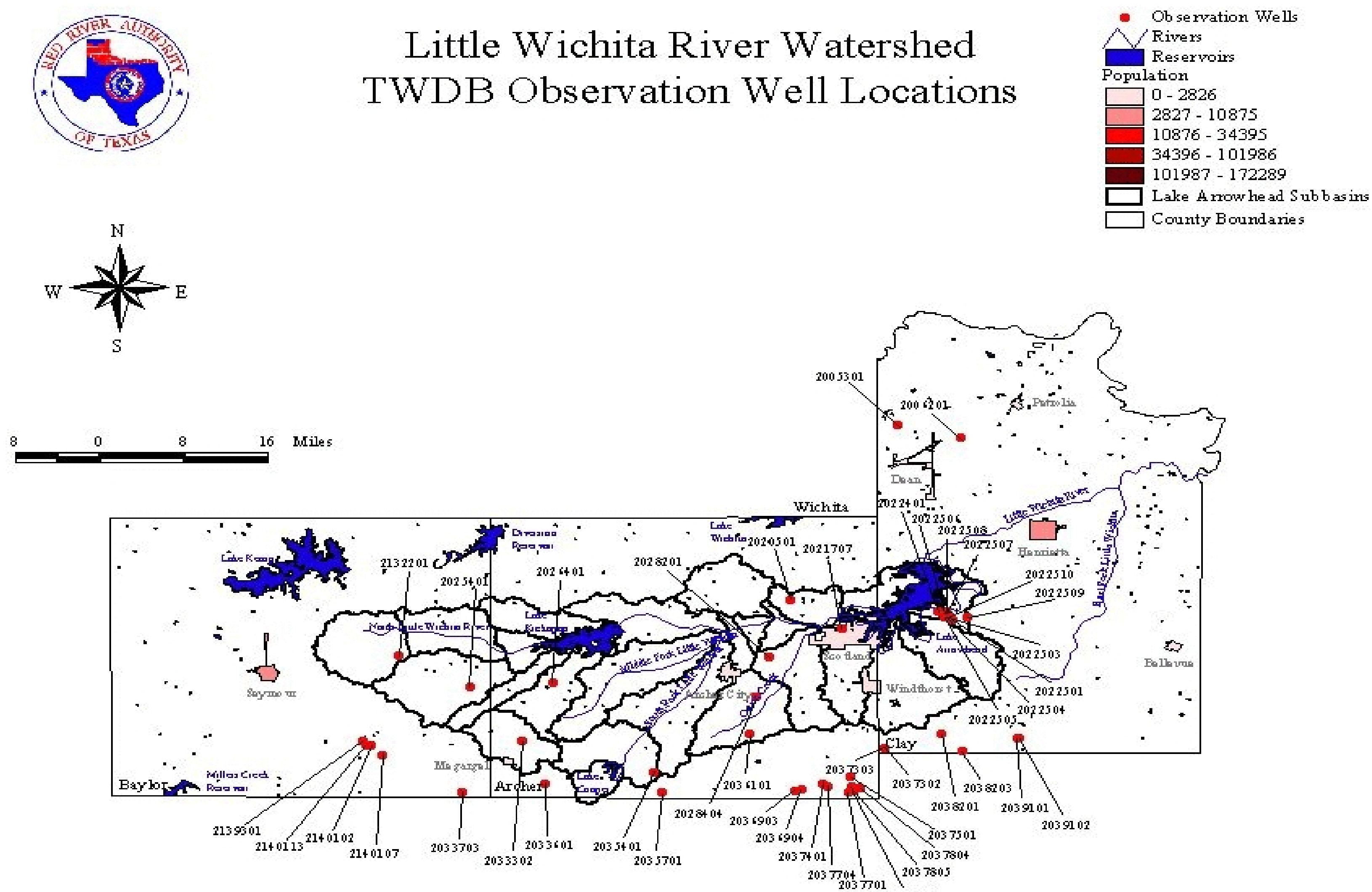


Figure 6

Little Wichita River Watershed
Geologic Cross-Section of Major Formations

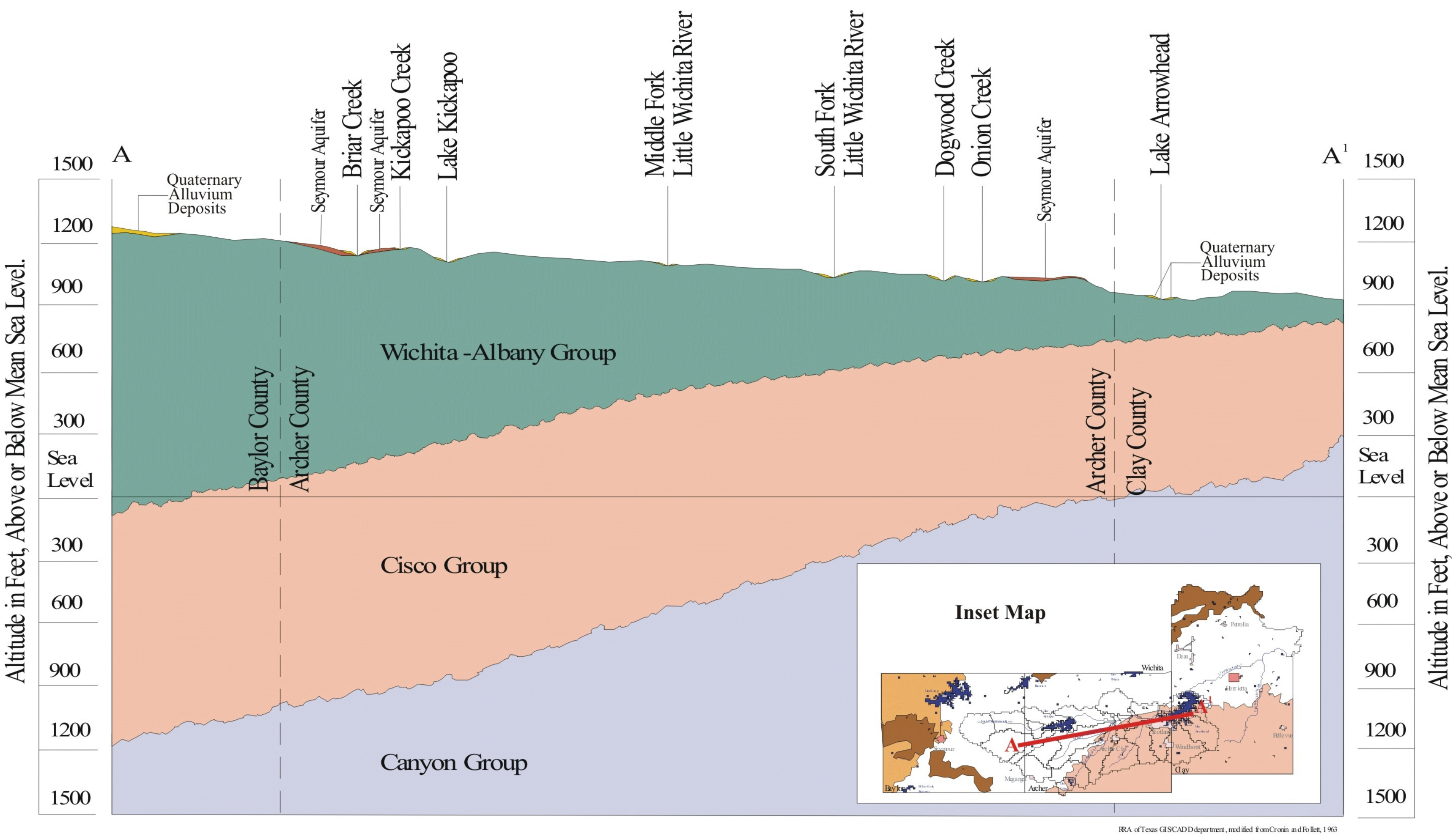


Figure 7

3.0 HYDROLOGIC EVALUATION (continued)

3.6 Description of Watershed Hydrologic System

Total annual water use from the watershed for all purposes has shown a steady increase from 19,135 acre-feet in 1963 to 29,981 acre-feet in 1999, which is consistent with the increase in regional population over the same period. About 99.2% of the total water use is from surface water with only about 0.8% coming from ground water, primarily the Cisco and the Wichita-Albany formations. The majority of all surface water used is diverted outside the watershed.

The Little 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 and broader extremes in water temperatures.

The smalleye and sharpnose shiners have been listed on the Texas Parks and Wildlife (TPWD) threatened and/or endangered species list. Refer to **Table A-1** in the Appendix for a listing of fish and wildlife in the 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 U.S. Fish and Wildlife Service (USFWS) occur within the watershed area only as migrants or as wanderers normally found along the Gulf coast.

While surface water quality in the watershed is good, water quality of the extremely limited ground water is impaired for many uses and by a number of influencing factors. The chemical character of ground water mirrors the mineral composition of the rocks through which it has passed. Ground water 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 available ground water is produced from small pockets in the Pennsylvanian and Permian Formations. Many of the wells inventoried produced very small amounts and are unable to sustain continuous pumpage limiting its use to livestock and individual domestic purposes. Wells are scattered throughout the watershed with no heavy concentrations in any one 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, hydro-geologic, geologic, climate and ecological condition of the Little Wichita River watershed above Lake Arrowhead. 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 has impacted streamflow since 1946. Most changes appear to be advantageous in terms of resource management. Streamflow has shown an increase of 12.4 percent or 9.6 acre-feet per square mile over the historical average, believed to be due to improved land resource management practices. This would further demonstrate that removal of noxious brush would prove feasible and substantially increase overall watershed yield.

- The annual watershed runoff was 19,506 acre-feet in 1999. This is 39,536 acre feet less (about 66%) than the historical long-term average of 59,642 acre-feet. The historical high annual watershed runoff was 288,116 acre-feet or 379.6 acre-feet per square mile of contributing drainage area in 1990. This occurred during a period in which annual rainfall exceeded 30 inches for three consecutive years.

- The Lake Arrowhead watershed is dependent upon surface water (99.2%) for most uses, while ground water is not considered to be a major factor in the watershed due to its very limited quantity and poor quality. The total surface water utilized out of the watershed study area averages about 23,856 acre-feet per year. Most of the water is pumped from Lake Kickapoo and Lake Arrowhead and utilized for municipal and some industrial uses. Considering the long-term average annual streamflow of 59,042 acre-feet per year, the additional watershed yield provided by the brush control program would benefit the entire regional area through increased water supply availability.

3.0 HYDROLOGIC EVALUATION (continued)

3.7 Summary and Conclusions

- Climate conditions appear to be changing with annual rainfall rates showing a 4.7 percent decrease due in part to extended durations over the last ten years when the average rainfall-days decreased from 41.2 days per year to 34.6 days per year over the watershed. Long-term evaporation rates (40-year) have increased an average 61.3 inches per year with a matching record high of 74.5 inches being set in 1963. Average annual temperatures have remained relatively constant over the past 100 years with an average of 63.5° F.

- The aquatic habitat appears to be stable and supports an abundance of aquatic life throughout the Little Wichita River system. The added quantity of water through removal of noxious brush would be most beneficial in maintaining the health and abundance of the aquatic habitats within the watershed area. The improved habitat areas would further promote the proliferation of popular game for hunting, such as quail, dove, deer, and turkey that would add a direct economical benefit to landowners for leased hunting.

- In 1998, there were five mammals, three fish, one reptiles, and nine birds among the species native to this area listed as endangered or threatened. They include the following:

Table 3-2 – Threatened and Endangered Species

	Mammals	Fish	Reptiles	Birds
Endangered	Black-Footed Ferret Red Wolf			Black-Capped Vireo Brown Pelican Eskimo Curlew Least Tern White-Faced Ibis Whooping Crane
Threatened	Cave Myotis Plains Spotted Skunk Texas Kangaroo Rat	Sharpnose Shiner Smalleye Shiner	Texas Horned Lizard	Bald Eagle Peregrine Falcon Reddish Egret

3.0 HYDROLOGIC EVALUATION (continued)

3.7 Summary and Conclusions

- The ecological transformation was a gradual process that began with early settlement in the late 1800's and the onset of major ranching and farming activities to the point that the watershed population peaked at 19,063 in 1920. The economy collapsed with the Great Depression and area population has stabilized to around 15,000 in 2000. However, ranching continued to prevail as the leading enterprise with overgrazing, numerous droughts, and range fire suppression becoming the principal cause for the spread of noxious brush to the extent that the once open prairie range is now populated with more than 73 percent of brush covering the landscape (about 386,374 acres).

- Although early records do not reflect the density of brush in the area, accounts of longtime residents agree that mesquite covered an estimated 30 percent of the open range areas (about 158,814 acres) after 1930 and began rapidly spreading throughout the watershed, limiting land uses, livestock production, and utilizing much of the water resources. Refer to **Table A-7, Sub-basin Data and Watershed Yield** in the Appendix on page A-22 for additional information.

- Although Lakes Cooper, Kickapoo and Arrowhead are modifications to the natural prairie stream, they provide several definite advantages. The reservoirs provide a healthy aquatic habitat for fish and wildlife, as well as a good quality source of water for municipal and some industrial uses. The reservoirs are the primary surface water supplies for Wichita Falls and the surrounding areas, and are identified in the State's Regional Water Plan for Area B as a regional water supply source. Given the projected reduced yield characteristics due to years of sedimentation, the brush control program in the watershed could greatly enhance the beneficial uses of the reservoirs and extend the need for future water resource development to well into the future.

- Due to the moderately 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 Methodology

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 Lake Arrowhead 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 28 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 mesquite. 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, ground water and surface water uses, channel hydrology, water quality conditions, and water transfers. The model was employed and calibrated by the USDA-Natural Resources 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 of 1960 through 1999.

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

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.2 Watershed Data

Physical Data – Lake Arrowhead is a reservoir on the Little Wichita River in the Red River Basin with a normal pool area of 16,200 surface acres. It impounds 262,100 acre-feet of water at normal pool elevation. This impoundment provides for municipal, industrial, and recreational use. Lake Kickapoo, a 6,200 surface acre reservoir, lies upstream in west central Archer County. The watershed originates in eastern Baylor County and flows in an easterly direction through Archer and part of Clay Counties for approximately 45 miles before entering Lake Arrowhead. The Lake Arrowhead watershed has an area of about 529,280 acres (827 square miles), nearly all of which is in farms and ranches.

Land Use/Land Cover – The land use/land cover was derived from the Landsat 7 classification imagery utilizing ground control points collected by local NRCS personnel. Software accuracy assessment based on ground control points was approximately 75 percent. About 78 percent of the watershed is in some type of rangeland or pasture cover. Approximately 52 percent of the watershed is moderate or heavy brush that was converted to open rangeland in the SWAT simulation. No juniper categories were developed since juniper is not a significant brush species in this watershed.

Soils – The watershed is in three land resource areas: the Central Rolling Red Plains, the Central Rolling Red Prairies, and the Texas north-central Prairies. The soils of the Central Rolling Red Plains consist of nearly level to gently sloping, moderately deep with deep, clayey and loamy soils. The soils of the Central Rolling Red Prairies are nearly level to sloping, well drained or moderately well drained, deep or moderately deep clayey and loamy soils. The soils of the Texas north-central prairies consist of well drained and moderately well drained, somewhat stony, and medium textured to fine textured soils. Nearly all of the area is in farms or ranches.

The dominant soil series in the Lake Arrowhead watershed are Vernon, Kamay, Bastrop, Tillman, Knoco, Jolly, Mangum, Aspermont, Port, Bluegrove, Weswind, and Renfrow. These twelve soil series represent about 75 percent of the watershed area. A short description of each follows:

Vernon: The Vernon series consists 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. Slopes range from 1 to 45 percent.

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.2 Watershed Data

Kamay: The Kamay series consists of very deep, well drained, slowly permeable soils that formed in clayey redbeds. These soils are on nearly level to very gently sloping uplands. Slopes range from 0 to 3 percent.

Bastrop: The Bastrop series consists of very deep, well drained, moderately permeable soils formed in loamy alluvial materials. These soils are on nearly level to moderately sloping upland stream terraces. Slopes range from 0 to 8 percent.

Tillman: The Tillman series consists of very deep, well drained, slowly permeable soils. These soils formed in loamy and clayey alluvium derived from redbed clays and claystone sediments of the Permain age. These soils are on nearly level to gently sloping uplands. Slope ranges from 0 to 5 percent.

Knoco: The Knoco series consists of very shallow and shallow, well drained, very slowly permeable soils that formed in residuum over dense non-cemented claystone bedrock of the Permian age. These soils are on very gently sloping to very steep ridges, side slopes, and erosional foot slopes on uplands. Slopes range from 1 to 60 percent.

Jolly: The Jolly series consists of shallow, well drained, moderately permeable soils that developed in residuum and colluvium derived from sandstone. These soils are on gently sloping to strongly sloping uplands. Slopes range from 1 to 12 percent.

Mangum: The Mangum series consists of very deep, well drained, very slowly permeable soils that formed in calcareous clayey alluvial materials. These soils are on nearly level flood plains of major streams. Slopes range from 0 to 1 percent.

Aspermont: The Aspermont series consists of very deep, well drained, moderately permeable soils. These soils formed in calcareous silty colluvium over redbed silt stone and claystone of the Permian age. These very gently sloping to steep soils are on side slopes or summits on uplands. Slope ranges from 1 to 25 percent.

Port: The Port series consists of very deep, well drained, moderately permeable flood plain soils that formed in calcareous loamy alluvium of recent age. These nearly level to very gently sloping soils are on narrow flood plains. Slopes range from 0 to 3 percent.

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.2 Watershed Data

Bluegrove: The Bluegrove series consists of moderately deep, well drained, moderately slowly permeable soils formed in residuum weathered from sandstone and shale. These soils are on gently sloping and sloping uplands. Slopes range from 1 to 8 percent.

Weswind: The Weswind series consists of very deep, moderately well drained, moderately slowly permeable soils formed in inter bedded sandstone and shale materials. These gently sloping and strongly sloping upland soils have slopes ranging from 1 to 8 percent.

Renfrow: The Renfrow series consists of very deep, well drained, very slowly permeable soils that formed in material weathered from clayey shale of the Permian age. These nearly level to gently sloping soils are on broad, smooth convex ridges and side slopes of uplands. Slopes range from 0 to 5 percent.

Topography – Topography of the watershed is moderate to gently rolling. Elevations range from 918 feet on the flood plain above Lake Arrowhead to over 1,410 feet above mean sea level on parts of the escarpment.

Geology – Geologic strata cropping out in the watershed were deposited during the early Permian Period and Quaternary Period.

The Archer City Formation and Nacona Formation are dominantly Permian "red-bed" sediments that were deposited on the eastern flank of the Permian Basin in a deltaic-shallow water environment. Consequently, they dip gently northwest and strike generally northeast to southwest.

Quaternary sediments mapped within the watershed are Late Pleistocene-Early Holocene fluvial deposits under relict terraces, and modern Holocene flood plain alluvium. The relict terraces are located above the modern flood plain along the Little Wichita River flood plain.

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.2 Watershed Data

Climate – The average annual precipitation during the 1960 through 1999 study period varied from 25.4 inches in the western portion of the Lake Arrowhead watershed to 31.0 inches in the eastern portion. The composite average for the entire watershed was 28.0 inches. Average temperatures range from 83 degrees Fahrenheit (F) in the summer to 44 degrees in the winter. The normal frost-free season of 227 days extends from March 28th to November 9th.

Ponds and Reservoirs – Surface runoff is the principal source of water for all purposes, due to the deep water table and poor quality of underground water. Three storage reservoirs in this watershed furnish water for municipal and industrial uses. Lake Kickapoo and Lake Arrowhead furnish municipal water to the City of Wichita Falls. Lake Cooper furnishes water to the City of Olney. Farm ponds supply a majority of the farmers and ranchers with water for domestic and livestock use.

Model Inputs – Significant input variables for the SWAT model for the Lake Arrowhead Watershed are shown in **Table 4-1**. Input variables were adjusted as needed in order to calibrate flow at the applicable USGS stream gage or reservoir. The calibration simulation represents the current "with brush" condition.

The input variables for the no-brush condition, with one exception, were the same as the calibration variables, with the change in land use being the only difference between the two simulations. The exception is that we assumed the shallow aquifer re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and the 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 0.1 for non brush HRU's.

4.3 Lake Arrowhead Watershed Results

Calibration – SWAT was calibrated against measured streamflow and reservoir volumes by varying selected model parameters (Table 4-1). The model was calibrated for flow at stream gage 07314500, Little Wichita River near Archer City, (Table A-2) and for storage volume at two reservoirs (07314000 – Lake Kickapoo and 07314800 – Lake Arrowhead). Stream gage and reservoir volume data were retrieved from U.S. Geological Survey (USGS) databases and annual hydrologic data reports.

4.0 WATERSHED DELINEATION AND MODELING (continued)

Table 4-1 – SWAT Input Variables

Variable		Adjustment/Value
Runoff Curve Number Adjustment		None
Soil Available Water Capacity Adjustment (inches H^2O/in soil)		None
Soil Crack Volume Factor		None
Soil Saturated Conductivity (inches/hour)		None
Soil Evaporation Compensation Factor		0.850
Minimum Shallow Aquifer Storage for Ground Water Flow (inches)		0.079
Minimum Shallow Aquifer Storage for Revap (inches)		0.085
Shallow Aquifer Re-evaporation (revap) Coefficient	Brush	0.400
	All Others	0.003
Channel Transmission Loss (inches/hour)		0.080
Sub-basin Transmission Loss (inches/hour)		0.120
Bank Coefficient		0.500
Reservoir Evaporation Coefficient		1.000
Reservoir Seepage Rate (inches/hour)	Lake Arrowhead	0.004
	Lake Kickapoo	0.003
Principal Spillway Release Rate (cfs)	Lake Arrowhead	353
	Lake Kickapoo	353
Potential Heat Units (°c)	Heavy Mesquite	3,346
	Heavy Mixed Brush	3,705
	Moderate Mesquite	3,067
	Heavy Oak	3,466
	Moderate Oak	3,067
	Light Brush and Open Range/Pasture	2,669
Plant Rooting Depth (feet)	Heavy and Moderate Brush	6.5
	Light Brush and Open Range/Pasture	3.3
Maximum Leaf Area Index	Heavy Mesquite	4
	Heavy Mixed Brush	4
	Moderate Mesquite	2
	Heavy Oak	4
	Moderate Oak	3
	Light Brush	2
	Open Range/Pasture	1

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.3 Lake Arrowhead Watershed Results

The calculated difference between measured and predicted values expressed as a residual of the means squared is the root means square error (RMSE). One way to gage the accuracy of the calibration is to compare the mean measured monthly flow or reservoir volume with the RMSE. The lower the RMSE compared to the measured values the more precise the comparison.

Lake Kickapoo: The average measured and predicted monthly volumes were within 9.5 percent for Lake Kickapoo, with an RMSE 0.19 times mean monthly volume. The low RMSE values indicate that the model did a good job in simulating reservoir storage volumes.

Lake Arrowhead: The average measured and predicted monthly volumes were within 4.6 percent for Lake Arrowhead, with RMSE of 0.15 times measured mean monthly volume. Again, SWAT simulated reservoir volume accurately.

Little Wichita River: The calibration period for the stream gage was from 1967 through 1999. Average measured and predicted monthly flows were within 5 percent, with RMSE about 1.4 times measured mean monthly flow. Although the RMSE is still acceptable, it indicates that SWAT was not as accurate in predicting monthly flow.

Brush Removal Simulation – Brush control was simulated by replacing all heavy and moderate mesquite and mixed brush categories with open range. Model inputs for curve number, leaf area, rooting depth, and ground water re-evaporation coefficient were changed to reflect the conversion of brush to grass**.**

Average annual evapotranspiration (ET) was 24.04 inches for the brush condition (calibration) and 19.39 inches for the no-brush condition. This represents 86 percent and 69 percent of precipitation for the brush and no-brush conditions, respectively.

4.0 WATERSHED DELINEATION AND MODELING (continued)

4.3 Lake Arrowhead Watershed Results

The 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 increase for each sub-basin is shown in **Table 4-2**. The amount of annual increases varied between the sub-basins and ranged from 96,876 gallons per acre of brush removed per year in sub-basin number 5, to 331,070 gallons per acre in sub-basin number 28.

The large increases in water yields for the sub-basins containing Lake Arrowhead (sub-basin 28) and Lake Kickapoo (sub-basin 12) were most likely due to the presence of predominantly muck soils with high runoff potential associated with heavy brush.

Variations in the amount of increased water yield were expected and influenced by brush type, brush density, soil type, and average annual rainfall. The larger water yields were most likely due to greater rainfall volumes, as well as increased density and canopy of brush.

The increase in volume of flow to the reservoirs was less than the water yield because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occurred between each sub-basin and the watershed outlet.

For the entire simulated watershed, the average annual water yield increased by about 88 percent or 151,623 acre-feet, and flow at the watershed outlet (Lake Arrowhead) increased by 113,860 acre-feet/year.

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	28,436	13,386	0.47	160,960	2,154,658,197
2	22,639	12,963	0.57	123,733	1,603,971,605
3	34,477	19,315	0.56	136,944	2,645,021,025
4	15,948	10,003	0.63	114,914	1,149,475,605
5	7,650	5,399	0.71	96,876	523,014,768
6	12,094	6,252	0.52	169,672	1,060,752,122
7	19,194	6,906	0.36	180,492	1,246,555,856
8	21,360	13,422	0.63	186,871	2,508,188,911
9	22,955	12,437	0.54	138,624	1,724,107,667
10	36,915	22,181	0.60	186,112	4,128,213,443
11	39,126	20,641	0.53	202,270	4,175,057,884
12	6,465	1,525	0.24	250,943	382,626,357
13	25,740	17,583	0.68	196,202	3,449,892,862
14	22,557	13,611	0.60	199,419	2,714,347,320
15	12,271	6,000	0.49	198,127	1,188,731,222
16	5,823	3,870	0.66	253,559	981,314,990
17	4,255	2,892	0.68	226,774	655,942,859
18	5,703	2,871	0.50	193,938	556,785,853
19	29,269	15,494	0.53	182,240	2,823,542,989
20	25,931	13,739	0.53	177,612	2,440,216,220
21	19,745	6,280	0.32	161,702	1,015,478,004
22	4,924	1,392	0.28	195,682	272,324,895
23	34,833	16,066	0.46	201,608	3,239,088,907
24	27,197	15,172	0.56	199,036	3,019,716,470
25	11,277	4,688	0.42	190,648	893,808,938
26	10,378	7,362	0.71	237,128	1,745,624,225
27	7,842	4,796	0.61	133,644	640,949,627
28	14,348	1,410	0.10	331,070	466,961,687
Total/Average	**529,352**	**277,656**	**0.52**	**186,671**	**49,406,370,508**

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 costs of a brush control program for water yield for the Lake Arrowhead watershed

5.2 Brush Control Cost

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5 percent or less and maintain it at the reduced level for at least 10 years. Obviously, the costs of control will vary among 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 $21.70 for moderate mesquite that initially can be controlled with herbicide treatments to $140.75 for mechanical control of heavy mesquite. Costs of treatments and year those treatments are needed for each brush type – density category are detailed in **Table 5-1**.

Table 5-1 – Little Wichita River
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	19.80
7	Choice Type IPT or Burn	15.00	9.98
			$ 54.78

5.0 ECONOMIC ANALYSIS (continued)

5.3 Landowner 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 reasonably be 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 $19.43 per acre for the control of heavy mesquite to $17.54 per acre for control of moderate mesquite.

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 $156.14 for mechanical control of heavy mesquite to $18.03 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 5-2**.

Table 5-2 – Little Wichita River Watershed
Cost Per Acre-Foot of Added Water From Brush Control by Sub-Basin

Heavy Mesquite Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Tree Doze or Root Plow, Rake and Burn	$ 165.00	$ 165.00
6	Choice Type IPT or Burn	15.00	10.57
			$ 175.57

5.0 ECONOMIC ANALYSIS (continued)

5.3 Landowner Benefits Versus Cost Share

Table 5-2 – Little Wichita River Watershed
Cost Per Acre-Foot of Added Water From Brush Control by Sub-Basin

Moderate Mesquite Aerial Chemical			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
6	Choice Type IPT or Burn	15.00	10.57
			$ 35.57

Moderate Mesquite Mechanical Choice			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Grub, Rake, and Burn	$ 100.00	$ 100.00
6	Choice Type IPT or Burn	15.00	10.57
			$ 110.57

Moderate Mesquite Shears			
Year	**Treatment Description**	**Cost/Unit**	**Present Value**
0	Skid Steer with Shears	$ 35.00	$ 35.00
6	Choice Type IPT or Burn	15.00	10.57
			$ 45.57

5.0 ECONOMIC ANALYSIS (continued)

Table 5-2 – Little Wichita River Watershed
Cost Per Acre-Foot of Added Water From Brush Control by Sub-Basin

Brush (Type and Density)	Acreage Impacted	Rancher Cost Share	Rancher Percent	State Cost Share	State Percent	Present Value Total Cost
Heavy Mesquite	138,880	19.43	11.07-35.47	35.35-156.14	64.53-88.93	54.78-175.57
Moderate Mesquite	134,400	17.54	15.86-49.31	18.03-93.03	50.69-84.14	35.57-110.57
Total/Average	**273,280**	**$ 18.49**	**27.93%**	**$75.64**	**72.08%**	**$94.13**

5.4 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 $14.83 per acre-foot for the entire Lake Arrowhead Watershed while sub-basins range from costs per added acre foot of $6.84 to $26.38.

Table 5-3 – Little Wichita River Watershed
Cost Per Acre-Foot of Added Water From Brush Control by Sub-Basin

Sub-basin	Total State Cost	Added Gallons Per Year	Added Acre-Feet Per Year	Total Acre-Feet Per 10 Years	Cost Per Acre-Foot
1	$ 890,835.69	2,154,658,197.03	6,612.40	51,587.94	$ 17.27
2	792,839.56	1,603,971,605.12	4,922.41	38,403.11	20.65
3	1,193,772.24	2,645,021,025.03	8,117.27	63,328.45	18.85
4	645,032.32	1,149,475,605.35	3,527.61	27,521.34	23.44
5	330,284.29	523,014,767.61	1,605.07	12,522.29	26.38
6	385,074.33	1,060,752,122.04	3,255.33	25,397.07	15.16
7	451,240.14	1,246,555,855.56	3,825.54	29,845.68	15.12
8	893,199.99	2,508,188,911.38	7,697.35	60,052.35	14.87
9	789,409.91	1,724,107,666.62	5,291.09	41,279.47	19.12
10	1,390,116.97	4,128,213,443.23	12,669.02	98,839.81	14.06
11	1,304,918.20	4,175,057,884.49	12,812.78	99,961.38	13.05
12	87,872.64	382,626,356.77	1,174.24	9,161.04	9.59
13	1,164,934.45	3,449,892,862.07	10,587.33	82,599.11	14.10
14	855,343.01	2,714,347,320.33	8,330.03	64,988.30	13.16
15	326,603.70	1,188,731,222.13	3,648.08	28,461.21	11.48
16	257,684.25	981,314,990.05	3,011.55	23,495.15	10.97
17	177,614.54	655,942,859.17	2,013.01	15,704.92	11.31
18	166,110.60	556,785,852.99	1,708.71	13,330.85	12.46
19	1,029,797.78	2,823,542,988.67	8,665.14	67,602.72	15.23
20	886,216.09	2,440,216,220.39	7,488.75	58,424.91	15.17
21	364,992.01	1,015,478,003.63	3,116.39	24,313.10	15.01
22	75,349.90	272,324,895.18	835.73	6,520.14	11.56
23	905,677.75	3,239,088,907.36	9,940.40	77,551.93	11.68
24	946,411.68	3,019,716,470.06	9,267.17	72,299.61	13.09
25	293,211.92	893,809,938.15	2,743.00	21,400.06	13.70
26	546,610.84	1,745,624,225.02	5,357.12	41,794.63	13.08
27	318,222.59	640,949,626.80	1,967.00	15,345.95	20.74
28	76,455.03	466,961,686.53	1,433.05	11,180.24	6.84
Total/Avg	**$ 17,545,832.44**			**1,182,912.76**	**$14.83**

6.0 Program Implementation

Based on the results shown in this study, it is recommended that implementation of the Lake Arrowhead Watershed 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 also be given to requesting participation from beneficiary entities such as the City of Wichita Falls. Beneficiary entities could provide cost share financing in support of the program to offset landowner and/or state costs as the projected gain in water yields will increase or at least expand the firm yield of the existing reservoirs.

BIBLIOGRAPHY

National Climate Data Center (NCDC) and National Oceanic and Atmospheric Administration (NOAA). *Regional Climatology Data*, Online Database, 2002.

Red River Authority of Texas. *Red River Basin Information Repository*, http:/www.rra.dst.tx.us/ public information repository/default htm, 2002.

Smiens, Fuhlendorf and Taylor, Jr., Texas A&M Extension Service (TAMES). *Environmental and Land Use Changes*, Sonora, Texas, 1997.

Texas Department of Water Resources. *Climate Atlas of Texas*, Report 192, 1983.

Texas Department of Water Resources. *Erosion and Sedimentation by Water in Texas*, Report 268, 1982.

Texas Natural Resource Conservation Commission. *North Texas Alluvium and Paleozoic Outcrop*, Priority Groundwater Management Area (PGMA) File Report, 1998.

Texas Parks and Wildlife Department. *Evaluation of Selected Natural Resources of North Central Texas*, 1998.

Texas Parks and Wildlife Department, Moulton, D.W. and Baird, A.L. *Species of Special Concern*, 1998.

Texas Water Development Board. *Climate Atlas of Texas*, Online Database, 2002.

Texas Water Development Board. *Evaluation of Water Resources in Parts of the Rolling Prairies Region of North Texas*, Report 337, 1992.

Texas Water Development Board. *Rolling Prairies Region*, File Report 98-03, Report 337 Update, Priority Groundwater Management Area (PGMA)-16 Update, 1998.

Texas Water Development Board. *Surveys of Irrigation in Texas*, Report 347, 1996.

Texas Water Development Board. *Water for Texas, Consensus Water Plan*, GP-6-2, 1997.

Texas Water Development Board. *Groundwater Data System, Well Records Inventory*, Selected Aquifers and Counties, 2002.

United States Geological Survey. *Streamflow Gages, Texas Section*, Online Historical Database, 2002.

Texas Online Data Base – County Information.

APPENDICES

Table A-1 – Fish and Wildlife Inventory

Common Name	Scientific Name	Native	Introduced	Vulnerable	Threatened	Endangered
MAMMALS						
American Beaver	*Castor canadensis*	•				
American Badger	*Taxidea taxus*	•				
Big Brown Bat	*Vespertilionidae Eptesicus*	•				
Black-Footed Ferret	*Mustela nigripes*					•
Black-Tailed Prairie Dog	*Cynomys ludovicianus*	•				
Black-Tailed Jackrabbit	*Lepus californicus*	•				
Bobcat	*Lynx rufus*	•				
Brazilian Free-Tailed Bat	*Molossidae T. brasiliensis*	•				
Cave Myotis	*Myotis velifer*				•	
Collared Peccary	*Tayassu tajacu*	•				
Common Muskrat	*Ondatra zibethicus*	•				
Common Raccoon	*Procyon lotor*	•				
Common Gray Fox	*Urocyon cinereoargenteus*	•				
Coyote	*Canis latrans*	•				
Deer Mouse	*Peromyscus maniculatus*	•				
Desert Shrew	*Soricidae Notiosorex*	•				
Desert Cottontail	*Sylvilagus audubonii*	•				
Eastern Flying Squirrel	*Glaucomys volans*	•				
Eastern Mole	*Talpidae Scalopus*	•				
Eastern Woodrat	*Neotoma floridana*	•				
Eastern Cottontail	*Sylvilagus floridanus*	•				
Fox Squirrel	*Sciurus niger*	•				
Fulvous Harvest Mouse	*Reithrodontomys fulvescens*	•				
Golden Mouse	*Ochrotomys nuttalli*	•				
Gray Wolf	*Canis lupus*	•				
Hispid Pocket Mouse	*Chaetodipus hispidus*	•				
Hispid Cotton Rat	*Sigmodon hispidus*	•				
House Mouse	*Mus musculus*	•				
Least Shrew	*Soricidae Cryptotis*	•				
Long-Tailed Weasel	*Mustela frenata*	•				
Mearn's Grasshopper Mouse	*Onychomys arenicola*	•				
Merriam's Pocket Mouse	*Perognathus merriami*	•				
Mexican Woodrat	*Neotoma mexicana*	•				
Mexican Ground Squirrel	*Spermophilus mexicanus*	•				
Mink	*Mustela vison*	•				
Mountain Lion	*Felis concolor*	•				
Nine-Banded Armadillo	*Dasypus novemcinctus*	•				
Northern Pygmy Mouse	*Baiomys taylori*	•				
Northern Grasshopper Mouse	*Onychomys leucogaster*	•				
Norway Rat	*Rattus norvegicus*	•				

Table A-1 – Fish and Wildlife Inventory

Common Name	Scientific Name	Native	Introduced	Vulnerable	Threatened	Endangered
Nutria	*Myocastor coypus*	•				
Ord's Kangaroo Rat	*Dipodomys ordii*	•				
Piñon Mouse	*Peromyscus truei*	•				
Plains Pocket Gopher	*Geomys bursarius*	•				
Plains Pocket Mouse	*Perognathus flavescens*	•				
Plains Spotted Skunk	*Spilogale putorius interrupta*				•	
Plains Harvest Mouse	*Reithrodontomys montanus*	•				
Porcupine	*Erethizon dorsatum*	•				
Pronghorn	*Antilocapra americana*	•				
Red Wolf	*Canis rufus*					•
Red Fox	*Vulpes vulpes*	•				
Ringtail	*Bassariscus astutus*	•				
River Otter	*Lutra canadensis*	•				
Roof Rat	*Rattus rattus*	•				
Silver-Haired Bat	*Vespertilionidae Lasionycteris*	•				
Southern Plains Woodrat	*Neotoma micropus*	•				
Striped Skunk	*Mephitis mephitis*	•				
Texas Kangaroo Rat	*Dipodomys elator*				•	
Texas Mouse	*Peromyscus attwateri*	•				
Virginia Opossum	*Didelphis virginiana*	•				
White-Ankled Mouse	*Peromyscus pectoralis*	•				
White-Footed Mouse	*Peromyscus leucopus*	•				
White-Nosed Coati	*Nasua narica*	•				
White-Tailed Deer	*Odocoileus virginianus*	•				
White-Throated Woodrat	*Neotoma albigula*	•				
Woodland Vole	*Microtus pinetorum*	•				
Yellow-Faced Pocket Gopher	*Cratogeomys castanops*	•				
FISH						
Alligator Gar	*Lepisosteus spatula*	•				
Atlantic Needlefish	*Strongylura marina*	•				
Bigmouth Buffalo	*Ictiobus cyprinellus*	•				
Bigscale Logperch	*Percina macrolepida*	•				
Black Buffalo	*Ictiobus niger*	•				
Blackstripe Topminnow	*Fundulus notatus*	•				
Blacktail Shiner	*Cyprinella venusta*	•				
Blue Sucker	*Cycleptus elongatus*	•				
Blue Catfish	*Ictalurus furcatus*	•				
Bluegill	*Lepomis macrochirus*	•				
Bowfin	*Amia calva*	•				
Brook Silverside	*Labidesthes sicculus*	•				
Central Stoneroller	*Campostoma anomalum*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Channel Catfish	*Ictalurus punctatus*	•				
Chub Shiner	*Notropis potteri*		•			
Common Carp	*Cyprinus carpio*	•				
Creek Chub	*Semotilus atromaculatus*	•				
Flathead Catfish	*Pylodictis olivaris*	•				
Flier	*Centrarchus macropterus*	•				
Gizzard Shad	*Dorosoma cepedianum*	•				
Golden Redhorse	*Moxostoma erythrurum*	•				
Goldfish	*Carassius auratus*		•			
Green Sunfish	*Lepomis cyanellus*	•				
Highfin Carpsucker	*Carpiodes velifer*	•				
Ide	*Leuciscus idus*	•				
Inland Silverside	*Menidia beryllina*	•	•			
Lake Chubsucker	*Erimyzon sucetta*	•				
Largemouth Bass	*Micropterus salmoides*	•	•			
Longear Sunfish	*Lepomis megalotis*	•	•			
Longnose Gar	*Lepisosteus osseus*	•				
Orangespotted Sunfish	*Lepomis humilis*	•				
Paddlefish	*Polyodon spathula*	•				
Pirate Perch	*Aphredoderus sayanus*	•				
Plains Minnow	*Hybognathus placitus*	•				
Plains Killifish	*Fundalus zebrinus*	•				
Red River Shiner	*Notropis bairdi*	•				
Red Drum	*Sciaenops ocellatus*		•			
Red River Pupfish	*Cyprinodon rubrofluviatilis*	•				
Red Shiner	*Cyprinella lutrensis*	•				
Redbreast Sunfish	*Lepomis auritus*		•			
Redear Sunfish	*Lepomis microlophus*	•	•			
River Carpsucker	*Carpiodes carpio*	•				
Rough Silverside	*Membras martinica*	•	•			
Sharpnose Shiner	*Notropis oxyrhynchus*				•	
Shortnose Gar	*Lepisosteus platostomus*	•				
Silver Chub	*Macrhybopsis storeriana*	•				
Skipjack Herring	*Alosa chrysochloris*	•				
Smalleye Shiner	*Notropis buccula*				•	
Smallmouth Bass	*Micropterus dolomieu*		•			
Smallmouth Buffalo	*Ictiobus bubalus*	•				
Speckled Chub	*Macrhybopsis aestivalis*	•				
Spot	*Leiostomus xanthurus*	•				
Spotted Sucker	*Minytrema melanops*	•				
Spotted Gar	*Lepisosteus oculatus*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Spotted Bass	*Micropterus punctulatus*	•	•			
Striped Bass	*Morone saxatilis*		•			
Striped Mullet	*Mugil cephalus*	•				
Warmouth	*Lepomis gulosus*	•				
Wester Sand Darter	*Ammocrypta clara*	•				
Western Spotted Sunfish	*Lepomis miniatus*	•	•			
White Bass	*Morone chrysops*	•				
Yellow Bullhead	*Ameiurus natalis*	•				
Yellow Bass	*Morone mississippiensis*	•				
AMPHIBIANS AND REPTILES						
Barred Tiger Salamander	*Ambystoma tigrinum*	•				
Brown Snake	*Storeria dekayi*	•				
Bullfrog	*Rana catesbeiana*	•				
Bullsnake	*Pituophis melanoleucus*	•				
Checkered Garter Snake	*Thamnophis marcianus*	•				
Coachwhip Snake	*Masticophis flagellum*	•				
Common Snapping Turtle	*Chelydra serpentina*	•				
Common Kingsnake	*Lampropeltis getula*	•				
Copperhead Snake	*Agkistrodon contortrix*	•				
Corn Snake	*Elaphe guttata*	•				
Cottonmouth Snake	*Agkistrodon piscivorus*	•				
Couch's Spadefoot	*Scaphiopus couchi*	•				
Cricket Frog	*Acris crepitans*	•				
Diamondback Water Snake	*Nerodia erythrogaster*	•				
Eastern Racer Snake	*Coluber constrictor*	•				
Eastern Rat Snake	*Elaphe obsoleta*	•				
Eastern Glossy Snake	*Arizona elegans*	•				
Eastern Collared Lizard	*Crotaphytus collaris*	•				
Fence Lizard	*Sceloporus undulatus*	•				
Flathead Snake	*Tantilla gracilis*	•				
Graham's Crayfish Snake	*Regina grahami*	•				
Great Plains Toad	*Bufo cognatus*	•				
Great Plains Narrowmouth Toad	*Gastrophryne olivacea*	•				
Great Plains Skink	*Eumeces obsoletus*	•				
Greater Earless Lizard	*Cophosaurus texanus*	•				
Green Toad	*Bufo debilis*	•				
Ground Snake	*Sonora semiannulata*	•				
Ground Skink	*Scincella lateralis*	•				
Lesser Earless Lizard	*Holbrookia maculata*	•				
Lined Snake	*Tropidoclonion lineatum*	•				
Longnose Snake	*Rhinocheilus lecontei*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Massasauga Snake	*Sistrurus catenatus*	•				
New Mexico Spadefoot	*Spea multiplicata*	•				
Night Snake	*Hypsiglena torquata*	•				
Ornate Box Turtle	*Terrapene ornata*	•				
Plainbelly Water Snake	*Nerodia erythrogaster*	•				
Plains Spadefoot	*Spea bombifrons*	•				
Plains Leopard Frog	*Rana blairi*	•				
Plains Blackhead Snake	*Tantilla nigriceps*	•				
Prairie Kingsnake	*Lampropeltis calligaster*	•				
Prairie Rattlesnake	*Crotalus viridis*	•				
Ringneck Snake	*Diadophis punctatus*	•				
Rough Green Snake	*Opheodrys aestivus*	•				
Roundtail Horned Lizard	*Phrynosoma modestum*	•				
Six-Lined Racerunner	*Cnemidophorus sexlineatus*	•				
Slender Glass Lizard	*Ophisaurus attenuatus*	•				
Slider Turtle	*Trachemys scripta*	•				
Smooth Softshell Turtle	*Apalone mutica*	•				
Southern Prairie Skink	*Eumeces septentionalis*	•				
Spiny Softshell Turtle	*Apalone spinifera*	•				
Spotted Chorus Frog	*Pseudacris clarki*	•				
Texas Blind Snake	*Leptotyphlops dulcis*	•				
Texas Spiny Lizard	*Sceloporus undulatus*	•				
Texas Horned Lizard	*Phrynosoma cornutum*				•	
Texas Spotted Whiptail Lizard	*Cnemidophorus gularis*	•				
Texas Toad	*Bufo speciosus*	•				
Western Diamondback Rattlesnake	*Crotalus atrox*	•				
Western Hognose Snake	*Heterodon nasicus*	•				
Western Earth Snake	*Virginia valeriae*	•				
Western Ribbon Snake	*Thamnophis proximus*	•				
Woodhouse's Toad	*Bufo woodhousii*	•				
Yellow Mud Turtle	*Kinosternon flavescens*	•				
BIRDS						
Acorn Woodpecker	*Melanerpes formicivorus formicivorus*	•				
American Robin	*Turdus migratorius*	•				
American Dipper	*Cinclus mexicanus unicolor*	•				
American Woodcock	*Scolopax minor*	•				
American Black Duck	*Anas rubripes*	•				
American Coot	*Fulica americana americana*	•				
American Wigeon	*Anas americana*	•				
American Kestrel	*Falco sparverius*	•				
American White Pelican	*Pelecanus erythrorhynchos*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
American Bittern	*Botaurus lentiginosus*	•				
American Crow	*Corvus brachyrhynchos brachyrhynchos*	•				
American Golden-Plover	*Pluvialis dominicus dominica*	•				
American Tree Sparrow	*Spizella arborea ochracea*	•				
American Goldfinch	*Carduelis tristis*	•				
American Pipit	*Anthus rubescens*	•				
American Avocet	*Recurvirostra americana*	•				
American Redstart	*Setophaga ruticilla*	•				
Anna's Hummingbird	*Calypte anna*	•				
Ash-Throated Flycatcher	*Myiarchus cinerascens cinerascens*	•				
Baird's Sandpiper	*Calidris bairdii*	•				
Baird's Sparrow	*Ammodramus bairdii*	•				
Bald Eagle	*Haliaeetus leucocephalus*				•	
Baltimore Oriole	*Icterus galbula*	•				
Band-Tailed Pigeon	*Columba fasciata fasciata*	•				
Bank Swallow	*Riparia riparia*	•				
Barn Swallow	*Hirundo rustica erythrogaster*	•				
Barn Owl	*Tyto alba pratincola*	•				
Barred Owl	*Strix varia varia*	•				
Barrow's Goldeneye	*Bucephala islandica*	•				
Bay-Breasted Warbler	*Dendroica castanea*	•				
Bell's Vireo	*Vireo belli*	•				
Belted Kingfisher	*Ceryle alcyon alcyon*	•				
Bewick's Wren	*Thryomanes bewickii*	•				
Black Rail	*Laterallus jamaicensis jamaicensis*	•				
Black Phoebe	*Sayornis nigricans semiatra*	•				
Black Vulture	*Coragyps atratus*	•				
Black Tern	*Chlidonias niger surinamensis*	•				
Black-Bellied Whistling-Duck	*Dendrocygna autumnalis fulgens*	•				
Black-Bellied Plover	*Pluvialis squatarola*	•				
Black-Billed Magpie	*Pica pica hudsonica*	•				
Black-Billed Cuckoo	*Coccyzus erythrophthalmus*	•				
Black-Capped Chickadee	*Poecile atricapillus garrinus*	•				
Black-Capped Vireo	*Vireo atricapillus*					•
Black-Chinned Sparrow	*Spizella atrogularis evura*	•				
Black-Chinned Hummingbird	*Archilochus alexandri*	•				
Black-Crowned Night-Heron	*Nycticorax nycticorax hoactli*	•				
Black-Headed Grosbeak	*Pheucticus melanocephalus*	•				
Black-Necked Stilt	*Himantopus mexicanus mexicanus*	•				
Black-Throated Sparrow	*Amphispiza bilineata bilineata*	•				
Blackburnian Warbler	*Dendroica fusca*	•				

Table A-1 – Fish and Wildlife Inventory

Common Name	Scientific Name	Native	Introduced	Vulnerable	Threatened	Endangered
Blackpoll Warbler	*Dendroica striata*	•				
Blue Grosbeak	*Guiraca caerulea*	•				
Blue Jay	*Cyanocitta cristata*	•				
Blue-Gray Gnatcatcher	*Polioptila caerulea caerulea*	•				
Blue-Headed Vireo	*Vireo solitarius*	•				
Blue-Winged Teal	*Anas discors*	•				
Bobolink	*Dolichonyx oryzivorus*	•				
Bohemian Waxwing	*Bombycilla garrulus pallidiceps*	•				
Bonaparte's Gull	*Larus philadelphia*	•				
Brant	*Branta bernicola*	•				
Brewer's Sparrow	*Spizella breweri breweri*	•				
Brewer's Blackbird	*Euphagus cyanocephalus*	•				
Broad-Winged Hawk	*Buteo platypterus platypterus*	•				
Brown Pelican	*Pelecanus occidentalis carolinensis*					•
Brown Thrasher	*Toxostoma rufum*	•				
Brown Creeper	*Certhia americana*	•				
Brown-Headed Cowbird	*Molotrus ater*	•				
Buff-Breasted Sandpiper	*Tryngites subruficollis*	•				
Bufflehead	*Bucephala albeola*	•				
Bullock's Oriole	*Icterus bullockii*	•				
Burrowing Owl	*Athene cunicularia hypugaea*	•				
Bushtit	*Psaltriparus minimus*	•				
Cactus Wren	*Campylorhynchus brunneicapillus couesi*	•				
Canada Warbler	*Wilsonia canadensis*	•				
Canada Goose	*Branta canadensis*	•				
Canvasback	*Aythya valisineria*	•				
Canyon Wren	*Catherpes mexicanus consperus*	•				
Canyon Towhee	*Pipilo fuscus*	•				
Cape May Warbler	*Dendroica tigrina*	•				
Carolina Wren	*Thryothorus ludovicianus ludovicianus*	•				
Carolina Chickadee	*Poecile carolinensis*	•				
Caspian Tern	*Sterna caspia*	•				
Cassin's Finch	*Carpodacus cassinii*	•				
Cassin's Kingbird	*Tyrannus vociferans vociferans*	•				
Cassin's Sparrow	*Aimophila cassinii*	•				
Cattle Egret	*Bubulcus ibis ibis*	•				
Cave Swallow	*Petrochelidon fulva pallida*	•				
Cedar Waxwing	*Bombycilla cedrorum*	•				
Chestnut-Collared Longspur	*Calcarius ornatus*	•				
Chestnut-Sided Warbler	*Dendroica pensylvanica*	•				
Chihuahuan Raven	*Corvus cryptoleucus*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Chimney Swift	*Chaetura pelagica*	•				
Chipping Sparrow	*Spizella passerina arizonae*	•				
Chuck-Will's-Widow	*Caprimulgus carolinensis*	•				
Cinnamon Teal	*Anas cyanoptera septentrionalium*	•				
Clark's Nutcracker	*Nucifraga columbiana*	•				
Clay-Colored Sparrow	*Spizella pallida*	•				
Cliff Swallow	*Petrochelidon pyrrhonota pyrrhonota*	•				
Common Snipe	*Gallinago gallinago delicata*	•				
Common Moorhen	*Gallinula chloropus cachinnans*	•				
Common Ground-Dove	*Columbina passerina*	•				
Common Loon	*Gavia immer*	•				
Common Redpoll	*Carduelis flammea*	•				
Common Grackle	*Quiscalus quiscula versicolor*	•				
Common Merganser	*Mergus merganser americana*	•				
Common Raven	*Corvus corax sinuatus*	•				
Common Nighthawk	*Chordeiles minor*	•				
Common Yellowthroat	*Geothlypis trichas*	•				
Common Goldeneye	*Bucephala clangula americana*	•				
Common Poorwill	*Phalaenoptilus nuttallii nuttallii*	•				
Cooper's Hawk	*Accipiter cooperii*	•				
Curve-Billed Thrasher	*Toxostoma curvirostre celsum*	•				
Dark-Eyed Junco	*Junco hyemalis*	•				
Dickcissel	*Spiza americana*	•				
Double-Crested Cormorant	*Phalacrocorax auritus auritus*	•				
Downy Woodpecker	*Picoides pubescens*	•				
Dunlin	*Calidris aplina pacifica*	•				
Dusky Flycatcher	*Empidonax oberholseri*	•				
Eared Grebe	*Podiceps nigricollis californicus*	•				
Eastern Bluebird	*Sialia sialis*	•				
Eastern Screech-Owl	*Otus asio*	•				
Eastern Meadowlark	*Sturnella magna*	•				
Eastern Kingbird	*Tyrannus tyrannus*	•				
Eastern Wood-Pewee	*Contopus virens*	•				
Eskimo Curlew	*Numenius borealis*					•
European Starling	*Sturnus vulgaris vulgaris*	•				
Evening Grosbeak	*Coccothraustes vespertinus*	•				
Ferruginous Hawk	*Buteo regalis*			•		
Field Sparrow	*Spizella pusilla*	•				
Fish Crow	*Corvus ossifragus*	•				
Forster's Tern	*Sterna forsteri*	•				
Fox Sparrow	*Passerella iliaca*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Franklin's Gull	*Larus pipixcan*	•				
Fulvous Whistling-Duck	*Dendrocygna bicolor helva*	•				
Gadwall	*Anas strepera*	•				
Golden Eagle	*Aquila chrysaetos canadensis*	•				
Golden-Crowned Kinglet	*Regulus satrapa satrapa*	•				
Golden-Fronted Woodpecker	*Melanerpes aurifrons*	•				
Golden-Winged Warbler	*Vermivora chrysoptera*	•				
Grasshopper Sparrow	*Ammodramus savannarum*	•				
Gray Catbird	*Dumatella carolinensis*	•				
Great Blue Heron	*Ardea herodias treganzai*	•				
Great Horned Owl	*Bubo virginianus*	•				
Great Crested Flycatcher	*Myiarchus crinitus boreus*	•				
Great Egret	*Ardea albus egretta*	•				
Great-Tailed Grackle	*Quiscalus mexicanus prosopidicola*	•				
Greater Prairie-Chicken	*Tympanuchus cupido pinnatus*	•				
Greater White-Fronted Goose	*Anser albifrons*	•				
Greater Yellowlegs	*Tringa melanoleuca*	•				
Greater Roadrunner	*Geococcyx californianus*	•				
Greater Scaup	*Aythya marila nearctica*	•				
Green Heron	*Butorides virescens virescens*	•				
Green-Tailed Towhee	*Pipilo chlorurus*	•				
Green-Winged Teal	*Anas crecca*	•				
Groove-Billed Ani	*Crotophaga sulcirostris sulcirostris*	•				
Hairy Woodpecker	*Picoides villosus villosus*	•				
Harris's Hawk	*Parabuteo unicinctus harrisi*	•				
Hermit Thrush	*Catharus guttatus guttatus*	•				
Herring Gull	*Larus argentatus smithsonianus*	•				
Hooded Merganser	*Lophodytes cucullatus*	•				
Horned Grebe	*Podiceps auritus cornutus*	•				
Horned Lark	*Eremophila alpestris*	•				
House Sparrow	*Passer domesticus domesticus*	•				
House Finch	*Carpodacus mexicanus frontalis*	•				
House Wren	*Troglodytes aedon*	•				
Inca Dove	*Scardafella inca*	•				
Indigo Bunting	*Passerina cyanea*	•				
Killdeer	*Charadrius vociferus vociferus*	•				
King Rail	*Rallus elegans elegans audubon.*	•				
Ladder-Backed Woodpecker	*Picoides scalaris*	•				
Lapland Longspur	*Calcarius lapponicus lapponicus*	•				
Lark Bunting	*Calomospiza melanocorys*	•				
Lark Sparrow	*Chondestes grammacus*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Least Tern	*Sterna antillarum*					•
Least Flycatcher	*Empidonax minimus*	•				
Least Sandpiper	*Calidris minutilla*	•				
Least Bittern	*Ixobrychus exilis exilis*	•				
Leconte's Sparrow	*Ammodramus leconteii*	•				
Lesser Nighthawk	*Chordeiles acutipennis texensis*	•				
Lesser Yellowlegs	*Tringa flavipes*	•				
Lesser Prairie-Chicken	*Tympanuchus pallidicinctus*	•				
Lesser Goldfinch	*Carduelis psaltria psaltria*	•				
Lesser Scaup	*Aythya affinis*	•				
Lewis's Woodpecker	*Melanerpes lewis*	•				
Lincoln's Sparrow	*Melospiza lincolnii*	•				
Little Blue Heron	*Egretta caerulea caerulea*	•				
Loggerhead Shrike	*Lanius ludovicianus*			•		
Long-Billed Curlew	*Numenius americanus americanus*	•				
Long-Billed Dowitcher	*Limnodromus scolopaceus*	•				
Long-Eared Owl	*Asio otus wilsonianus*	•				
Magnolia Warbler	*Dendroica magnolia*	•				
Mallard	*Anas platyrhynchos*	•				
Marbled Godwit	*Limosa fedoa*	•				
Marsh Wren	*Cistotherus palustris*	•				
McCown's Longspur	*Calcarius mccownii*	•				
Merlin	*Falco columbarius*	•				
Mississippi Kite	*Ictinia mississippiensis*	•				
Mottled Duck	*Anas fulvigula maculosa*	•				
Mountain Plover	*Charadrius montanus*	•				
Mountain Bluebird	*Sialia currucoides*	•				
Mountain Chickadee	*Poecile gambeli gambeli*	•				
Mourning Dove	*Zenaida macroura*	•				
Nashville Warbler	*Vermivora ruficapilla*	•				
Neotropic Cormorant	*Phalacrocorax brasilianus mexicanus*	•				
Northern Pintail	*Anas acuta*	•				
Northern Flicker	*Colaptes auratus*	•				
Northern Bobwhite	*Colinus virginianus*	•				
Northern Shoveler	*Anas clypeata*	•				
Northern Waterthrush	*Seiurus novaboracensis*	•				
Northern Rough-Winged Swallow	*Stelgidopteryx serripennis serripennis*	•				
Northern Mockingbird	*Mimus polyglottos leucopterus*	•				
Northern Harrier	*Circus cyaneus hudsonicus*	•				
Northern Cardinal	*Cardinalis cardinalis*	•				
Northern Shrike	*Lanius excubiter invictus*	•				

Table A-1 – Fish and Wildlife Inventory

Common Name	Scientific Name	Native	Introduced	Vulnerable	Threatened	Endangered
Northern Goshawk	*Accipiter gentilis atricapillus*	•				
Oldsquaw	*Clangula hyemalis*	•				
Olivaceous Cormorant	*Phalacrocorax brasilianus*	•				
Olive-Sided Flycatcher	*Contopus cooperi*	•				
Orange-Crowned Warbler	*Vermivora celata celata*	•				
Orchard Oriole	*Icterus spurius spurius*	•				
Osprey	*Pandion haliaetus carolinensis*	•				
Pacific Loon	*Gavia pacifica*	•				
Painted Bunting	*Passerina ciris*	•				
Palm Warbler	*Dendroica palmarum palmarum*	•				
Pectoral Sandpiper	*Calidris melanotos*	•				
Peregrine Falcon	*Falco peregrinus*				•	
Phainopepla	*Phainopepla nitens*	•				
Philadelphia Vireo	*Vireo philadelphica*	•				
Pied-Billed Grebe	*Podilymbus podiceps podiceps*	•				
Pileated Woodpecker	*Dryocopus pileatus pileatus*	•				
Pine Warbler	*Dendroica pinus pinus*	•				
Pine Siskin	*Carduelis pinus pinus*	•				
Pinyon Jay	*Gymnorhinus cyanocephalus*	•				
Prairie Falcon	*Falco mexicanus*	•				
Purple Finch	*Carpodacus purpureus purpureus*	•				
Purple Gallinule	*Porphyrula martinica*	•				
Purple Martin	*Progne subis subis*	•				
Pygmy Nuthatch	*Sitta pygmaea melanotis*	•				
Pyrrhuloxia	*Cardinalis sinuatus sinuatus*	•				
Red Crossbill	*Loxia curvirostra*	•				
Red Phalarope	*Phalaropus fulicaria*	•				
Red-Bellied Woodpecker	*Melanerpes carolinus*	•				
Red-Breasted Nuthatch	*Sitta canadensis*	•				
Red-Breasted Merganser	*Mergus serrator serrator*	•				
Red-Eyed Vireo	*Vireo olivaceus*	•				
Red-Headed Woodpecker	*Melanerpes erythrocephalus*	•				
Red-Necked Grebe	*Podiceps grisegena holbollii*	•				
Red-Necked Phalarope	*Phalaropus lobatus*	•				
Red-Shouldered Hawk	*Buteo lineatus alleni*	•				
Red-Tailed Hawk	*Buteo jamaicensis*	•				
Red-Throated Loon	*Gavia stellata*	•				
Red-Winged Blackbird	*Agelaius phoeniceus*	•				
Reddish Egret	*Egretta rufescens rufescens*				•	
Redhead	*Aythya americana*	•				
Ring-Billed Gull	*Larus delawarensis*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Ring-Necked Duck	*Aythya collaris*	•				
Ring-Necked Pheasant	*Phasianus colchicus introduced.*	•				
Rock Dove	*Columba livia*	•				
Rose-Breasted Grosbeak	*Pheucticus ludovicianus*	•				
Ross's Goose	*Chen rossii*	•				
Rough-Legged Hawk	*Buteo lagopus sanctijohannis*	•				
Ruby-Crowned Kinglet	*Regulus calendula calendula*	•				
Ruddy Duck	*Oxyura jamaicensis rubida*	•				
Rufous-Backed Robin	*Turdus rufopalliatus*	•				
Rufous-Crowned Sparrow	*Aimophila ruficeps eremoeca*	•				
Rusty Blackbird	*Euphagus carolinus*	•				
Sabine's Gull	*Xema sabini sabini*	•				
Sage Thrasher	*Oreoscoptes montanus*	•				
Sandhill Crane	*Grus canadensis*	•				
Savannah Sparrow	*Passerculus sandwichensis*	•				
Say's Phoebe	*Sayornis saya saya*	•				
Scaled Quail	*Callipepla squamata*	•				
Scissor-Tailed Flycatcher	*Tyrannus forficatus*	•				
Sedge Wren	*Cistithorus latensis stellaris*	•				
Semipalmated Sandpiper	*Calidris pusilla*	•				
Semipalmated Plover	*Charadrius semipalmatus*	•				
Sharp-Shinned Hawk	*Accipiter striatus velox*	•				
Short-Eared Owl	*Asio flammeus flammeus*	•				
Smith's Longspur	*Calcarius pictus*	•				
Snow Goose	*Chen caerulescens caerulescens*	•				
Snowy Egret	*Egretta thula thula*	•				
Snowy Plover	*Charadrius alexandrinus*	•				
Solitary Sandpiper	*Tringa solitaria*	•				
Song Sparrow	*Melospiza melodia*	•				
Sora	*Porzana carolina*	•				
Spotted Sandpiper	*Actitis macularia*	•				
Spotted Towhee	*Pipilo maculatus arcticus*	•				
Sprague's Pipit	*Anthus spragueii*	•				
Steller's Jay	*Cyanocitta stelleri macrolopha*	•				
Stilt Sandpiper	*Calidris himantopus*	•				
Surf Scoter	*Melanitta perspicillata*	•				
Swainson's Thrush	*Catharus ustulatus*	•				
Swainson's Hawk	*Buteo swainsoni*	•				
Swallow-Tailed Kite	*Elanoides forficatus forficatus*	•				
Tennessee Warbler	*Vermivora peregrina*	•				
Townsend's Solitaire	*Myadestes townsendi townsendi*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Townsend's Warbler	*Dendroica townsendi*	•				
Tree Swallow	*Tachycineta bicolor*	•				
Tricolored Heron	*Egretta tricolor ruficollis*	•				
Tufted Titmouse	*Baeolophus bicolor*	•				
Tundra Swan	*Cygnus columbianus*	•				
Turkey Vulture	*Cathartes aura septentrionalis*	•				
Upland Sandpiper	*Bartramia longicauda*	•				
Varied Thrush	*Ixoreus naevius*	•				
Veery	*Catharus fuscescens*	•				
Verdin	*Auriparus flaviceps ornatus*	•				
Vermilion Flycatcher	*Pyrocephalus rubinus mexicanus*	•				
Vesper Sparrow	*Pooecetes gramineus*	•				
Violet-Green Swallow	*Tachycineta thalassina lepida*	•				
Virginia Rail	*Rallus limicola limicola*	•				
Western Sandpiper	*Calidris mauri*	•				
Western Grebe	*Aechmophorus occidentalis*	•				
Western Kingbird	*Tyrannus verticalis*	•				
Western Scrub Jay	*Aphelocoma californicatexana*	•				
Western Bluebird	*Sialia mexicana bairdi*	•				
Western Meadowlark	*Sturnella neglecta*	•				
Western Wood-Pewee	*Contopus sordidulus veliei*	•				
Whimbrel	*Numenius phaeopus hudsonicus*	•				
Whip-Poor-Will	*Caprimulgus vociferus vociferus*	•				
White Ibis	*Eudocimus albus*	•				
White-Breasted Nuthatch	*Sitta carolinensis*	•				
White-Crowned Sparrow	*Zonotrichia leucophrys*	•				
White-Eyed Vireo	*Vireo griseus*	•				
White-Faced Ibis	*Plegadis chihi*					•
White-Rumped Sandpiper	*Calidris fuscicollis*	•				
White-Throated Swift	*Aeronautes saxatilis saxatilis*	•				
White-Winged Dove	*Zenaida asiatica*	•				
White-Winged Scoter	*Melanitta fusca deglandi*	•				
White-Winged Crossbill	*Loxia leucoptera*	•				
Whooping Crane	*Grus americanus*					•
Wild Turkey	*Meleagris gallopavo*	•				
Willet	*Catoptrophorus semipalmatus inornatus*	•				
Willow Flycatcher	*Empidonax traillii*	•				
Wilson's Warbler	*Wilsonia pusilla*	•				
Wilson's Phalarope	*Phalaropus tricolor*	•				
Winter Wren	*Troglodytes troglodytes hiemalis*	•				
Wood Duck	*Aix sponsa*	•				

Table A-1 – Fish and Wildlife Inventory						
Common Name	**Scientific Name**	**Native**	**Introduced**	**Vulnerable**	**Threatened**	**Endangered**
Yellow Warbler	*Denroica petechia*	•				
Yellow Rail	*Coturnicops noveboracensis noveboracensis*	•				
Yellow-Bellied Sapsucker	*Sphyrapicus varius*	•				
Yellow-Billed Cuckoo	*Coccyzus americanus americanus*	•				
Yellow-Breasted Chat	*Icteria virens*	•				
Yellow-Crowned Night-Heron	*Nyctanassa violacea violacea*	•				
Yellow-Headed Blackbird	*Xanthocephalus xanthocephalus*	•				
Yellow-Rumped Warbler	*Dendroica coronata*	•				
Yellow-Shafted Flicker	*Colaptes auratus auratus*	•				

References:

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

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

U.S. Fish and Wildlife Service Online Database.

Area B Regional Water Plan, January 2001.

Table A-2 – USGS Streamflow Gage

Little Wichita River near Archer City USGS Station 07314500				
Year	**Average**	**Minimum**	**Maximum**	**Total**
1946	37.43	0.21	168.00	449.11
1947	38.90	0.00	257.00	466.82
1948	19.57	0.27	108.00	234.84
1949	41.27	0.04	190.00	495.23
1950	171.11	0.00	1,337.00	2,053.28
1951	18.81	0.00	115.00	225.75
1952	4.74	0.00	28.20	56.89
1953	31.24	0.00	314.00	374.84
1954	33.63	0.00	249.00	403.54
1955	88.62	0.00	512.00	1,063.38
1967	9.84	0.00	47.80	118.06
1968	38.92	0.59	117.00	467.09
1969	47.81	0.12	189.00	573.77
1970	11.83	0.08	89.10	142.01
1971	26.22	0.00	143.00	314.70
1972	21.57	0.00	96.80	258.83
1973	32.01	0.05	96.90	384.17
1974	32.83	0.00	171.00	393.90
1975	89.64	0.03	521.00	1,075.62
1976	17.69	0.37	91.20	212.23
1977	15.24	0.15	69.10	182.93
1978	8.07	0.28	47.70	96.86
1979	15.15	0.01	77.00	181.85
1980	32.85	0.00	225.00	394.17
1981	82.85	0.00	771.00	994.23
1982	158.35	0.04	1,224.00	1,900.23
1983	12.50	0.00	62.70	149.95
1984	14.38	0.00	79.10	172.60
1985	161.80	1.31	944.00	1,941.60
1986	78.95	0.26	275.00	947.42
1987	66.49	0.05	203.00	797.93
1988	2.72	0.05	17.20	32.68
1989	153.32	0.02	677.00	1,839.80
1990	242.21	0.08	1,062.00	2,906.53
1991	29.70	0.00	194.00	356.43
1992	101.91	0.06	696.00	1,222.87
1993	92.06	0.06	465.00	1,104.75
1994	11.92	0.10	64.20	143.07
1995	36.74	0.03	194.00	440.90
1996	4.83	0.01	29.30	57.94
1997	12.04	0.00	80.20	144.47
1998	15.17	0.00	123.00	182.09
1999	16.56	0.08	115.00	198.73
2000	20.29	0.00	153.00	243.51
2001	52.69	0.00	254.00	632.25
Average	**50.05**	**0.10**	**287.61**	**600.66**

Table A-3 – Regional Climatology Data Above Lake Arrowhead

Year	Rainfall	Evaporation	Year	Rainfall	Evaporation
1940	29.26	–	1971	26.63	67.08
1941	48.37	–	1972	27.91	63.86
1942	29.11	–	1973	29.75	56.45
1943	18.51	–	1974	28.42	66.20
1944	27.13	–	1975	31.31	56.53
1945	26.39	–	1976	26.95	60.05
1946	26.69	–	1977	20.97	62.52
1947	23.05	–	1978	25.71	63.41
1948	19.13	–	1979	26.06	58.84
1949	32.53	–	1980	25.61	70.76
1950	31.56	–	1981	29.51	58.49
1951	21.40	–	1982	33.56	58.29
1952	15.39	–	1983	25.62	57.99
1953	23.14	–	1984	24.67	66.19
1954	19.97	63.86	1985	29.84	59.14
1955	26.11	60.50	1986	35.15	59.67
1956	14.11	73.55	1987	29.85	58.40
1957	38.24	50.67	1988	22.23	63.91
1958	23.92	49.98	1989	30.94	65.48
1959	27.65	49.96	1990	38.13	61.48
1960	27.21	49.64	1991	34.91	73.77
1961	28.79	46.92	1992	33.01	59.39
1962	33.01	47.31	1993	27.29	74.55
1963	21.33	44.59	1994	28.07	67.97
1964	26.39	67.31	1995	35.95	63.56
1965	25.01	67.87	1996	27.02	69.60
1966	29.16	64.95	1997	32.90	61.72
1967	23.16	66.99	1998	20.81	70.42
1968	31.14	56.19	1999	24.12	61.77
1969	32.87	59.01	2000	25.93	62.49
1970	18.17	61.60			

Average Rainfall . . . . 27.49 ”
Average Maximum Rainfall . . . . 48.37 ”
Average Minimum Rainfall . . . . 14.11 ”

Average Evaporation . . . . 61.29 ”
Average Maximum Evaporation . . . . 74.55 ”
Average Minimum Evaporation . . . . 44.59 ”

Table A-4
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
Quaternary	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		----	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		----	Fossiliferous limestone, marl, and clay; some sand near the top	Yields small quantities of water to shallow wells
Cretaceous	Trinity Group		----	Fine to coarse sand, interbedded calcareous shale, conglomerate, limestone, clay, and anhydrite	Not included in study area
Triassic	Dockum Formation		----	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	----	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
Permian	Clear Fork Group		----	Chiefly shale and thin beds of limestone, marl, dolomite, anhydrite, gypsum, and sandstone	Yields small quantities of slightly to moderately saline water
Permian	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
Pennsylvanian	Cisco Group		1,200	Shale sandstone, conglomerate, limestone, and a few beds of coral	Yields small to moderate quantities of fresh to moderately saline water for public supply, industrial irrigation, domestic, and stock wells
Pennsylvanian	Canyon Group		1,600	Chiefly limestone and shale; minor amounts of sandstone and conglomerate	Yields small quantities of fresh to slightly saline water to wells in and near the outcrop
Pennsylvanian	Strawn Group		2,500	Alternating beds of shale, conglomerate, and sandstone; minor amounts of limestone and coal	Yields small quantities of slightly to moderately saline water from sandstone and conglomerate in and near the outcrop

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

Table A-5
Texas Water Development Board Observation Well Inventory

Well Number	County	Owner	Well Depth (ft)	Elevation AMSL	Aquifer Code	Water Use	Remarks
2025401	Baylor	American Petrofina	946	1,175	318WCHT	Industrial	Converted oil test used in water-flooding operation.
2033703	Baylor	Mrs. J. L. Hargraves	27	1,256	100ALVM	Unused	Dug well. Windmill broken.
2132201	Baylor	Skelly Oil Company	4,250	1,270	321CNYN	Unused	Formerly used to supply salt water for water flooding. Re-entry of oil test. Produced from Canyon Reef (Pennsylvanian).
2139301	Baylor	Jim Welch	20	1,208	100ALVM	Unused	Dug well. Formerly domestic and livestock supply.
2140102	Baylor	Portwood Ranch and Co.	35	1,226	100ALVM	Stock	Dug well.
2140107	Baylor	Mrs. S. S. Knox	16	1,190	100ALVM	Stock	Dug well.
2140113	Baylor	Lincoln Burns Estate	12	1,197	100ALVM	Unused	Dug well. Windmill broken. Formerly used as livestock supply.
2020501	Archer	Doug and Jill Dunkel	125	996	318WCHT	Stock	Water-level observation well.
2021707	Archer	Ray Hemmi	90	971	318WCHT	Unused	Water-level observation well.
2026401	Archer	J. R. Parkey, Jr.	32	1,120	318WCHT	Domestic	Dug well.
2028201	Archer	R. C. Kinder	30	1,041	318WCHT	Domestic	Dug well.
2028404	Archer	Duren Bell	45	1,025	318WCHT	Domestic	Dug well.
2033302	Archer	A. B. Alexander	50	1,200	318WCHT	Stock	Slotted or perforated interval not known.
2033601	Archer	R. M. Echols	20	1,238	318WCHT	Stock	Dug well.
2035401	Archer	Jack Neal	100	1,272	318WCHT	Stock	Waters livestock and reported at 48-53'.
2035701	Archer	E. Alsup	28	1,258	318WCHT	Domestic	Dug well.
2036101	Archer	L. T. Burns	80	1,118	318WCHT	Domestic	Well located in cellar.
2036903	Archer	Kouri Oil Company	102	1,107	321CSCO	Domestic	Oil lease supply well. Drilled to 300' and plugged back to 102'.
2036904	Archer	C. C. Prideaux	50	1,085	321CSCO	Domestic	Dug well.
2037401	Archer	Timberlake, et al.	650	1,130	321CSCO	Industrial	Water-flood supply well.
2037501	Archer	H. O. Prideaux	550	1,065	321CSCO	Domestic	Water-level observation well.
2037701	Archer	E. Woody	475	1,033	321CSCO	Unused	Well abandoned.
2037704	Archer	Timberlake, et al	650	1,102	321CSCO	Industrial	Water-flood supply well. Casing perforated at 475'.
2037801	Archer	B S and M Oil Co.	650	1,050	321CSCO	Industrial	Water-flood supply well.
2037804	Archer	O. L. Matlock	650	1,034	321CSCO	Industrial	Plugged oil test. Casing perforated at 520'.
2037805	Archer	Erno Woody	350	1,025	321CSCO	Industrial	Water-flood supply well.
2005301	Clay	Joe L. Hale	47	928	110ALVM	Stock	Former water-level observation well. Steel casing perforated from 34-40'.
2006201	Clay	C. E. Halford	102	978	318WCHT	Domestic	Steel casing perforated from 62-67' and 73-92'.

Table A-5
Texas Water Development Board Observation Well Inventory

Well Number	County	Owner	Well Depth (ft)	Elevation AMSL	Aquifer Code	Water Use	Remarks
2022401	Clay	Nelson Hopkins	94	954	321CSCO	Stock	Casing slotted from 15-25 and 68-78' cemented from 15' to surface.
2022501	Clay	Leon F. Wines	101	1,023	321CSCO	Domestic	Casing perforated from 88-101'.
2022503	Clay	P. V. Howard	60	1,004	321CSCO	Domestic	Casing set to total depth and perforated, interval not known.
2022504	Clay	M. A. Browning	61	1,004	321CSCO	Unused	Screened or open interval not known.
2022505	Clay	M. A. Browning	66	1,000	321CSCO	Domestic	Screened or open interval not known.
2022506	Clay	M. A. Browning	100	960	321CSCO	Unused	Screened open interval not known. Well originals drilled for a rig supply. Reported flows during wet years.
2022507	Clay	P. V. Howard	60	968	321CSCO	Stock	Casing perforated, interval not known.
2022508	Clay	P. V. Howard	60	956	321CSCO	Unused	Waters and reported to occur between 40-60'. Casing is perforated opposite water sand.
2022509	Clay	Ed McAlvain	110	1,018	319ARCT	Domestic	Reported yield 12 gpm. Cemented from 0-25'.
2022510	Clay	Robert Howard	100	982	319ARCT	Domestic	Reported yield 12 gpm. Cemented from 30-40'.
2037302	Clay	Barney Oliver	110	1,112	321CSCO	Unused	Screened or open interval not reported. Drilled for a livestock supply. Unused due to insufficient yield.
2037303	Clay	Barney Oliver	240	1,112	321CSCO	Domestic	Screened or open interval not reported. Gravel pack from 30-240'. Casing cemented from 30' to surface.
2038201	Clay	Granvel M. Wells	225	1,123	321CSCO	Domestic	Casing perforated from 195-220'. Cemented from 23' to surface.
2038203	Clay	Coy Simons	180	1,005	321CSCO	Domestic	Casing slotted from 135-145 and 165-175'. Well used to water yard. Not used for drinking.
2039101	Clay	L. V. Martin	200	1,065	321CSCO	Domestic	Casing perforated from 160-200'. Reported yield 7 gpm.
2039102	Clay	L. V. Martin	206	1,065	321CSCO	Unused	Casing slotted from 35-50, 90-100 and 180-200'. Reported yield 12 gpm.

100ALVM – Alluvium
110ALVM – Quaternary Alluvium
318WCHT – Wichita Formation or Group
319ARCT – Archer City Formation
321CNYN – Canyon Group
321CSCO – Cisco Group

Table A-6
Artesian Springs Inventory
Little Wichita River Watershed above Lake Arrowhead

County	Medium to Large	Medium	Small	Very Small	Seeps	Former	Total
Archer	0	0	1	4	7	2	14
Baylor	0	0	7	3	9	0	19
Clay	0	0	3	3	8	7	21
Total	0	0	11	10	24	9	54

Table A-7
Sub-Basin Data and Watershed Yield

Sub-Basin	Sub-Basin Acres	Brush Area (Treated Acres)	Brush Fraction (Treated)	Increase in Water Yield (Gal/Acre/Yr)	Increase in Water Yield (Ac-Ft/Yr)
1	28,436	13,386	0.47	160,960	6,618.17
2	22,639	12,963	0.57	123,733	4,926.74
3	34,477	19,315	0.56	136,944	8,124.69
4	15,948	10,003	0.63	114,914	3,530.79
5	7,650	5,399	0.71	96,876	1,606.57
6	12,094	6,252	0.52	169,672	3,258.35
7	19,194	6,906	0.36	180,492	3,828.72
8	21,360	13,422	0.63	186,871	7,704.21
9	22,955	12,437	0.54	138,624	5,295.70
10	36,915	22,181	0.60	186,112	12,680.15
11	39,126	20,641	0.53	202,270	12,824.23
12	6,465	1,525	0.24	250,943	1,175.48
13	25,740	17,583	0.68	196,202	10,596.57
14	22,557	13,611	0.60	199,419	8,337.30
15	12,271	6,000	0.49	198,127	3,651.44
16	5,823	3,870	0.66	253,559	3,014.11
17	4,255	2,892	0.68	226,774	2,014.47
18	5,703	2,871	0.50	193,938	1,710.27
19	29,269	15,494	0.53	182,240	8,673.14
20	25,931	13,739	0.53	177,612	7,495.43
21	19,745	6,280	0.32	161,702	3,119.21
22	4,924	1,392	0.28	195,682	836.68
23	34,833	16,066	0.46	201,608	9,949.12
24	27,197	15,172	0.56	199,036	9,275.63
25	11,277	4,688	0.42	190,648	2,745.29
26	10,378	7,362	0.71	237,128	5,362.26
27	7,842	4,796	0.61	133,644	1,968.78
28	14,348	1,410	0.10	331,070	1,433.86
Totals	**529,352**	**277,656**		**5,226,800**	**151,757.34**
Average	—	—	**0.52**	—	—

TECHNICAL APPENDICES

CHAPTER 1

BRUSH / WATER YIELD FEASIBILITY STUDIES II

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Abstract: The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in four watersheds in Texas for 1960 through 1999. Methods used in this study were similar to methods used in a previous study (TAES, 2000) in which eight watersheds were analyzed. Landsat 7 satellite imagery was used to classify land use, and the 1:24,000 scale digital elevation model (DEM) was used to delineate watershed boundaries and subbasins. SWAT was calibrated to measured stream gauge flow and reservoir storage. Brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Simulated changes in water yield due to brush treatment varied by subbasin, with all subbasins showing increased water yield as a result of removing brush. Average annual water yield increases ranged from about 111,000 gallons per treated acre in the Fort Phantom Hill watershed to about 178,000 gallons per treated acre in the Palo Pinto watershed. Water yield increases per treated acre were similar to a previous study (COE, 2002), but higher than TAES (2000). As in previous studies, there was a strong, positive correlation between water yield increase and precipitation.

BACKGROUND

Increases in brush area and density may contribute to a decrease in water yield, possibly due to increased evapotranspiration (ET) on watersheds with brush as compared to those with grass (Thurow, 1998; Dugas et al., 1998). Previous modeling studies of watersheds in Texas (Upper Colorado River Authority, 1998; TAES, 2000) indicated that removing brush might result in a significant increase in water yield.

During the 2000-2001 legislative session, the Texas Legislature appropriated funds to study the effects of brush removal on water yield in watersheds above Lake Arrowhead, Lake Brownwood, Lake Fort Phantom Hill, and Lake Palo Pinto (Figure 1-1). The hydrologic "feasibility" studies were conducted by a team from the Texas Agricultural Experiment Station (TAES), U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) and Agricultural Research Service (ARS), and the Texas State Soil and Water Conservation Board (TSSWCB).

The objective of this study was to quantify the hydrologic and economic implications of brush removal in the selected watersheds. This chapter will focus on general hydrologic modeling methods, inputs, and results across watersheds. Chapter 2 contains similar information for economics. Subsequent chapters contain detailed methods and results of the modeling and economics for each watershed.

METHODS

SWAT Model Description

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998) is the continuation of a long-term effort of nonpoint source pollution modeling by the USDA-ARS, including development of CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985; Arnold et al., 1990), and ROTO (Arnold et al., 1995b).

SWAT was developed to predict the impact of climate and management (e.g. vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large un-gauged basins. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; (d) operates on a daily time step; and (e) is capable of simulating long periods for computing the effects of management changes. SWAT allows a watershed to be divided into hundreds or thousands of grid cells or sub-watersheds.

SWAT was used to simulate water yield (equal to the sum of surface runoff + shallow aquifer flow + lateral soil flow – subbasin transmission losses) and stream flow in each watershed under current conditions and under conditions associated with brush removal.

Geographic Information System (GIS)

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (e.g., soils, land use, and topography) for comprehensive simulation models and to spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS (Srinivasan and Engel, 1991; Rewerts and Engel, 1991). An interface was developed for SWAT (Srinivasan and Arnold, 1994) using the Graphical Resources Analysis Support System (GRASS) (U.S. Army, 1988). The input interface extracts model input data from map layers and associated relational databases for each subbasin. Soils, land use, weather, management, and topographic data are collected and written to appropriate model input files. The output interface allows the user to display output maps and graph output data by selecting a subbasin from a GIS map. The study was performed using GRASS GIS integrated with the SWAT model, both of which operate in the UNIX operating system.

SWAT Model and GIS Interface Changes

The modeling methods in this study are similar to those used in TAES (2000). However, several changes were made in the model and GIS interface as follows:

1. The canopy interception algorithm was changed to reflect recent juniper interception measurements on the Edwards Plateau (Owens et al., 2001). The fraction of a daily rainfall event (mm/day) intercepted was calculated as follows: Fraction = X*-.1182*ln(rainfall)+1, where X was assumed to be 0.2 and 0.5 for moderate (20% average canopy) and heavy (50% average canopy) juniper, respectively, and 0.1 and 0.25 for moderate and heavy canopies of mixed brush (50 percent juniper), respectively. In general, interception was reduced about 50 percent using this equation relative to algorithms used in TAES (2000).

2. The equation for calculation of potential evapotranspiration (PET) using the Priestley-Taylor equation was corrected (it was in error for the TAES [2000] study). This decreased PET relative to that calculated in TAES (2000) by about 25 percent.

3. The GRASS GIS interface for the SWAT model was modified to allow greater input detail.

4. The reservoir and pond evaporation algorithms were changed from 0.6 * PET to 1.0 * PET so that predicted reservoir evaporation would be approximately equal to lake measurements. This change resulted in an increase in reservoir evaporation relative to the TAES (2000) study.

GIS Data

Development of databases and GIS layers was an integral part of the feasibility study. The data were assembled at the highest level of detail possible in order to accurately define the physical characteristics of each watershed.

Land Use/Land Cover. Land use and cover affect, among other processes, surface erosion, water runoff, and ET in a watershed. Development of detailed land use/land cover information for the watersheds in the project area was accomplished by classifying Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data. The ETM+ instrument is an eight-band multi-spectral scanning radiometer capable of providing high-resolution information of the Earth's surface. It detects spectrally filtered radiation at visible, near-infrared, short wave, and thermal infrared frequency bands.

Portions of four Landsat 7 scenes were classified using ground control points (GCP) collected by NRCS field personnel. The Landsat 7 satellite images used a resolution of six spectral channels (the thermal band (6) and panchromatic band (Pan) were not used in the classification) and a spatial resolution of 30 meters. The imagery was taken from July 23, 1999 through August 15, 1999 in order to obtain relatively cloud-free scenes during the growing season for the project areas. These images were radiometrically and precision terrain corrected (personal communication, Gordon Wells, TNRIS, 2000).

Approximately 650 GCP's were located and described by NRCS field personnel in November and December 2001. Global positioning System (GPS) receivers were utilized to locate the latitude and longitude of the control points. A database was developed from the GCP's with information including the land cover, brush species, estimated canopy cover, aerial extent, and other pertinent information about each point.

The Landsat 7 images were imported into GIS software. Adjoining scenes in each watershed were histogram matched or regression corrected to the scene containing the highest number of GCP's (this was done in order to adjust for the differences in scenes because of dates, time of day, atmospheric conditions, etc.). Adjoining scenes were mosaiced and trimmed into one image that covered an individual watershed.

The GCP's were employed to instruct the software to recognize differing land uses based on spectral properties. Individual GCP's were "grown" into areas approximating the aerial extent as reported by the data collector. One-meter resolution Digital Ortho Quarter Quads (DOQQ) were used to correct or enhance the aerial extent of the points. Spectral signatures were collected by overlaying these areas over the imagery and collecting pixel values from the six imagery layers. A supervised maximum likelihood classification of the image was performed with the spectral signatures for various land use classes. The GCP's were used to perform an accuracy assessment of the resulting image. NRCS field personnel further verified a sampling of the initial classification.

Although vegetation classes varied slightly among all watersheds, land use and cover was generally classified as follows:

Heavy Cedar, Mesquite, Oak, Mixed	Mostly pure stands of cedar (juniper), mesquite, and oak, or mixed brush with average canopy cover greater than 30 percent.
Moderate Cedar, Mesquite, Oak, Mixed	Mostly pure stands of cedar, mesquite, and oak, or mixed brush with average canopy cover of 10 to 30 percent.
Light Cedar, Mesquite, Oak, Mixed	Mostly pure stands of cedar, mesquite, and oak, or mixed brush with average canopy cover less than 10 percent.
Range/Pasture	Various species of native grasses or improved pasture.
Cropland	All cultivated cropland.
Water	Ponds, reservoirs, and large perennial streams.
Barren	Bare Ground
Urban/Roads	Developed residential, industrial, transportation.
Other	Other small insignificant categories.

The accuracy of the classified images varied from 60 to 80 percent. All watersheds had a large percentage of heavy and moderate brush (Table 1-1).

Table 1-1. Land Use and Percent Cover in Each Watershed

	Percent Cover					
Watershed	**Heavy and Moderate Brush (no oak)**	**Oak**	**Light Brush (no oak)**	**Pastureland Rangeland**	**Cropland**	**Other, Water, Urban, Roads, Barren**
Arrowhead	52	2	21	3	14	8
Brownwood	46	13	14	4	16	7
Fort Phantom Hill	46	4	9	5	26	10
Palo Pinto	47	24	12	6	6	3

Soils. The soils database describes the surface and upper subsurface of a watershed and is used to determine a water budget for the soil profile, daily runoff, and erosion. The SWAT model uses information about each soil horizon (e.g., thickness, depth, texture, water holding capacity, etc.).

The soils database used for this project was developed from three major sources from the NRCS:

1. The database known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) is a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. The CBMS database differs from some grid GIS databases in that the attribute of each cell was determined by the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell.

2. The Soil Survey Geographic (SSURGO) is the most detailed soil database available. This 1:24,000-scale soils database is available as printed county soil surveys for over 90% of Texas counties. However, not all mapped counties are available in GIS format (vector or high resolution cell data). In the SSURGO database, each soil delineation (mapping unit) is described as a single soil series.

3. The soils database currently available for all of Texas is the State Soil Geographic (STATSGO) 1:250,000-scale soils database, which covers the entire United States. In the STATSGO database, each soil delineation or mapping unit is made up of more than one soil series. Some STATSGO mapping units contain as many as twenty SSURGO soil series. The dominant SSURGO soil series within an individual STATSGO polygon was selected to represent that area.

The GIS layer representing the soils within each watershed was a compilation of CBMS, SSURGO, and STATSGO information. The most detailed information available was selected for each county and patched together to create the final soils layer. SSURGO data was available for approximately 90 percent of Phantom Hill and 75 percent of Palo Pinto watersheds. CBMS soils were used in about 90 percent of Brownwood and essentially all of Arrowhead watersheds. Very little STATSGO soils were used in any of the watersheds.

SWAT used the soils series name as the data link between the soils GIS layer and the soils properties database. County soil surveys were used to verify data for selected dominant soils within each watershed.

Topography. The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of a watershed as a topographical database. The DEM available for the project area is a 1:24,000 scale map. The resolution of the DEM is 30 meters, allowing detailed delineation of watershed boundaries (Figure 1-1) and subbasins within each watershed (Table 1-2).

Table 1-2. Watershed Area, Number of Subbasins, and Average Annual Precipitation

Watershed	Total Area (acres)	Number of Subbasins	Average Annual Precipitation (inches)
Lake Arrowhead	529,354	28	28.0
Lake Brownwood	997,039	48	26.5
Lake Fort Phantom Hill	301,118	17	25.4
Lake Palo Pinto	296,398	22	30.4

Climate. Daily precipitation totals were obtained for National Weather Service (NWS) stations within and adjacent to the watersheds for 1960 through 1999. Data from nearby stations were substituted for missing precipitation data in each station record. Daily maximum and minimum temperatures were obtained for the same NWS stations. A weather generator was used to generate missing temperature data and all solar radiation for each climate station. Average annual precipitation decreased from east to west (Table 1-2 and Figure 1-1).

Model Inputs

Required inputs for each subbasin (e.g. soils, land use/cover, topography, and climate) were extracted and formatted using the SWAT/GRASS input interface (Srinivasan and Arnold, 1994). Specific values used in each watershed are discussed in the individual chapters.

Hydrologic Response Units (HRU). The input interface divided each subbasin into HRU's. A single land use and soil were selected for each HRU. The number of HRU's within a subbasin was determined by: (1) creating an HRU for each land use that equaled or exceeded 0.1 percent of the area of a subbasin; and (2) creating an HRU for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). The total number of HRU's for each watershed, dependent on the number of subbasins and the variability of the land use and soils within the watershed, ranged from 677 in Fort Phantom Hill to 2,074 in Brownwood.

Surface Runoff. Surface runoff was predicted using the SCS curve number equation (USDA-Soil Conservation Service, 1972). Higher curve numbers represent greater runoff potential. Curve numbers were selected assuming existing brush sites were in fair hydrologic condition and existing open range and pasture sites with no brush were in good hydrologic condition.

Soil Properties. Soil available water capacity is water available for use by plants if the soil was at field capacity. Crack volume controls the amount of surface cracking in dry clayey soils. Saturated conductivity is a measure of the ease of water movement through the soil. These inputs were adjusted to match county soil survey data.

The soil evaporation compensation factor adjusts the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracks. A factor of 0.85 is normally used, but lower values are used in dry climates to account for moisture loss from deeper soil layers.

Shallow Aquifer Properties. Shallow aquifer storage is water stored below the root zone. Flow from the shallow aquifer is not allowed until the depth of water in the aquifer is equal to or greater than the input value. Shallow aquifer re-evaporation coefficient controls the amount of water that will move from the shallow aquifer to the root zone as a result of soil moisture depletion, and the amount of direct water uptake by deep-rooted trees and shrubs. Higher values represent higher potential water loss. Setting the minimum depth of water in the shallow aquifer before re-evaporation is allowed also controls the amount of re-evaporation. Shallow aquifer storage and re-evaporation inputs affect base flow.

Transmission Losses. Channel transmission loss is the effective hydraulic conductivity of channel alluvium, or water loss in the stream channel. Transmission losses were estimated from NRCS geologic site investigations in the vicinity of the watersheds (personal communication, Pete Waldo, NRCS geologist, Fort Worth, 2002). The fraction of transmission loss that returns to the stream channel as base flow was also adjusted.

Plant Growth Parameters. Potential heat units (PHU) are the number of growing degree days needed to bring a plant to maturity and varies by latitude. PHU decreases as latitude increases. PHU’s were obtained from published data (NOAA, 1980).

The leaf area index (LAI) specifies the projected vegetation area per ground surface area. Plant rooting depth, canopy height, albedo, and maximum LAI were based on observed values and modeling experience.

Model Calibration

The calibration period was based on the available period of record for stream gauge flow and reservoir volumes within each watershed. Measured stream flow was obtained from USGS. Measured monthly reservoir storage and reservoir withdrawals were obtained from USGS, Texas Water Development Board (TWDB), river authorities, water districts, reservoir managers, and other water users. A base flow filter (Arnold et al., 1995a) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

Appropriate plant growth parameters for brush, native grass, and other land covers were input for each model simulation. Adjustments were made to runoff curve number, soil evaporation compensation factor, shallow aquifer storage, shallow aquifer re-evaporation, and channel transmission loss until the simulated total flow and fraction of base flow were approximately equal to the measured total flow and base flow, respectively. Predicted reservoir storage was also compared to measured storage when data were available.

Brush Removal Simulations

In order to simulate the "treated" or "no-brush" condition, input files for all areas of heavy and moderate brush (except oak) were converted to native grass rangeland. Appropriate adjustments were made in model inputs (e.g. runoff curve number, PHU, LAI, plant rooting depth, canopy height, and re-evaporation coefficient) to simulate the replacement of brush with grass. All other calibration parameters and inputs were held constant. It was assumed all categories of oak and light brush would not be treated.

After calibration of flow, each watershed was simulated for the brush and no-brush conditions for the years 1960 through 1999.

RESULTS

Comparisons of watershed characteristics, water yield, and stream flow across all watersheds are presented in this chapter. Comparisons of modeling results of this study to previous studies (TAES, 2000; COE, 2002) are also presented. Detailed results of flow calibration and brush treatment simulations for individual watersheds are presented in subsequent chapters of this report.

Watershed Calibration

Measured and predicted flows and measured and predicted reservoir volumes were within about 7 percent of each other, on the average (see chapters 3, 5, 7, and 9). Deviations between predicted and measured values were attributed to precipitation variability that was not reflected in measured climate data, errors in estimated model inputs, or other factors.

Brush Removal Simulations

All watersheds showed an increase in water yield and stream flow as a result of removing brush. Average annual water yield increase varied by watershed and ranged from about 111,000 gallons per treated acre in the Fort Phantom Hill watershed to about 178,000 gallons per treated acre in the Palo Pinto watershed (Figure 1-2). As in previous studies (TAES, 2000; COE, 2002) water yield increases were higher for watersheds with greater annual precipitation.

Stream flow increase at the watershed outlet (Figure 1-2) ranged from about 32,000 gallons per treated acre in Fort Phantom Hill to about 127,000 gallons per treated acre in Arrowhead. Average annual stream flow increases were less than water yield increases because of channel transmission losses that occur between each subbasin and the watershed outlet, and capture of runoff by upstream reservoirs. Stream flow increases for Fort Phantom Hill and Palo Pinto were significantly less than water yield increases because these two watersheds had higher channel transmission losses and upstream reservoirs had a greater effect on stream flow.

Average annual inflow increases for lakes at each watershed outlet were higher for watersheds with greater drainage area (Figure 1-3). One exception was Fort Phantom Hill, which had less inflow increase than Palo Pinto, even though the drainage area of Fort Phantom Hill was slightly greater. This was most likely due to lower annual rainfall and higher channel transmission loss in Fort Phantom Hill.

Water yield increases for watersheds in this study were similar to COE (2002), but slightly higher than TAES (2000) (Figure 1-4). In TAES (2000), removal of all brush was simulated, and in COE (2002) several scenarios of partial brush removal were simulated. The data for COE (2002) shown in Figure 1-4 are for Scenario I – removal of all brush on slopes less than 15 percent.

Water yield increases for the current study and COE (2002) were higher than TAES (2000) because of SWAT model changes after the TAES (2000) study was completed, especially a reduction in calculated PET.

The higher water yield for Arrowhead (Figure 1-4) was likely due to the higher percentage of hydrologic group "D" soils in this watershed (54 percent versus 39, 21, 38 for Brownwood, Phantom Hill, and Palo Pinto, respectively) that produced a greater difference in annual runoff volume between brush and no-brush conditions.

SUMMARY

The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in four watersheds in Texas for 1960 through 1999. Landsat 7 satellite imagery from 1999 was used to classify current land use and cover for all watersheds. Brush cover was separated by species (cedar, mesquite, oak, and mixed) and by density (heavy, moderate, light). After calibration of SWAT to existing stream gauge and reservoir data, brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Removal of light brush was not simulated.

Simulated changes in water yield resulting from brush treatment varied by subbasin, with all subbasins showing increased water yield as a result of removing brush. Average annual water yield increases ranged from about 111,000 gallons per treated acre in the Fort Phantom Hill watershed to about 178,000 gallons per treated acre in the Palo Pinto watershed. Water yield increases per treated acre were similar to a previous study (COE, 2002), but higher than TAES (2000). As in previous studies, there was a strong, positive correlation between water yield increase and precipitation.

For this study, we assumed removal of 100 percent of heavy and moderate categories of brush (except oak). Actual amounts and locations of brush removed will be dependent on economics and wildlife habitat considerations.

The hydrologic response of each watershed is directly dependent on receiving precipitation events that provide the opportunity for surface runoff and ground water flow.

LITERATURE CITED

Arnold, J.G., P.M. Allen, R.S. Muttiah, G. Bernhardt. 1995a. Automated Base Flow Separation and Recession Analysis Techniques. GROUND WATER, Vol. 33, No. 6, November-December.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment, Part 1: Model Development. Journal of American Water Resources Association. 34(1): 73-89.

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management. Texas A&M Univ. Press, College Station.

Arnold, J.G., J.R. Williams, D.R. Maidment. 1995b. A Continuous Water and Sediment Routing Model for Large Basins. American Society of Civil Engineers Journal of Hydraulic Engineering. 121(2): 171-183.

COE. 2002. Corps of Engineers Brush Control/Water Yield/Wildlife Study Final Report. In preparation by Texas Agricultural Experiment Station.

Dugas, W.A., R.A. Hicks, and P. Wright. 1998. Effect of Removal of Juniperus Ashei on Evapotranspiration and Runoff in the Seco Creek Watershed. Water Resources Research, Vol. 34, No. 6, 1499-1506.

Knisel, W.G. 1980. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. United States Department of Agriculture Conservation Research Report No. 26.

Nichols, J.D. 1975. Characteristics of Computerized Soil Maps. Soil Science Society of America Proceedings. Volume 39, No. 5.

National Oceanic and Atmospheric Administration (NOAA). 1980. Climatology of the United States No. 20, Climatic Summaries for Selected Sites, 1951 – 1980, Texas.

Owens, M.K., R. Lyons, and C. Kneuper. 2001. Evaporation and Interception Water Loss from Juniper Communities on the Edwards Aquifer Recharge Area. Final Report to Funding Agencies. June 25, 2001. Data available at http://uvalde.tamu.edu/intercept/

Rewerts, C.C. and B.A. Engel. 1991. Answers on GRASS: Integrating a watershed simulation with a GIS. ASAE Paper No. 91-2621, American Society of Agricultural Engineers, St. Joseph, MI.

Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin Scale Water Quality Model With GIS. Water Resources Bulletin, Vol. 30, No. 3, June.

Srinivasan, R. and B.A. Engel. 1991. A Knowledge Based Approach to Exact Input data From GIS. ASAE Paper No. 91-7045, American Society of Agricultural Engineers, St. Joseph, MI.

TAES. 2000. Brush Management/Water Yield Feasibility Studies for Eight Watersheds in Texas. Final Report to the Texas State Soil and Water Conservation Board. November 13, 2000. Texas Water Resources Institute Technical Report No. TR-182.

Thurow, T.L. 1998. Assessment of Brush Management as a Strategy for Enhancing Water Yield. Proceedings of the 25th Water For Texas Conference.

Thurow T.L., and C.A. Taylor Jr. 1995. Juniper Effects on the Water Yield of Central Texas Rangeland. Proc. 24th Water for Texas Conference, Texas Water Resources Institute, Austin, Texas January 26-27; Ed. Ric Jensen.

Upper Colorado River Authority. 1998. North Concho River Watershed – Brush Control Planning, Assessment and Feasibility Study. Available in microfiche from Texas State Publications: http://www.tsl.state.tx.us/statepubs/microfiche/200004-06mforder.pdf

U.S. Army. 1988. GRASS Reference Manual. USA CERL, Champaign, IL.

U.S. Department of Agriculture, Soil Conservation Service, 1972. National Engineering Handbook, Section 4-Hydrology, Chapters 4-10.

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator for Water Resources in Rural Basins. J. Hydraulic Eng., ASCE, 111(6): 970-986.

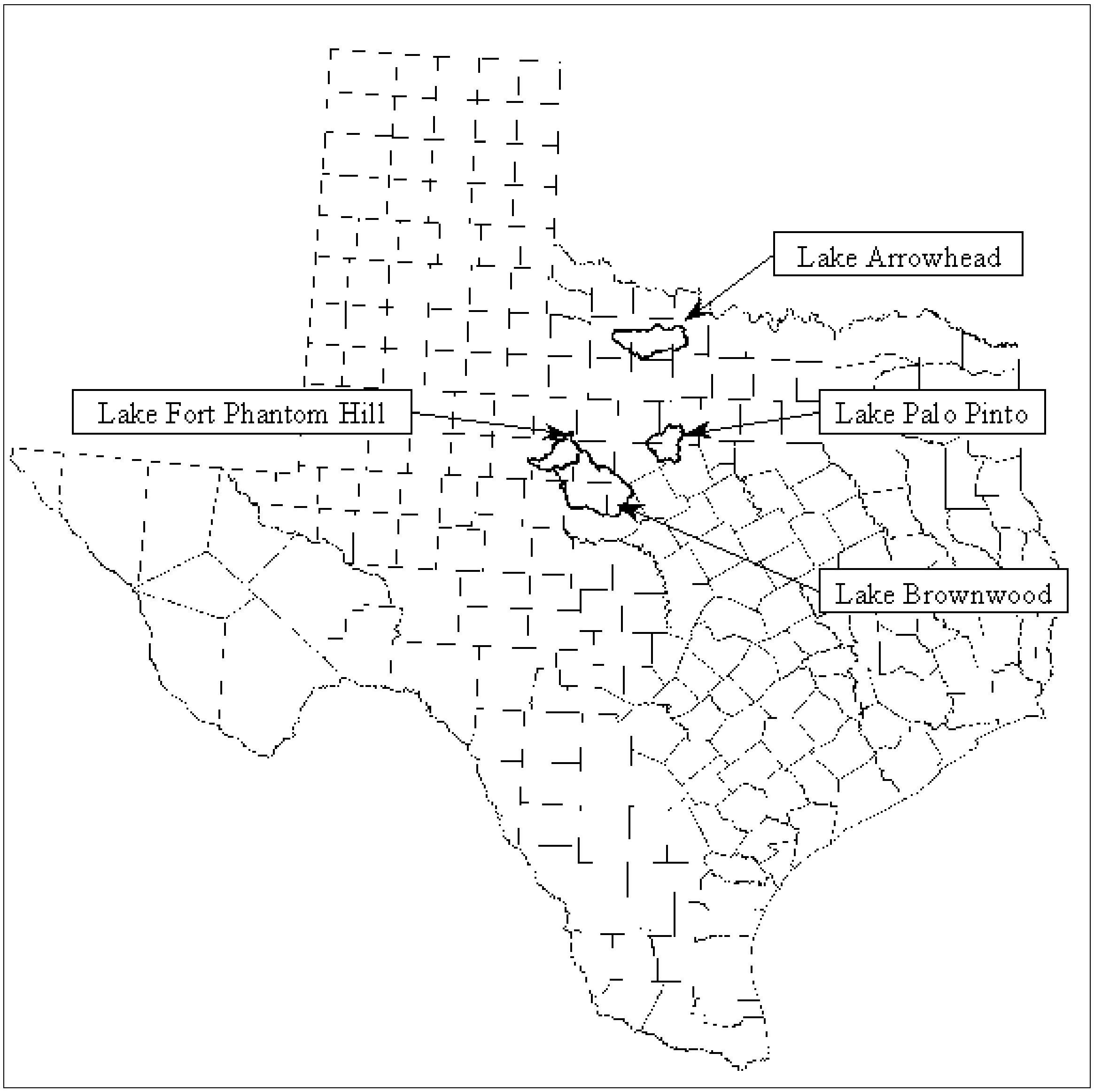

Figure 1-1. Watersheds included in the study area.

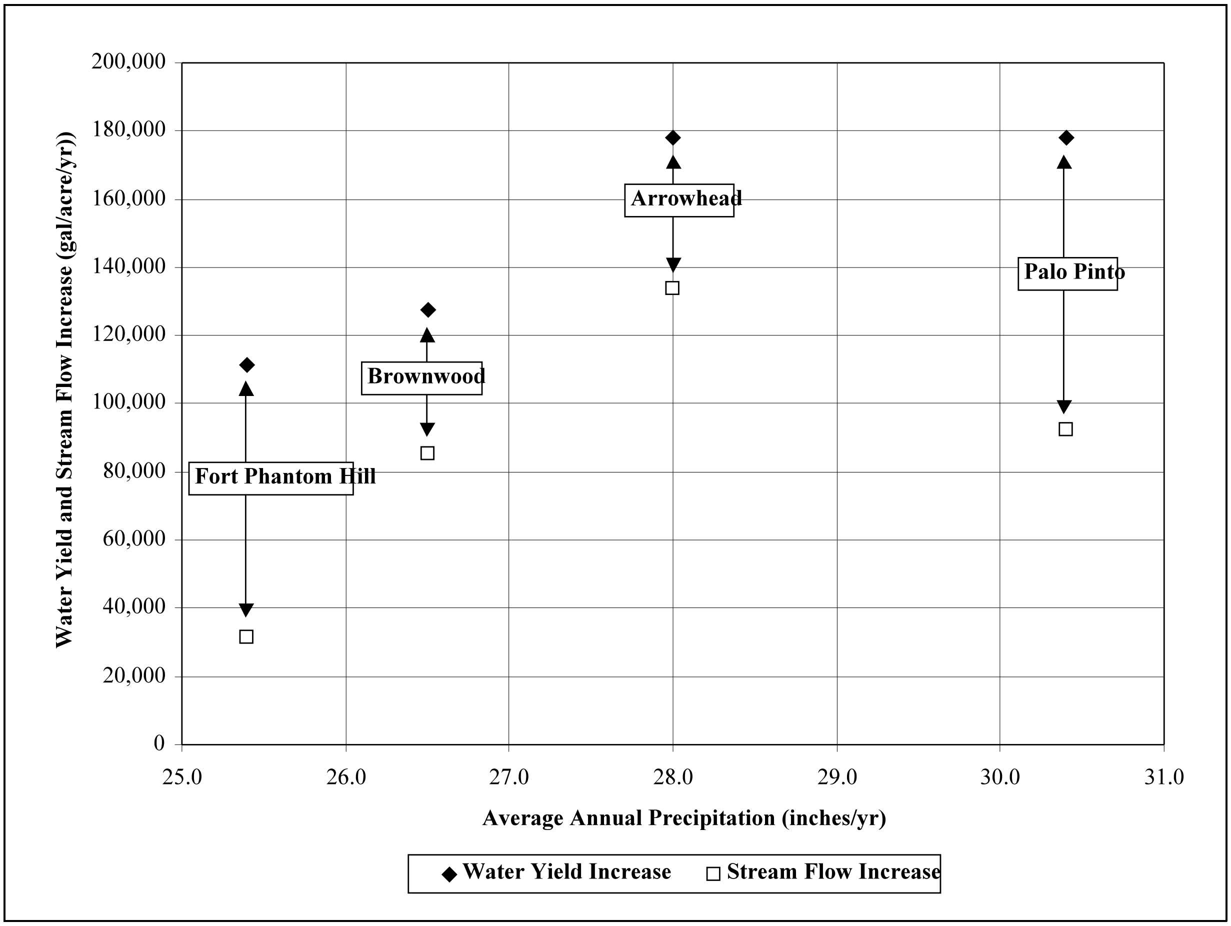

Figure 1-2. Average annual water yield and stream flow increases per treated acre versus average annual precipitation for watersheds in this study, 1960 through 1999.

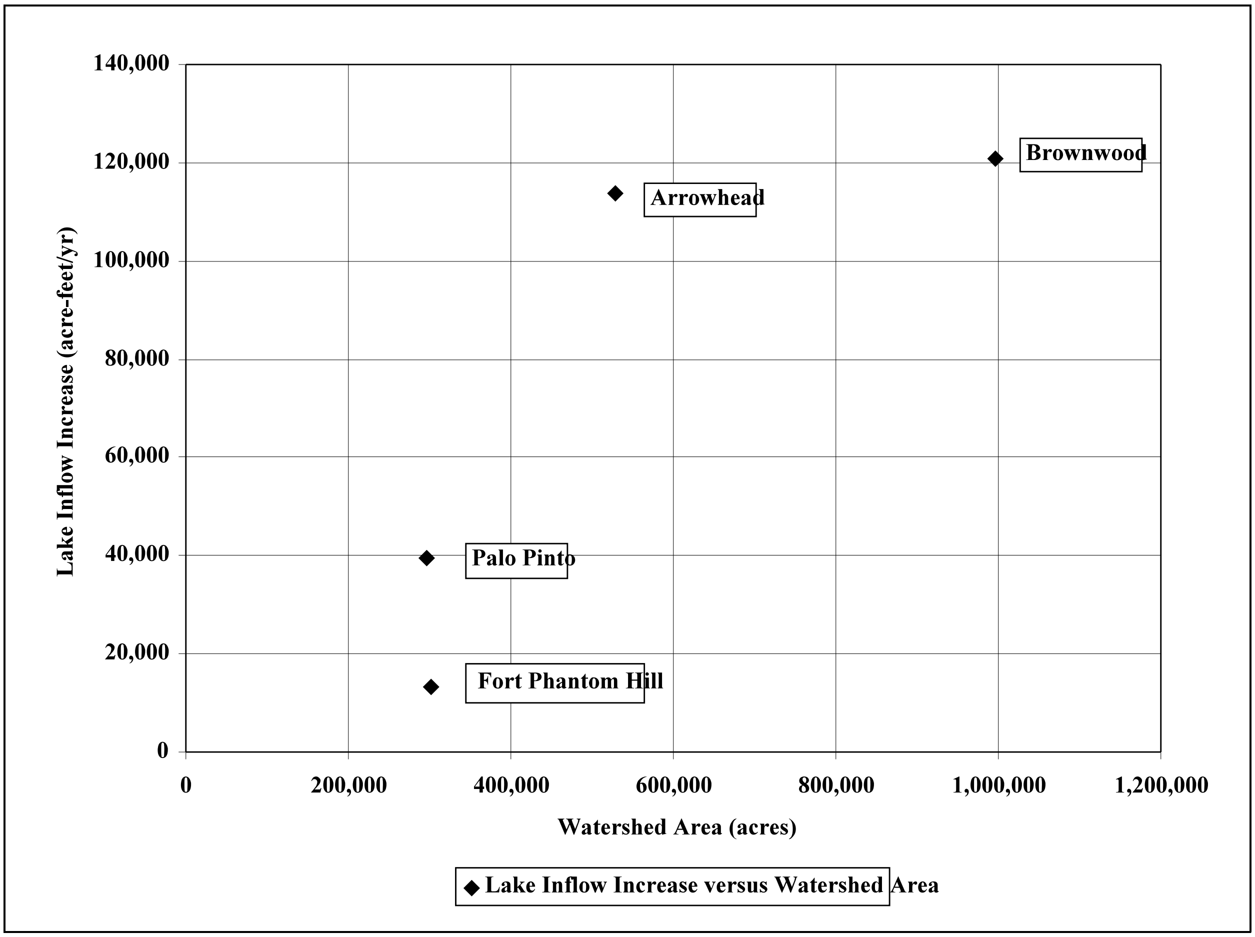

Figure 1-3. Average annual lake inflow increase resulting from brush removal versus watershed drainage area for watersheds in this study, 1960 through 1999.

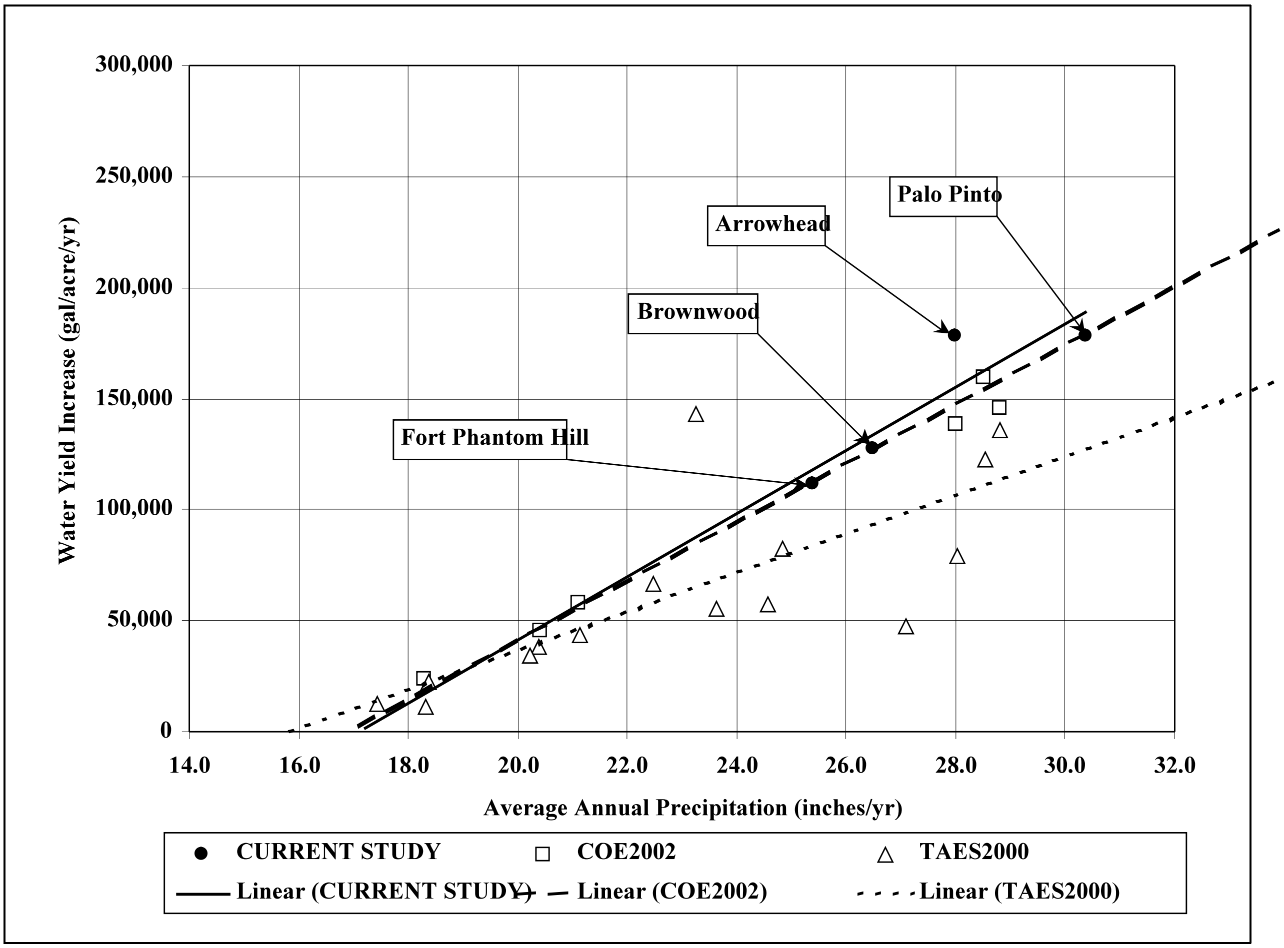

Figure 1-4. Water yield increase versus average annual precipitation - current study, COE (2002), and TAES (2000). Points are labeled for watersheds in current study.

CHAPTER 2

ASSESSING THE ECONOMIC FEASIBILITY OF BRUSH CONTROL TO ENHANCE OFF-SITE WATER YIELD

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Abstract: A feasibility study of brush control for off-site water yield was undertaken in 1998 on the North Concho River near San Angelo, Texas. In 2000, feasibility studies were conducted on eight additional Texas watersheds. This year, studies of four additional Texas watersheds were completed and the results reported herein. Economic analysis was based on estimated control costs of the different options compared to the estimated landowner benefits from brush control. Control costs included initial and follow-up treatments required to reduce brush canopy to between eight and 3 percent and maintain it at the reduced level for ten years. The state cost share was estimated by subtracting the present value of landowner benefits from the present value of the total cost of the control program. The total cost of additional water was determined by dividing the total state cost share if all eligible acreage were enrolled by the total added water estimated to result from the brush control program. This procedure resulted in present values of total control costs per acre ranging from $35.57 to $203.17. Rancher benefits, based on the present value of the improved net returns to typical cattle, sheep, goat, and wildlife enterprises, ranged from $37.20 per acre to $17.09. Present values of the state cost share per acre ranged from $140.62 to $39.20. The cost of added water estimated for the four watersheds ranged from $14.83 to $35.41 per acre-foot averaged over each watershed.

INTRODUCTION

As was reported in Chapter 1 of this report, feasibility studies of brush control for water yield were previously conducted on the North Concho River near San Angelo, Texas (Bach and Conner, 1998) and in eight additional watersheds across Texas (Conner and Bach, 2000). These studies indicated that removing brush would produce cost-effective increases in water yield for most of the watersheds studied. Subsequently, in 2001, the Texas Legislature appropriated funds for feasibility studies on four additional watersheds. The watersheds (Lake Arrowhead, Lake Brownwood, Lake Fort Phantom Hill, and Lake Palo Pinto) are all located in North Central Texas, primarily in the Rolling Plains Land Resource Region. Detailed reports of the economic analysis results of the feasibility studies for each of the four watersheds are the subject of subsequent chapters.

Objectives

This chapter reports the assumptions and methods for estimating the economic feasibility of a program to encourage rangeland owners to engage in brush control for purposes of enhancing off-site (downstream) water availability. Vegetative cover determination and categorization through use of Landsat imagery and the estimation of increased water yield from control of the different brush type-density categories using the SWAT simulation model for the watersheds are described in Chapter 1. The data created by these efforts (along with primary data gathered from landowners and federal and state agency personnel) were used as the basis for the economic analysis.

This chapter provides details on how brush control costs and benefits were calculated for the different brush type-densities and illustrates their use in determining cost-share amounts for participating private landowners-ranchers and the State of Texas. SWAT model estimates of additional off-site water yield resulting from the brush control program are used with the cost estimates to obtain estimates of per acre-foot costs of added water gained through the program.

BRUSH CONTROL

It should be noted that public benefit in the form of additional water depends on landowner participation and proper implementation and maintenance of the appropriate brush control practices. It is also important to understand that rancher participation in a brush control program primarily depends on the rancher's expected economic consequences resulting from participation. With this in mind, the analyses described in this report are predicated on the objective of limiting rancher costs associated with participation in the program to no more than the benefits that would be expected to accrue to the rancher as a result of participation.

It is explicitly assumed that the difference between the total cost of the brush control practices and the value of the practice to the participating landowner would have to be contributed by the state in order to encourage landowner participation. Thus, the state (public) must determine whether the benefits, in the form of additional water for public use, are equal to or greater than the state's share of the costs of the brush control program. Administrative costs (state costs) which would be incurred in implementing, administering, and monitoring a brush control project or program are not included in this analysis.

Brush Type-Density Categories

Land cover categories identified and quantified for the four watersheds in Chapter 1 included four brush types: cedar (juniper), mesquite, oaks, and mixed brush. Landowners statewide indicated they were not interested in controlling oaks, so the type category was not considered eligible for inclusion in a brush control program. Two density categories, heavy and moderate, were used. These six type-density categories were used to estimate total costs, landowner benefits, and the amount of cost-share that would be required of the state.

Brush control practices include initial and follow-up treatments required to reduce the current canopies of all categories of brush types and densities to three to 8 percent and maintain it at the reduced level for at least ten years. These practices, or brush control treatments, differed among watersheds due to differences in terrain, soils, amount, and distribution of crop land in close proximity to the rangeland, etc. An example of the alternative control practices, the time (year) of application, and costs for the Lake Arrowhead/Watershed are outlined in Table 2-1. Year 0 in Table 2-1 is the year that the initial practice is applied while years one through nine refer to follow-up treatments in specific years following the initial practice.

The appropriate brush control practices, or treatments, for each brush type-density category and their estimated costs were obtained from focus groups of landowners and NRCS and Extension personnel in each watershed.

Control Costs
Yearly costs for the brush control treatments and the present value of those costs (assuming a 6 percent discount rate as opportunity cost for rancher investment capital) is also displayed in Table 2-1. Present values of control programs are used for comparison since some of the treatments will be required in the first year to initiate the program, while others will not be needed until later years. Present values of total per acre control costs range from $35.57 for moderate mesquite that can be initially controlled with herbicide treatments to $175.57 for heavy mesquite that cannot be controlled with herbicide but must be initially controlled with mechanical tree bulldozing or root plowing.

Landowner Benefits From Brush Control
As was mentioned earlier, one objective of the analysis is to equate rancher benefits with rancher costs. Therefore, the task of discovering the rancher cost (and thus, the rancher cost share) for brush control was reduced to estimating the ten-year stream of region-specific benefits that would be expected to accrue to any rancher participating in the program. These benefits are based on the present value of increased net returns made available to the ranching operation through increases or expansions of the typical livestock (cattle, sheep, or goats) and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program.

Rancher benefits were calculated for changes in existing wildlife operations. Most of these operations were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. For control of heavy mesquite, mixed brush, and cedar, wildlife revenues are expected to increase about $1.00 per acre due principally to the resulting improvement in quail habitat and hunter access to quail. Increased wildlife revenues were included only for the heavy brush categories because no changes in wildlife revenues were expected with control for the moderate brush type-density categories.

For the livestock enterprises, increased net returns would result from increased amounts of usable forage (grazing capacity) produced by removal of the brush and thus, eliminating much of the competition for light, water, and nutrients within the plant communities on which the enterprise is based. For the wildlife enterprises, improvements in net returns are based on an increased ability to access wildlife for use by paying sportsmen.

As with the brush control methods and costs, estimates of vegetation (forage production/grazing capacity) responses used in the studies were obtained from landowner focus groups, Experiment Station and Extension Service scientists, and USDA-NRCS Range Specialists with brush control experience in the respective watersheds. Because of differences in soils and climate, livestock grazing capacities differ by location; in some cases significant differences were noted between sub-basins of a watershed. Grazing capacity estimates were collected for both pre- and post-control states of the brush type-density categories. The carrying capacities range from 45 acres per animal unit year (Ac/AUY) for land infested with heavy cedar to about 15 Ac/AUY for land on which mesquite is controlled to levels of brush less than 8 percent canopy cover (Table 2-2.).

Livestock production practices, revenues, and costs representative of the watersheds, or portions thereof, were also obtained from focus groups of local landowners. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into production-based investment analysis budgets.

For ranchers to benefit from the improved forage production resulting from brush control, livestock numbers must be changed as grazing capacity changes. In this study, it was assumed that ranchers would adjust livestock numbers to match grazing capacity changes on an annual basis. Annual benefits that result from brush control were measured as the net differences in annual revenue (added annual revenues minus added annualized costs) that would be expected with brush control as compared to without brush control. It is notable that many ranches preferred to maintain current levels of livestock, therefore realizing benefit in the form of reduced feeding and production risk. No change in perception of value was noted for either type of projected benefit.

The analysis of rancher benefits was done assuming a hypothetical 1,000 acre management unit for facilitating calculations. The investment analysis budget information, carrying capacity information, and brush control methods and costs comprised the data sets that were entered into the investment analysis model ECON (Conner, 1990). The ECON model yields net present values (NPV) for rancher benefits accruing to the management unit over the ten-year life of the projects being considered in the feasibility studies. An example of this process is shown in Table 2-3 for the control of heavy mesquite in the Lake Brownwood Watershed.

Since a 1,000 acre management unit was used, benefits needed to be converted to a per acre basis. To get per acre benefits, the accumulated net present value of $28,136 shown in Table 2-3 must be divided by 1,000, which results in $28.14 as the estimated present value of the per acre net benefit to a rancher. The resulting net benefit estimates for all of the type-density categories for all watersheds are shown in Table 2-4. Present values of landowner benefits differ by location within and across watersheds. They range from a low of $17.09 per acre for control of moderate mesquite in the Lake Palo Pinto Watershed to $37.20 per acre for control of heavy Shinnery Oak in the Lake Palo Pinto Watershed.

State Cost Share

The total benefits that are expected to accrue to the rancher from implementation of a brush control program 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).

Using this logic, 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 ranchers' participation. Present values of the state cost share per acre of brush controlled are also shown in Table 2-4. The state's cost share ranges from a low of $42.53 for control of moderate mesquite in the Fort Phantom Hill Watershed to $131.61 for control of heavy cedar in the Lake Brownwood Watershed.

The costs to the state include only the cost for the state's cost share for brush control. Costs that are not accounted for, but which must be incurred, include costs for administering the program. Under current law, this task will be the responsibility of the Texas State Soil and Water Conservation Board.

COSTS OF ADDED 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. The brush control program water yields and the estimated acreage by brush type-density category by subbasin were supplied by the Blacklands Research Center, Texas Agricultural Experiment Station in Temple, Texas (see Chapter 1). The total state cost share for each subbasin 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 subbasin. The cost of added water resulting from the control of the eligible brush in each subbasin 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 using a 6 percent discount rate). Table 2-5 provides a detailed example for the Lake Arrowhead Watershed. The cost of added water from brush control for the Lake Arrowhead Watershed is estimated to average $14.83 per acre-foot for the entire watershed. Subbasin costs per added acre-foot within the watershed range from $6.84 to $26.38.

ADDITIONAL CONSIDERATIONS

Total state costs and total possible added water discussed above are based on the assumption that 100 percent of the eligible acres in each type-density category would enroll in the program. There are several reasons why this will not likely occur. Foremost, there are wildlife considerations. Most wildlife managers recommend maintaining more than 10 percent brush canopy cover for wildlife habitat, especially white tailed deer. Since deer hunting is an important enterprise on almost all ranches in these four watersheds, it is expected that ranchers will want to leave varying, but significant amounts of brush in strategic locations to provide escape cover and travel lanes for wildlife. The program has consistently encouraged landowners to work with technical specialists from the NRCS and Texas Parks and Wildlife Department to determine how the program can be used with brush sculpting methods to create a balance of benefits.

Another reason that less than 100 percent of the brush will be enrolled is that many of the tracts where a particular type-density category are located will be so small that it will be infeasible to enroll them in the control program. An additional consideration is found in research work by Thurow, et. al. (2001) that indicated that only about 66 percent of ranchers surveyed were willing to enroll their land in a similarly characterized program. Also, some landowners will not be financially able to incur the costs expected of them in the beginning of the program due to current debt loads.

Based on these considerations, it is reasonable to expect that less than 100 percent of the eligible land will be enrolled, and, therefore, less water will be added each year than is projected. However, it is likewise reasonable that participation can be encouraged by designing the project to include the concerns of the eligible landowners-ranchers.

LITERATURE CITED

Bach, Joel P. and J. Richard Conner. 1998. Economic Analysis of Brush Control Practices for Increased Water Yield: The North Concho River Example. In: Proceedings of the 25th Water for Texas Conference – Water Planning Strategies for Senate Bill 1. R. Jensen, editor. A Texas Water Resources Institute Conference Held in Austin, Texas, December 1-2, 1998. Pgs. 209-217.

Conner, J.R. 1990. ECON: An Investment Analysis Procedure for Range Improvement Practices. Texas Agricultural Experiment Station Documentation Series MP-1717.

Conner, J.R. and J.P. Bach. 2000. Assessing the Economic Feasibility of Brush Control to Enhance Off-Site Water Yield. Chapter 2 in: *Brush Management / Water Yield Feasibility Studies for Eight Watersheds in Texas*. Final Report to the Texas State Soil and Water Conservation Board. Published by Texas Water Research Institute, TWRI TR-182.

Thurow, A., J.R. Conner, T. Thurow and M. Garriga. 2001. Modeling Texas Ranchers' Willingness to Participate in a Brush Control Cost-Sharing Program to Improve Off-Site Water Yields. *Ecological Economics*: 37 (Apr. 2001):137-150.

Table 2-1. Cost of Water Yield Brush Control Programs by Type-Density Category

Heavy Mesquite – Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
4	Aerial Spray Herbicide	25.00	19.80
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**$ 54.78**

Heavy Mesquite – Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Doze/Root Plow, Rake, Stack and Burn	$ 165.00	$ 165.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 175.57**

Modern Mesquite – Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 35.57**

Moderate Mesquite – Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Grub, Rake, Stack and Burn	$ 100.00	$ 100.00
6	Aerial Spray Herbicide	15.00	15.00
		TOTAL	**$ 110.57**

Moderate Mesquite – Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Skid Steer with Shears	$ 35.00	$ 35.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 45.57**

Table 2-2. Grazing Capacity in Acres per AUY Before and After Brush Control by Brush Type-Density Category

	Brush Type-Density Category and Brush Control State															
	Heavy Cedar		Heavy Mesquite		Heavy Mixed Brush		Moderate Cedar		Moderate Mesquite		Moderate Mixed Brush		Heavy Post Oak/ Shinnery Oak/Elm		Moderate Post Oak/ Shinnery Oak/Elm	
Watershed	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**	**Pre-**	**Post-**
Lake Arrowhead	–	–	28	22	–	–	–	–	25	22	–	–	–	–	–	–
Lake Brownwood	40	25	20	15	35	20	35	25	17	15	28	20	30	20	28	20
Fort Phantom Hill	45	25	20	15	35	20	17	15	35	25	28	20	–	–	–	–
Palo Pinto	45	25	25	18	35	20	35	25	20	18	28	20	40	20	25	20

Table 2-3. NPV Report – Lake Brownwood Watershed, Heavy Mesquite

Year	Animal Units	Total Increase in Sales	Total Added Investment	Increased Variable Costs	Additional Revenues	Cash Flow	Annual NPV	Accumulated NPV
0	50	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0	–
1	53.3	1,292	2,100	417	1,000	(225)	(212)	$ (212)
2	57.1	3,015	2,800	973	1,000	242	215	3
3	61.5	4,737	2,800	1,529	1,000	1,408	1,182	1,185
4	66.7	6,890	5,000	2,224	1,000	666	528	1,713
5	66.7	6,890	0	2,224	1,000	5,666	4,234	5,947
6	66.7	6,890	0	2,224	1,000	5,666	3,995	9,942
7	66.7	6,890	0	2,224	1,000	5,666	3,768	13,710
8	66.7	6,890	0	2,224	1,000	5,666	3,555	17,265
9	66.7	6,890	0	2,224	1,000	5,666	3,354	20,619
				Salvage Value		**$ 12,700**	**$ 7,517**	**$ 28,136**

Table 2-4. Landowner and State Shares of Brush Control Costs by Brush Type-Density Category by Watershed

	Brush Type-Density Category and Brush Control State															
	Heavy Cedar		Heavy Mesquite		Heavy Mixed Brush		Moderate Cedar		Moderate Mesquite		Moderate Mixed Brush		Heavy Post Oak/Shinnery Oak/Elm		Moderate Post Oak/Shinnery Oak/Elm	
Watershed	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**	**Owner**	**State Costs**
Lake Arrowhead	–	–	19.43	83.67	–	–	–	–	17.54	48.03	–	–	–	–	–	–
Lake Brownwood	25.96	140.61	28.14	80.96	35.55	140.62	24.79	83.78	21.37	51.95	28.05	88.52	29.05	51.52	28.05	52.52
Fort Phantom Hill	30.04	92.53	28.14	56.96	35.55	92.62	24.79	59.78	21.37	39.20	28.05	63.02	–	–	–	–
Palo Pinto	28.94	86.09	26.00	81.68	34.18	99.39	24.04	72.53	17.09	50.73	27.11	68.67	37.20	43.37	22.74	57.83

Table 2-5. Cost of Added Water From Brush Control by Subbasin (Acre-Foot-Lake Arrowhead Watershed)

Subbasin	Total State Cost ($)	Added Gallons Per Year	Added Acre Foot/Year	Total Acre/Ft 10 Yrs Dsctd	State Cost/ Acre Foot ($)
1	$ 890,835.69	2,154,658,197.03	6,612.40	51,587.94	$ 17.27
2	792,839.56	1,603,971,605.12	4,922.41	38,403.11	20.65
3	1,193,772.24	2,645,021,025.03	8,117.27	63,328.45	18.85
4	645,032.32	1,149,475,605.35	3,527.61	27,521.34	23.44
5	330,284.29	523,014,767.61	1,605.07	12,522.29	26.38
6	385,074.33	1,060,752,122.04	3,255.33	25,397.07	15.16
7	451,240.14	1,246,555,855.56	3,825.54	29,845.68	15.12
8	893,199.99	2,508,188,911.38	7,697.35	60,052.35	14.87
9	789,409.91	1,724,107,666.62	5,291.09	41,279.47	19.12
10	1,390,116.97	4,128,213,443.23	12,669.02	98,839.81	14.06
11	1,304,918.20	4,175,057,884.49	12,812.78	99,961.38	13.05
12	87,872.64	382,626,356.77	1,174.24	9,161.04	9.59
13	1,164,934.45	3,449,892,862.07	10,587.33	82,599.11	14.10
14	855,343.01	2,714,347,320.33	8,330.03	64,988.30	13.16
15	326,603.70	1,188,731,222.13	3,648.08	28,461.21	11.48
16	257,684.25	981,314,990.05	3,011.55	23,495.15	10.97
17	177,614.54	655,942,859.17	2,013.01	15,704.92	11.31
18	166,110.60	556,785,852.99	1,708.71	13,330.85	12.46
19	1,029,797.78	2,823,542,988.67	8,665.14	67,602.72	15.23
20	886,216.09	2,440,216,220.39	7,488.75	58,424.91	15.17
21	364,992.01	1,015,478,003.63	3,116.39	24,313.10	15.01
22	75,349.90	272,324,895.18	835.73	6,520.14	11.56
23	905,677.75	3,239,088,907.36	9,940.40	77,551.93	11.68
24	946,411.68	3,019,716,470.06	9,267.17	72,299.61	13.09
25	293,211.92	893,809,938.15	2,743.00	21,400.06	13.70
26	546,610.84	1,745,624,225.02	5,357.12	41,794.63	13.08
27	318,222.59	640,949,626.80	1,967.00	15,345.95	20.74
28	76,455.03	466,961,686.53	1,433.05	11,180.24	6.84
Total	**$ 17,545,832.44**			**1,182,912.76**	
Average					**$ 14.90**

CHAPTER 3

LAKE ARROWHEAD WATERSHED – HYDROLOGIC SIMULATION

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WATERSHED DATA

Physical Data

Lake Arrowhead is a reservoir on the Little Wichita River in the Red River basin, has a normal pool area of 16,200 surface acres, and impounds 262,100 acre-feet of water at normal pool elevation (USGS, 2001). This impoundment provides for municipal, industrial, and recreational use (Handbook of Texas Online, 2002). Lake Kickapoo, a 6,200 surface acre reservoir, lies upstream in west central Archer County (USGS, 2001). The watershed originates in eastern Baylor County and flows in an easterly direction through Archer and part of Clay Counties for a distance of approximately 45 miles before entering Lake Arrowhead. The Lake Arrowhead watershed has an area of about 529,400 acres (827 square miles), nearly all of which is in farms and ranches.

Subbasins, county boundaries, and major roads (obtained from the Census Bureau) are shown in Figure 3-1. The outlet or "catchment" for the watershed simulated in this study is Lake Arrowhead located in subbasin number 28.

METHODS

Land Use/Land Cover

The land use / land cover was derived from the classification of Landsat 7 imagery utilizing ground control points collected by local NRCS personnel. Software accuracy assessment based on ground control points was approximately 75 percent. About 78 percent of the watershed is in some type of rangeland or pasture cover. Approximately 52 percent of the watershed is moderate or heavy brush that was converted to open rangeland in the SWAT simulation. No juniper categories were developed since juniper is not a significant brush species in this watershed.

Soils

The watershed is in three land resource areas, namely: the Central Rolling Red Plains, the Central Rolling Red Prairies, and the Texas north-central Prairies. The soils of the Central Rolling Red Plains consist of nearly level to gently sloping, moderately deep and deep, clayey and loamy soils. The soils of the Central Rolling Red Prairies consist of nearly level to sloping, well drained or moderately well drained, deep or moderately deep clayey and loamy soils. The soils of the Texas North-Central Prairies consist of well drained and moderately well drained, somewhat stony, and medium textured to fine textured soils. Nearly all of the area is in farms or ranches.

The dominant soil series in the Lake Arrowhead watershed are Vernon, Kamay, Bastrop, Tillman, Knoco, Jolly, Mangum, Aspermont, Port, Bluegrove, Weswind and Renfrow. These twelve soil series represent about 75 percent of the watershed area. A short description of each follows:

Vernon. The Vernon series consists 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. Slopes range from 1 to 45 percent.

Kamay. The Kamay series consists of very deep, well drained, slowly permeable soils that formed in clayey redbeds. These soils are on nearly level to very gently sloping uplands. Slopes range from 0 to 3 percent.

Bastrop. The Bastrop series consists of very deep, well drained, moderately permeable soils formed in loamy alluvial materials. These soils are on nearly level to moderately sloping upland stream terraces. Slopes range from 0 to 8 percent.

Tillman. The Tillman series consists of very deep, well drained, slowly permeable soils. These soils formed in loamy and clayey alluvium derived from redbed clays and claystone sediments of Permain age. These soils are on nearly level to gently sloping uplands. Slope ranges from 0 to 5 percent.

Knoco. The Knoco series consists of very shallow and shallow, well drained, very slowly permeable soils that formed in residuum over dense noncemented claystone bedrock of Permian age. These soils are on very gently sloping to very steep ridges, sideslopes and erosional footslopes on uplands. Slopes range from 1 to 60 percent.

Jolly. The Jolly series consists of shallow, well drained, moderately permeable soils that developed in residuum and colluvium derived from sandstone. These soils are on gently sloping to strongly sloping uplands. Slopes range from 1 to 12 percent.

Mangum. The Mangum series consists of very deep, well drained, very slowly permeable soils that formed in calcareous clayey alluvial materials. These soils are on nearly level flood plains of major streams. Slopes range from 0 to 1 percent.

Aspermont. The Aspermont series consists of very deep, well drained, moderately permeable soils. These soils formed in calcareous silty colluvium over redbed siltstone and claystone of Permian age. These very gently sloping to steep soils are on sideslopes or summits on uplands. Slope ranges from 1 to 25 percent.

Port. The Port series consists of very deep, well drained, moderately permeable flood plain soils that formed in calcareous loamy alluvium of recent age. These nearly level to very gently sloping soils are on narrow flood plains. Slopes range from 0 to 3 percent.

Bluegrove. The Bluegrove series consists of moderately deep, well drained, moderately slowly permeable soils formed in residuum weathered from sandstone and shale. These soils are on gently sloping and sloping uplands. Slopes range from 1 to 8 percent.

Weswind. The Weswind series consists of very deep, moderately well drained, moderately slowly permeable soils formed in interbedded sandstone and shale materials. These gently sloping and strongly sloping upland soils have slopes ranging from 1 to 8 percent.

Renfrow. The Renfrow series consists of very deep, well drained, very slowly permeable soils that formed in material weathered from clayey shale of Permian age. These nearly level to gently sloping soils are on broad smooth convex ridges and side slopes of uplands. Slopes range from 0 to 5 percent.

Topography

Topography of the watershed is moderate to gently rolling. Elevations range from 918 feet on the flood plain above Lake Arrowhead to over 1,410 feet above mean sea level on parts of the escarpment.

Geology

Geologic strata cropping out in the watershed were deposited during the early Permian Period and Quaternary Period.

The Archer City Formation and Nacona Formation are dominantly Permian “red-bed” sediments that were deposited on the eastern flank of the Permian Basin in a deltaic-shallow water environment. Consequently, they dip gently northwest and strike generally northeast–southwest (NRCS, 1998).

Quaternary sediments mapped within the watershed are Late Pleistocene-Early Holocene fluvial deposits under relict terraces, and modern Holocene flood plain alluvium. The relict terraces are located above the modern flood plain along the Little Wichita River flood plain (NRCS, 1998).

Climate

The average annual precipitation during the 1960 through 1999 study period varied from 25.4 inches in the western portion of the Lake Arrowhead watershed to 31.0 inches in the eastern portion. The composite average for the entire watershed was 28.0 inches. Average temperatures range from 83 degrees Fahrenheit in the summer to 44 degrees in the winter. The normal frost-free season of 227 days extends from March 28 to November 9.

Climate stations are shown in Figure 3-2. For each subbasin, precipitation and temperature data were retrieved by the SWAT input interface for the climate station nearest the centroid of the subbasin. USGS stream gage stations also are shown in this figure.

Ponds and Reservoirs

Surface runoff is the principal source of water for all purposes, due to the deep water table and poor quality of underground water. Three storage reservoirs in this watershed furnish water for municipal and industrial uses. Lake Kickapoo and Lake Arrowhead furnish municipal water to Wichita Falls. Lake Cooper furnishes water to the city of Olney. Farm ponds supply a majority of the farmers and ranchers with water for domestic and livestock use. Figure 3-3 shows the distribution of the inventory-sized ponds and reservoirs in the watershed.

Surface area, storage, and drainage area for existing inventory-sized ponds and reservoirs in the watershed were obtained from the Texas Natural Resource Conservation Commission (TNRCC), and input to the SWAT model. Withdrawals from reservoirs for municipal and other uses were estimated from data obtained from the Texas Water Development Board (TWDB).

Model Inputs

Significant input variables for the SWAT model for the Lake Arrowhead Watershed are shown in Table 3-1. Input variables were adjusted as needed in order to calibrate flow at the applicable USGS stream gage or reservoir. The calibration simulation represents the current "with brush" condition.

The input variables for the no-brush condition, with one exception, were the same as the calibration variables, with the change in land use being the only difference between the two simulations. The exception is that we assumed the shallow aquifer re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and the 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 is 0.1.

Model Calibration

SWAT was calibrated against measured stream flow and reservoir volumes by varying selected model parameters (Table 3-1). The model was calibrated for flow at stream gage 07314500, Little Wichita River near Archer City, (Figure 3-2) and for storage volume at two reservoirs (07314000 - Lake Kickapoo and 07314800 - Lake Arrowhead) (Figure 3-3). Stream gage and reservoir volume data were retrieved from U.S. Geological Survey (USGS) databases and annual hydrologic data reports.

Brush Removal Simulation

Brush control was simulated by replacing all heavy and moderate mesquite and mixed brush categories with open range. Model inputs for curve number, leaf area, rooting depth, and ground water re-evaporation coefficient were changed to reflect the conversion of brush to grass.

RESULTS

Model Calibration

The calculated difference between measured and predicted values expressed as a residual of the means squared is the root means square error (RMSE). One way to gage the accuracy of the calibration is to compare the mean measured monthly flow or reservoir volume with the RMSE. The lower the RMSE compared to the measured values the more precise the comparison.

> Lake Kickapoo. (Figure 3-4) The average measured and predicted monthly volumes were within 9.5 percent for Lake Kickapoo, with an RMSE 0.19 times mean monthly volume. The low RMSE values indicate that the model did a good job in simulating reservoir storage volumes.

Lake Arrowhead. (Figure 3-5) The average measured and predicted monthly volumes were within 4.6 percent for Lake Arrowhead, with a RMSE of 0.15 times measured mean monthly volume. Again, SWAT simulated reservoir volume accurately.

Little Wichita River. (Figure 3-6) The calibration period for the stream gage was from 1967 through 1999. Average measured and predicted monthly flows were within 5 percent, with RASE about 1.4 times measured mean monthly flow. Although the RMSE is still acceptable, it indicates that SWAT was not as accurate in predicting monthly flow.

Brush Removal Simulation

Average annual evapotranspiration (ET) was 24.04 inches for the brush condition (calibration) and 19.39 inches for the no-brush condition. This represents 86 percent and 69 percent of precipitation for the brush and no-brush conditions, respectively. Figures 3-7 through 3-9 show the cumulative monthly total flow to Lake Kickapoo, Lake Cooper, and Lake Arrowhead, respectively, for the brush and no-brush conditions from 1960 through 1999.

The total subbasin area, area of brush treated, fraction of subbasin treated, water yield increase per acre of brush treated, and total water yield increase for each subbasin is shown in Table 3-2. The amount of annual increase varied between the subbasins and ranged from 96,876 gallons per acre of brush removed per year in subbasin number 5, to 331,070 gallons per acre in subbasin number 28.

The large increase in water yield for the subbasins containing Lake Arrowhead (subbasin 28) and Lake Kickapoo (subbasin 12) was most likely due to the presence of predominantly muck soils with high runoff potential associated with heavy brush.

Variations in the amount of increased water yield were expected and influenced by brush type, brush density, soil type, and average annual rainfall. The larger water yields were most likely due to greater rainfall volumes, as well as increased density and canopy of brush.

The increase in volume of flow to the reservoirs was less than the water yield because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occurred between each subbasin and the watershed outlet.

For the entire simulated watershed, the average annual water yield increased by about 88 percent or 151,623 acre-feet, and flow at the watershed outlet (Lake Arrowhead) increased by 113,860 acre-feet/year.

LITERATURE CITED

The Handbook of Texas Online. 2002. "Archer, Baylor, and Clay Counties." http://www.tsha.utexas.edu/handbook/online/articles/view/AA/hca5.html. Accessed Mon. August 5, 2002.

U.S. Department of Agriculture, Natural Resources Conservation Service, 1998. Natural Resources Plan for Watershed Protection. Lower Little Wichita River Watershed. Planning Staff. Temple, Texas.

U.S. Department of Interior, U.S. Geological Survey, 2001. Water Resources Data – Texas Water Year 2001. Water-Data Report TX-01-1.

Table 3-1. SWAT Input Variables for Lake Arrowhead Watershed

VARIABLE		ADJUSTMENT or VALUE
Runoff Curve Number Adjustment		None
Soil Available Water Capacity Adjustment (inches H^2O/in. soil)		None
Soil Crack Volume Factor		None
Soil Saturated Conductivity (inches/hour)		None
Soil Evaporation Compensation Factor		0.85
Minimum Shallow Aquifer Storage for Groundwater Flow (inches)		0.079
Minimum Shallow Aquifer Storage for Revap Inches)		0.085
Shallow Aquifer Re-Evaporation (Revap) Coefficient		
	Brush	0.40
	All Others	0.003
Channel Transmission Loss (inches/hour)		0.08
Subbasin Transmission Loss (inches/hour)		0.12
Bank Coefficient		0.50
Reservoir Evaporation Coefficient		1.00
Reservoir Seepage Rate (inches/hour)		
	Lake Arrowhead	0.004
	Lake Kickapoo	0.003
Principal Spillway Release Rate (cfs)		
	Lake Arrowhead	353
	Lake Kickapoo	353
Potential Heat Units (°C)		
	Heavy Mesquite	3,346
	Heavy Mixed Brush	3,705
	Moderate Mesquite	3,067
	Heavy Oak	3,466
	Moderate Oak	3,067
	Light Brush and Open Range/Pasture	2,669
Plant Rooting Depth (feet)		
	Heavy and Moderate Brush	6.5
	Light Brush and Open Range/Pasture	3.3
Maximum Leaf Area Index		
	Heavy Mesquite	4
	Heavy Mixed Brush	4
	Moderate Mesquite	2
	Heavy Oak	4
	Moderate Oak	3
	Light Brush	2
	Open Range/Pasture	1

Table 3-2. Subbasin Data – Lake Arrowhead Watershed

Subbasin	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
1	28,436	13,386	0.47	160,960	2,154,658,197
2	22,639	12,963	0.57	123,733	1,603,971,605
3	34,477	19,315	0.56	136,944	2,645,021,025
4	15,948	10,003	0.63	114,914	1,149,475,605
5	7,650	5,399	0.71	96,876	523,014,768
6	12,094	6,252	0.52	169,672	1,060,752,122
7	19,194	6,906	0.36	180,492	1,246,555,856
8	21,360	13,422	0.63	186,871	2,508,188,911
9	22,955	12,437	0.54	138,624	1,724,107,667
10	36,915	22,181	0.60	186,112	4,128,213,443
11	39,126	20,641	0.53	202,270	4,175,057,884
12	6,465	1,525	0.24	250,943	382,626,357
13	25,740	17,583	0.68	196,202	3,449,892,862
14	22,557	13,611	0.60	199,419	2,714,347,320
15	12,271	6,000	0.49	198,127	1,188,731,222
16	5,823	3,870	0.66	253,559	981,314,990
17	4,255	2,892	0.68	226,774	655,942,859
18	5,703	2,871	0.50	193,938	556,785,853
19	29,269	15,494	0.53	182,240	2,823,542,989
20	25,931	13,739	0.53	177,612	2,440,216,220
21	19,745	6,280	0.32	161,702	1,015,478,004
22	4,924	1,392	0.28	195,682	272,324,895
23	34,833	16,066	0.46	201,608	3,239,088,907
24	27,197	15,172	0.56	199,036	3,019,716,470
25	11,277	4,688	0.42	190,648	893,808,938
26	10,378	7,362	0.71	237,128	1,745,624,225
27	7,842	4,796	0.61	133,644	640,949,627
28	14,348	1,410	0.10	331,070	466,961,687
	529,354 **Watershed Total**	277,657 **Watershed Total**	0.52 **Watershed Average**	177,940 **Watershed Average**	49,406,371,509 **Watershed Total**

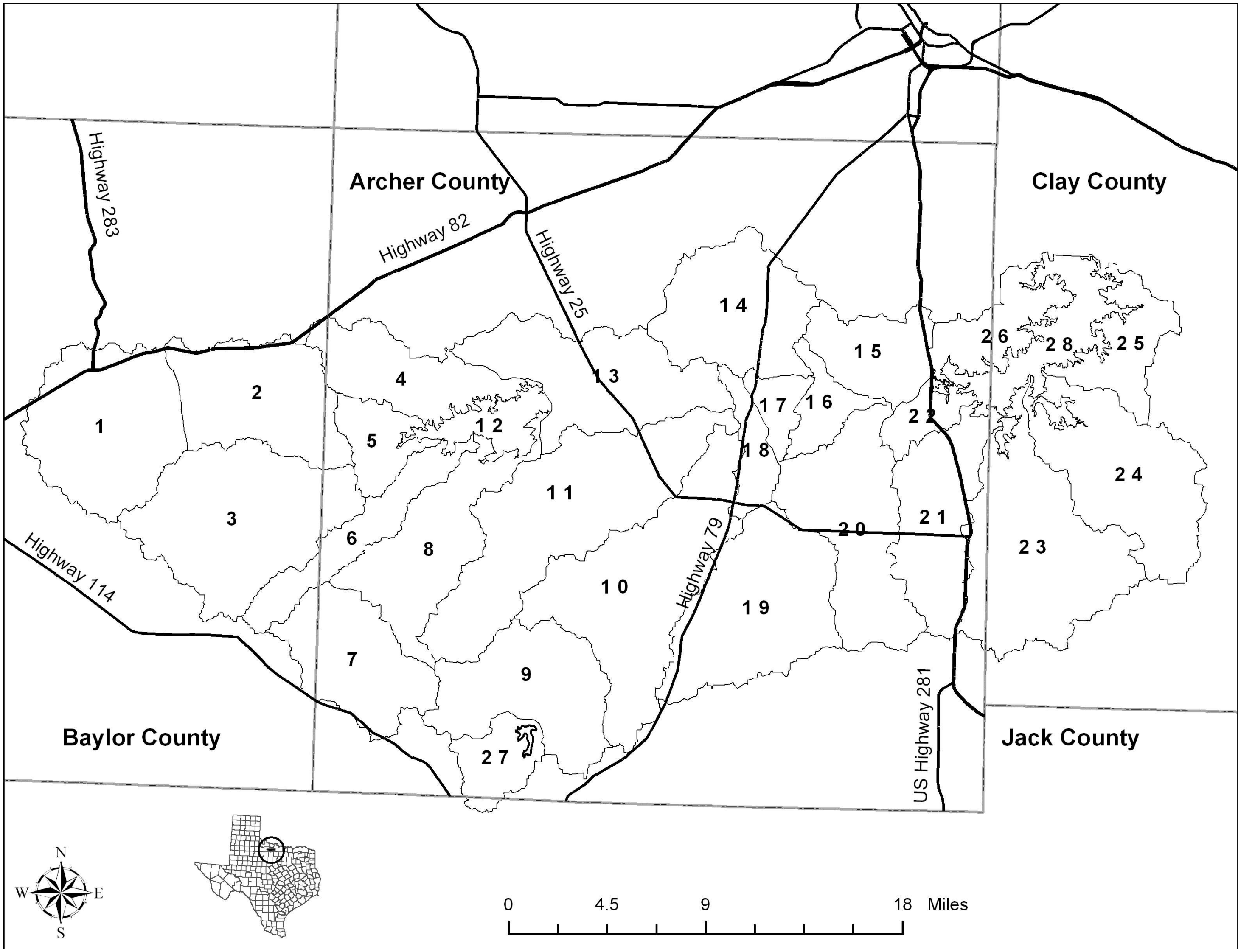

Figure 3-1. Lake Arrowhead watershed subbasin map with major roads.

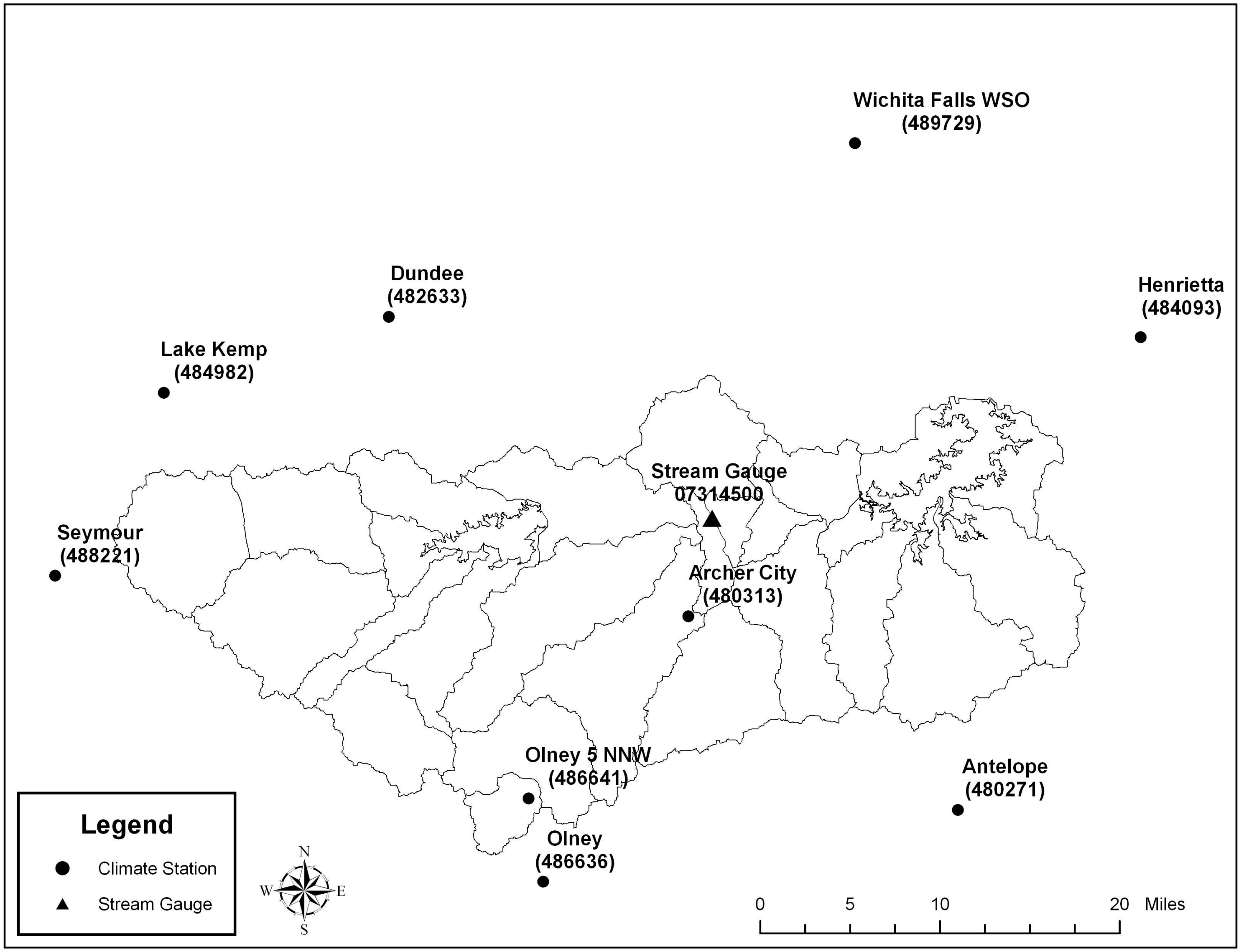

Figure 3-2. Climate and stream gage stations in the Lake Arrowhead watershed.

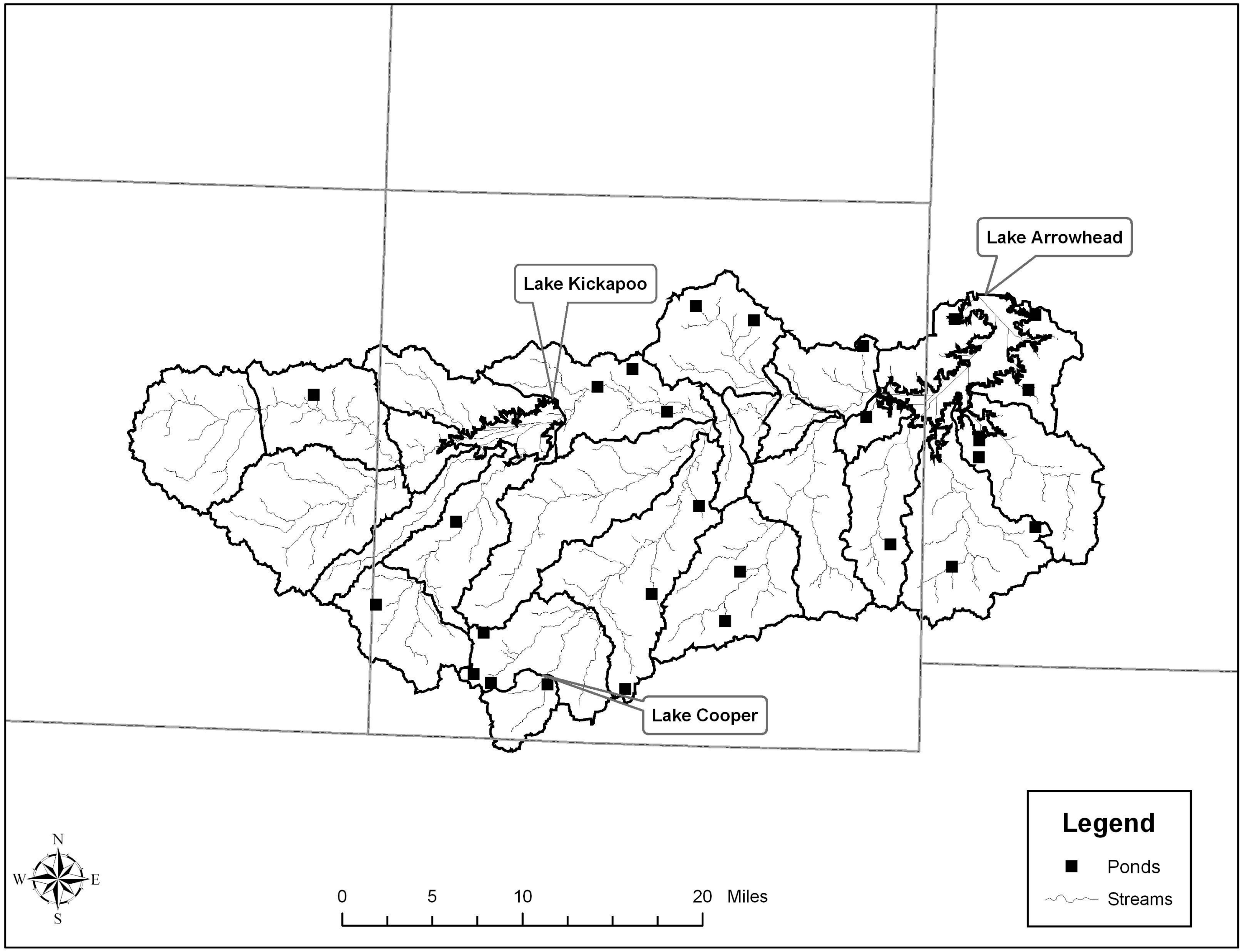

Figure 3-3. Inventory-sized ponds and reservoirs in the Lake Arrowhead watershed.

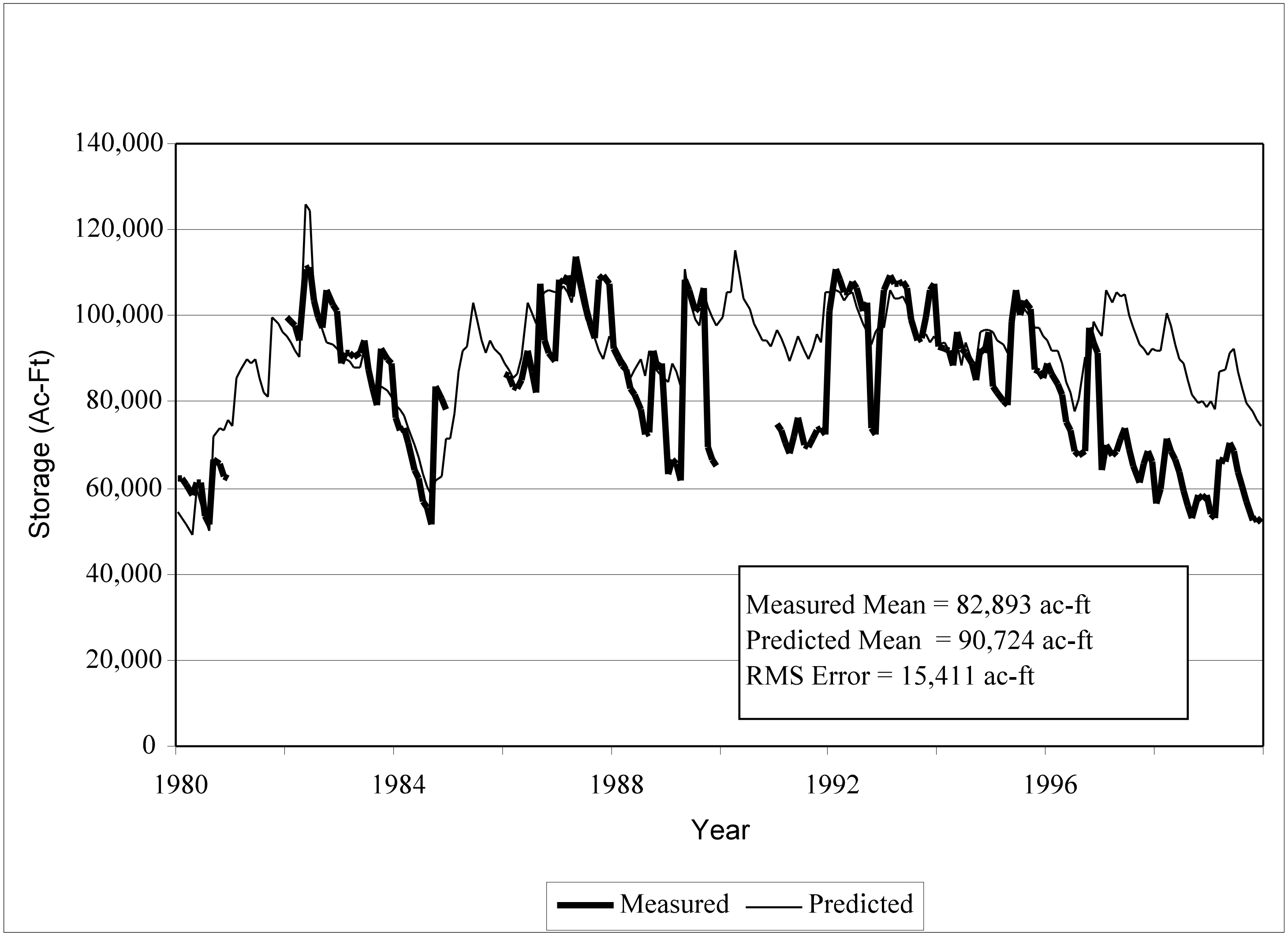

Figure 3-4. Measured and predicted monthly storage in Lake Kickapoo, 1980 through 1999. Measured data was only available from 1980 through 1999, and included data gaps. Monthly statistics shown in box are for months with measured data.

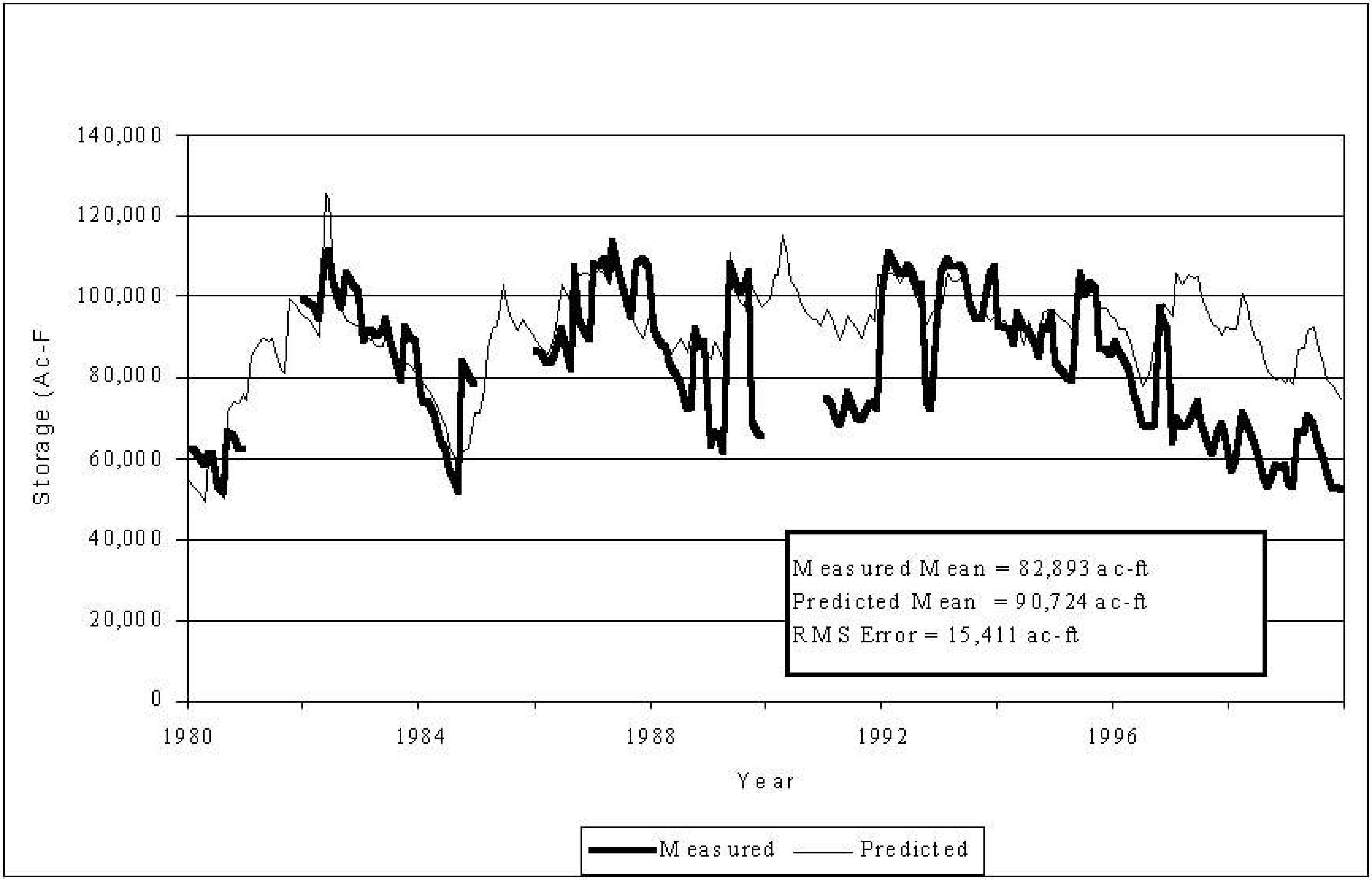

Figure 3-5. Measured and predicted monthly storage in Lake Arrowhead, 1967 through 1999. Measured data was only available from 1967 through 1999, and included data gaps. Monthly statistics shown in box are for months with measured data.

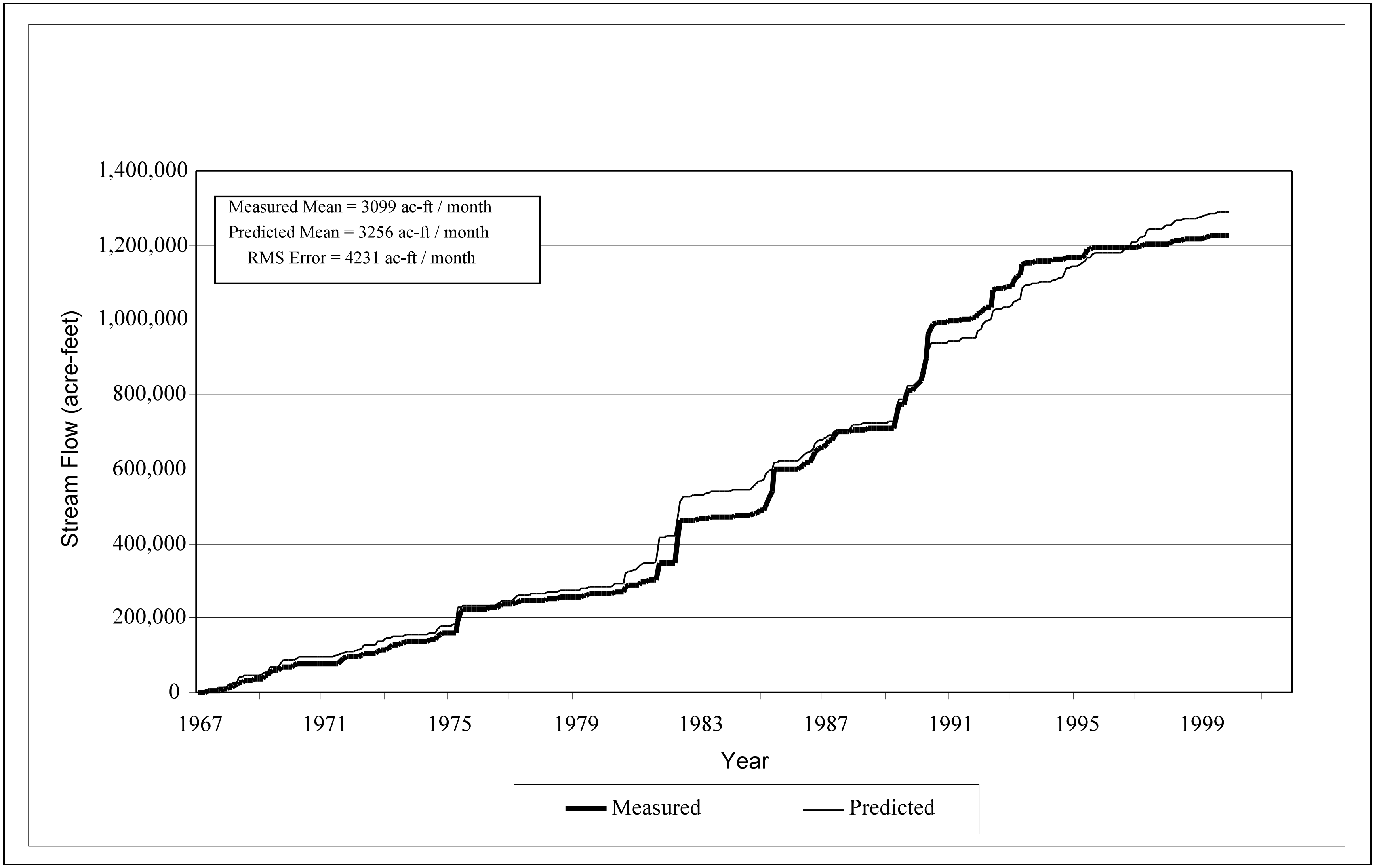

Figure 3-6. Cumulative monthly measured and predicted stream flow at gage 07314500 (near Archer City), 1967 through 1999. Monthly statistics are shown in box.

Figure 3-7. Predicted cumulative monthly stream flow into Lake Kickapoo for brush and no brush conditions.

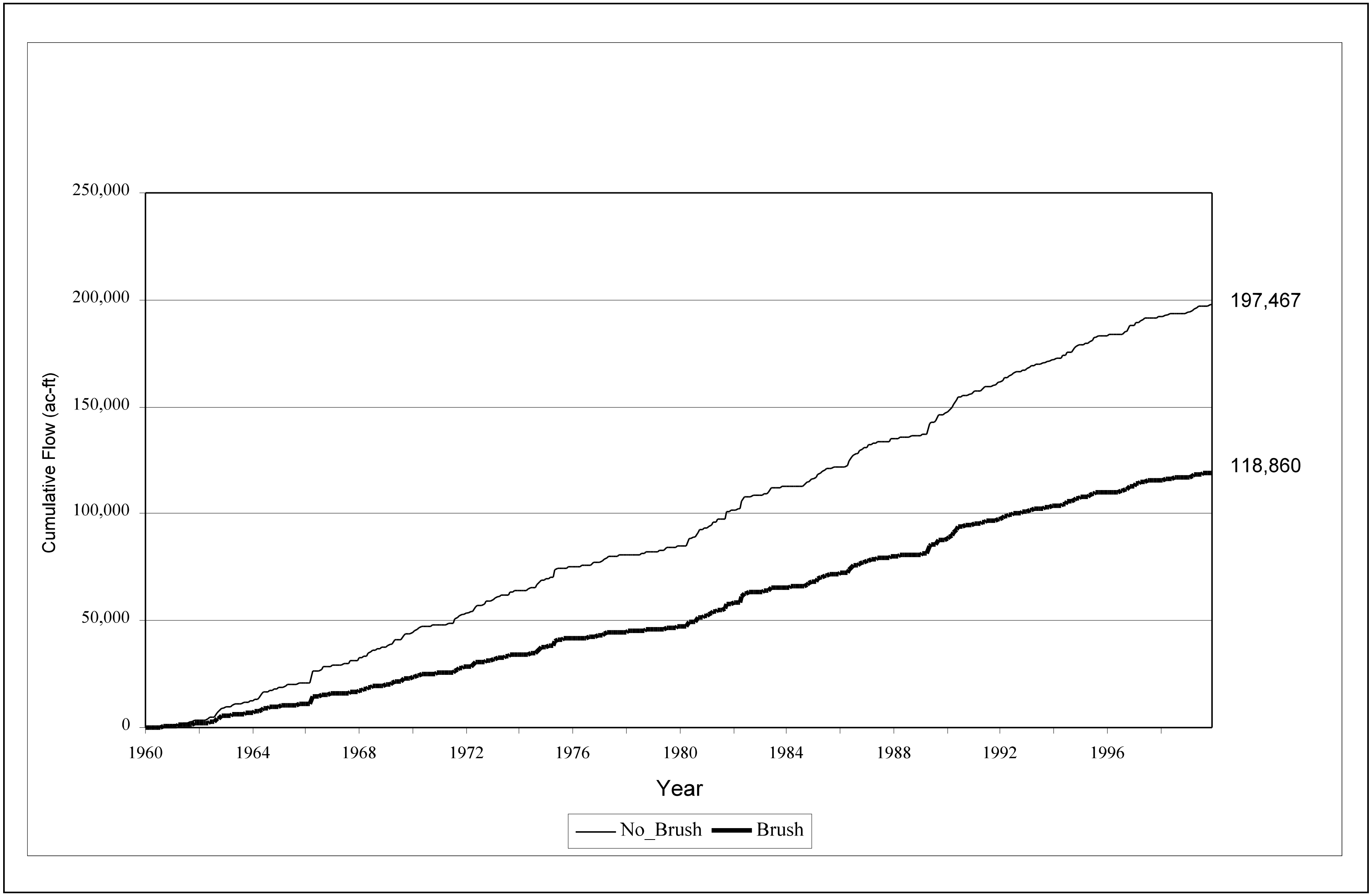

Figure 3-8. Predicted cumulative monthly stream flow into Lake Cooper for brush and no brush conditions.

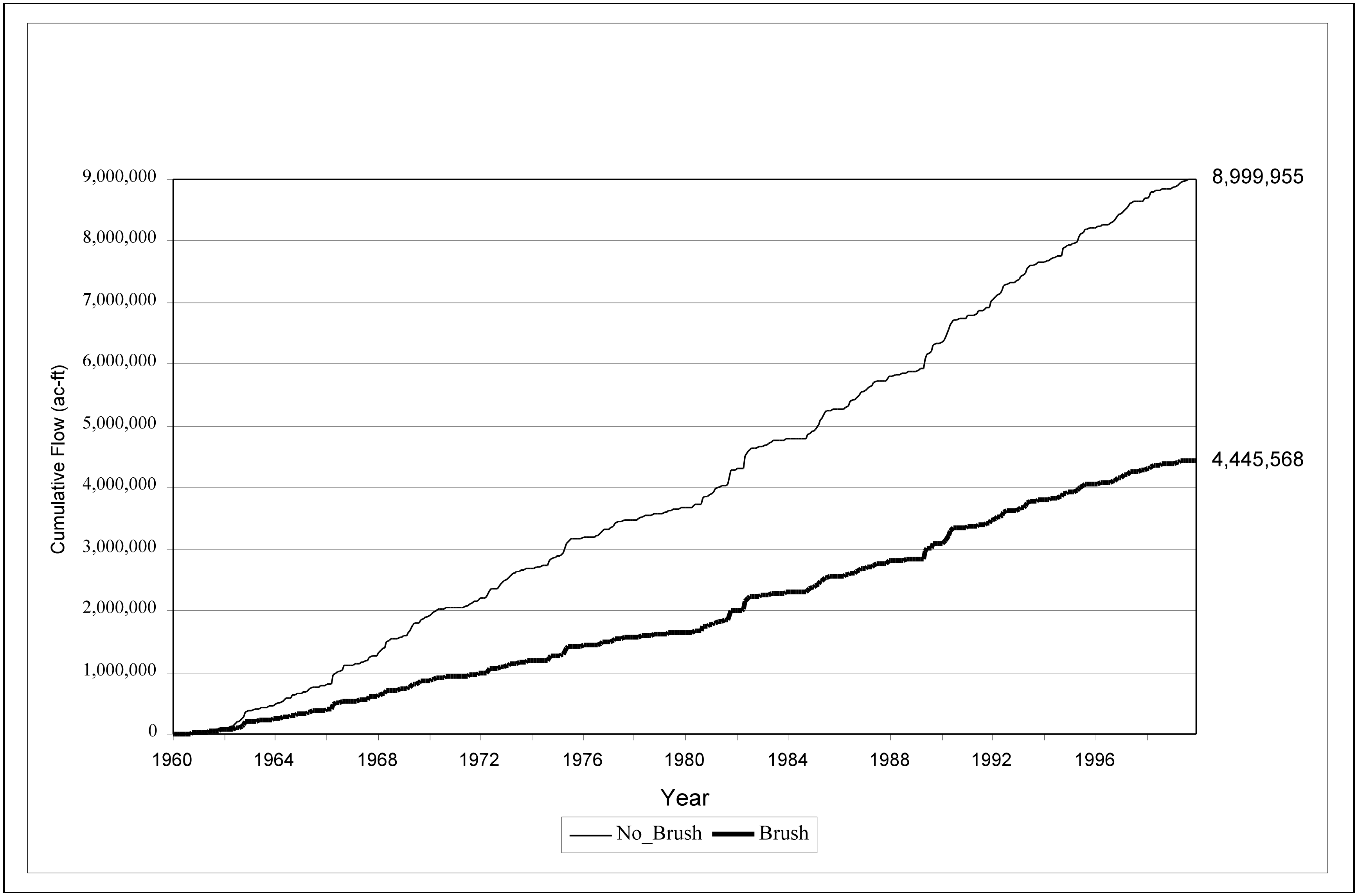

Figure 3-9. Predicted cumulative monthly stream flow into Lake Arrowhead for brush and no brush conditions.

CHAPTER 4

LAKE ARROWHEAD WATERSHED – ECONOMIC ANALYSIS

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INTRODUCTION

Amounts of the various types and densities of brush cover in the watershed were detailed in Chapter 3. 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 costs of a brush control program for water yield for the Lake Arrowhead watershed.

BRUSH CONTROL COSTS

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5 percent or less and maintain it at the reduced level for at least ten years. Both the types of treatments and their costs were obtained from meetings with landowners and Range Specialists of the Texas Agriculture Experiment Station and Cooperative Extension, and USDA-NRCS with brush control experience in the project areas. All current information available (such as costs from recently contracted control work) was used to formulate an average cost for the various treatments for each brush type-density category.

Obviously, the costs of control will vary among brush type-density categories. Present values (using a 6 percent discount rate) 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 in the project area (per acre) range from $35.57 for moderate mesquite that can be initially controlled with herbicide treatments to $175.57 for mechanical control of heavy mesquite. Costs of treatments and year those treatments are needed for each brush type – density category are detailed in Table 4-1.

LANDOWNER AND STATE COST SHARES

Rancher benefits are the total benefits that will accrue to the rancher as a result of the brush control program. These total benefits are based on the present value of the improved net returns to the ranching operation through typical cattle, sheep, goat, and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, an improvement in net returns would result from increased amounts of usable forage produced by controlling the brush and, thus, eliminating much of the competition for water and nutrients within the plant communities on which the enterprise is based. The differences in grazing capacity with and without brush control for each of the brush type-density categories in the watersheds draining to Lake Arrowhead are shown in Table 4-2. Data relating to grazing capacity was entered into the investment analysis model (see Chapter 2).

Livestock production practices, revenues, and costs representative of the watershed were obtained from personal interviews with a focus group of local ranchers. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into livestock production investment analysis budgets. This information for the livestock enterprises (cattle) in the project areas is shown in Table 4-3. It is important to note once again (refer to Chapter 2) that the investment analysis budgets are for analytical purposes only, as they do not include all revenues nor all costs associated with a production enterprise. The data are reported per animal unit for each of the livestock enterprises. From these budgets, data were entered into the investment analysis model, which was also described in Chapter 2.

Rancher benefits were also calculated for the financial changes in existing wildlife operations. Most of these operations in this region were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. Therefore, wildlife costs and revenues were entered into the model as simple entries in the project period. For control of heavy brush categories, wildlife revenues are expected to increase by about $1.00 per acre due principally to the resulting improvement in quail habitat. Wildlife revenues would not be expected to change with implementation of brush control for the moderate brush type-density categories.

With the above information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $17.54 per acre for control of moderate mesquite to $19.43 per acre for the control of heavy mesquite (Table 4-4).

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 per acre cost share of brush control in the project area range from $18.03 for control of moderate mesquite with chemical treatments to $156.14 for control of heavy mesquite by mechanical methods. Total treatment costs and landowner and state cost shares for all brush type-density categories are shown by both cost-share percentage and actual costs in Table 4-4.

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. The brush control program water yields and the estimated acreage by brush type-density category by subbasin were supplied by the Blacklands Research Center, Texas Agricultural Experiment Station in Temple, Texas (see previous Chapter). The total state cost share for each subbasin 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 subbasin. The cost of added water resulting from the control of the eligible brush in each subbasin 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 10-year period using a 6 percent discount rate).

The cost of added water was determined to average $14.83 per acre foot for the entire Lake Arrowhead Watershed (Table 4-5). Subbasins range from costs per added acre foot of $6.84 to $26.38.

Table 4-1. Cost of Water Yield Brush Control Programs by Type-Density Category

Heavy Mesquite – Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
4	Aerial Spray Herbicide	25.00	19.80
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**$ 54.78**

Heavy Mesquite – Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Doze/Root Plow, Rake, Stack, Burn	$ 165.00	$ 165.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 175.57**

Moderate Mesquite – Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Aerial Spray Herbicide	$ 25.00	$ 25.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 35.57**

Moderate Mesquite – Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Grub, Rake, Stack and Burn	$ 100.00	$ 100.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 110.57**

Moderate Mesquite – Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acre
0	Skid Steer with Shears	$ 35.00	$ 35.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$ 45.57**

Table 4-2. Grazing Capacity With and Without Brush Control (Acres/AUY)

Brush Type/ Category	Brush Control	Program Year									
		0	1	2	3	4	5	6	7	8	9
Heavy Mesquite	Brush Control	28.00	26.50	25.00	23.50	22.00	22.00	22.00	22.00	22.00	22.00
	No Control	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00	28.00
Moderate Mesquite	Brush Control	25.00	24.25	23.50	22.75	22.00	22.00	22.00	22.00	22.00	22.00
	No Control	25.00	25.33	25.67	26.00	26.33	26.67	27.00	27.33	27.67	28.00

Table 4-3. Investment Analysis Budget, Cow-Calf Production

Partial Revenues:

Revenue Item Description	Marketed	Quantity	Unit	$ Per Unit	$ Return
Calves	90%	5.5	Cwt.	0.87	$ 430.65
				TOTAL	**$ 430.65**

Partial Variable Costs:

Variable Cost Item Description		Quantity	Unit	$ Per Unit	Cost
Supplemental Feed		1	1	$ 48.00	$ 48.00
Cattle Marketing – All Cattle		———	Head	———	16.00
Vitamin/Salt/Minerals		60	Pound	0.10	11.00
Veterinary Medicine		1	Head	14.00	20.00
Miscellaneous		1	Head	12.00	12.00
Net Cost for Replacement Cows		———	Head	700.00	40.00
Net Cost for Replacement Bulls		———	Head	1,500.00	4.00
				TOTAL	**$ 151.00**

Table 4-4. Landowner/State Cost-Shares of Brush Control

Brush Type and Density	Control Practice	PV of Total Cost ($/Acre)	Rancher Share ($/Acre)	Rancher %	State Share ($/Acre)	State %
Heavy Mesquite	Chemical	54.78	19.43	35.47	35.35	64.53
	Grub or Doze	175.57	19.43	11.07	156.14	88.93
Moderate Mesquite	Chemical	35.57	17.54	49.31	18.03	50.69
	Grub or Doze	110.57	17.54	15.86	93.03	84.14
Average		94.12	18.49	27.93	75.64	72.07

Table 4-5. Cost of Added Water From Brush Control by Subbasin (Acre Foot)

Subbasin	Total State Cost ($)	Added Gallons Per Year	Added Acre Foot/Year	Total Acre/Ft 10 Yrs Dsctd	State Cost/ Acre Foot ($)
1	$ 890,835.69	2,154,658,197.03	6,612.40	51,587.94	$ 17.27
2	792,839.56	1,603,971,605.12	4,922.41	38,403.11	20.65
3	1,193,772.24	2,645,021,025.03	8,117.27	63,328.45	18.85
4	645,032.32	1,149,475,605.35	3,527.61	27,521.34	23.44
5	330,284.29	523,014,767.61	1,605.07	12,522.29	26.38
6	385,074.33	1,060,752,122.04	3,255.33	25,397.07	15.16
7	451,240.14	1,246,555,855.56	3,825.54	29,845.68	15.12
8	893,199.99	2,508,188,911.38	7,697.35	60,052.35	14.87
9	789,409.91	1,724,107,666.62	5,291.09	41,279.47	19.12
10	1,390,116.97	4,128,213,443.23	12,669.02	98,839.81	14.06
11	1,304,918.20	4,175,057,884.49	12,812.78	99,961.38	13.05
12	87,872.64	382,626,356.77	1,174.24	9,161.04	9.59
13	1,164,934.45	3,449,892,862.07	10,587.33	82,599.11	14.10
14	855,343.01	2,714,347,320.33	8,330.03	64,988.30	13.16
15	326,603.70	1,188,731,222.13	3,648.08	28,461.21	11.48
16	257,684.25	981,314,990.05	3,011.55	23,495.15	10.97
17	177,614.54	655,942,859.17	2,013.01	15,704.92	11.31
18	166,110.60	556,785,852.99	1,708.71	13,330.85	12.46
19	1,029,797.78	2,823,542,988.67	8,665.14	67,602.72	15.23
20	886,216.09	2,440,216,220.39	7,488.75	58,424.91	15.17
21	364,992.01	1,015,478,003.63	3,116.39	24,313.10	15.01
22	75,349.90	272,324,895.18	835.73	6,520.14	11.56
23	905,677.75	3,239,088,907.36	9,940.40	77,551.93	11.68
24	946,411.68	3,019,716,470.06	9,267.17	72,299.61	13.09
25	293,211.92	893,809,938.15	2,743.00	21,400.06	13.70
26	546,610.84	1,745,624,225.02	5,357.12	41,794.63	13.08
27	318,222.59	640,949,626.80	1,967.00	15,345.95	20.74
28	76,455.03	466,961,686.53	1,433.05	11,180.24	6.84
Total	**$ 17,545,832.44**			**1,182,912.76**	
Average					**$ 14.90**