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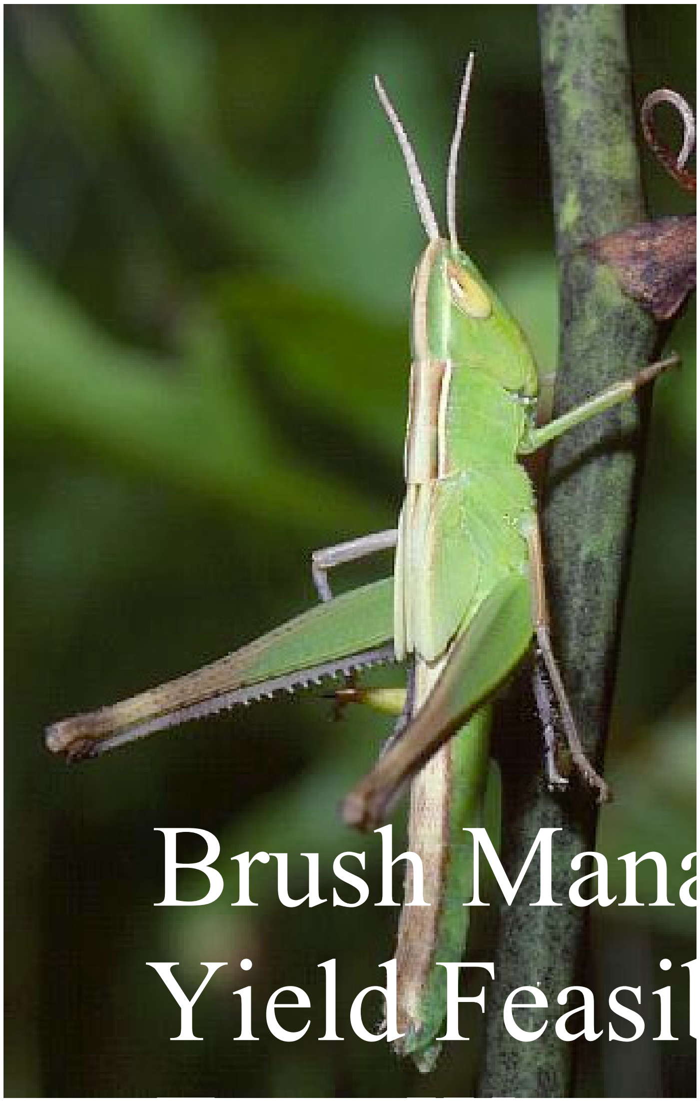

Brush Management/Water Yield Feasibility Study for Four Watersheds In Texas

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 8 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 was 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).

<u>Soils.</u> 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.

<u>Topography.</u> 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).

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 seven 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 vs. 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.

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Table 1-1. Land use and percent cover in each watershed.

Watershed	Percent Cover					
	Heavy & Mod. 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
Ft. Phantom Hill	46	4	9	5	26	10
Palo Pinto	47	23	11	6	6	7

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

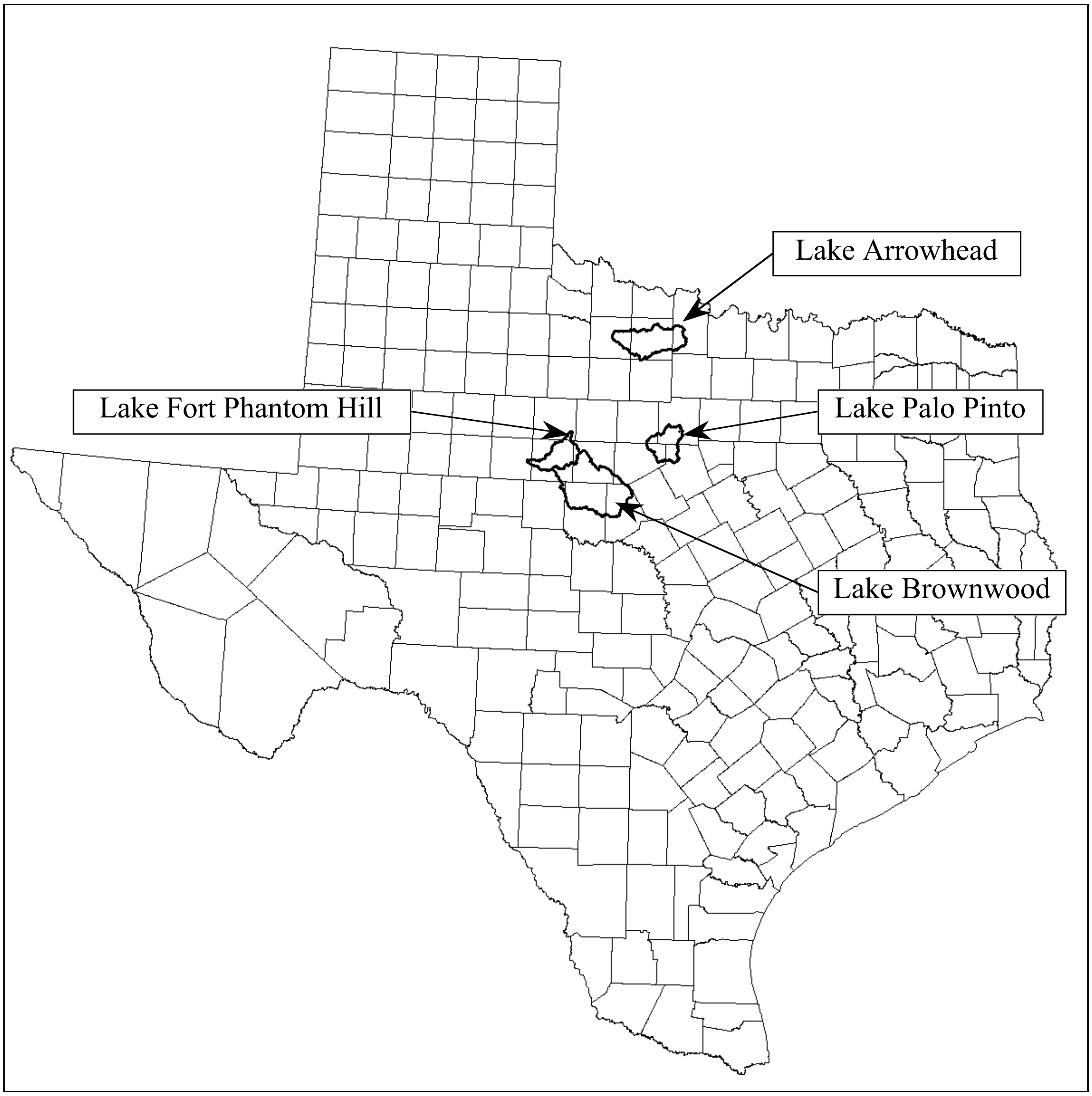

Figure 1-1. Watersheds included in the study area.

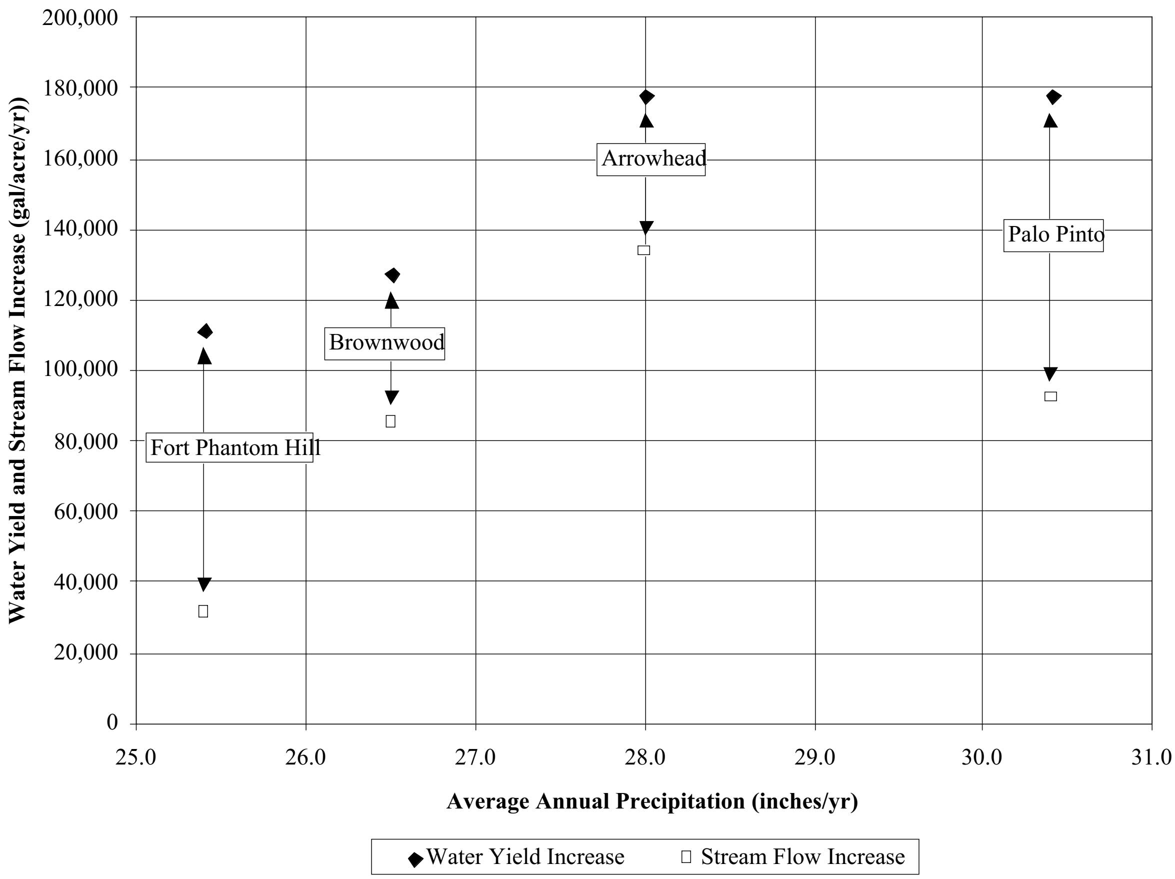

Figure 1-2. Average annual water yield and stream flow increases per treated acre versus average annual precipitation for watersheds in this study, 1960 through 1999.

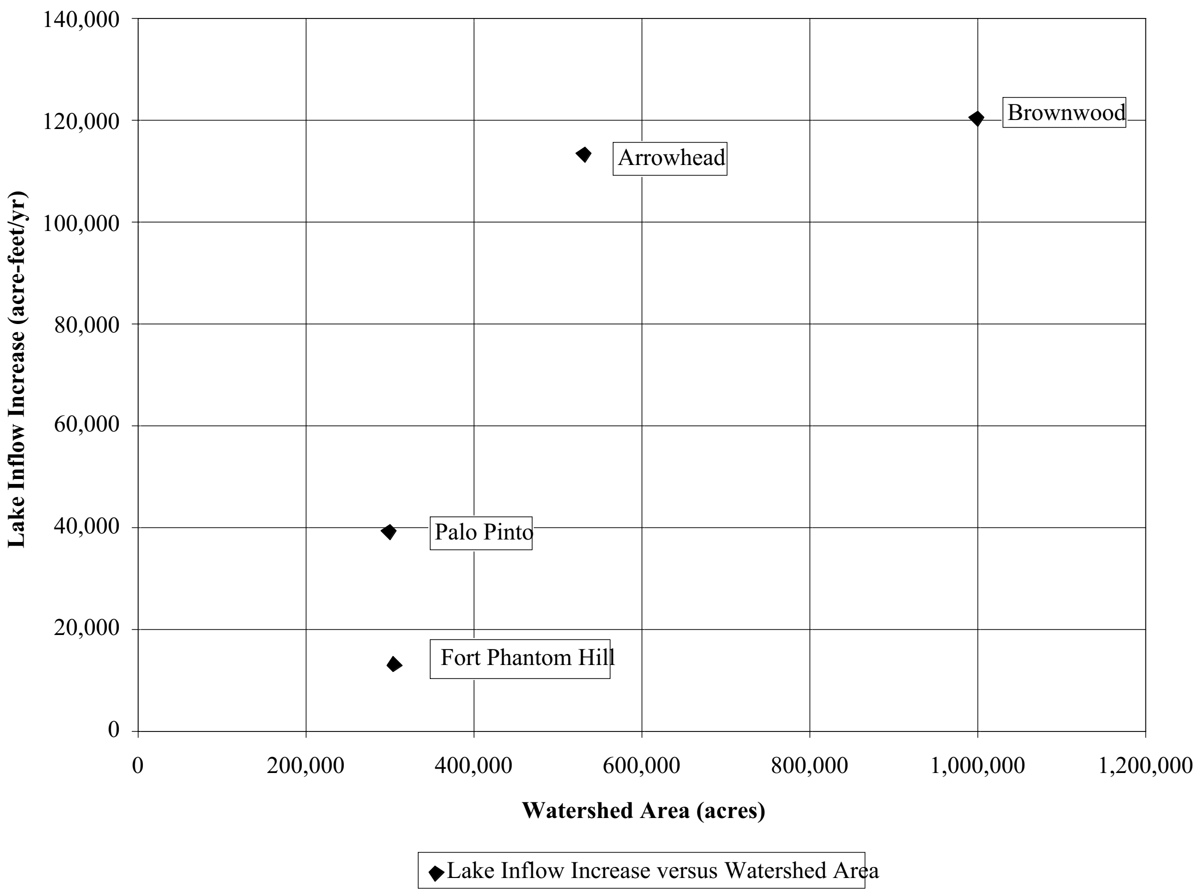

Figure 1-3. Average annual lake inflow increase resulting from brush removal versus watershed drainage area for watersheds in this study, 1960 through 1999.

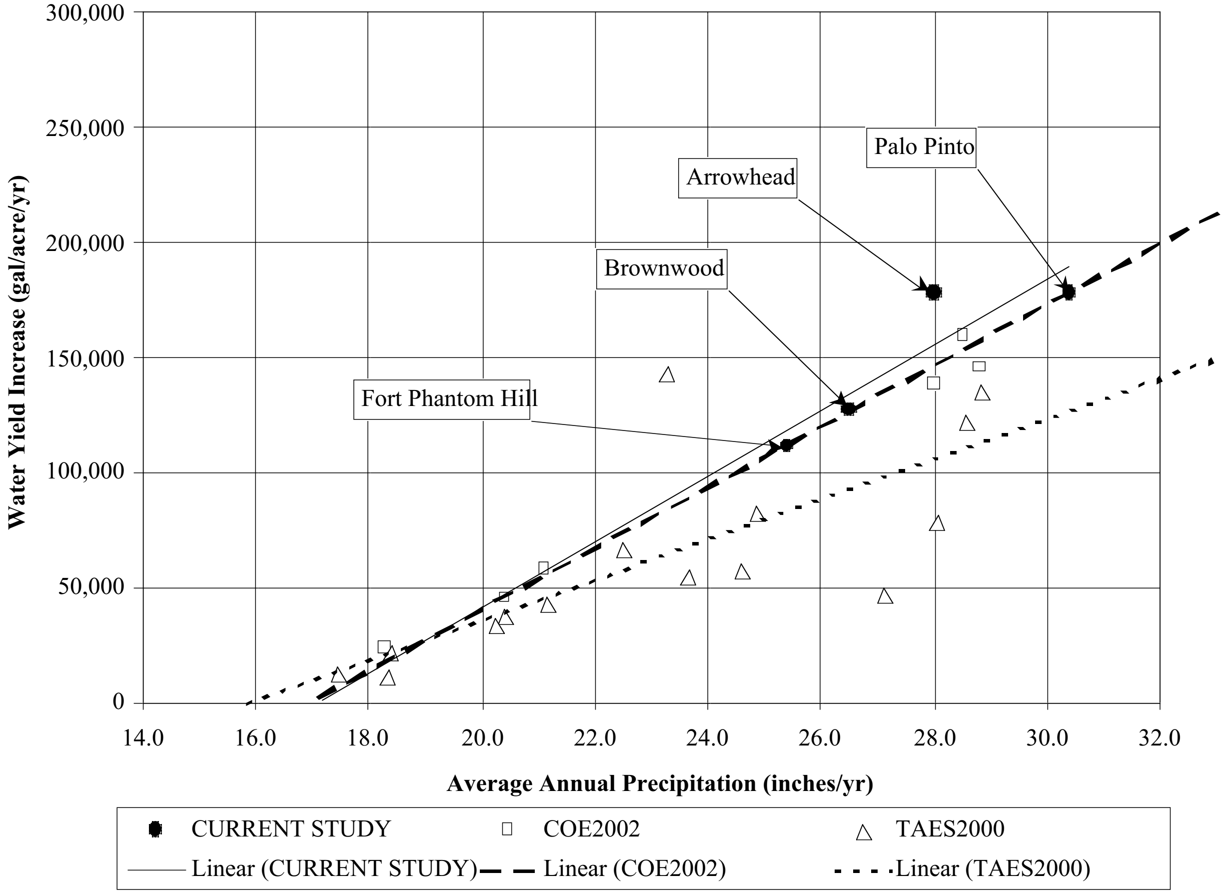

Figure 1-4. Water yield increase versus average annual precipitation - current study, COE (2002), and TAES (2000). Points are labeled for watersheds in current study.

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 8% and 3% and maintain it at the reduced level for 10 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, the Texas Legislature, in 2001, 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 3-8% percent and maintain it at the reduced level for at least 10 years. These practices, or brush control treatments, differed among watersheds due to differences in terrain, soils, amount, and distribution of cropland 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 1 - 9 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% discount rate as opportunity cost for rancher investment capital) are 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 rootplowing.

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 10 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% 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 10 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 rancher 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 10-year period using a 6% 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 cost 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% 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% 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% 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% 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 load.

Based on these considerations, it is reasonable to expect that less than 100% 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.

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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**

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

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
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					14.83

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 consists of nearly level to gently sloping, moderately deep and deep, clayey and loamy soils. The soils of the Central Rolling Red Prairies consists 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 consists 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 consist 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 gauge 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 uses. 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 gauge 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 gauge 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 gauge 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 gauge 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% 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 gauge was from 1967 through 1999. Average measured and predicted monthly flows were within five percent, with an 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

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% and 69% 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 are shown in Table 3-2. The amount of annual increase varied among 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% or 151,623 acre-feet, and flow at the watershed outlet (Lake Arrowhead) increased by 113,860 acre-feet/year.

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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	0.10
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 (^{o}C)		
	Heavy Mesquite	3346
	Heavy Mixed Brush	3705
	Moderate Mesquite	3067
	Heavy Oak	3466
	Moderate Oak	3067
	Light Brush & Open Range/Pasture	2669
Plant Rooting Depth (feet)		
	Heavy and Moderate Brush	6.5
	Light Brush & 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	893,809,938
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*

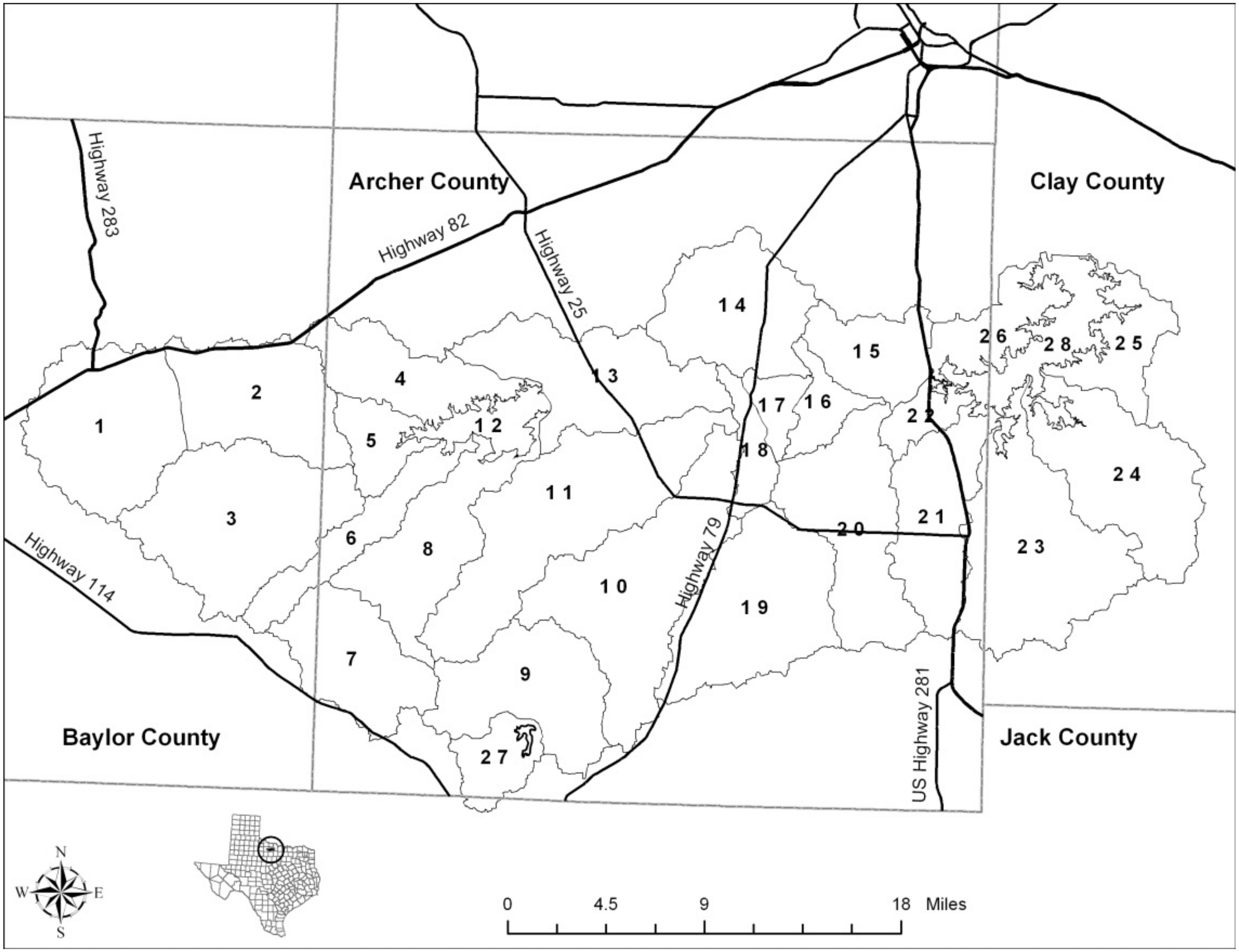

Figure 3-1. Lake Arrowhead watershed subbasin map with major roads.

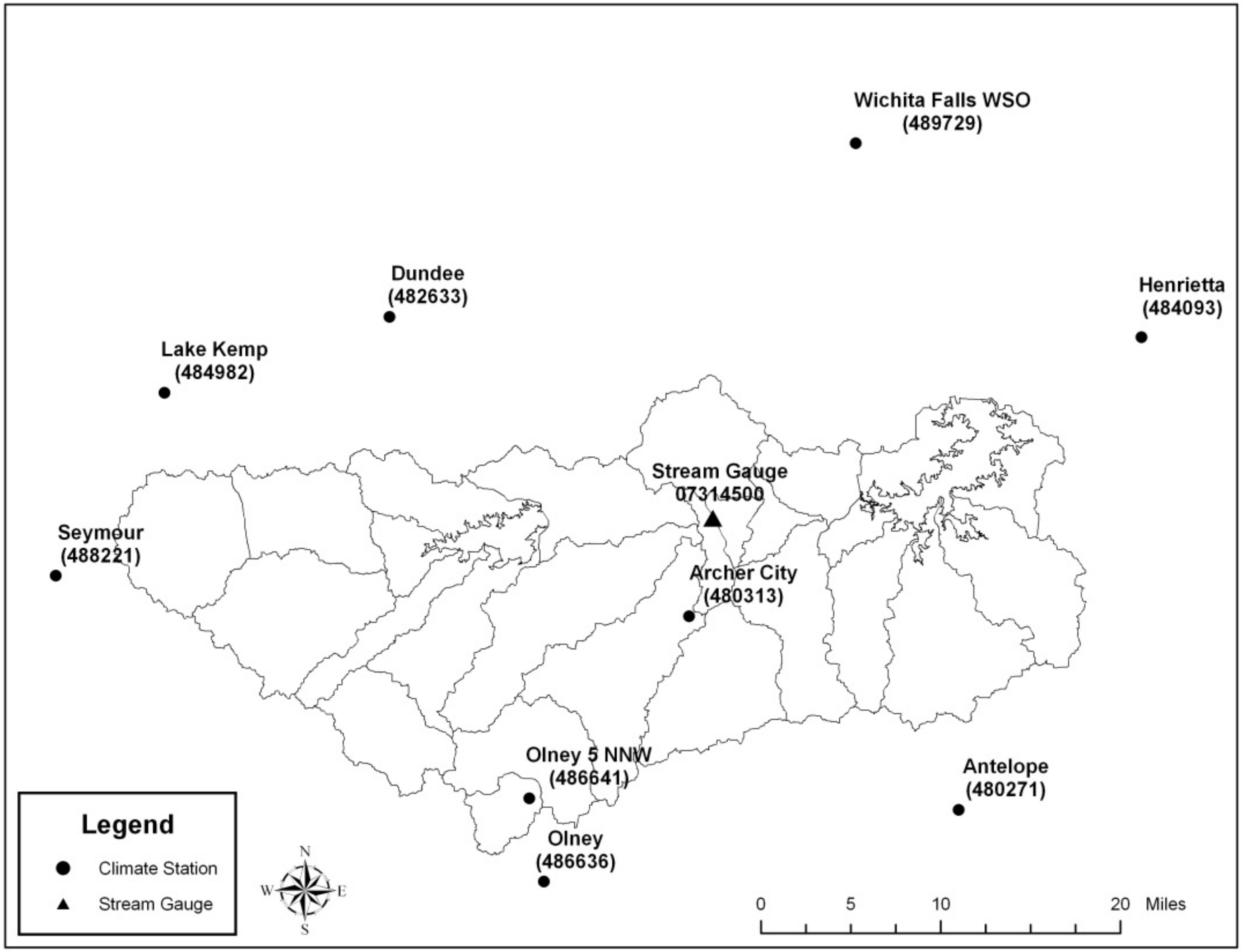

Figure 3-2. Climate and stream gauge stations in the Lake Arrowhead watershed.

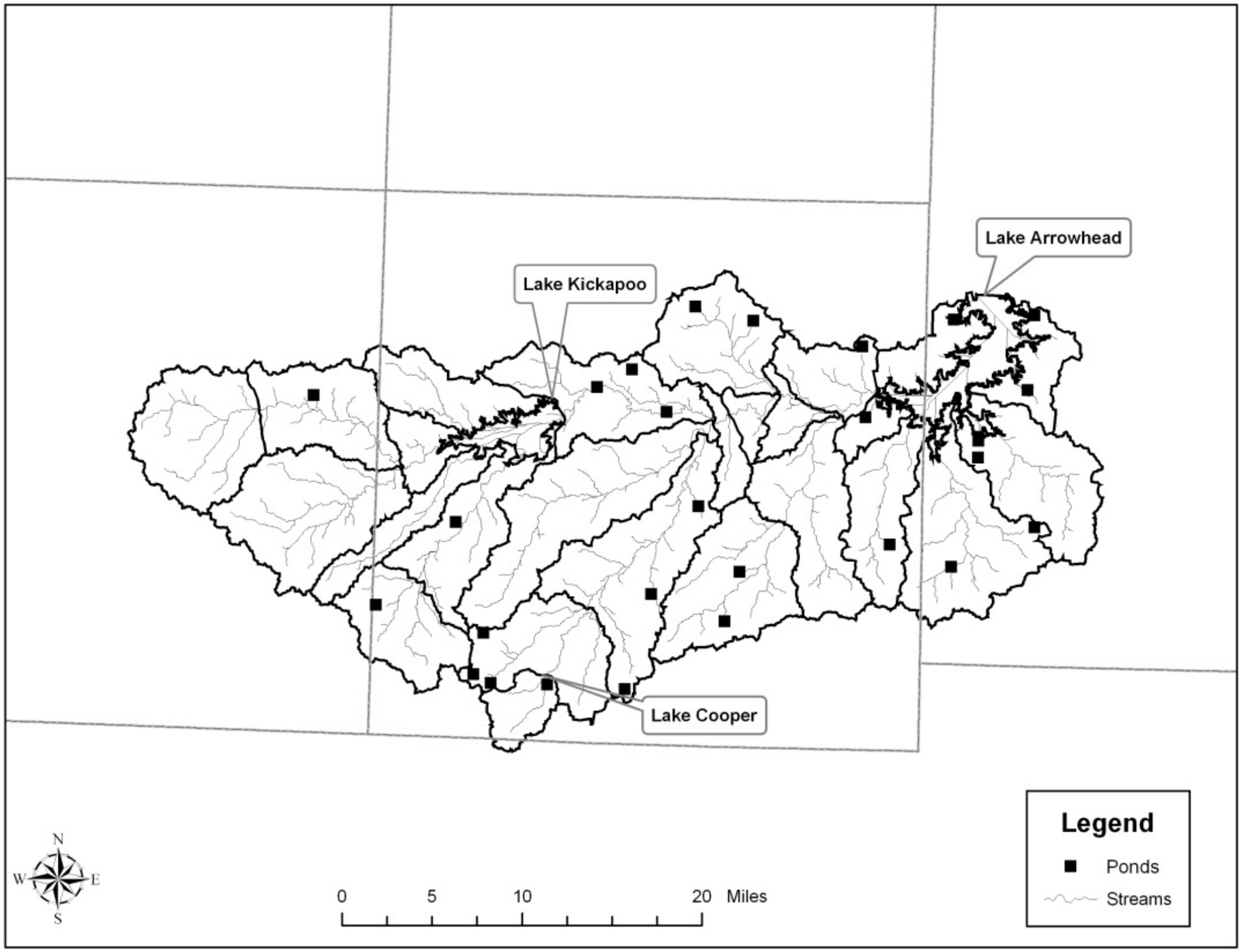

Figure 3-3. Inventory-sized ponds and reservoirs in the Lake Arrowhead watershed.

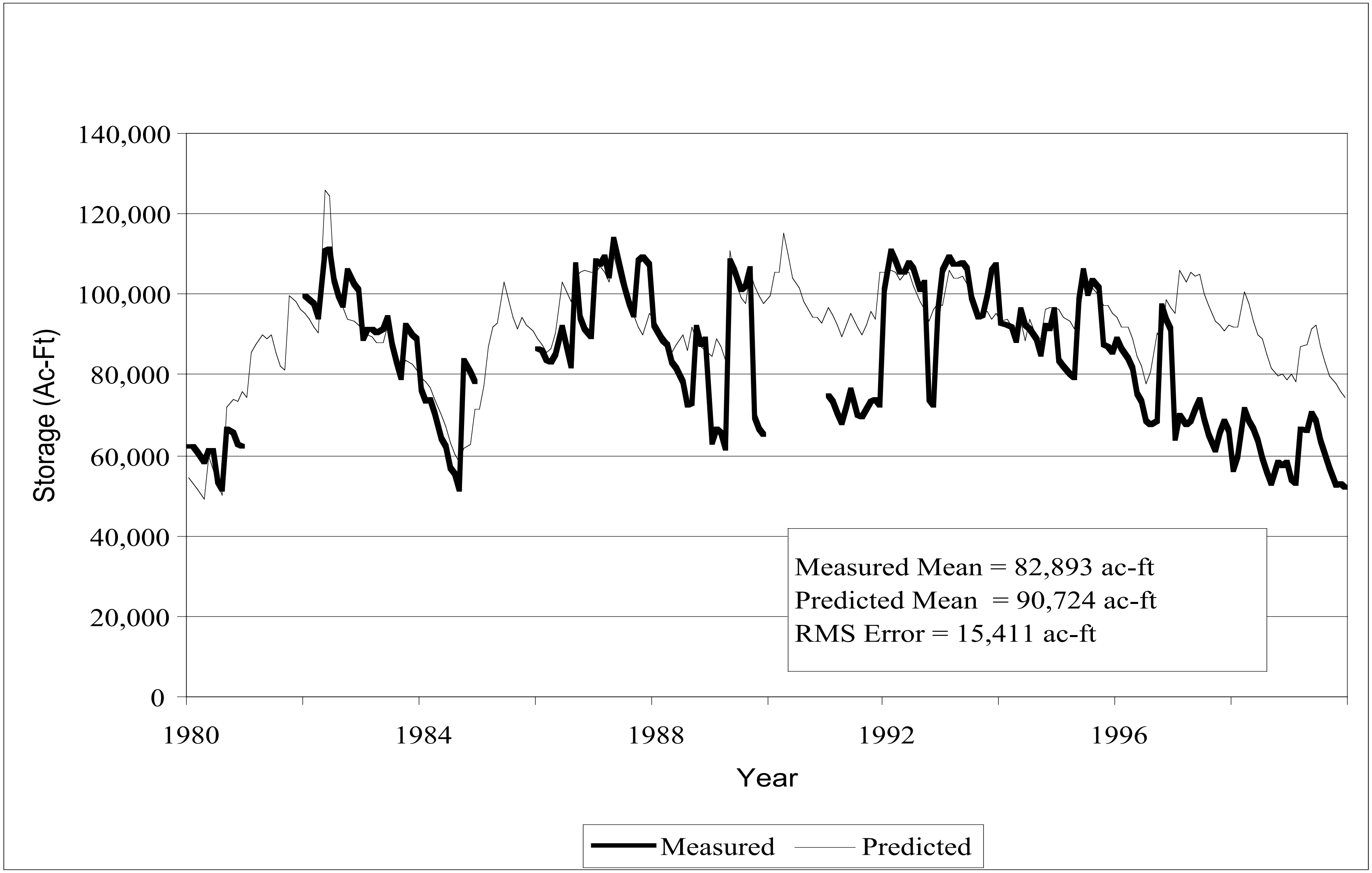

Figure 3-4. Measured and predicted monthly storage in Lake Kickapoo, 1980 through 1999. Measured data was only available from 1980 through 1999, and included data gaps. Monthly statistics shown in box are for months with measured data.

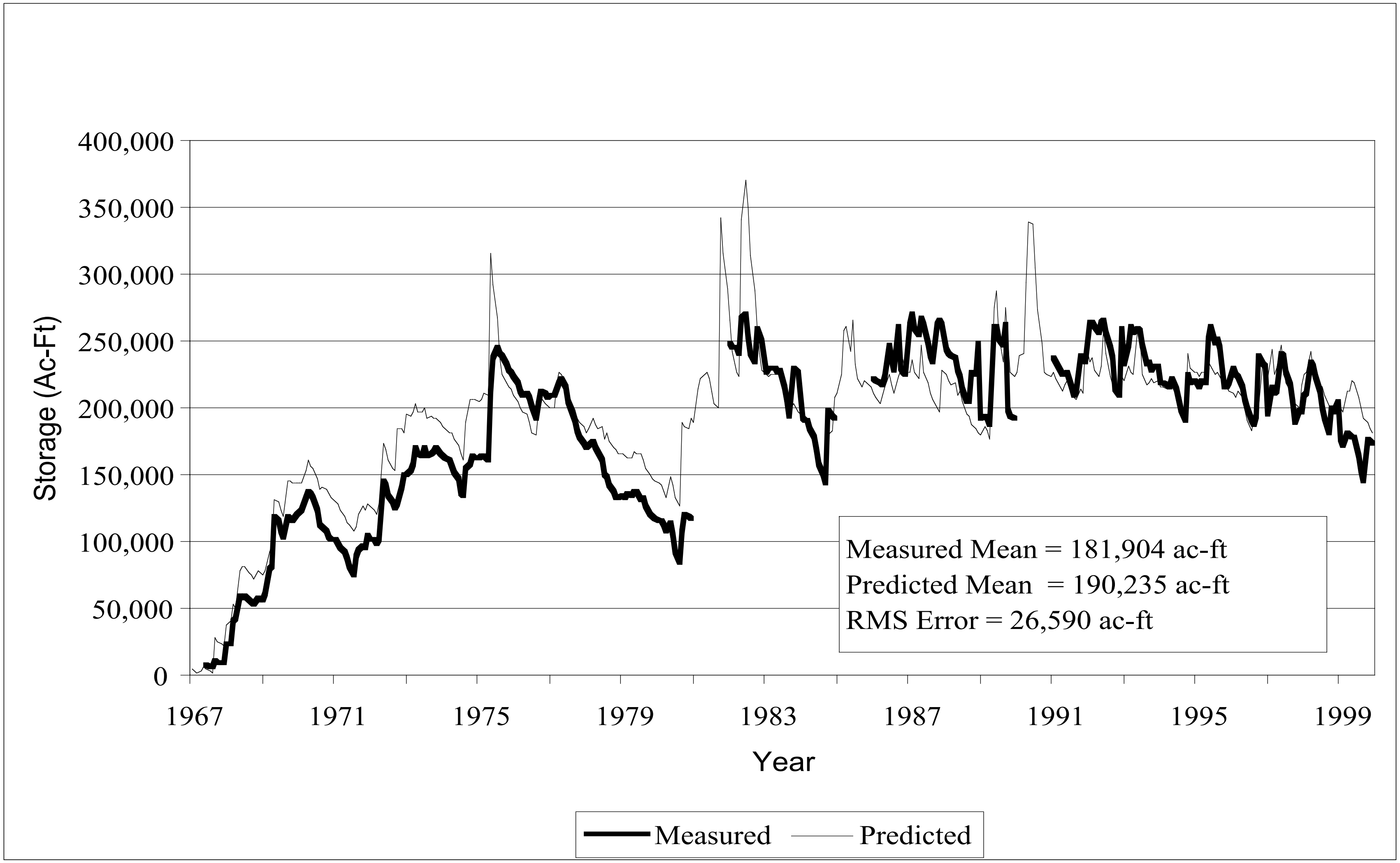

Figure 3-5. Measured and predicted monthly storage in Lake Arrowhead, 1967 through 1999. Measured data was only available from 1967 through 1999, and included data gaps. Monthly statistics shown in box are for months with measured data.

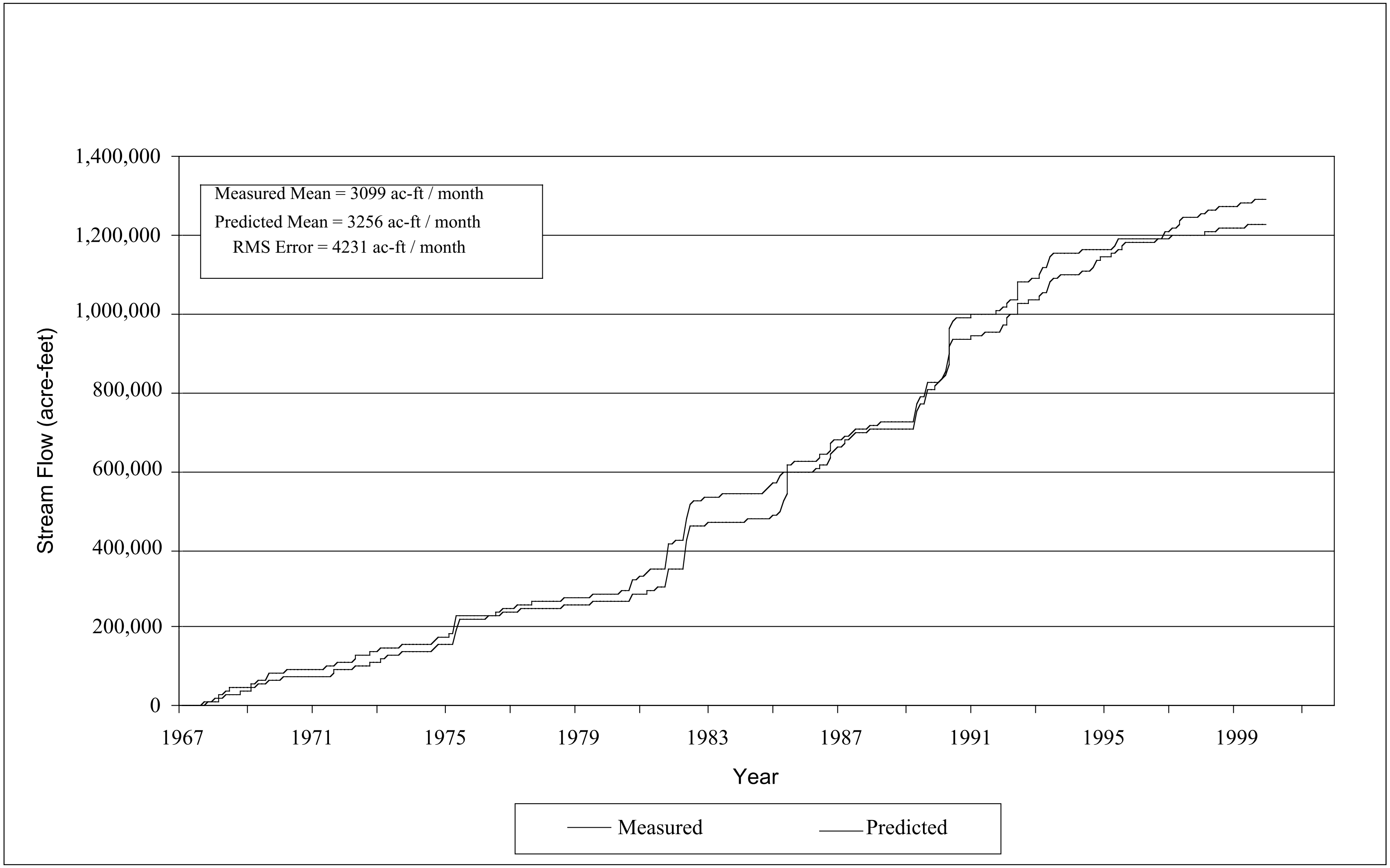

Figure 3-6. Cumulative monthly measured and predicted stream flow at gauge 07314500 (near Archer City), 1967 through 1999. Monthly statistics are shown in box.

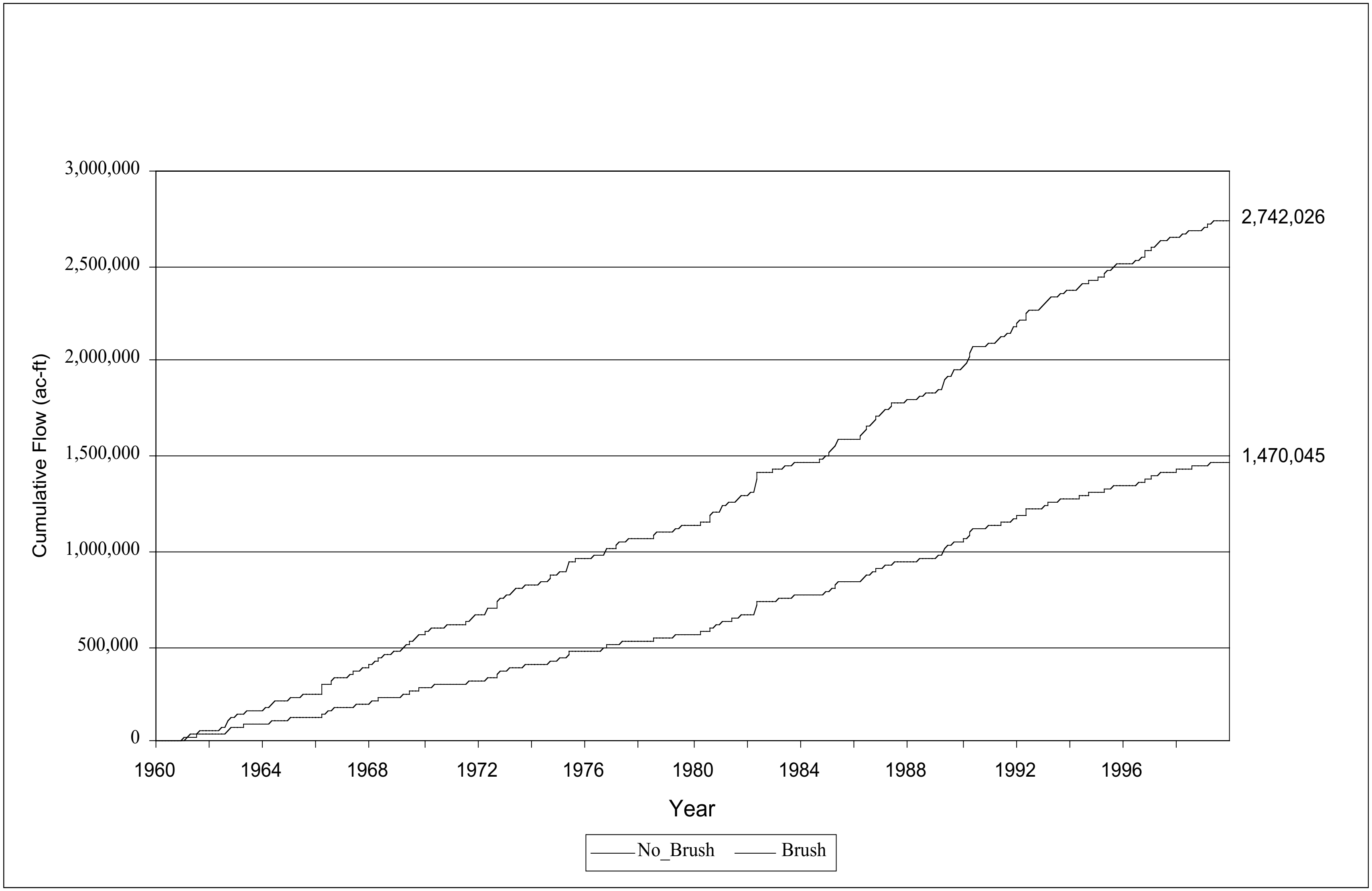

Figure 3-7. Predicted cumulative monthly stream flow into Lake Kickapoo for brush and no brush conditions.

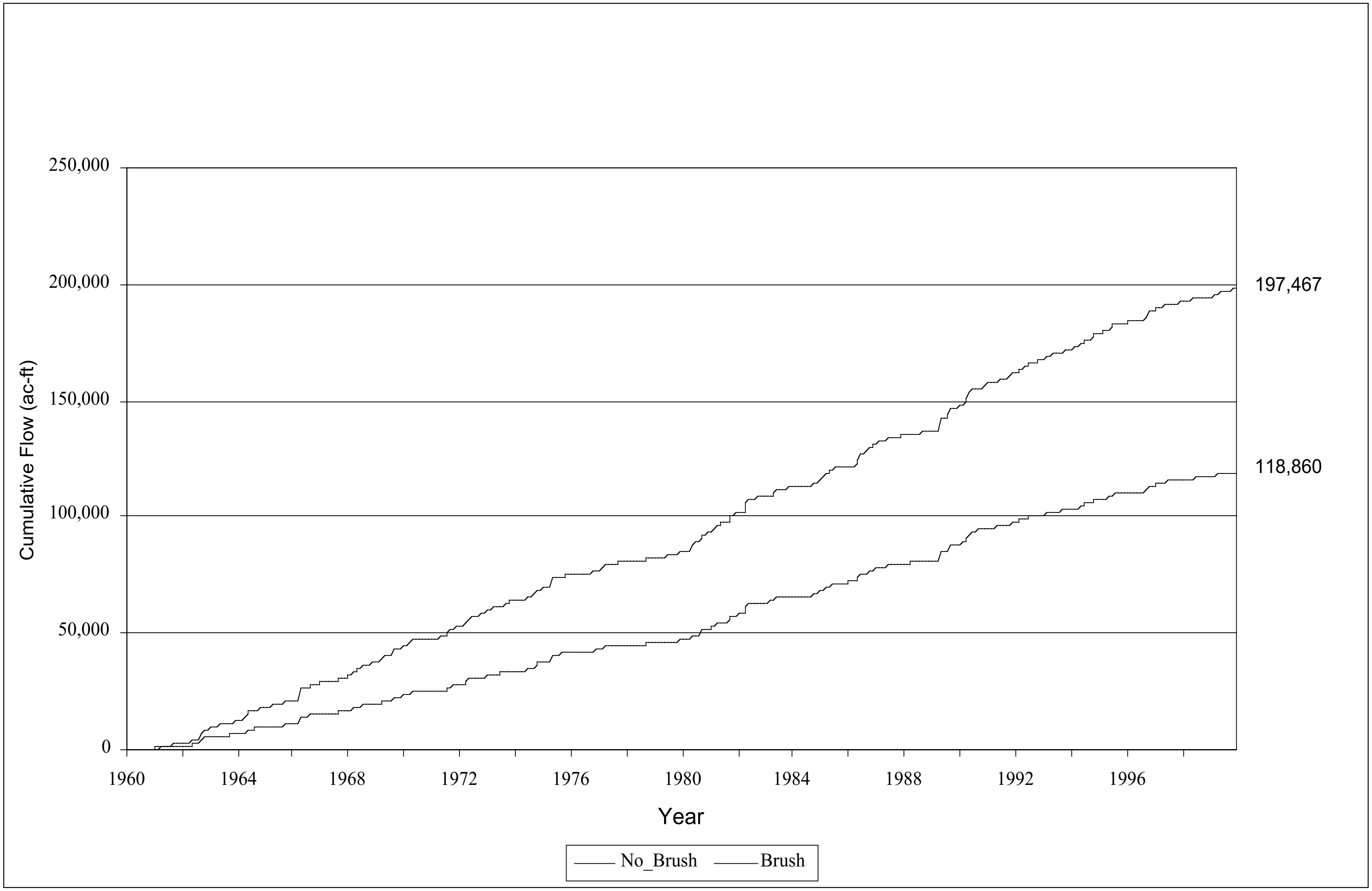

Figure 3-8. Predicted cumulative monthly stream flow into Lake Cooper for brush and no brush conditions.

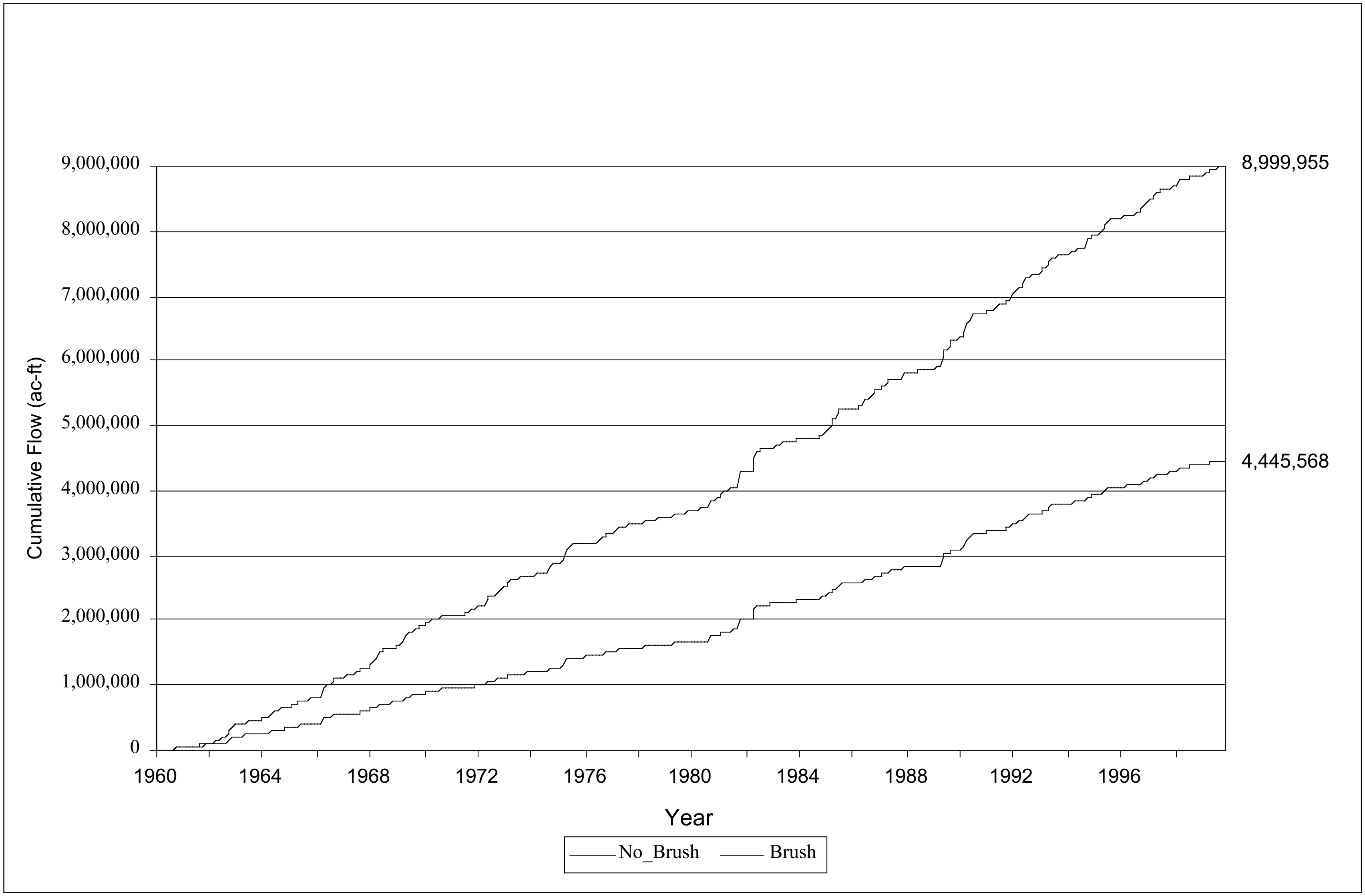

Figure 3-9. Predicted cumulative monthly stream flow into Lake Arrowhead for brush and no brush conditions

CHAPTER 4

LAKE ARROWHEAD WATERSHED – ECONOMIC ANALYSIS

Linda Dumke, Research Assistant; Brian Maxwell, Research Assistant; J. Richard Conner, Professor; Department of Agricultural Economics
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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% or less and maintain it at the reduced level for at least 10 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% 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 6 or 7. 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% 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 and 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 Desription	**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	1500.00	4.00
				TOTAL	**151.00**

Table 4-4. Landowner/State cost-shares of brush control.

Brush Type & 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

Table 4-5. Cost of added water from brush control by subbasin (acre-foot).

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10 Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
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					14.83

CHAPTER 5

LAKE BROWNWOOD WATERSHED – HYDROLOGIC SIMULATION

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Blackland Research Center

WATERSHED DATA

Physical Data

Lake Brownwood, also known as Brownwood Reservoir, is an artificial lake on Pecan Bayou, eight miles north of Brownwood in north central Brown County. The project is owned and operated by Brown County Water Improvement District Number 1. The surface area is 7,300 acres. The lake's normal capacity is 118,900 acre-feet; its maximum capacity is 448,200 acre-feet. The spillway elevation is 1,425 feet above mean sea level (Handbook of Texas Online, 2002). This impoundment provides water to the Cities of Brownwood, Early, and Bangs for municipal, industrial, irrigation, and recreational use.

The two major tributaries of the Lake Brownwood watershed are Jim Ned Creek and Pecan Bayou. The watershed originates in southeast Taylor County (Jim Ned Creek) and in west-central Callahan County (Pecan Bayou). Jim Ned Creek flows in a southeasterly direction through Taylor, Coleman, and Brown Counties for a distance of approximately 73 miles and into Lake Brownwood. Pecan Bayou flows southeast through Callahan, Coleman, and Brown Counties for approximately 85 miles before entering Lake Brownwood. The Lake Brownwood watershed has an area of approximately 997,000 acres (1,558 square miles), nearly all of which is in farms and ranches.

Interest in an irrigation dam below the confluence of Pecan Bayou and Jim Ned Creek first arose during a serious drought that afflicted the area in 1894 and 1895. Initial attempts to fund the project failed, but in 1928 voters of the Brownwood Water District approved bonds for $2.5 million to construct the dam, which was completed in 1932. Depression conditions made local bond funding for canals impossible, but the federal government granted $450,000 to carry water from Lake Brownwood to thirsty land. It was predicted that several years of normal rainfall would be required to fill the lake behind the dam, but an almost unprecedented storm in July 1932 filled it in six hours (Handbook of Texas Online, 2002).

The outlet or "catchment" for the watershed simulated in this study is Lake Brownwood labeled subbasin number 48. The subbasin delineation, numbers, county boundaries, and major roads (obtained from the Census Bureau) are shown in Figure 5-1.

METHODS

Land Use/Land Cover

The land use map 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. Over 75 percent of the watershed is in some type of rangeland or pasture cover. Approximately 46 percent of the watershed is moderate or heavy brush that was converted to open rangeland in the SWAT simulation.

Soils

The watershed is in five land resource areas, namely: the Rolling Plains, the North Central Prairie, the West Cross Timbers, the Grand Prairie, and the Edwards Plateau (USDA Handbook 296, 1981). The soils of the Edwards Plateau consist of stony, very shallow clays on steep slopes and are used almost exclusively for rangeland. The West Cross Timbers soils (fine sandy loams with slowly permeable to moderately permeable sandy clay subsoils) are confined to relatively narrow bands cropping out near or on the watershed divide. Soils of the Rolling Plains consist of two groups: deep, silty clay loam soils suitable for cultivation and shallow, somewhat stony, fine textured soils on hills and ridges. The lower portion of the watershed consists of the varied soils of the North Central Prairie having surface textures ranging from fines to coarse sands with very slow to moderately permeable subsoils. A very small percentage of the watershed is in the Grand Prairie MLRA.

The dominant soil series in the Lake Brownwood watershed are Tarrant, Speck, Pedernales, Throck, Frio, Tobosa, Bonti, Sagerton, and Callahan. These nine soil series represent about 50 percent of the watershed area. A short description of each from the USDA-NRCS soil survey follows:

Tarrant. The Tarrant series consists of very shallow and shallow, well drained, moderately slowly permeable soils on uplands. They formed in residuum from limestone, and include interbedded marls, chalks, and marly materials. Slopes are mainly 1 to 8 percent, but some are as much as 50 percent.

Speck. The Speck series consists of shallow, well-drained, slowly permeable soils formed in residuum and colluvium derived from indurated limestone. These soils are on nearly level to sloping uplands. Slopes range from 0 to 8 percent.

Pedernales. The Pedernales series consists of very deep, well-drained, moderately slowly permeable soils that formed in loamy and clayey, calcareous sediments. These soils are on nearly level to moderately sloping uplands. Slopes range from 0 to 8 percent.

Throck. The Throck series consists of soils that are moderately deep and deep to dense weathered shale. They are calcareous, well drained, slowly permeable soils that formed in residuum and colluvium derived from clayey marl and shales. They are on gently sloping to steep uplands. Slopes range from 1 to 30 percent.

Frio. The Frio series consists of very deep, well-drained, moderately slowly permeable soils that formed in loamy and clayey calcareous alluvium. These flood plain soils have slopes ranging from 0 to 2 percent.

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

Bonti. The Bonti series consists of moderately deep, well-drained, moderately slowly permeable soils formed in residuum of interbedded sandstone and clayey materials. These upland soils have slopes ranging from 1 to 40 percent.

Sagerton. The Sagerton series consists of very deep, well-drained, moderately slowly permeable soils that formed in calcareous clayey and loamy sediments. These nearly level to gently sloping soils are on uplands. Slopes range from 0 to 5 percent.

Callahan. The Callahan series consists of moderately deep, well drained, very slowly permeable soils that formed in clayey shale interbedded with thin sandstone strata. These soils are on gently to strongly sloping uplands. Slopes range from 1 to 12 percent.

Topography

Topography of the watershed is moderate to gently rolling, with areas of rather pronounced relief along portions of the northeastern and western margins. Elevations range from 1,430 feet on the flood plain above Lake Brownwood to over 2,300 feet above mean sea level on parts of the escarpment.

Geology

Rocks of four major geologic periods: Pennsylvanian, Permian, Cretaceous, and Quaternary, crop out in the watershed. The Pennsylvanian formations (represented by the shales, sandstones, conglomerates, and limestones of the Cisco and Canyon groups) are located mostly in the Brown County portion of the watershed. Formations of the Wichita group of Permian age are located across most of the Coleman County portion of the watershed and consist of hard limestone alternating with blue shale. The Cretaceous period consists mainly of the Trinity group (poorly consolidated sandstones, silt-stones, and clays) and is exposed along most of the northern one-third and western margin of the watershed. The Quaternary period is limited to deep clayey flood pain deposits along major streams and a few isolated terrace deposits (SCS, 1960 and SCS, 1964).

Climate

The average annual rainfall (1960 – 1999 SWAT climate data) for the Lake Brownwood Watershed varies from 24.4 inches in the western portion of the watershed to 30.6 inches in the eastern portion. The composite average for the entire watershed was 26.5 inches. Average temperatures range from 84 degrees Fahrenheit in the summer to 43 degrees in the winter. The normal frost-free season of 232 days extends from March 25 to November 12.

Climate stations are shown in Figure 5-2. 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 gauge stations are also shown in this figure.

Ponds and Reservoirs

Surface runoff is the principal source of water for all purposes, due to the low water table and poor quality of underground water. Seven storage reservoirs in this watershed furnish water for municipal and industrial uses. Lake Scarborough, Hords Creek Reservoir, and Lake Coleman furnish water to Coleman. Old and New Lakes Santa Anna, supplemented by a pipeline from Lake Brownwood, furnish Santa Anna's water. Lake Novice supplies Novice, and Lake Brownwood supplies Bangs, Early, and Brownwood. Three PL-566 watershed protection and flood prevention projects (Jim Ned Creek, Pecan Bayou, and Turkey Creek) are in the Lake Brownwood watershed with 74 installed structures. Farm ponds supply a majority of the farmers and ranchers with water for domestic and livestock uses. Figure 5-3 shows the distribution of the major lakes and inventory-sized reservoirs.

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

Model Inputs

Significant input variables for the SWAT model for the Lake Brownwood Watershed are shown in Table 5-1. Input variables were adjusted as needed to calibrate flow at the applicable USGS stream gauge or reservoir. The calibration simulation represents the current "with brush" condition.

Model Calibration

SWAT was calibrated against measured stream flow and reservoir volumes by varying selected model parameters (Table 5-1). The model was calibrated for flow at four USGS stream gauges (08141500 – Hords Creek near Valera, Texas; 08142000 – Hords Creek near Coleman, Texas; 08140800 – Jim Ned Creek near Coleman, Texas; and 08140700 – Pecan Bayou near Cross Cut, Texas) (Figure 5-2) and for storage volume at two reservoirs (08140100 - Hords Creek Reservoir and 08143000 - Lake Brownwood) (Figure 5-3).

Brush Removal Simulation

The input variables for the no-brush condition, with one exception, were the same as the calibration variables, with the change in landuse 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.

RESULTS

Model Calibration

The results of reservoir storage calibrations are shown on Figures 5-4 and 5-5. Measured and predicted mean monthly volumes were within 4.9% (Hords Creek Reservoir) and 3.5% (Lake Brownwood). The calculated difference between measured and predicted values expressed as a residual of the means squared is the root mean square error (RMSE). One way to gauge the accuracy of the calibration is to divide the RMSE by the mean measured monthly value. The lower the result of this calculation, the more precise the comparison. The RSME/actual storage values were very low (0.3 and 0.1 respectively, for Hords Creek and Brownwood) which indicate that the model did a good job simulating actual storage volumes.

The results of calibration are shown for the stream gauges on Figures 5-6 through 5-9. The calibration period for each stream gauge varied but all fell within the range from 1960 through 1990. Comparisons of measured flow versus predicted flow (cumulative average monthly flow) yielded the following differences: 24.7% (08141500; 1960-1990), 3.5% (08142000; 1960 - 1970), 0.2%(08140800; 1965 - 1980), and 6.1% (08140700; 1968 - 1979). The RSME/actual flow values for different calibration points in the watershed are as follows: 3.3 (08141500), 1.6 (08142000), 2.2 (08140800), and 0.5 (08140700). The calibration for stream gauge 08141500 (immediately downstream of Hords Creek reservoir) showed the poorest agreement for measured and predicted flow and RMSE. This particular calibration was considered acceptable only because it fell closely between two other calibration points (08140100 and 08142000) that demonstrated a good correlation.

Brush Removal Simulation

Average annual evapo-transpiration (ET) was 21.57 inches for the brush condition (calibration) and 19.05 inches for the no-brush condition. This represented 81% and 72% of precipitation for the brush and no-brush conditions, respectively.

Figures 5-10 through 5-12 shows the cumulative monthly total flow to Lake Clyde, Lake Coleman, and Lake Brownwood 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 are shown in Table 5-2. The amount of annual increase varied among the subbasins and ranged from 82,525 gallons per acre of brush removed per year in subbasin number 38, to 195,281 gallons per acre in subbasin number 48. The large increase in water yield for the subbasin containing Lake Brownwood (subbasin 48) was most likely due to the presence of predominantly muck soils (high runoff potential) associated with water bodies and heavy brush. Variations in the amount of increased water yield were expected and were 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 in some cases 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 68% or 180,782 acre-feet, and flow at the watershed outlet (Lake Brownwood) increased by 120,885 acre-feet per year.

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Table 5-1. SWAT input variables for Lake Brownwood watershed.

VARIABLE		ADJUSTMENT or VALUE
Runoff Curve Number Adjustment		
	Subbasins 1 - 46, 48	-4
	Subbasin 47	-6
Soil Available Water Capacity Adjustment (inches H^2O/in. soil)	(Tarrant soils only)	+0.05
Soil Crack Volume Factor	(Tarrant soils only)	0.1
Soil Saturated Conductivity (inches/hour)	(Tarrant soils only)	0.09
Soil Evaporation Compensation Factor		0.85
Minimum Shallow Aquifer Storage for Groundwater Flow (inches)		0.079
Minimum Shallow Aquifer Storage for Revap (inches)		0.081
Shallow Aquifer Re-Evaporation (Revap) Coefficient		
	Brush	0.40
	All Others	0.10
Channel Transmission Loss (inches/hour)		0.51
Subbasin Transmission Loss (inches/hour)		0.51
Bank Coefficient		0.50
Reservoir Evaporation Coefficient		1.00
Reservoir Seepage Rate (inches/hour)		
	Hords Creek	0.020
	All Others	0.003
Principal Spillway Release Rate (cfs)		
	Lake Clyde	35
	Lake Coleman	106
	Hords Creek Reservoir	35
	Lake Brownwood	35
Potential Heat Units (^oC)		
	Heavy Juniper	4106
	Heavy Mesquite	3572
	Heavy Mixed Brush	3818
	Moderate Juniper	3572
	Moderate Mesquite	3161
	Moderate Mixed Brush	N/A
	Heavy Oak	3572
	Moderate Oak	3161
	Light Brush & Open Range/Pasture	2792
Plant Rooting Depth (feet)		
	Heavy and Moderate Brush	6.5
	Light Brush & Open Range/Pasture	3.3
Maximum Leaf Area Index		
	Heavy Juniper	6
	Heavy Mesquite	4
	Heavy Mixed Brush	4
	Moderate Juniper	5
	Moderate Mesquite	2
	Moderate Mixed Brush	N/A
	Heavy Oak	4
	Moderate Oak	3
	Light Brush	2
	Open Range/Pasture	1

Table 5-2. Subbasin data, Lake Brownwood 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	25,617	8,869	0.35	137,472	1,219,276,894
2	30,540	16,987	0.56	111,550	1,894,866,042
3	23,327	12,565	0.54	95,621	1,201,473,087
4	27,219	15,609	0.57	110,148	1,719,308,991
5	42,066	13,866	0.33	120,178	1,666,429,696
6	28,445	10,117	0.36	163,070	1,649,738,485
7	27,498	11,928	0.43	93,274	1,112,575,178
8	38,692	14,485	0.37	125,413	1,816,571,291
9	22,989	8,796	0.38	139,997	1,231,364,247
10	17,631	9,570	0.54	101,460	971,016,486
11	25,073	11,440	0.46	116,775	1,335,892,971
12	33,045	13,527	0.41	166,418	2,251,154,588
13	22,217	10,584	0.48	139,795	1,479,657,613
14	32,391	18,222	0.56	122,241	2,227,513,874
15	22,368	14,243	0.64	121,523	1,730,857,364
16	19,037	9,290	0.49	148,380	1,378,511,437
17	3,193	1,678	0.53	93,554	156,976,239
18	21,212	10,015	0.47	143,474	1,436,890,202
19	24,908	8,881	0.36	180,460	1,602,703,172
20	22,082	10,164	0.46	171,040	1,738,506,551
21	31,412	20,372	0.65	147,565	3,006,142,542
22	26,801	13,948	0.52	153,976	2,147,640,587
23	17,089	6,850	0.40	190,608	1,305,694,922
24	26,060	10,475	0.40	125,119	1,310,585,407
25	24,079	5,526	0.23	150,100	829,481,189
26	28,464	8,040	0.28	151,081	1,214,741,178
27	21,316	10,287	0.48	125,667	1,292,688,590
28	17,282	9,289	0.54	118,778	1,103,341,675
29	24,880	12,919	0.52	96,725	1,249,553,800
30	16,742	7,282	0.43	159,884	1,164,290,131
31	30,497	15,241	0.50	130,108	1,982,946,055
32	23,208	12,110	0.52	121,098	1,466,499,942
33	22,714	13,189	0.58	96,449	1,272,096,859
34	21,217	12,471	0.59	97,451	1,215,353,909
35	20,722	6,714	0.32	162,762	1,092,745,898
36	4,397	2,179	0.50	139,778	304,609,070
37	9,302	4,746	0.51	106,360	504,808,369
38	15,734	7,416	0.47	82,525	612,035,793
39	6,048	4,092	0.68	95,140	389,309,229
40	19,735	11,057	0.56	82,606	913,416,273
41	8,965	4,421	0.49	124,487	550,353,625
42	3,789	1,579	0.42	163,938	258,892,221
43	586	399	0.68	134,084	53,528,368
44	16,613	8,693	0.52	124,890	1,085,681,071
45	10,807	4,651	0.43	134,756	626,777,246
46	1,121	714	0.64	100,136	71,484,841
47	31,345	15,596	0.50	119,120	1,857,770,513
48	6,565	1,046	0.16	195,281	204,320,909
	997,039 ***Watershed Total***	**462,141** ***Watershed Total***	**0.46** ***Watershed Average***	**127,468** ***Watershed Average***	**58,908,074,618** ***Watershed Total***

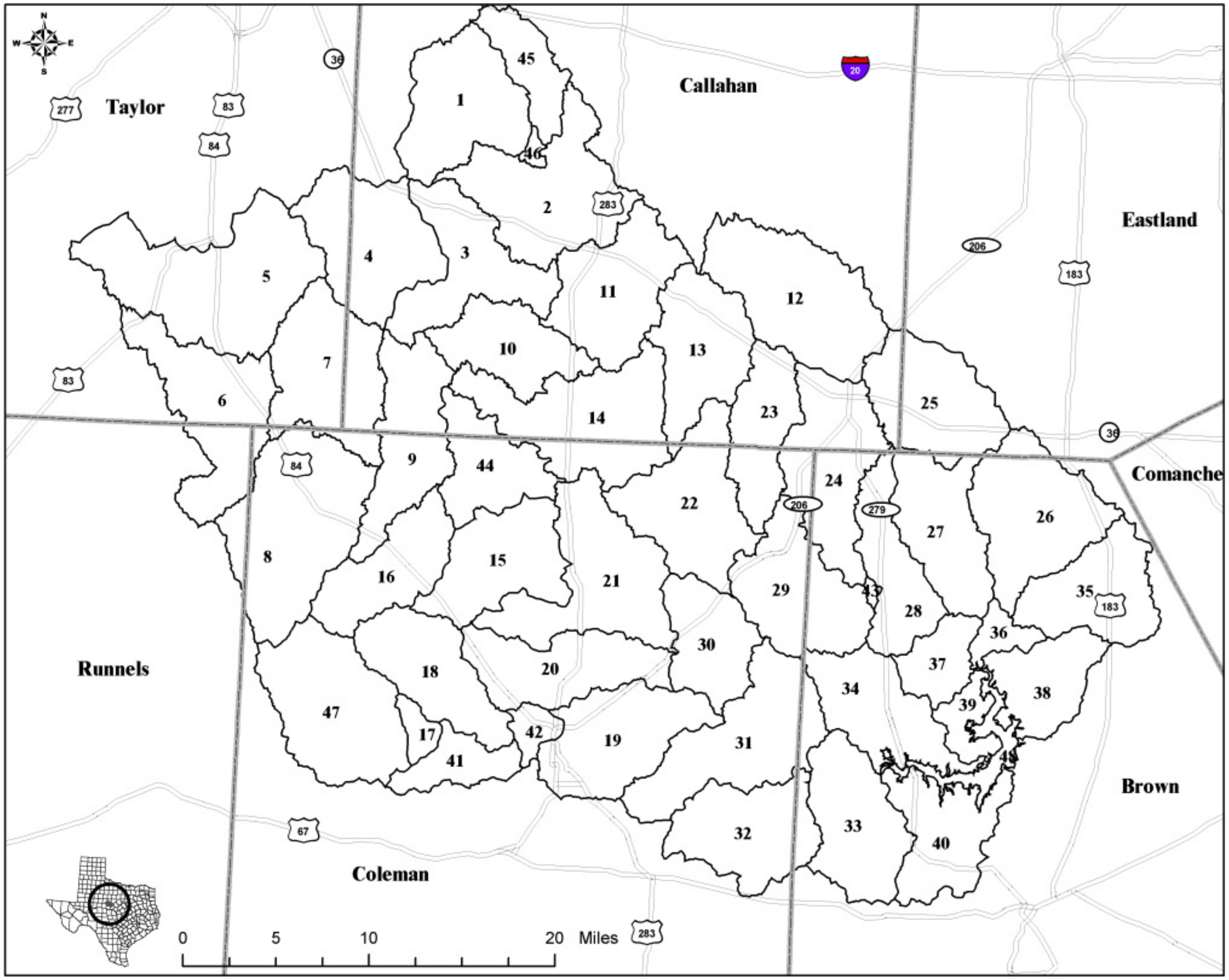

Figure 5-1. Lake Brownwood watershed subbasin map with major roads.

Figure 5-2. Climate and stream gauge stations in the Lake Brownwood watershed.

Figure 5-3. Inventory sized ponds and reservoirs in the Lake Brownwood watershed.

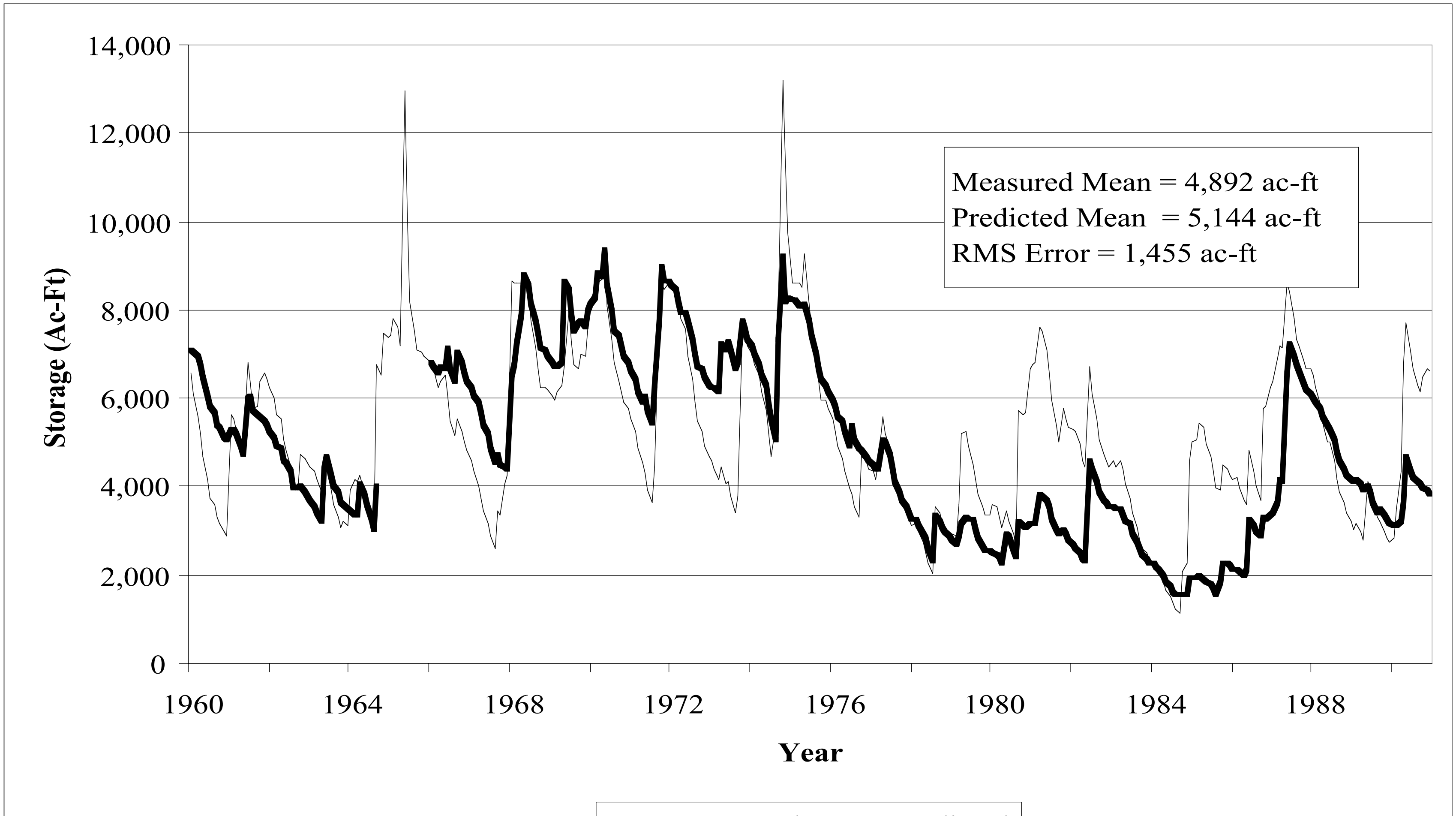

Figure 5-4. Measured and predicted monthly storage in Hords Creek Reservoir (USGS Gauge 08140100), 1960 through 1990. Measured data not available 10/1964 – 12/1965. Monthly statistics for months with measured data are shown in box.

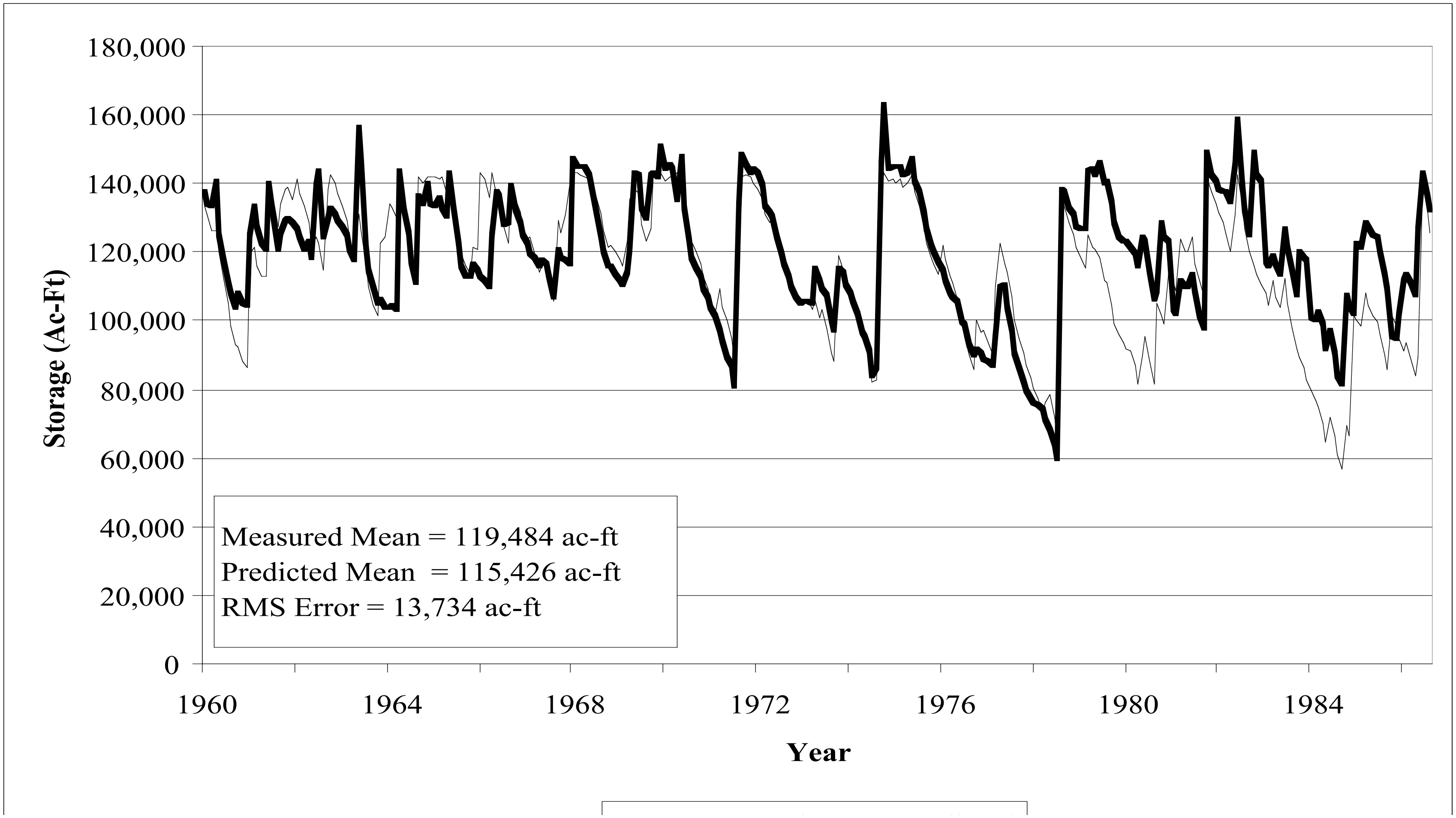

Figure 5-5. Measured and predicted monthly storage in Lake Brownwood (USGS Gauge 08143000), 1960 through 1986. Monthly statistics are shown in box.

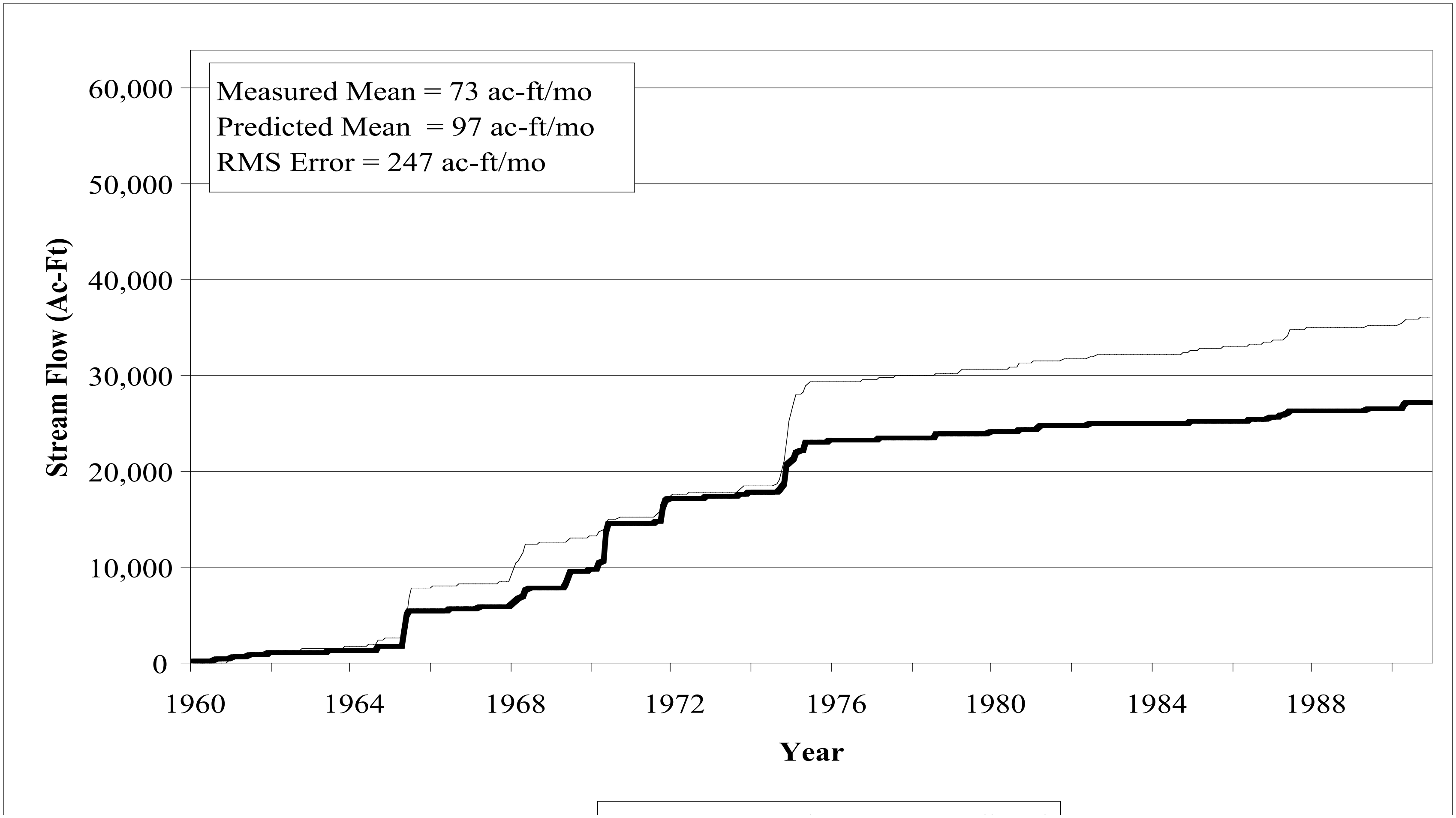

Figure 5-6. Cumulative monthly measured and predicted stream flow at gauge 08141500 (Hords Creek near Valera), 1960 through 1990. Monthly statistics are shown in box.

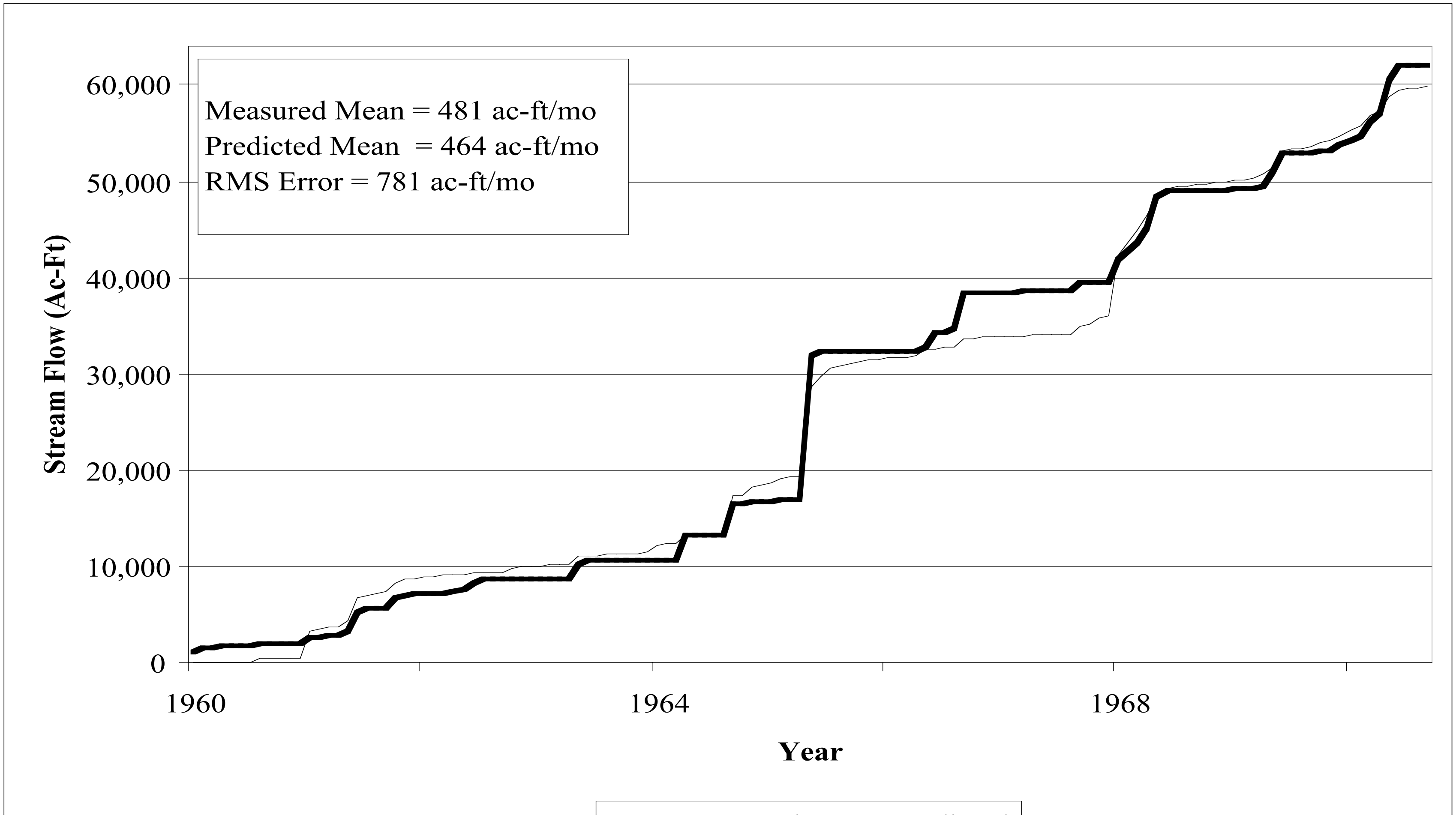

Figure 5-7. Cumulative monthly measured and predicted stream flow at gauge 08142000 (Hords Creek near Coleman), 1960 through 1970. Monthly statistics are shown in box.

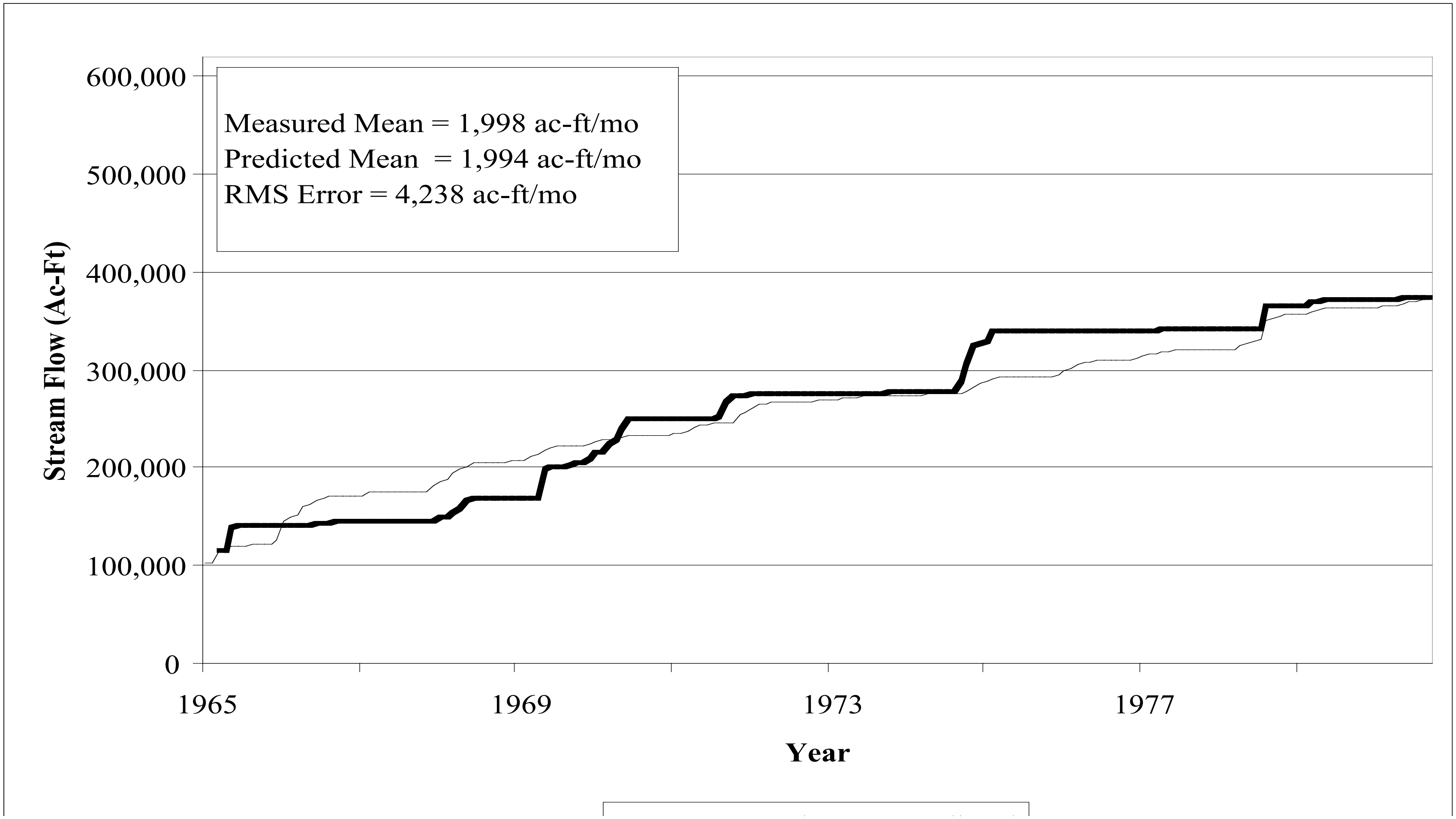

Figure 5-8. Cumulative monthly measured and predicted stream flow at gauge 08140800 (Jim Ned Creek near Coleman), 1965 through 1980. Monthly statistics are shown in box.

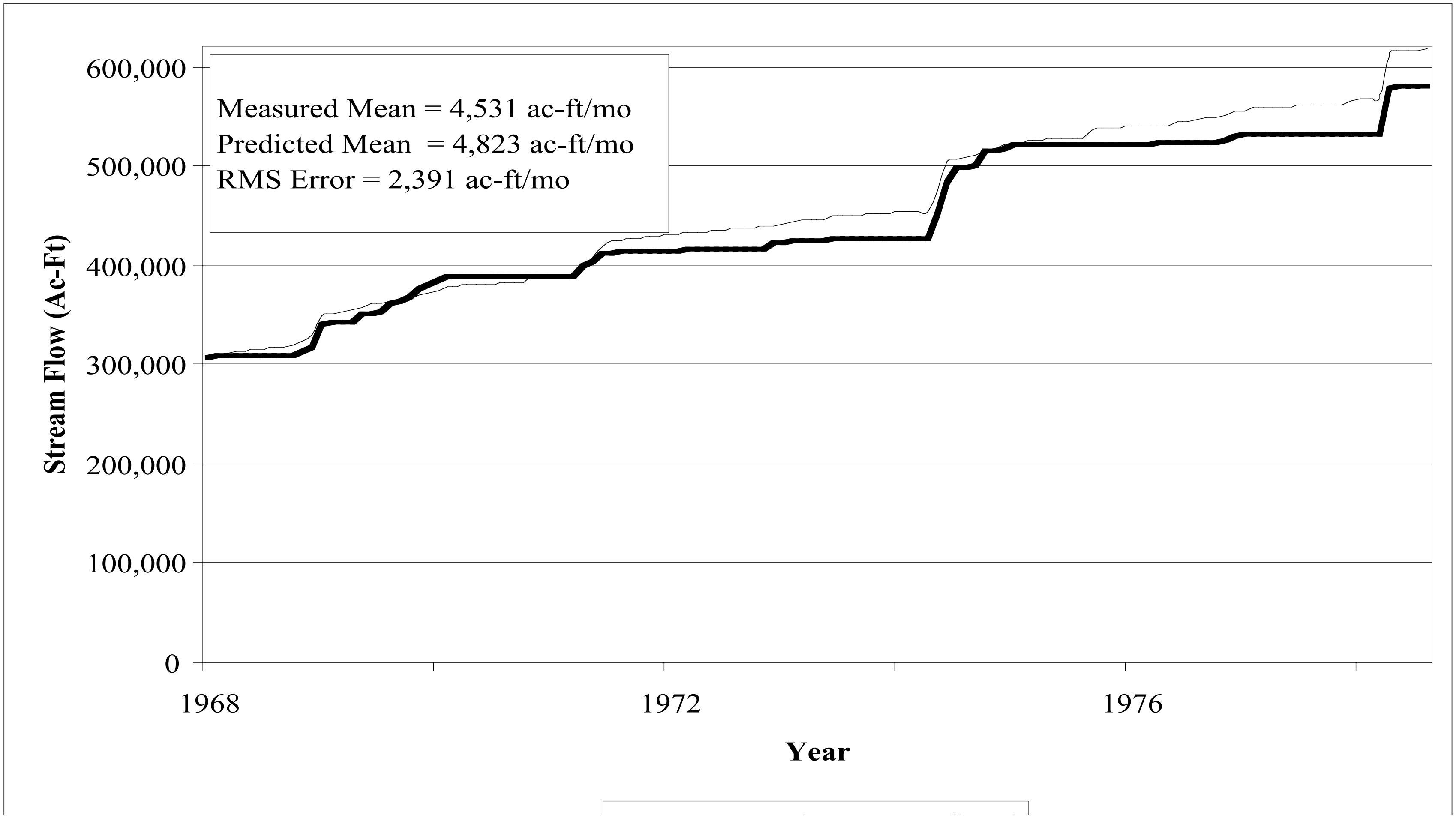

Figure 5-9. Cumulative monthly measured and predicted stream flow at gauge 08140700 (Pecan Bayou near Cross Cut), 1968 through 1978. Monthly statistics are shown in box.

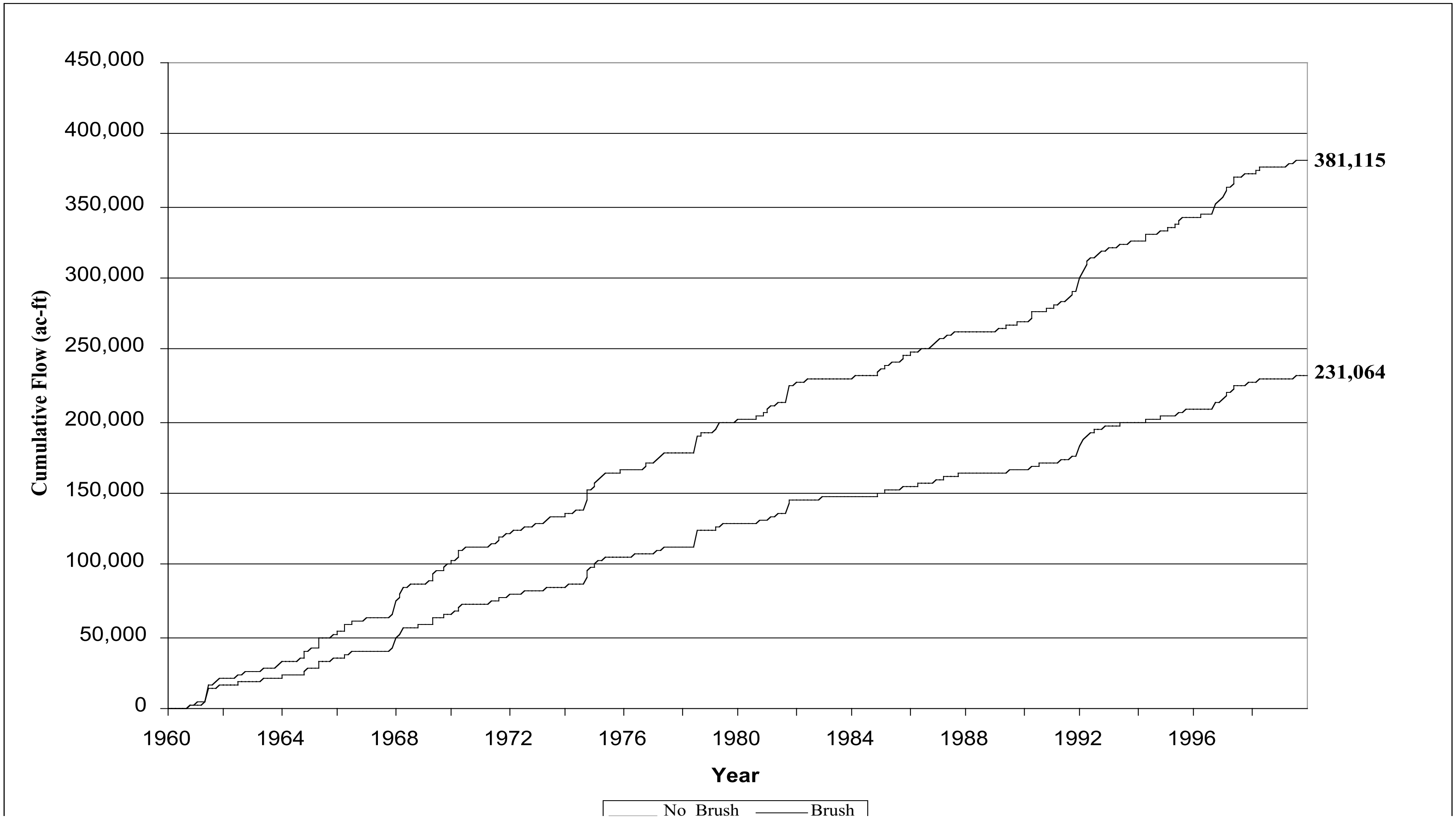

Figure 5-10. Predicted cumulative stream flow into Lake Clyde for brush and no-brush conditions.

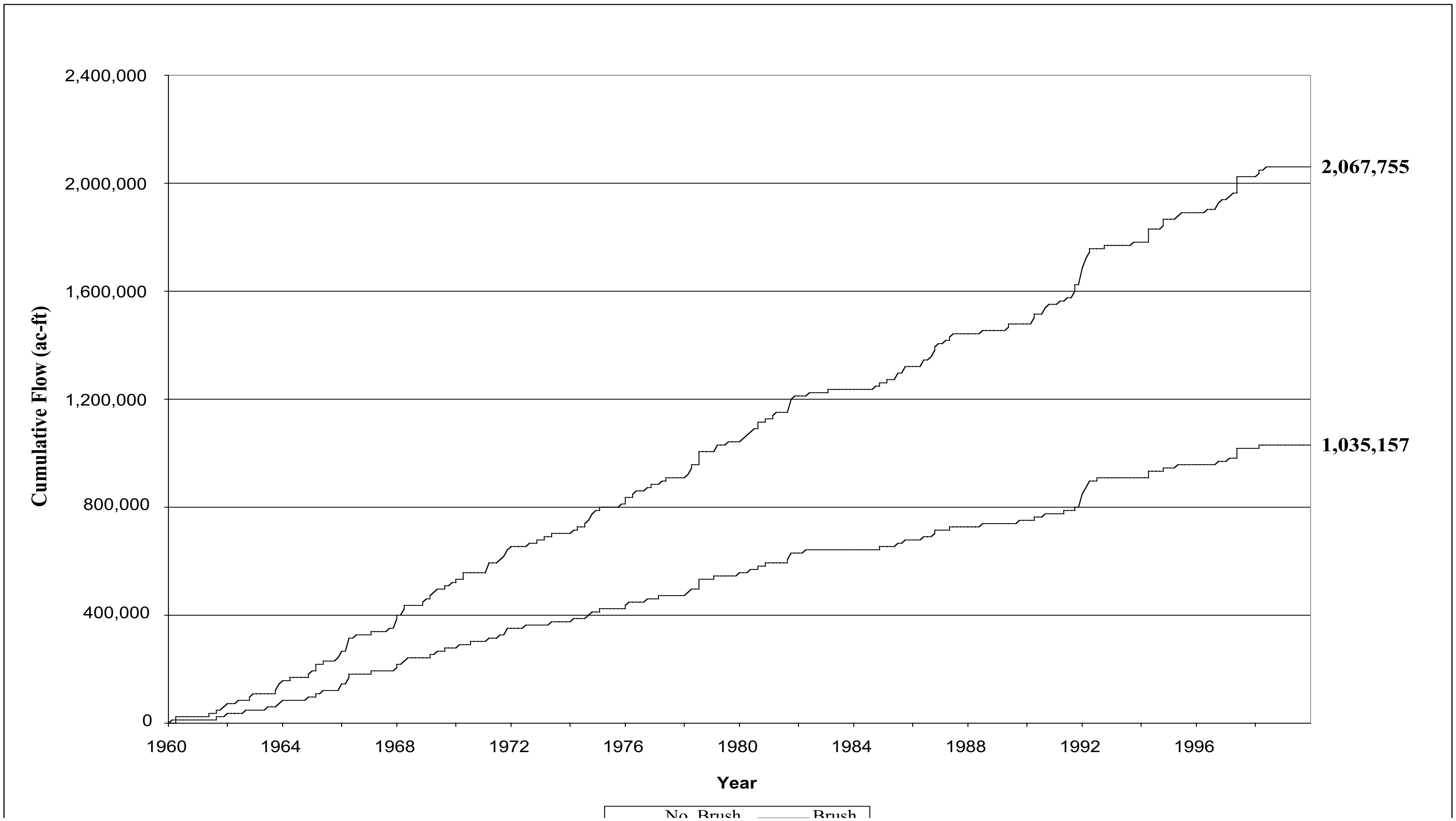

Figure 5-11. Predicted cumulative stream flow into Lake Coleman for brush and no-brush conditions.

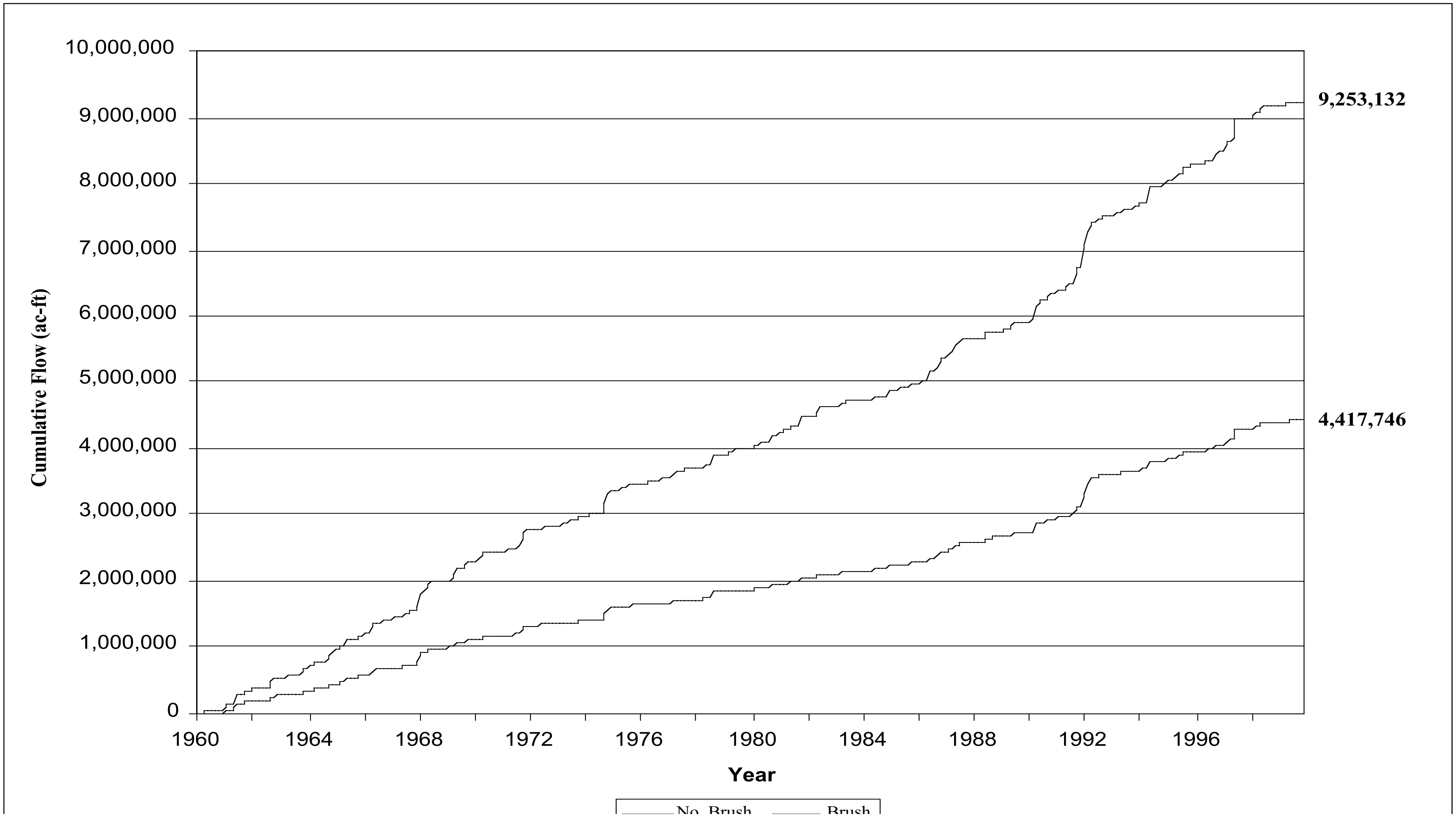

Figure 5-12. Predicted cumulative stream flow into Lake Brownwood for brush and no-brush conditions.

CHAPTER 6

LAKE BROWNWOOD 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 5. 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 Brownwood watershed.

BRUSH CONTROL COSTS

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5% or less and maintain it at the reduced level for at least 10 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% 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 6 or 7. 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 $203.17 for mechanical control of heavy mixed brush. Costs of treatments and year those treatments are needed for each brush type-density category are detailed in Table 6-1.

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 Brownwood are shown in Table 6-2. 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 6-3. 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 was 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 $21.37 per acre for control of moderate mesquite to $35.55 per acre for the control of heavy mixed brush (Table 6- 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 $14.20 for control of moderate mesquite with chemical treatments to $176.61 for control of heavy cedar 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 6-4.

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% discount rate).

The cost of added water was determined to average $35.41 per acre-foot for the entire Lake Brownwood Watershed (Table 6-5). Subbasins range from costs per added acre-foot of $19.42 to $100.49.

Table 6-1. Cost of water yield brush control programs by type-density category.

Heavy Mesquite - Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
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 ($)/Acre	Present Value ($)/Acres
0	Doze/Root Plow, Rake and Burn	180.00	180.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**190.57**

Heavy Cedar - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Doze/Grub, Rake, Stack and Burn	180.00	180.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**202.57**

Heavy Cedar - Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	90.00	90.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**112.57**

Heavy Mixed Brush - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Tree Doze/Grub, Rake, Stack and Burn	180.00	180.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**203.17**

Table 6-1. Cost of water yield brush control programs by type-density category, continued.

Heavy Mixed Brush - Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	90.00	90.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**113.17**

Heavy Post Oak/Shinnery Oak - Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Aerial Spray Spike	70.00	70.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**80.57**

Moderate Mesquite - Chemical

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

Moderate Mesquite - Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer w/Shears and Herbicide	50.00	50.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**60.57**

Moderate Mesquite - Mechanical/Grub

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Grub, Rake, Stack and Burn	130.00	130.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**140.57**

Moderate Cedar - Mechanical/Grub

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Grub, Rake, Stack and Burn	130.00	130.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**140.57**

Table 6-1. Cost of water yield brush control programs by type-density category, continued.

Moderate Cedar - Mechanical/Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	50.00	50.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**60.57**

Moderate Mixed Brush - Mechanical/Grub

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Grub, Rake, Stack and Burn	130.00	130.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**140.57**

Moderate Mixed Brush - Mechanical/Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	50.00	50.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**60.57**

Moderate Post Oak/Shinnery Oak - Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Aerial Spray Spike	70.00	70.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**80.57**

Table 6-3. Investment analysis budget, cow-calf production.

Partial Revenues:					
Revenue Item Desription	**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	----------	15.00
Vitamin/Salt/Minerals	60	Pound	0.10	6.00
Veterinary Medicine	1	Head	14.00	14.00
Miscellaneous	1	Head	12.00	12.00
Net Cost for Replacement Cows	----------	Head	700.00	40.00
Net Cost for Replacement Bulls	----------	Head	1500.00	4.00
			TOTAL	**139.00**

Table6-4. Landowner/State cost-shares of brush control.

Brush Type & Density	Control Practice	PV of Total Cost ($/acre)	Rancher Share ($/acre)	Rancher %	State Share ($/acre)	State %
Heavy Mesquite	Chemical	54.78	28.14	51.37	26.64	48.63
	Grub or Doze	190.57	28.14	14.77	162.43	85.24
Heavy Cedar	Grub or Doze	202.57	25.96	12.82	176.61	87.18
	Shears	112.57	25.96	23.06	86.61	76.94
Heavy Mixed-Brush	Grub or Doze	203.17	35.55	17.50	167.62	82.50
	Shears	113.17	35.55	31.41	77.62	68.59
Heavy Post/Shimmery Oak	Chemical	80.57	29.05	36.05	51.52	63.95
Moderate Mesquite	Chemical	35.57	21.37	60.07	14.20	39.93
	Shears	60.57	21.37	35.28	39.20	64.72
	Grub or Doze	140.57	21.37	15.20	119.20	84.80
Moderate Cedar	Mechanical Choice	140.57	24.79	17.63	115.78	82.37
	Shears	60.57	24.79	40.92	35.78	59.08
Moderate Mixed-Brush	Grub or Doze	140.57	28.05	19.95	112.52	80.05
	Shears	60.57	28.05	46.31	32.52	53.69
Moderate Post/Shimmery Oak	Chemical	80.57	28.05	34.81	52.52	65.18

Table 6-5. Cost of added water from brush control by subbasin (acre-foot).

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
1	867644.86	1219276893.56	3741.82	29192.55	29.72
2	1639769.61	1894866041.60	5815.13	45367.86	36.14
3	1279527.32	1201473087.05	3687.19	28766.29	44.48
4	1928553.23	1719308990.57	5276.37	41164.58	46.85
5	1622685.20	1666429695.57	5114.08	39898.52	40.67
6	957820.35	1649738485.26	5062.86	39498.89	24.25
7	1126172.85	1112575178.23	3414.37	26637.85	42.28
8	1475468.55	1816571291.29	5574.85	43493.28	33.92
9	786822.82	1231364246.73	3778.92	29481.96	26.69
10	753975.06	971016485.71	2979.94	23248.58	32.43
11	1071573.85	1335892970.60	4099.70	31984.64	33.50
12	1769525.67	2251154587.97	6908.54	53898.30	32.83
13	1178845.07	1479657612.51	4540.90	35426.72	33.28
14	1477138.14	2227513874.24	6835.99	53332.28	27.70
15	1512227.48	1730857363.57	5311.81	41441.08	36.49
16	952256.24	1378511436.79	4230.50	33005.03	28.85
17	174477.05	156976238.78	481.74	3758.41	46.42
18	1192299.49	1436890202.11	4409.65	34402.76	34.66
19	935076.23	1602703171.53	4918.52	38372.74	24.37
20	949856.02	1738506551.43	5335.28	41624.22	22.82
21	1779853.11	3006142541.89	9225.51	71974.61	24.73
22	1144308.58	2147640587.38	6590.87	51419.92	22.25
23	616490.51	1305694922.27	4007.03	31261.62	19.72
24	1212048.45	1310585406.81	4022.04	31378.71	38.63
25	764921.77	829481189.25	2545.58	19859.87	38.52
26	1033056.41	1214741177.56	3727.90	29083.96	35.52
27	1204344.21	1292688590.03	3967.12	30950.22	38.91
28	1142038.16	1103341675.25	3386.03	26416.77	43.23
29	1582599.75	1249553800.43	3834.74	29917.46	52.90
30	696222.91	1164290131.35	3573.08	27876.03	24.98
31	1843781.91	1982946055.50	6085.44	47476.71	38.84
32	1431138.27	1466499942.05	4500.52	35111.70	40.76
33	1699630.85	1272096859.32	3903.92	30457.20	55.80
34	1549705.93	1215353908.80	3729.78	29098.63	53.26
35	917642.02	1092745897.77	3353.51	26163.08	35.07
36	267133.90	304609070.01	934.81	7293.11	36.63
37	572942.68	504808369.04	1549.20	12086.38	47.40
38	910322.94	612035792.59	1878.27	14653.68	62.12
39	459247.45	389309229.50	1194.75	9321.04	49.27
40	1286160.60	913416272.75	2803.17	21869.48	58.81
41	449694.81	550353625.35	1688.97	13176.85	34.13
42	622906.45	258892220.84	794.51	6198.53	100.49
43	53014.00	53528367.66	164.27	1281.60	41.37
44	770528.68	1085681070.85	3331.83	25993.93	29.64
45	495281.15	626777246.50	1923.51	15006.62	33.00
46	52695.67	71484840.60	219.38	1711.53	30.79
47	1643952.90	1857770512.67	5701.29	44479.70	36.96
48	95005.60	204320909.36	627.04	4891.96	19.42
Total	49948384.77			1410407.43	
Average					35.41

CHAPTER 7

LAKE FORT PHANTOM HILL WATERSHED--HYDROLOGIC SIMULATION

W. D. Rosenthal, Assistant Professor, Blackland Research and Extension Center

WATERSHED DATA

Physical Data

The Fort Phantom Hill Reservoir Watershed is located in west central Texas and is a part of the Brazos River watershed. It covers an area of 301,118 acres (470 mi^2), mostly within Taylor County. The area was settled in the 1870's as primarily ranching cattle. The region became a center for north-south railroad transportation. Over the years, dry land farming of cotton, grain sorghum and pasture were introduced. Since the 1950's, the oil industry added to the economy in the region. Of the four watersheds studied in this project, it is the most urbanized watershed. Abilene (population ~150,000) is located in the center of the watershed. Today, the area is thriving economically through banking, construction, military training, and retail and wholesales businesses (Handbook of Texas Online, 2002). A map of the delineated subbasins and major roads is shown in Figure 7-1.

METHODS

Land Use/Land Cover

The land use map for the Ft. Phantom Hill and Lake Brownwood watersheds 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%. Over 75% is in some type of rangeland or pasture cover. The amount of treatable brush (medium and heavy mesquite, cedar, and mixed brush) is 138,396 ac (216 mi^2) or 46.0% of the watershed (Table 7-2). The majority of the brush is located in the western and southern areas of the watershed. Some cultivated cropland is located in the eastern part of the watershed. Urban areas represent approximately 10% of the watershed area.

Soils

Dominant soil series in the watershed include Sagerton, Tobosa, and Tarrant. They comprise about 38% of the watershed. Sagerton are deep, well-drained, loamy soils. They comprise approximately 14% of the watershed area. Tobosa are deep, well-drained clayey soils on the uplands and they comprise approximately 7% of the area. Tarrant are very shallow to shallow, well-drained soils on the uplands and they comprise approximately 17% of the watershed—primarily in the western part of the watershed. A short description of each and other minor soils follows:

<u>Miles</u>. The Miles series consists of deep, nearly level to gently undulating, well-drained, loamy soils on uplands. These soils formed in loamy sediment. Slopes are generally 0-5 percent.

Oplin. The Oplin series consists of very shallow and shallow, well-drained, moderately permeable soils formed in residuum from undulated limestone. These upland soils have slopes that range from 1 to 40 percent.

Sagerton. The Sagerton series consists of deep, nearly level to gently sloping, well-drained, loamy soils. These soils formed in calcareous loamy sediment. Slopes generally range from 0 to 3 percent.

Shep. The Shep series consists of deep, gently sloping to sloping, well-drained, loamy soils on uplands. These soils formed in loamy colluvial material. Slopes range from 1 to 8 percent.

Tobosa. The Tobosa series consists of deep, nearly level to gently sloping, well-drained, clayey soils on uplands. These soils formed in calcareous clayey sediment.

Tarrant. The Tarrant series consists of very shallow and shallow, well-drained, modeately slowly permeable soils on uplands. They formed in calcareous clayey sediment. Slopes are mainly 1 to 8 percent, but some are as much as 50 percent.

Topography

The watershed is nearly level to sloping plains and steep escarpments. These escarpments separate the Rolling Plains from the Edwards Plateau. Elevation ranges from 1,600 ft to 2,500 ft above sea level. The watershed drains from the west to the northeast into the Brazos River.

Geology

The watershed lies over the Trinity Aquifer formation. An outcrop of the aquifer is located in the western part of the watershed. The outcrop and the soils present in the western part of the watershed help contribute to a higher average hydraulic conductivity in the tributary channels of the watershed (approximately 0.79 in/hr) (Pete Waldo, 2002, personal communication).

Climate

Average rainfall for the area is 25.4 in/yr. Potential evapotranspiration (based on the Priestley-Taylor method) is 55.8 in/yr. Data from two weather stations and four USGS stream gauge sites were used in the analysis and calibration (Figure 7-2). Annual mean maximum and minimum temperatures are 76.3°F and 52.3°F, respectively. The average growing season length is 225 days.

Ponds/Reservoirs

The Fort Phantom Hill Reservoir, the primary reservoir (conservation storage—74,310 ac-ft) providing water for Abilene and the surrounding communities, is located at the outlet of the watershed. Other significant lakes in the watershed that are included in the analysis include Lake Lytle (conservation storage—3,100 ac-ft), Lake Abilene (conservation storage—9,790 ac-ft), and Kirby Lake (conservation storage—7,620 ac-ft). These lakes are minor sources of water for municipal and industry use. The primary creeks in the watershed include Elm, Little Elm, Cedar, Rainy, Buck, and Lytle Creeks. Figure 7-3 shows the location of inventory ponds and reservoirs in the watershed.

Model Inputs
To calibrate flow accurately, curve number adjustments were –2 and –12 from the default values. The –12 values were in the western part of the watershed where the dominant soils were Tarrant and Oplin (both very shallow soils that allow for greater infiltration). With urban areas being a significant part of the watershed, classified urban land was assigned a curve number of 92, which is representative of curve numbers for urban areas similar to Abilene (NRCS, 1986).

To adjust moisture holding capacities to those represented in the county soil survey, available soil water was increased from 0.02 to 0.05 in/in for the soil layers of Tarrant, Sagerton, Miles and Shep soil series. Since Tarrant and Oplin soils are very shallow, they had a crack flow coefficient of 0.1 and 0.3, respectively, to allow for deeper water penetration. Average daily release rates from Ft. Phantom Hill, Lakes Abilene and Kirby were 177, 706, and 247 cfs, respectively. An average water withdrawal from the reservoirs was input into the model. It was assumed that the seepage rates for the lakes were 0.004 in/hr. Other input values are in Table 7-1.

Model Calibration
The calibration simulation represented the current "brush" condition. SWAT was calibrated against measured stream flow and Ft. Phantom Hill Reservoir volumes by varying model parameters (Table 7-1). Monthly stream flow from four USGS stream gauge sites located throughout the watershed were used in the calibration—08083430, Elm Creek at Abilene; 08083470, Cedar Creek at Abilene; 08083300, Elm Creek near Abilene; and 08083400, Little Elm Creek near Abilene (Figure 7-2). The USGS site 08083420 was not used in the calibration because it represented only a small tributary (13 acres) that was not delineated as a subbasin. Ft. Phantom Hill Reservoir volume data were also available continuously from 1965 through 1985 and used in the calibration.

Brush Removal Simulation
With brush removal, brush vegetative characteristics of maximum leaf area index, rooting depth, and heat units to maturity were adjusted to represent native grassland (open range) conditions. Such changes included maximum leaf area indices of up to 6 decreased to 2; rooting depths decreased from 6.5 to 3.3 feet; and heat unit adjustments decreased from as high as 4300 heat units to 2974 heat units.

Except for the land use change for the no-brush condition, the only other change was that the re-evaporation coefficient was assumed to be greater for brush than other types of vegetation, because brush is deeper-rooted and the opportunity for re-evaporation from the shallow aquifer is greater. The coefficient for all brush hydrologic units was 0.4 and for non-brush units was 0.1. For the transition from brush to non-brush condition, the hydrologic condition changed from fair to good, which correspondingly affected curve number.

RESULTS

Model Calibration

Predicted cumulative flow was generally within 10% of measured flow at the four USGS stream gauge sites, (Figures 7-4—7-7). The exception was at stream gauge site 08083430 (Elm Creek) (Figure 7-4). The comparison of measured and predicted flow at that site was only for four years. In addition, there was only one significant runoff event that was over-predicted in October of 1981. With the stream gauge site downstream of Lake Abilene, it is likely that the amount of water withdrawn from Lake Abilene was underestimated. Also, during 1980 and the early part of 1981, precipitation was below average, suggesting low levels in the reservoir and greater potential storage for significant runoff events. As a result, the calibration estimate was not as good as the other sites.

The average simulated base flow was 35.6% of total water yield, which is in the range of the calculated base flow measured at the four USGS stream gauge stations (13-44% of water yield).

Given USGS data on Ft. Phantom Hill reservoir levels, the model was also calibrated to reservoir levels. The predicted was 7.9% higher than the measured reservoir level (Figure 7-8). The RMSE was roughly 22% of the measured mean. The estimate was better earlier in the simulation (1965-1976) and deviated from measured later in the simulation. This was likely due to the inaccurate estimation of municipal water use later in the simulation. With a greater Abilene population after 1976, municipal water use was greater and more variable.

Brush Removal Simulation

Average annual evapotranspiration was 18.8 inches for no-brush conditions and 21.1 inches for brush conditions. This represented 74% and 83% of precipitation for the no-brush and brush conditions, respectively. The effect of brush removal was dramatic over the entire watershed. At Lake Ft. Phantom Hill, the impact was a 64% increase in stream flow incoming to the lake (Figure 7-9) and a 78.5% increase in average annual water yield from the upstream subbasins. Within the watershed, the largest impact was at Lake Abilene with a 74.9% increase in flow (Figure 7-10) and an 85.2% in average annual water yield. This could be expected since this was the area with the largest area of treatable (removable) brush and the soils with the highest potential for runoff (Tarrant soils). After removing brush, inflow increases to Lakes Lytle and Kirby were lower in brush removal efficiency--68.3% and 75% increase in stream flow, respectively, by removing brush (these figures are for stream flow--Figures 7-11 and 7-12). A table containing the treated acreages and water yield increases is contained in Table 7-2. At the watershed outlet, annual flow increased by 31,524 gal/ac of treated brush. The increased water yield was 104,423 gal/ac of treated brush. These values were somewhat lower than other simulated watersheds in similar precipitation regimes from the previous study (TAES, 2000). This may be due to increased percolation into the aquifer because of higher hydraulic conductivity from the presence of the Trinity aquifer outcrop and shallower soils in the western areas of the watershed, and lower canopy interception in the current study.

Within the watershed, water yields varied from approximately 82,000 to 239,000 gal/acre/yr in subbasins 13 and 1 (Ft. Phantom Hill Reservoir), respectively (Table 7-2). Also, water yields were generally greater than 100,000 gal/acre/yr west of U.S. highways 83 and 84. This, again, was indicative of increased water yield efficiencies in the western part of the watershed. These variations again represented conditions in the soil, land use, and rainfall.

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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.

Table 7-1. SWAT input variables for Lake Fort Phantom Hill watershed.

ADJUSTMENTVARIABLEor VALUE Runoff Curve Number Adjustment	(subbasins 1-8,10-13)-

Table 7-2. Subbasin data—Lake Ft. Phantom Hill 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	2,540	537	0.21	238,892	128,331,478
2	12,087	3,735	0.31	118,572	442,913,464
3	4,451	1,114	0.25	112,286	125,077,783
4	453	149	0.33	108,484	16,186,269
5	30,985	9,356	0.30	109,228	1,021,940,999
6	21,928	7,275	0.33	106,471	774,615,893
7	12,483	4,431	0.35	92,874	411,535,286
8	68	28	0.40	123,145	3,392,881
9	11,914	5,931	0.50	109,046	646,798,230
10	27,797	12,690	0.46	111,254	1,411,813,104
11	38,084	14,597	0.38	85,206	1,243,780,102
12	28,282	11,245	0.40	91,332	1,026,985,460
13	13,045	5,672	0.43	82,080	465,592,188
14	23,069	12,073	0.52	102,331	1,235,415,245
15	36,789	24,241	0.66	119,368	2,893,594,610
16	28,340	19,218	0.68	104,404	2,006,453,271
17	8,803	6,102	0.69	97,874	597,273,452
	301,118 ***Watershed Total***	**138,396** ***Watershed Total***	**0.46** ***Watershed Average***	**104,423** ***Watershed Average***	**14,451,725,000** ***Watershed Total***

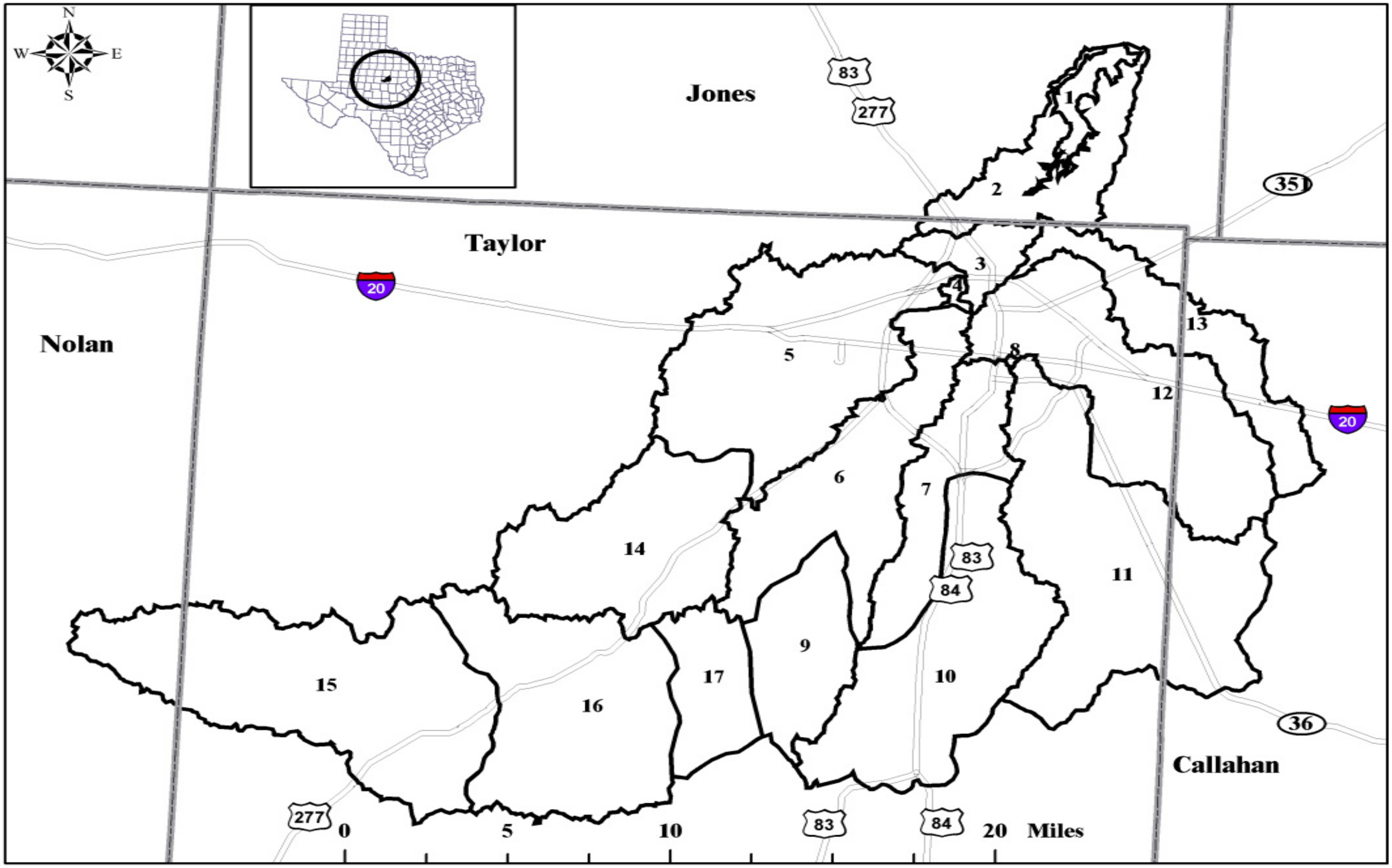

Figure 7-1. Subbasin map of the Lake Ft. Phantom Hill watershed with major roads.

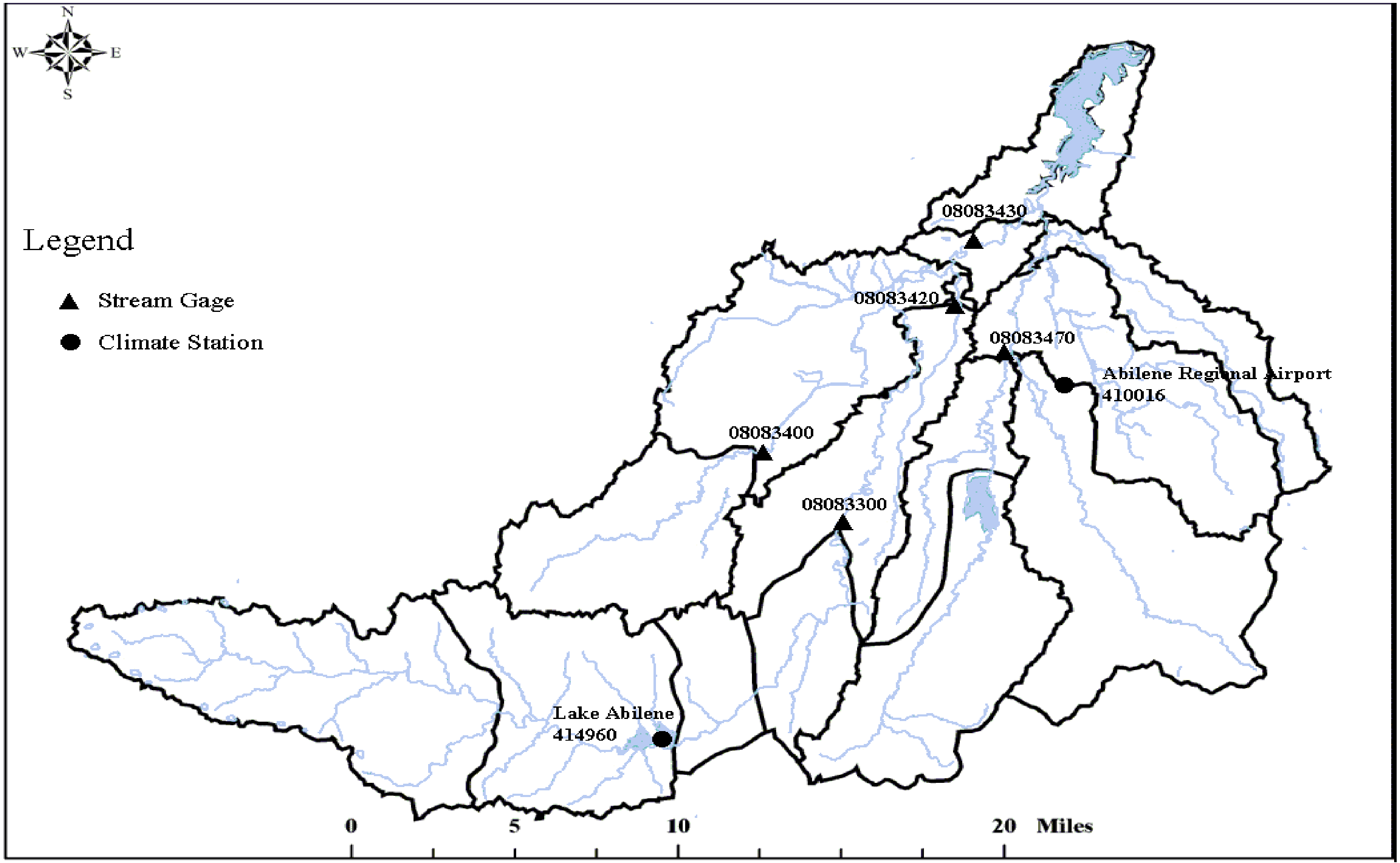

Figure 7-2. Climate and stream gauge stations in the Lake Ft. Phantom Hill watershed.

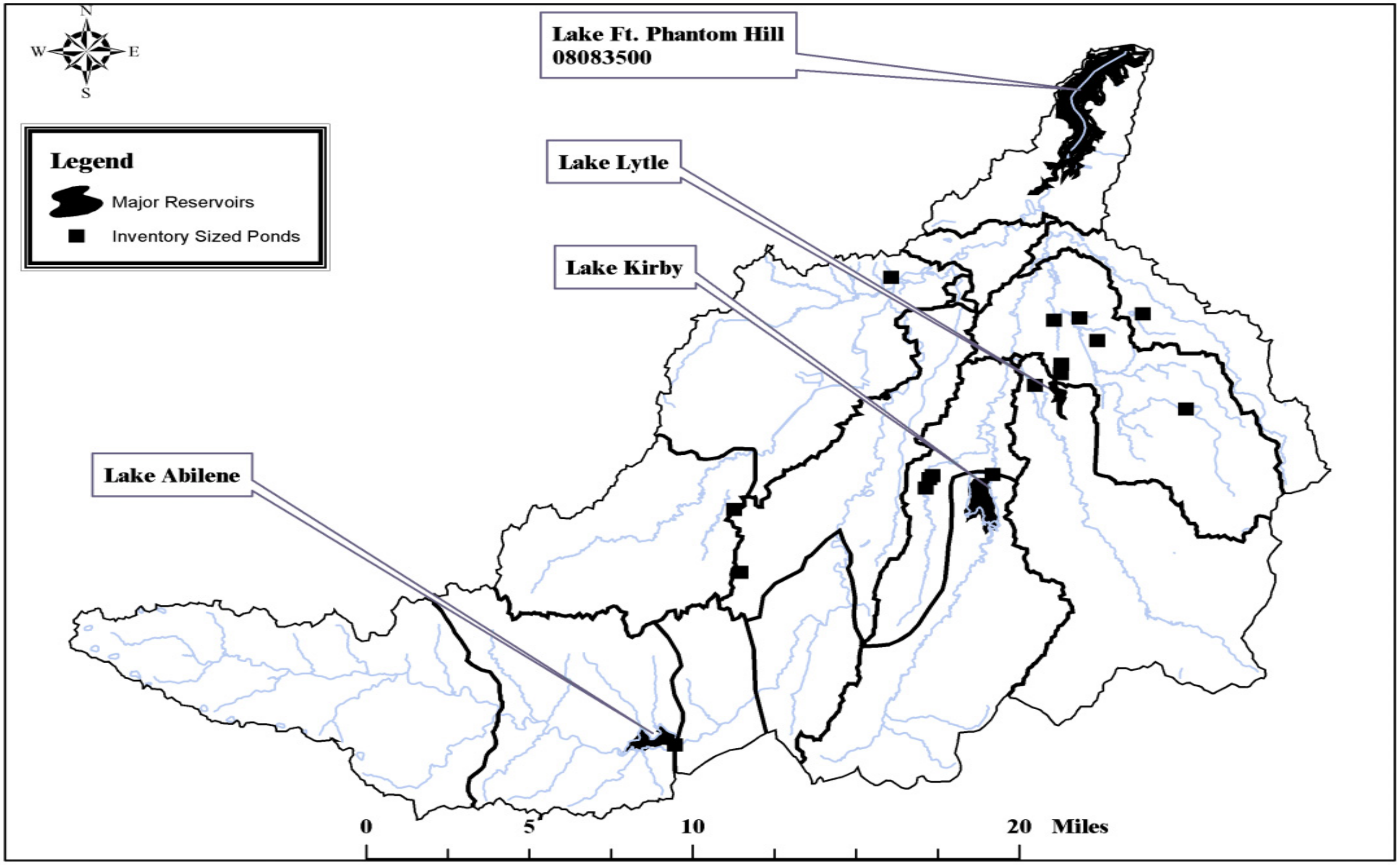

Figure 7-3. Inventory-sized ponds and reservoirs in the Ft. Phantom Hill watershed.

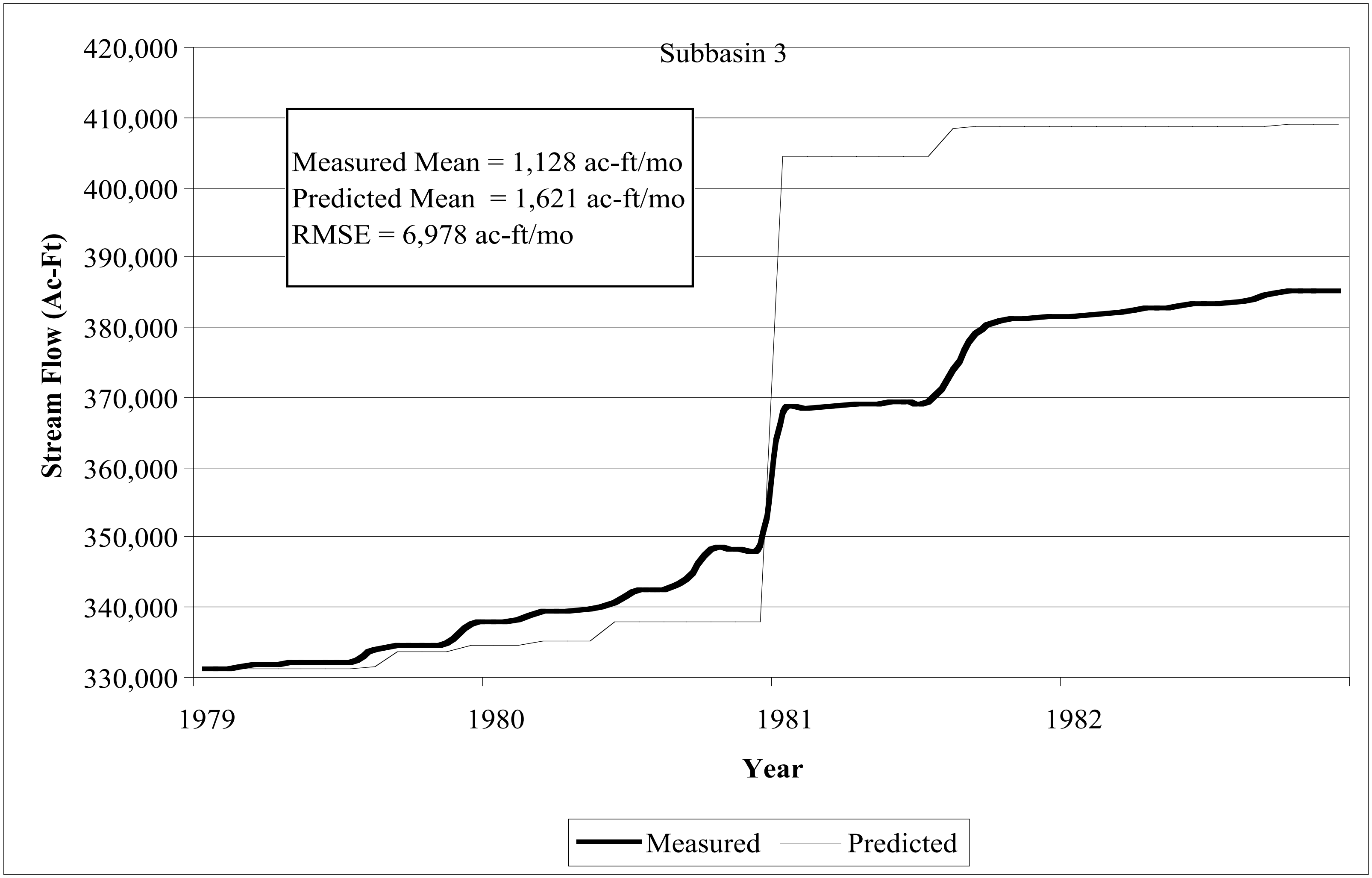

Figure 7-4. Cumulative monthly measured and predicted stream flow at gauge 08083430 (Elm Creek), Lake Fort Phantom Hill watershed, 1979 through 1983. Monthly statistics are shown in box.

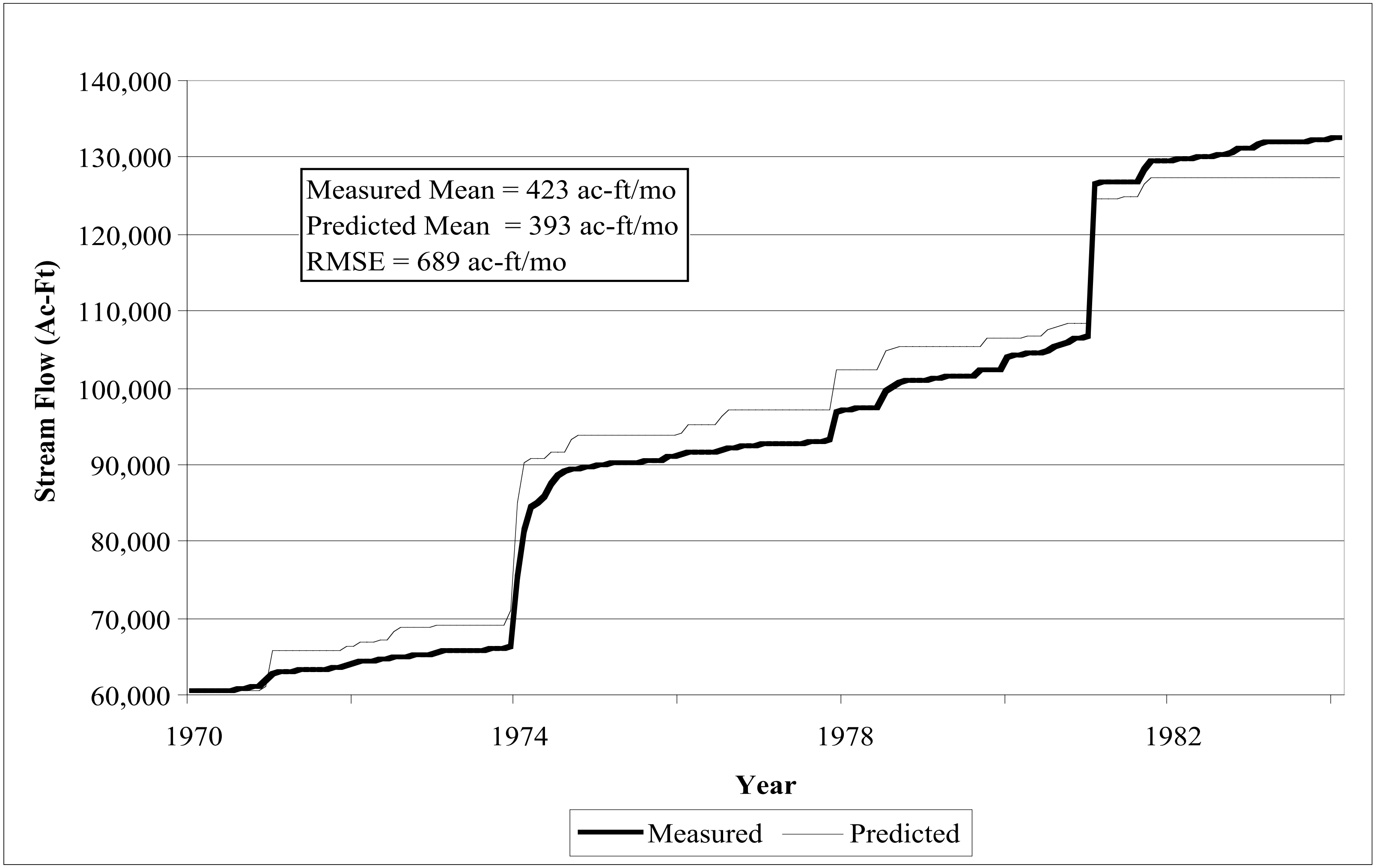

Figure 7-5. Cumulative monthly measured and predicted stream flow at gauge 08083470 (Cedar Creek), Lake Fort Phantom Hill watershed, 1970 through1984. Monthly statistics are shown in box.

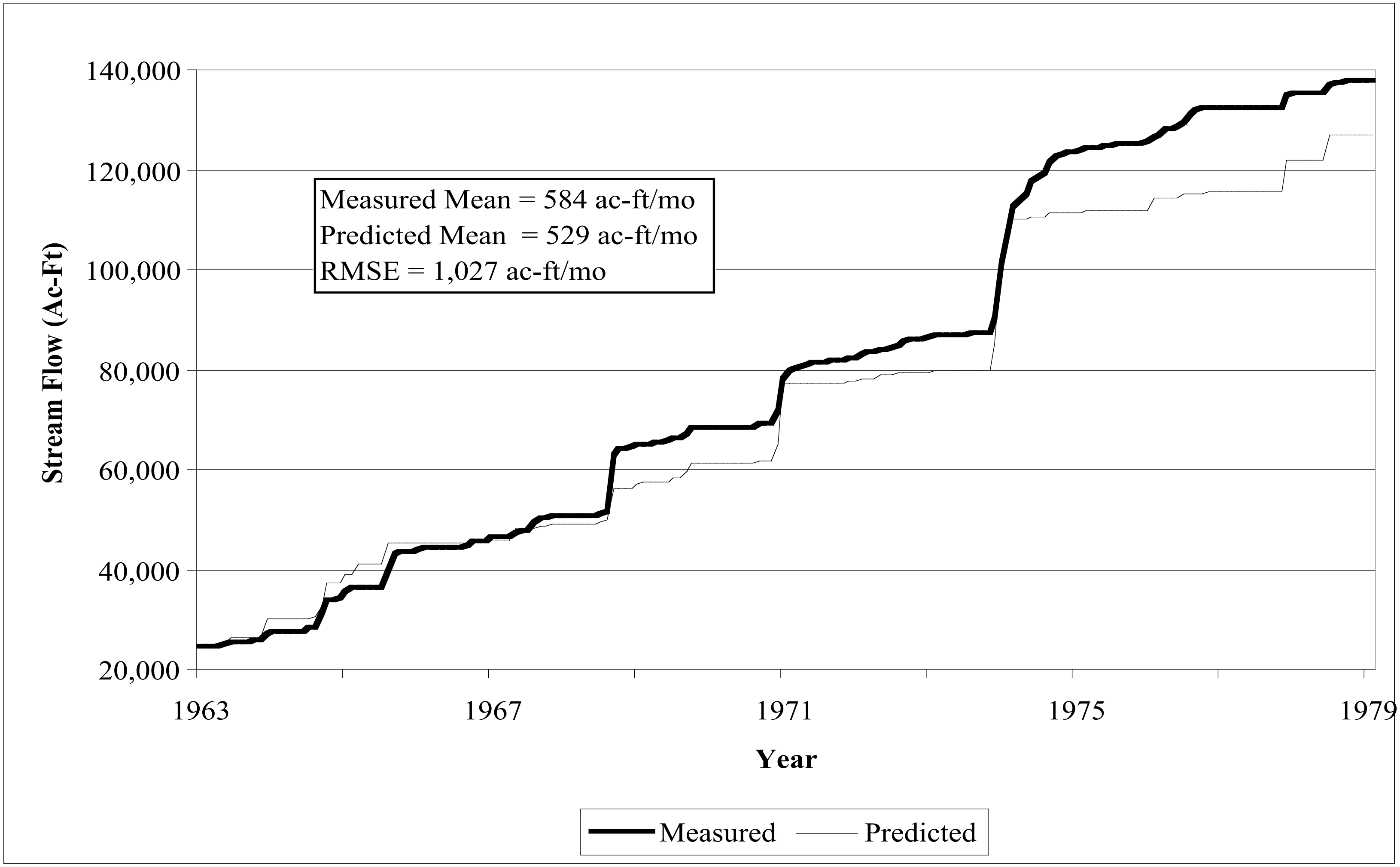

Figure 7-6. Cumulative monthly measured and predicted stream flow at gauge 08083300 (Elm Creek), Lake Fort Phantom Hill watershed, 1963 through 1979. Monthly statistics are shown in box.

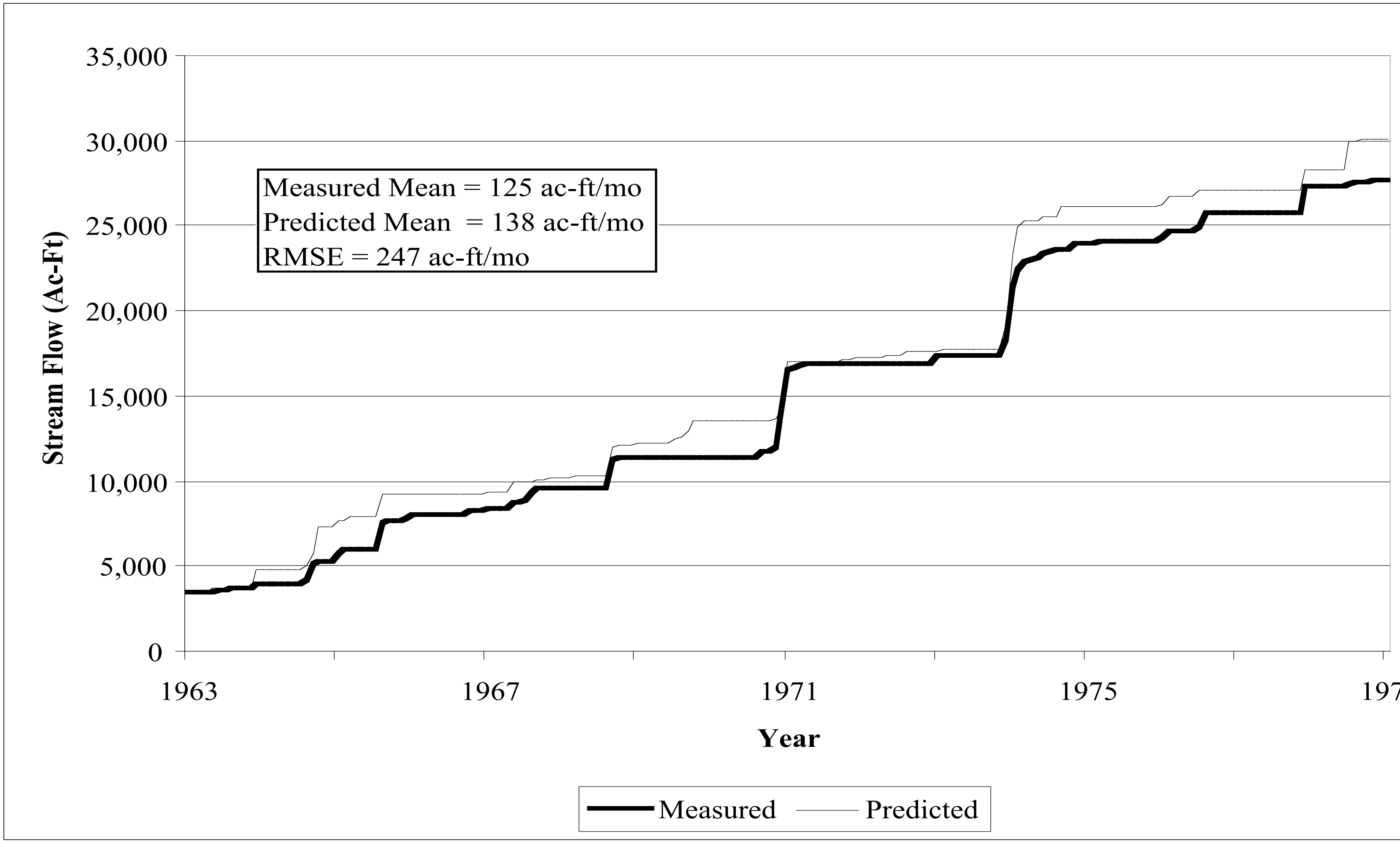

Figure 7-7. Cumulative monthly measured and predicted stream flow at gauge 08083400 (Little Elm Creek), Lake Fort Phantom Hill watershed, 1963 through 1979. Monthly statistics are shown in box.

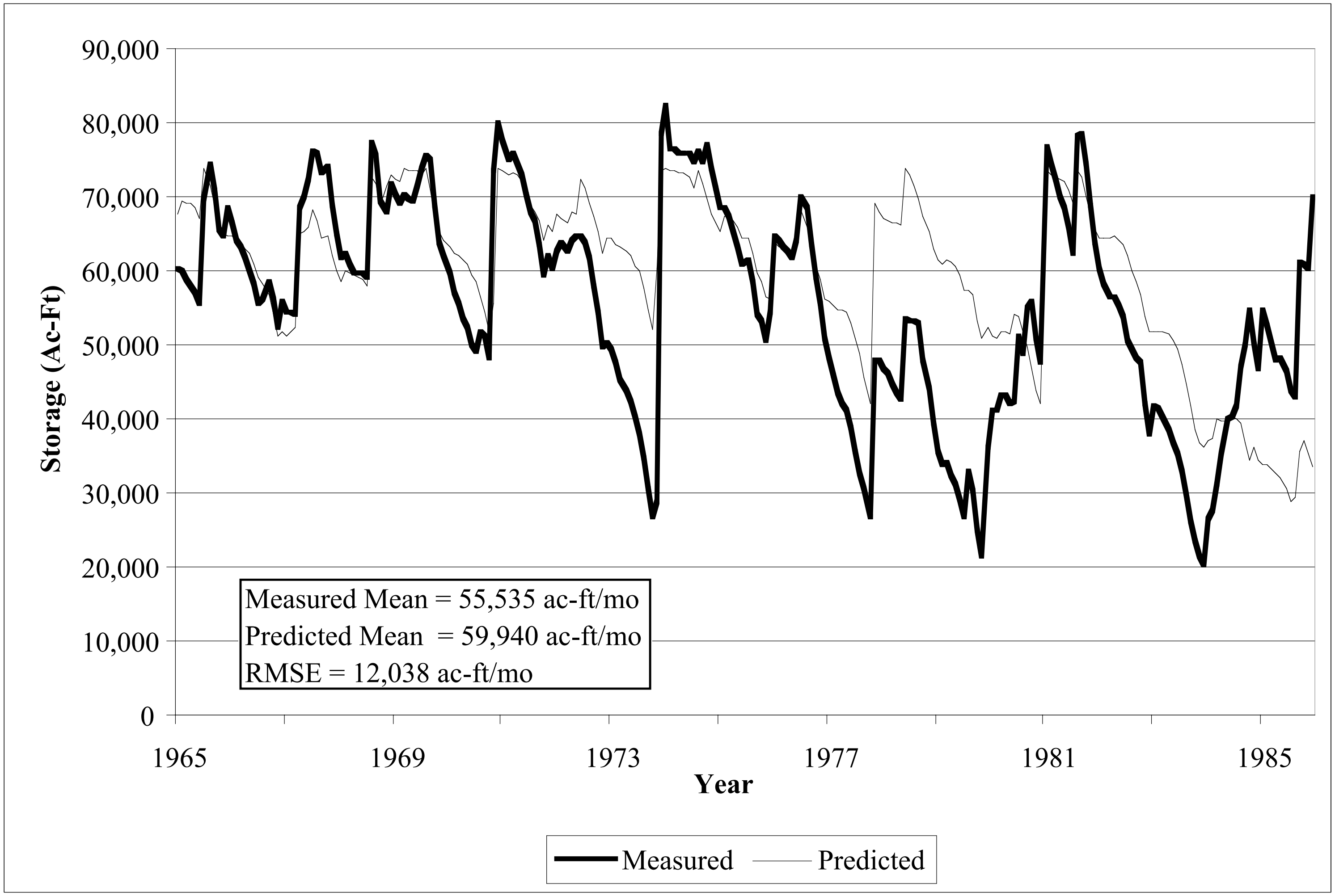

Figure 7-8. Measured and predicted monthly storage in Lake Ft. Phantom Hill (the recording period was from 1965-1986). Monthly statistics are in the box.

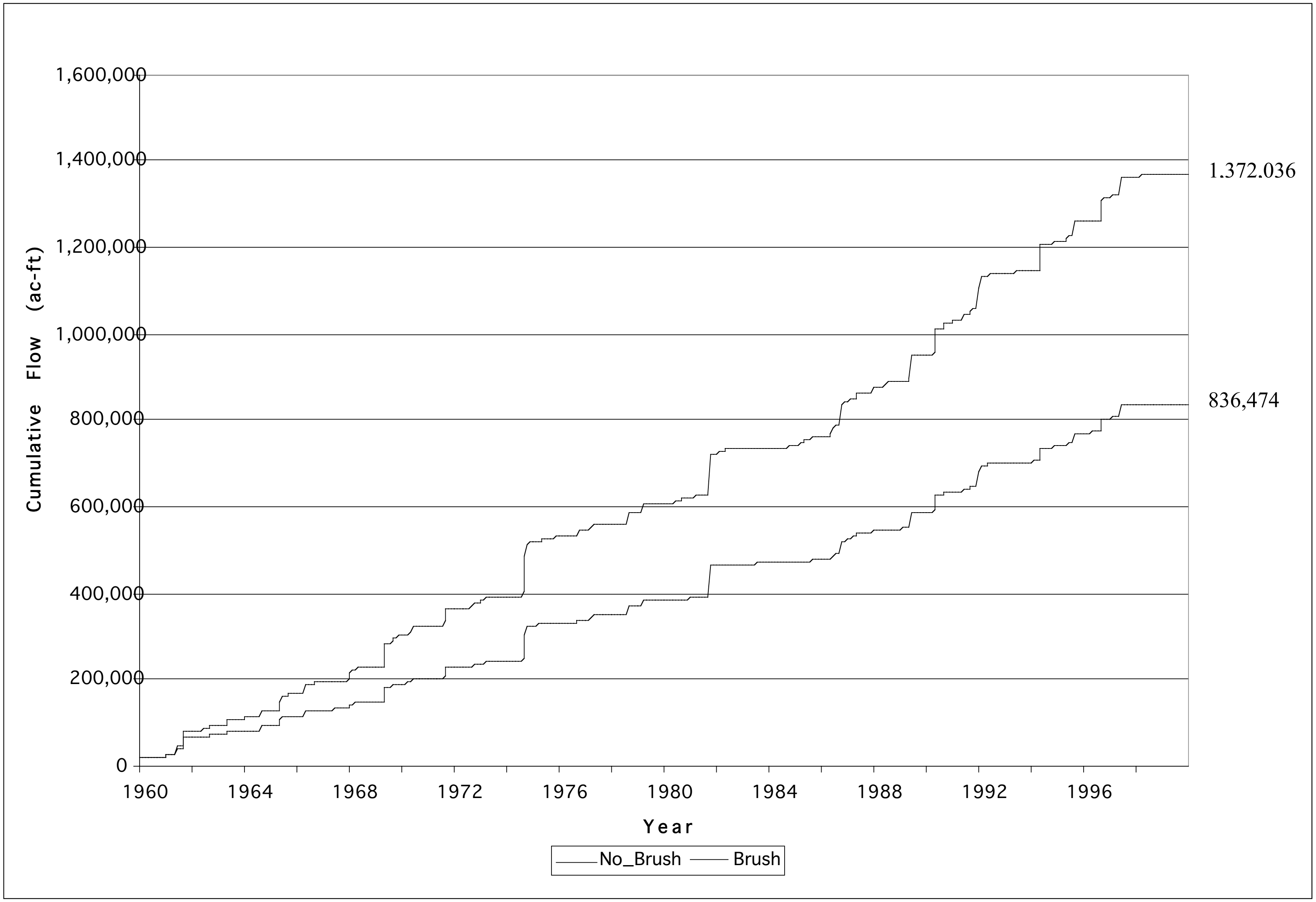

Figure 7-9. Predicted cumulative monthly stream flow into Lake Ft. Phantom Hill for brush and no-brush conditions.

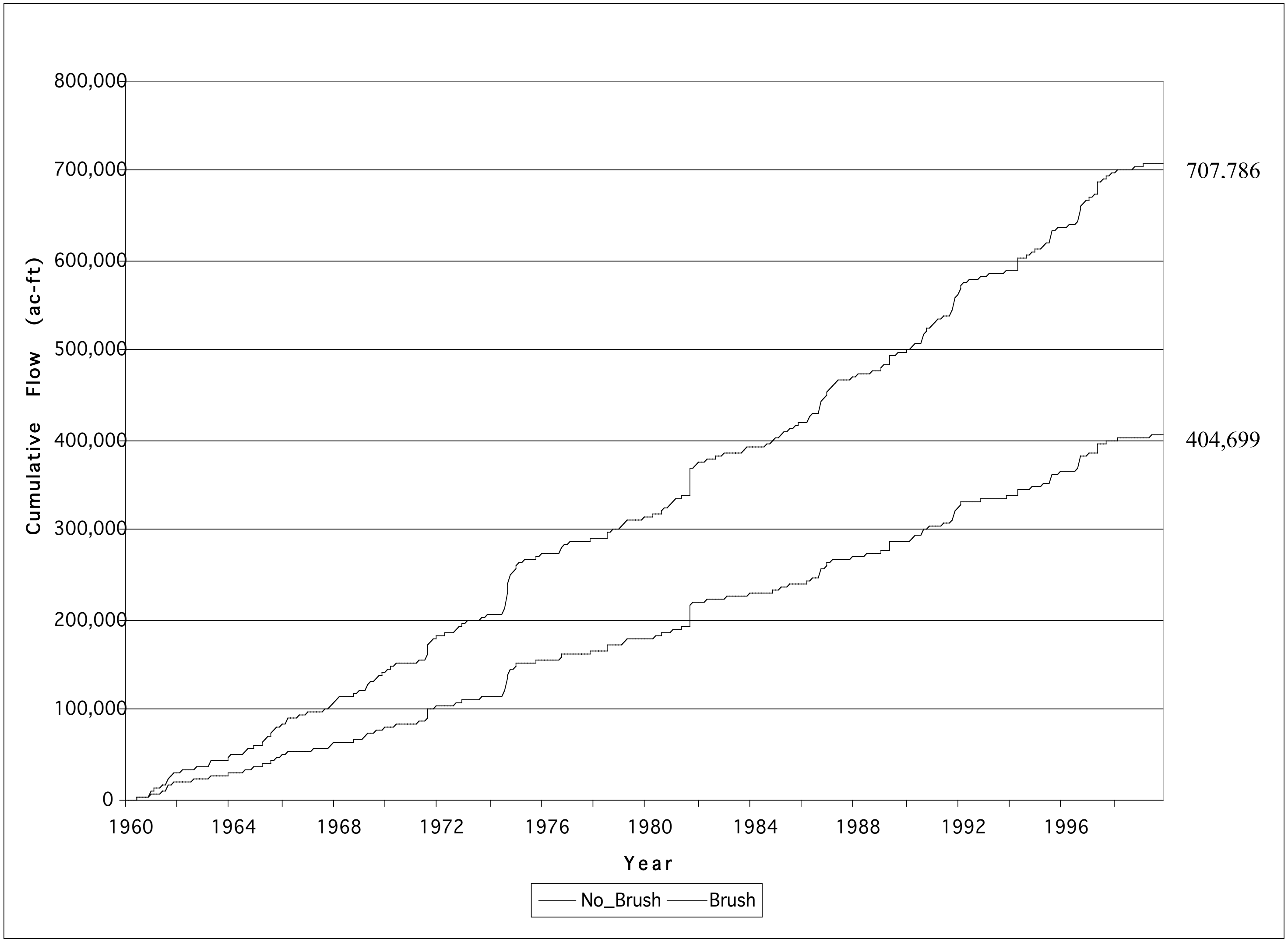

Figure 7-10. Predicted cumulative monthly stream flow into Lake Abilene for brush and no-brush conditions.

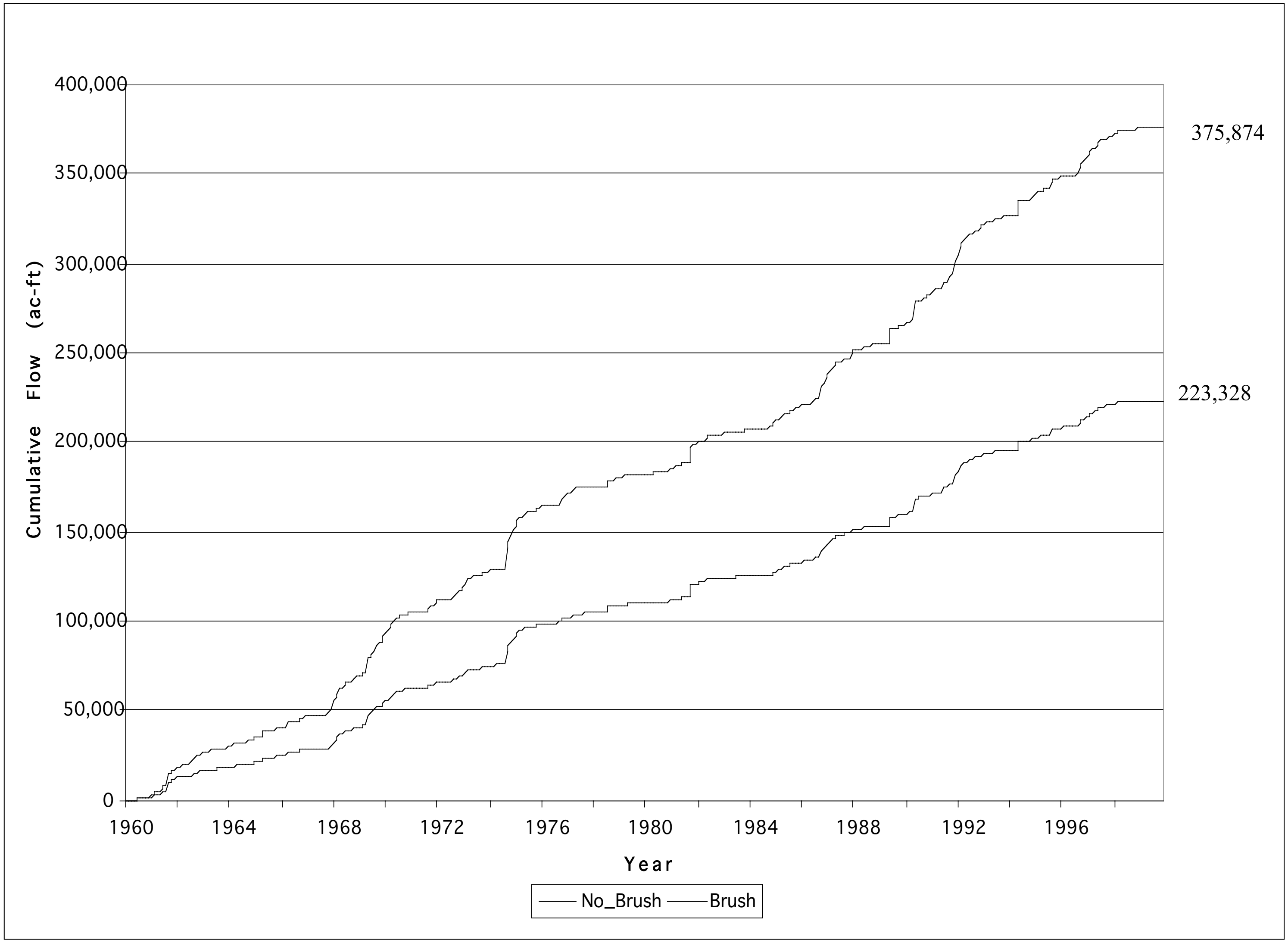

Figure 7-11. Predicted cumulative monthly stream flow into Lake Lytle for brush and no-brush conditions.

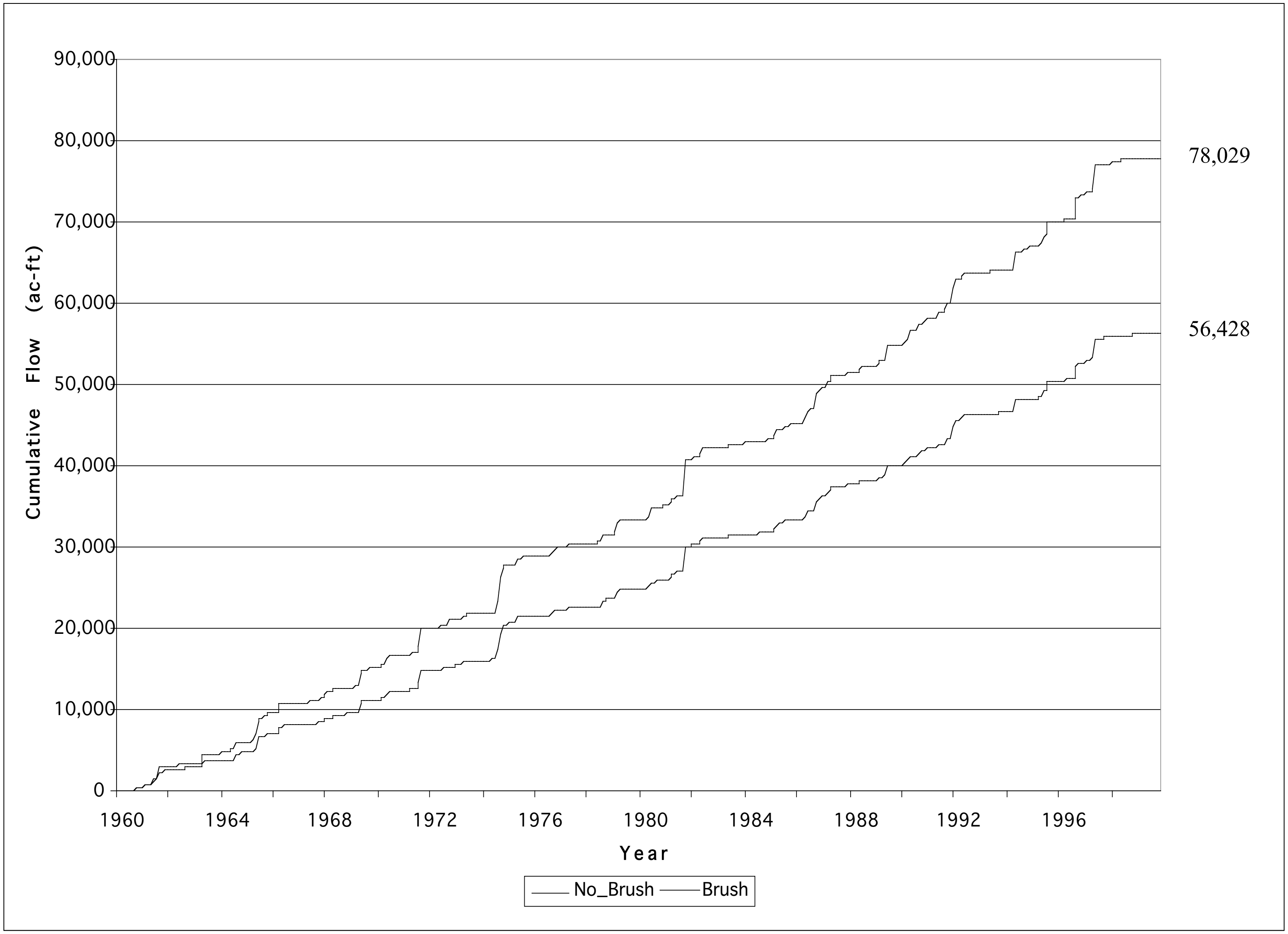

Figure 7-12. Predicted cumulative monthly stream flow into Lake Kirby for brush and no-brush conditions.

CHAPTER 8

LAKE FORT PHANTOM HILL 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 7. 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 Fort Phantom Hill watershed.

BRUSH CONTROL COSTS

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5% or less and maintain it at the reduced level for at least 10 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% 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 6 or 7. 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 $143.17 for mechanical control of heavy mixed brush. Costs of treatments and year those treatments are needed for each brush type - density category are detailed in Table 8-1.

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 Fort Phantom Hill are shown in Table 8-2. 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 8-3. 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 was 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 $21.37 per acre for control of moderate mesquite to $35.55 per acre for the control of heavy mixed brush (Table 8- 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 $14.20 for control of moderate mesquite with chemical treatments to $112.53 for control of heavy cedar 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 8-4.

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% discount rate).

The cost of added water was determined to average $29.45 per acre-foot for the entire Lake Fort Phantom Hill Watershed (Table 8-5). Subbasins range from costs per added acre-foot of $10.38 to $35.76.

Table 8-1. Cost of water yield brush control programs by type-density category.

Heavy Mesquite - Chemical			
Year	**Treatment Description**	**Treatment Cost ($)/Acre**	**Present Value ($)/Acres**
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 ($)/Acre	Present Value ($)/Acres
0	Doze/Root Plow, Rake and Burn	120.00	120.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**130.57**

Heavy Cedar - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Doze/Grub, Rake, Stack and Burn	120.00	120.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**142.57**

Heavy Cedar - Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	70.00	70.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**92.57**

Heavy Mixed Brush - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Tree Doze/Grub, Rake, Stack and Burn	120.00	120.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**143.17**

Table 8-1. Cost of water yield brush control programs by type-density category, continued.

Heavy Mixed Brush - Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value ($)/Acres
0	Skid Steer with Shears	70.00	70.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	93.17

Moderate Mesquite - Chemical

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

Moderate Mesquite - Shears

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

Moderate Mesquite - Mechanical/Grub

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

Moderate Cedar - Mechanical/Grub

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

Table 8-1. Cost of water yield brush control programs by type-density category, continued.

Moderate Cedar - Mechanical/Shears

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

Moderate Mixed Brush – Mechanical/Grub

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

Moderate Mixed Brush – Mechanical/Shears

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

Table 8-3. 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	----------	15.00
Vitamin/Salt/Minerals	60	Pound	0.10	6.00
Veterinary Medicine	1	Head	14.00	14.00
Miscellaneous	1	Head	12.00	12.00
Net Cost for Replacement Cows	----------	Head	700.00	40.00
Net Cost for Replacement Bulls	----------	Head	1500.00	4.00
			TOTAL	**139.00**

Table 8-4. Landowner/State cost-shares of brush control.

Brush Type & Density	Control Practice	PV of Total Cost ($/acre)	Rancher Share ($/acre)	Rancher %	State Share ($/acre)	State %
Heavy Mesquite	Chemical	54.78	28.14	51.37	26.64	48.63
	Grub or Doze	130.57	28.14	21.55	102.43	78.45
Heavy Cedar	Grub or Doze	142.57	30.04	21.07	112.53	78.93
	Shears	92.57	30.04	32.45	62.53	67.55
Heavy Mixed-Brush	Grub or Doze	143.17	35.55	24.83	107.62	75.17
	Shears	93.17	35.55	38.16	57.62	61.84
Moderate Mesquite	Chemical	35.57	21.37	60.07	14.20	39.93
	Shears	45.57	21.37	46.89	24.20	53.11
	Grub or Doze	110.57	21.37	19.33	89.20	80.67
Moderate Cedar	Mechanical Choice	110.57	24.79	22.42	85.78	77.58
	Shears	45.57	24.79	54.40	20.78	45.60
Moderate Mixed-Brush	Grub or Doze	110.47	28.05	25.39	82.52	74.70
	Shears	45.57	28.05	61.55	17.52	38.45

Table 8-5. Cost of added water from brush control by subbasin (acre-foot).

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
1	31,888.44	128,331,478.28	393.83	3,072.58	10.38
2	222,689.75	442,913,464.15	1,359.25	10,604.46	21.00
3	69,864.31	125,077,783.05	383.85	2,994.68	23.33
4	10,829.22	16,186,268.85	49.67	387.54	27.94
5	602,186.31	1,021,940,998.99	3,136.22	24,467.84	24.61
6	571,964.33	774,615,892.52	2,377.21	18,546.25	30.84
7	320,293.32	411,535,285.70	1,262.96	9,853.19	32.51
8	2,316.02	3,392,881.28	10.41	81.23	28.51
9	489,322.93	646,798,229.90	1,984.95	15,485.98	31.60
10	931,875.02	1,411,813,104.38	4,332.70	33,802.36	27.57
11	996,353.84	1,243,780,102.39	3,817.02	29,779.22	33.46
12	663,206.80	1,026,985,459.73	3,151.70	24,588.61	26.97
13	314,303.42	465,592,188.35	1,428.85	11,147.45	28.20
14	955,009.56	1,235,415,244.51	3,791.35	29,578.95	32.29
15	1,909,615.41	2,893,594,609.80	8,880.12	69,279.93	27.56
16	1,586,326.62	2,006,453,271.44	6,157.58	48,039.54	33.02
17	511,372.34	597,273,451.88	1,832.96	14,300.23	35.76
Total	10,189,417.63			346,010.03	
Average					29.45

CHAPTER 9

LAKE PALO PINTO WATERSHED – HYDROLOGIC SIMULATION

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WATERSHED DATA

Physical Data

Lake Palo Pinto drains approximately 296,000 acres (460 miles^2) of land area (here simply called the "watershed") within Palo Pinto, Erath, Eastland, and Stephens counties (see Figure 9-1). After settlement, covering some time between 1850-1870, the watershed saw dramatic changes to the landscape through cotton and corn production through the mid-1920s. The Boll weevil essentially brought the cotton production to a stand still, to be replaced by peanuts, fruits, corn, and grains. Oil discovery in the early part of the 20th century led to the oil industry being a leading source of economic activity in the counties even to this day. A predominant portion of agricultural activity in the area is now due to grazing and ranching (Handbook of Texas Online, 2002). Lake Palo Pinto is the largest water body of several dammed lakes, and numerous smaller ponds. Lake Palo Pinto, which is operated by the Palo Pinto County Water District, was built in 1964, and has a normal storage volume of 44,100 acre-feet. The primary stream in the watershed is the Palo Pinto Creek. The other smaller dams are Lake Thurber (700 acre-feet) and Lake Mingus (969 acre-feet) which drain Gibson Creek; and, Lake Tucker (1,200 acre-feet) which drains Russell Creek within the watershed. The average annual rainfall in the watershed is about 30 inches, and average temperatures range from a low of 33°F in January to a maximum of about 96°F in the summer. The outflow from the reservoir supplies water to the city of Mineral Wells (1990 census population: 14,338) before reaching the Brazos River. Nine years in ten, the growing season is above freezing temperature for 213 days (USDA-NRCS, 1981).

METHODS

Land Use/Cover

The Land Use/Cover for the hydrologic modeling study was developed using the Landsat-7 Themmatic Mapper ETM+ (see opening chapter) to cover the 1999 growing season. The ground resolution of the satellite sensor is about 30 meters. Classification of the satellite sensor data was dependent on the tree grouping within the 30 meter foot print. Three different brush densities were delineated: heavy (>30% tree density), moderate (10-30% density), and light (<10% density). The most common brush types in the watershed were Juniper (cedar) and oak, with lesser amounts of mesquite. All densities of mixed Cedar/Oak/Mesquite/Other brush (called "mixed" brush) within the sensor footprint accounted for nearly 25% of the brush coverage in the watershed. About 47% of the total land cover was heavy and moderate brush (except oak), which was converted to open rangeland for brush control treatment.

Soils

Soil are derived from a local parent material, or could have been transported from elsewhere via erosion mechanisms involving wind or water. The soil in the Palo Pinto watershed are located in the North Central Plains physiographic region. The geology in the watershed consists primarily of carboniferous Pennsylvanian age (circa 300 mya) sandstone and mudstone rocks (Strawn group). The most common soils in the watershed are the fine sandy loam Truce series (11.35%), extremely stony clay loam Palopinto series (9.39%), and the fine sandy loam Bonti series (8.7%). These and lesser soils are briefly described below from the USDA-NRCS soil survey.

<u>Truce (11.35%):</u> Deep, well drained, gently sloping soil in on convex uplands. Typically, the surface layer is slightly acid fine sandy loam about 7 inches thick. The upper 6 inches is brown, and lower 1 inch is pink. From 7-48 inches the soil is neutral clay that is yellowish red in the upper part, brown in the middle part, and brownish yellow in the lower part; 48-60 inches is moderately alkaline, pale yellow shaly clay interbedded with olive shaly clay and thin soft sandstone strata. Permeability is slow, and available water capacity is low. The surface layer is very hard and massive when the soil is dry. Because the surface crusts on convex slopes, runoff rate is high. *Water erosion hazard is severe*. Wind erosion hazard is moderate. Potential plant community is a mid grass, post oak savannah. Potential for wildlife habitat (Quail and Dove) is good.

<u>Palopinto (9.39%)</u>: Well drained, shallow, gently sloping to sloping soil on upland ridge tops. Limestone fragments, 6-30 inches in diameter, cover about 30% of the surface. Typically, the surface layer is moderately alkaline, dark grayish brown, extremely stony clay loam about 12 inches thick. It contains about 35-85% limestone fragments. Below 12 inches is fractured limestone bedrock. Surface runoff is medium to rapid. Permeability is moderate, and available water capacity is very low. The hazards of water erosion and wind erosion are slight. The potential plant community is a tall and mid grass, live oak savannah. Potential for wildlife habitat is fair.

<u>Bonti (8.70%)</u>: Moderately deep, well drained, gently sloping soil on uplands. The surface layer is slightly acidic, light brown fine sandy loam about 9 inches thick; 9-25 inches is medium acid, red clay; 25-36 inches is medium acid, yellowish red clay; Below 36 inches is reddish, strongly cemented sandstone bedrock. Permeability is moderately slow, and available water capacity is low. A hard crust forms on the surface when the soil is dry. Runoff rate is medium. The *hazard of water erosion is severe*, and wind erosion hazard is moderate. Potential plant community is mid grass, post oak savannah. Potential for wildlife habitat is good.

<u>Set (5.22%):</u> Deep, well drained, gently sloping soils on knolls and foot slopes. Typically, the surface layer is alkaline, dark grayish brown clay about 10 inches thick;10-42 inches is moderately alkaline clay that is pale brown in the upper part, and light yellowish brown in the lower part. Below that to a depth of 50 inches is moderately alkaline, very pale shaly clay. Permeability is slow, and available water capacity is high. Water erosion hazard is severe, and wind erosion hazard is slight. Potential plant community is mid to tall grasses. Potential for wildlife habitat is fair.

Leeray (4.39%): Deep, well drained soils on gently sloping uplands. Typically, the surface layer is moderately alkaline, dark grayish brown clay about 8 inches thick; 8-60 inches is moderately alkaline clay that is very dark grayish brown in the upper part, and grayish brown in the middle part, and olive brown in the lower part. Permeability is very slow, and available water capacity is high. When the soil is dry, water enters through cracks. Runoff is medium. *Water erosion hazard is severe*, and wind erosion hazard is slight. Potential plant community is mid to tall grasses. Potential for wildlife habitat is fair.

Hensley (3.85%): Shallow, well drained, level to gently sloping soils on uplands. Limestone fragments, 6-40 inches in diameter, covering 3-15% of the surface. Typically, the surface layer is neutral reddish brown very stony clay loam about 6 inches thick; 6-15 inches is neutral, dark reddish brown clay loam. Below that is hard limestone bedrock. Permeability is slow, and available water capacity is low. Runoff is medium. *Water erosion hazard is severe*. Wind erosion potential is slight. Potential plant community is a prairie of mid and tall grasses interspersed with widely scattered mottes of lives oak. Potential for wildlife habitat is fair.

Topography

Elevation ranges from about 820 feet at lake Palo Pinto to about 1,600 feet at the watershed divide.

Geology

The major geologic formations in the watershed belong to the Strawn and Cisco groups of Pennsylvanian age. These formations include: Brazos River formation of sandstone and mudstone; Mingus formation of shale, sandstone and limestone; and Home Creek Limestone (Bureau of Economic Geology, 1972). Quaternary alluvium dominate along streams.

Climate

The average annual precipitation within the watershed is about 30 inches. Temperatures range from near freezing to 96°F. The normal growing season has about 213 days. Figure 9-2 shows the climate stations used in the hydrologic simulations, along with the U.S. Geological Survey gauging station on the outflow side of the Palo Pinto reservoir.

Ponds and Reservoirs

Russell Creek drains into Lake Tucker; Gibson Creek is intercepted by Lake Mingus and Thurber. Several smaller ponds are located throughout the watershed (Figure 9-3). Lake Palo Pinto supplies water to the city of Mineral Wells. Available data on normal storage levels, maximum storage, and surface areas were obtained from the TNRCC for use in the SWAT model. Water withdrawal from Palo Pinto was estimated from county water withdrawals using the TWDB regional water use database. Water withdrawals from the smaller lakes were assumed negligible.

Model Inputs

The significant input variables in the SWAT model for the watershed are shown in Table 9-1. The input variables were calibrated according to best match of modeled outflow from Lake Palo Pinto against USGS measured flows at the Santo gauge. For “no-brush” condition, the input variables for all heavy and moderate brush categories were replaced by open range conditions.

Model Calibration

The SWAT model parameters were calibrated based on matching Lake Palo Pinto outflow predictions against gauge measurements at Santo about 10 miles downstream of the dam (Figure 9-4). Lake volumetric measurements were available, but not used because of very limited period of coverage (October, 1979- September, 1981). No gauges were known to exist within the watershed, constraining adequate capture of spatial variability of hydrologic phenomena in the watershed.

Brush Removal Simulation

Brush control was simulated by replacing all heavy and moderate brush types (mesquite, cedar, and mixed brush) with open range conditions. As a result of brush replacement by open range conditions, curve numbers, leaf area indices, rooting depth, and ground water re-evaporation by roots changed.

RESULTS

Model Calibration

Figure 9-4 shows the model predictions and observations at the Santo gauge near the Lake Palo Pinto outflow. The means are within 3% of each other, but the root mean square is about 156% of the mean observed value. This suggests that the model is doing well predicting the long-term mean hydrologic conditions of the watershed, but that monthly variability was not captured adequately. The model uses a fixed release rate for the reservoir, which imposes limitations on modeling reservoirs.

Brush Removal Simulation

As a result of brush control, the average annual Evapo-Transpiration (ET) as percentage of average annual precipitation decreased from 76% to 64%. The lowered ET and grass cover yielded higher runoff and groundwater flows. Figures 9-5 to 9-8, respectively show, the inflow increases into Lake Mingus, Thurber, Tucker and Palo Pinto as a result of brush control. The flow increases varied from 379 acre-feet/year into Lake Thurber to 39,485 acre-feet/year into Lake Palo Pinto.

Water yields in the sub-basins describes the water leaving each of the sub-basins shown in Figure 9-1. Water yields are higher than stream flows because of water loss from streams and upstream reservoirs to evaporation, and transmission loss. Table 9-2 shows the water yields gained due to brush control. Generally, the sub-basins gain over 100,000 gallons/treated acre of brush/year.

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The Handbook of Texas Online. 2002. “Palo Pinto, Erath, Stephens, and Eastlands Counties”. http://www.tsha.utexas.edu/handbook/online/articles/view/PP/hcp1.html [Accessed Mon. July 29 12:11:14 US/Central 2002].

USDA-Natural Resources Conservation Service (NRCS). 1981. Soil Survey of Palo Pinto County. Available from the Temple, Texas, USDA-NRCS office; Issued August, 1981.

Table 9-1. SWAT input variables for Lake Palo Pinto watershed.

VARIABLE	ADJUSTMENT or VALUE
Runoff Curve Number	-6
Available Water Capacity (inches/inches)	None (SSURGO defaults)
Crack Volume factor	None
Saturated Conductivity	None
Soil Evaporation Compensation Factor (ESCO)	0.85
Shallow Aquifer storage before Groundwater release, inches	0.0787
Shallow aquifer storage before re-evaporation , inches	0.065
Re-evaporation coefficient (Revap)	
Brush	0.40
No Brush	0.10
Stream channel transmission loss (inches/hour)	0.20
Sub-basin transmission loss on landscape (inches/hour)	1.00
Bank Coefficient	0.25
Reservoir Evaporation Coefficient	1.1
Reservoir seepage loss (inches/hour)	
Palo Pinto	0.0032
Mingus	0.0004
Tucker	0.0004
Thurber	0.0004
Principal Spillway Release rate (cubic feet per second, cfs)	
Palo Pinto	880
Tucker	35
Thurber	35
Mingus	35
Potential Heat Units (degree °C days)	
Heavy Cedar	3940
Moderate Cedar	3428
Heavy Mesquite	3428
Moderate Mesquite	3034
Heavy Mixed Brush	3664
Moderate Mixed Brush	3231
Heavy Oak	3428
Moderate Oak	3034
Light Brush & open range	2640
Pasture	2045
Agriculture (based on corn)	1875
Plant Rooting Depth (feet)	
Heavy and Moderate Brush	6.5
Open range and light brush	3.3
Maximum Leaf Area	
Heavy Cedar	6
Moderate Cedar	5
Heavy Mesquite	4
Moderate Mesquite	2
Heavy Mixed Brush	4
Moderate Mixed Brush	3
Heavy Oak	4
Moderate Oak	3
Light brush	2
Open range and pasture	1

Table 9-2. Subbasin data - Lake Palo Pinto 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)
2010801	9,300	4,221	0.45	113,895	480,749,115
2010802	15,484	9,211	0.59	137,757	1,268,882,407
2010803	4,737	2,904	0.61	188,670	547,897,400
2010804	17,250	7,646	0.44	212,757	1,626,742,164
2010806	33,939	18,738	0.55	164,347	3,079,537,933
2010807	28,017	15,161	0.54	165,565	2,510,125,319
2010808	8,521	3,442	0.40	191,047	657,582,182
2010809	7,778	2,926	0.38	208,636	610,470,019
2010810	15,946	6,289	0.39	194,025	1,220,221,283
2010901	16,708	7,454	0.45	178,709	1,332,094,232
2010902	31,717	16,642	0.52	212,200	3,531,425,395
2010903	2,216	55	0.02	229,788	12,638,350
2110801	16,307	7,465	0.46	151,978	1,134,515,066
2110802	8,712	5,899	0.68	142,219	838,948,578
211803	9,244	5,282	0.57	136,442	720,684,060
2110806	21,141	7,864	0.37	209,579	1,648,131,456
2110808	3,244	1,920	0.59	190,143	365,073,606
2110809	21,977	6,598	0.30	209,711	1383675725
2110810	4,705	1,710	0.36	185,248	316,773,663
2210808	10,558	4,579	0.43	199,649	914,193,891
2310808	5,969	2,307	0.39	182,253	420,458,163
2410808	2,930	1,112	0.38	208,015	231,312,171
	296,400 ***Watershed Total***	**139,425** ***Watershed Total***	**0.47** ***Watershed Average***	**178,247** ***Watershed Average***	**24,852,132,179** ***Watershed Total***

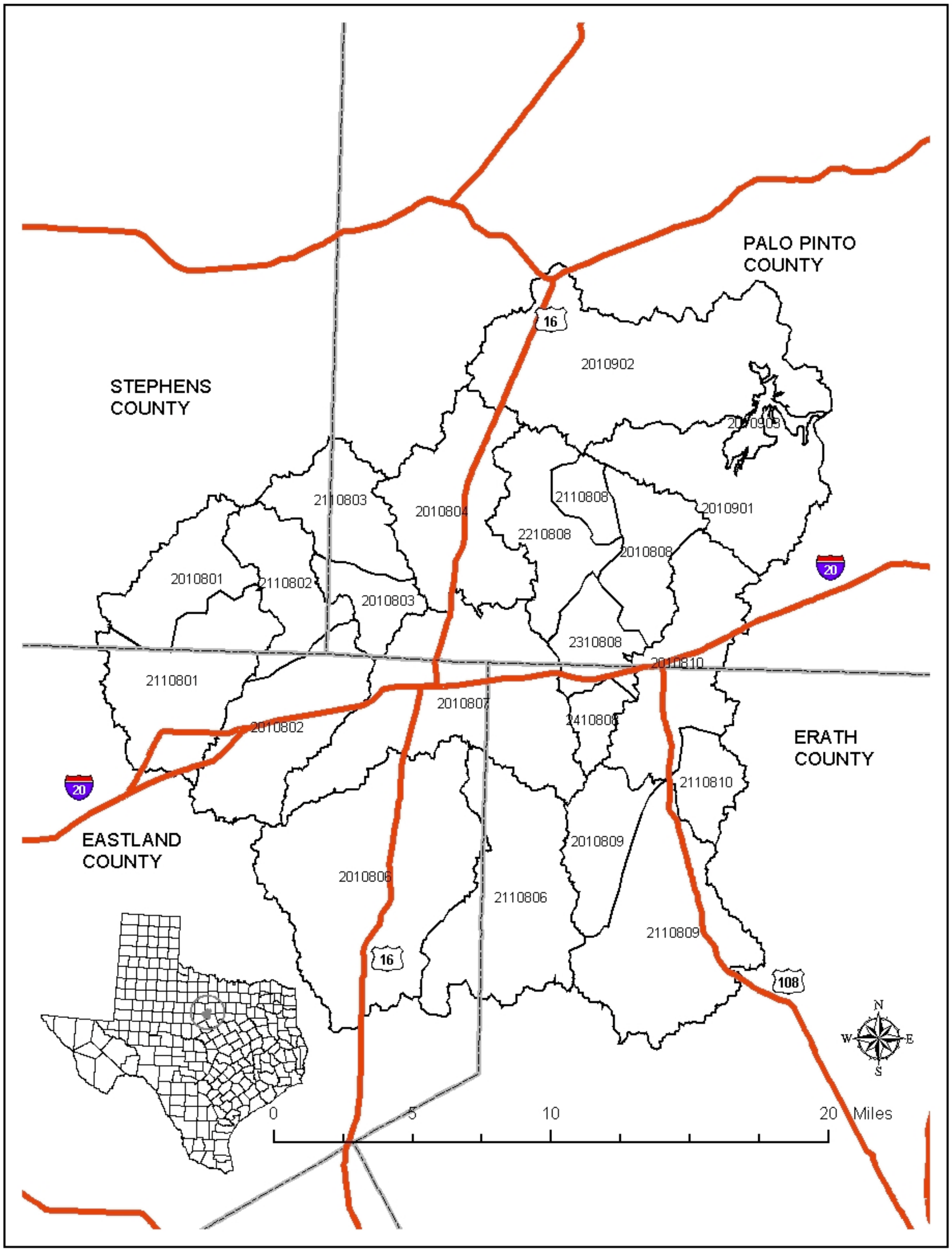

Figure 9-1. Lake Palo Pinto watershed sub-basin map with major roads.

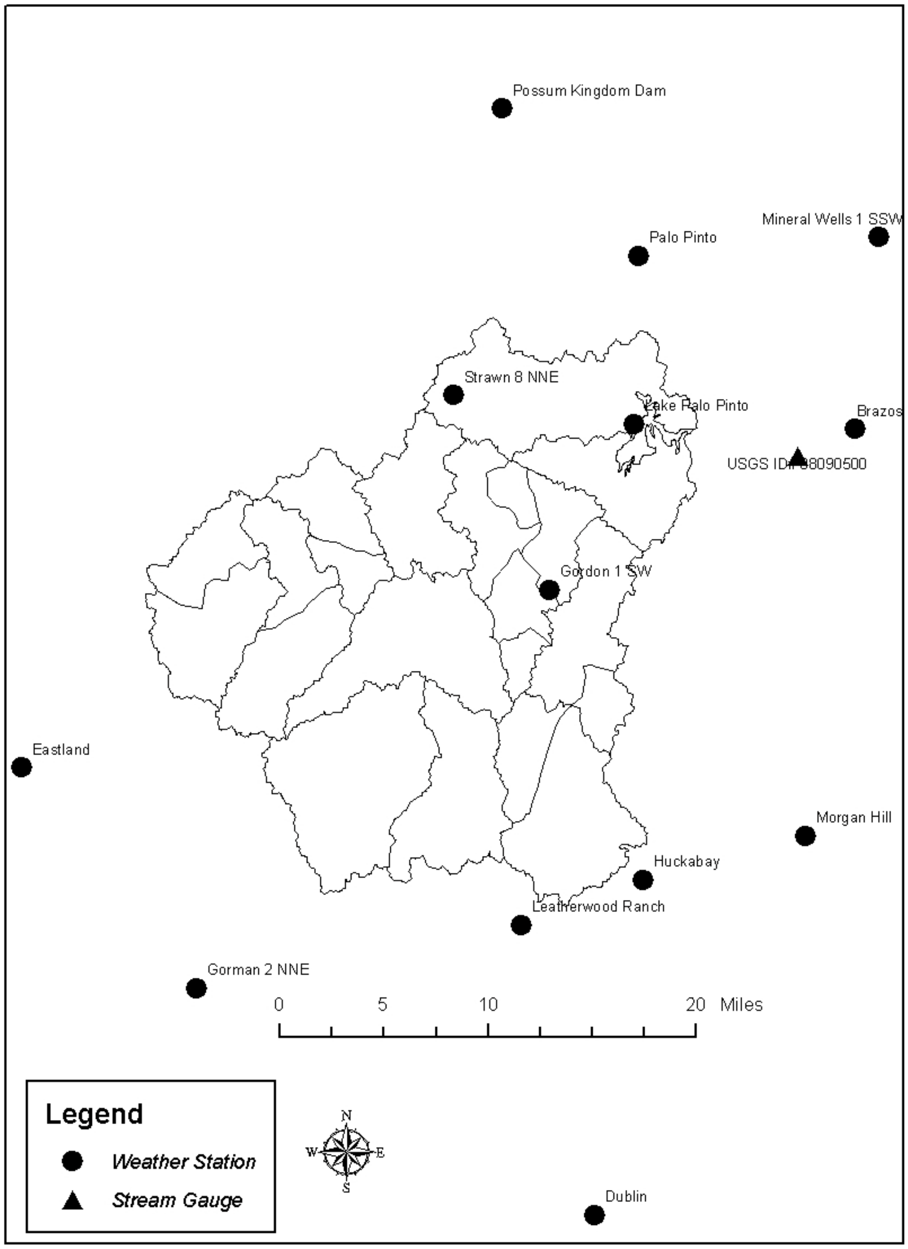

Figure 9-2. Climate and stream gauge stations in the Palo Pinto watershed.

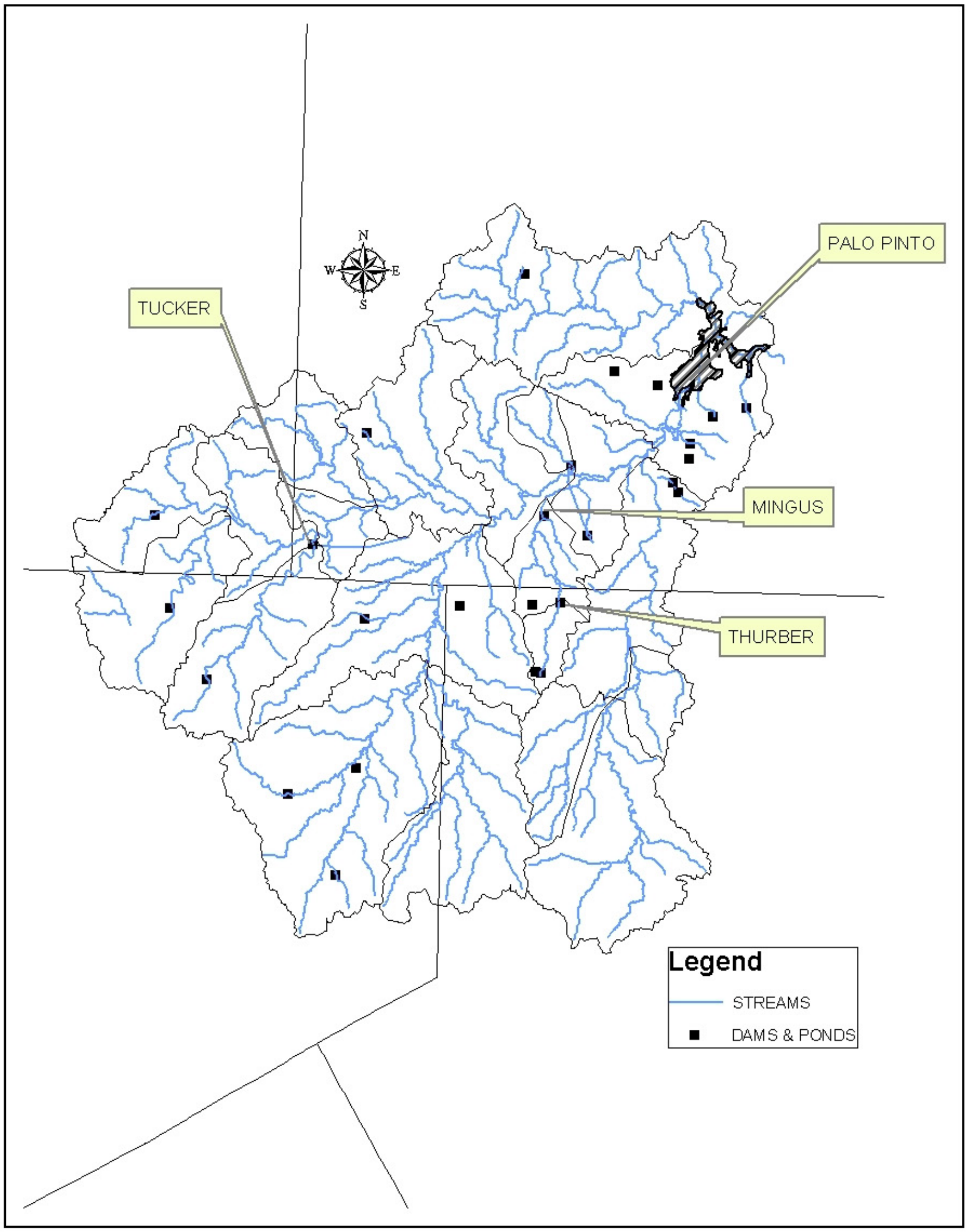

Figure 9-3. Inventory-sized ponds and reservoirs (labeled) in the Palo Pinto watershed.

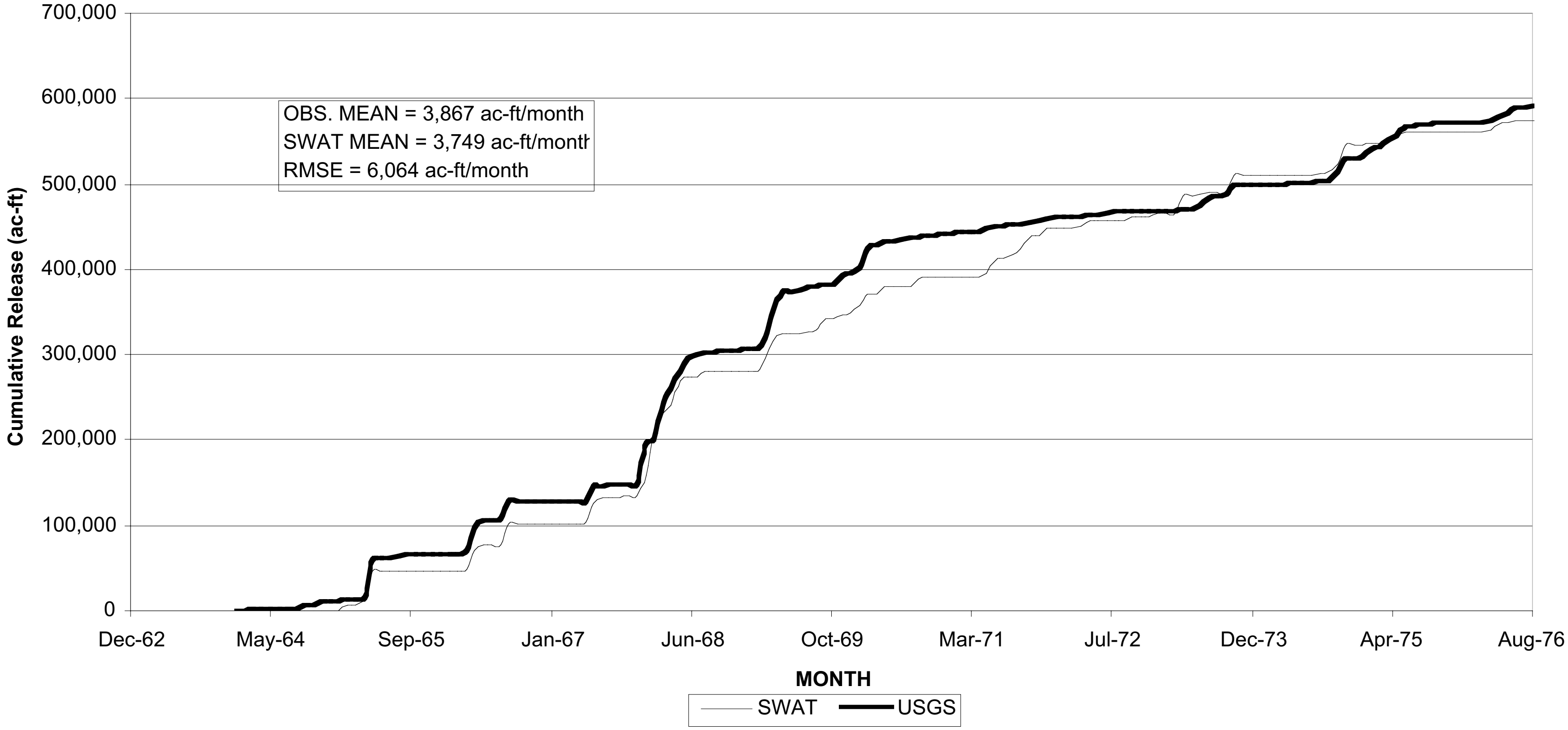

Figure 9-4. Calibration curve for SWAT (thin line) against measured USGS flows at the Santo gauge No. 08090500 about 10 miles downstream of Lake Palo Pinto. Note that the flows are through 1976.

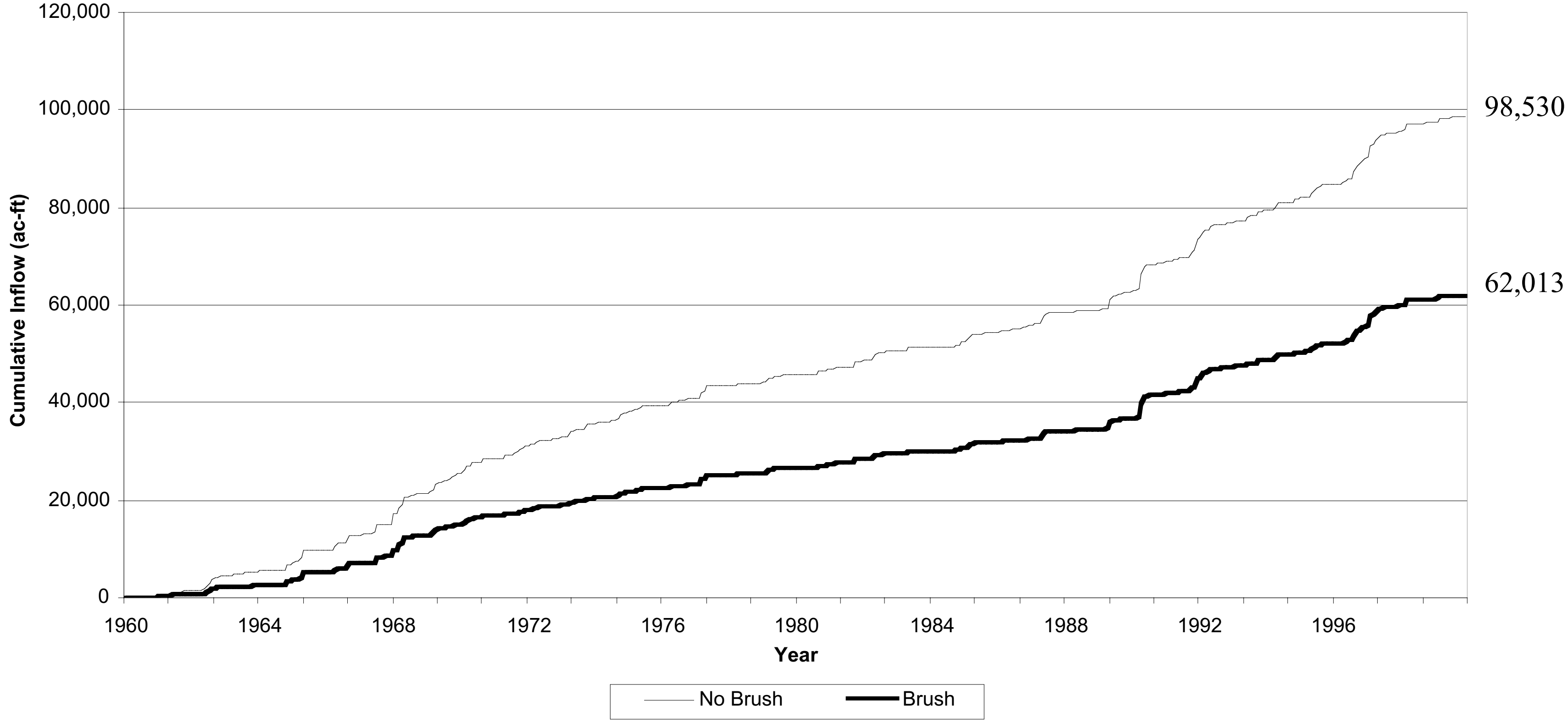

Figure 9-5. Predicted cumulative monthly stream flow into Lake Mingus for brush and no brush conditions.

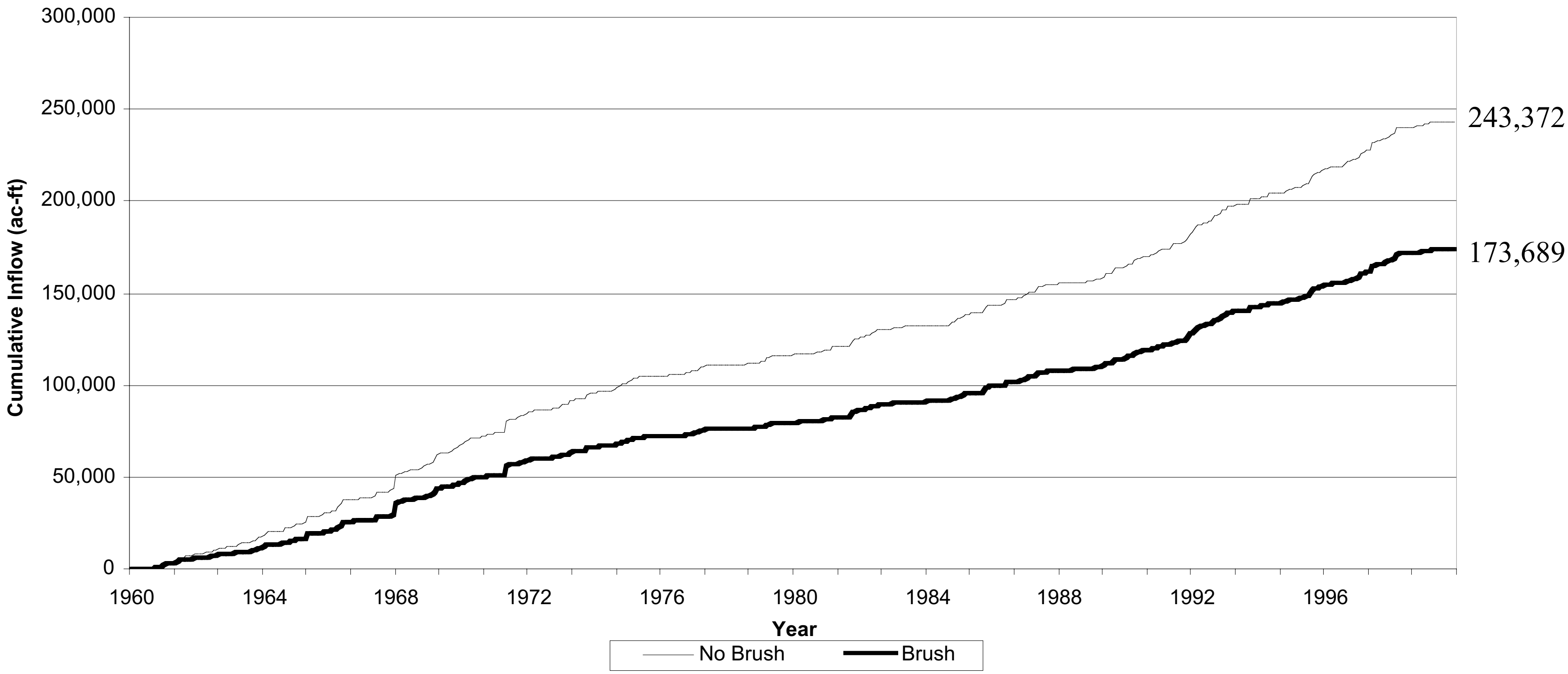

Figure 9-6. Predicted cumulative monthly stream flow into Lake Tucker for brush and no brush conditions.

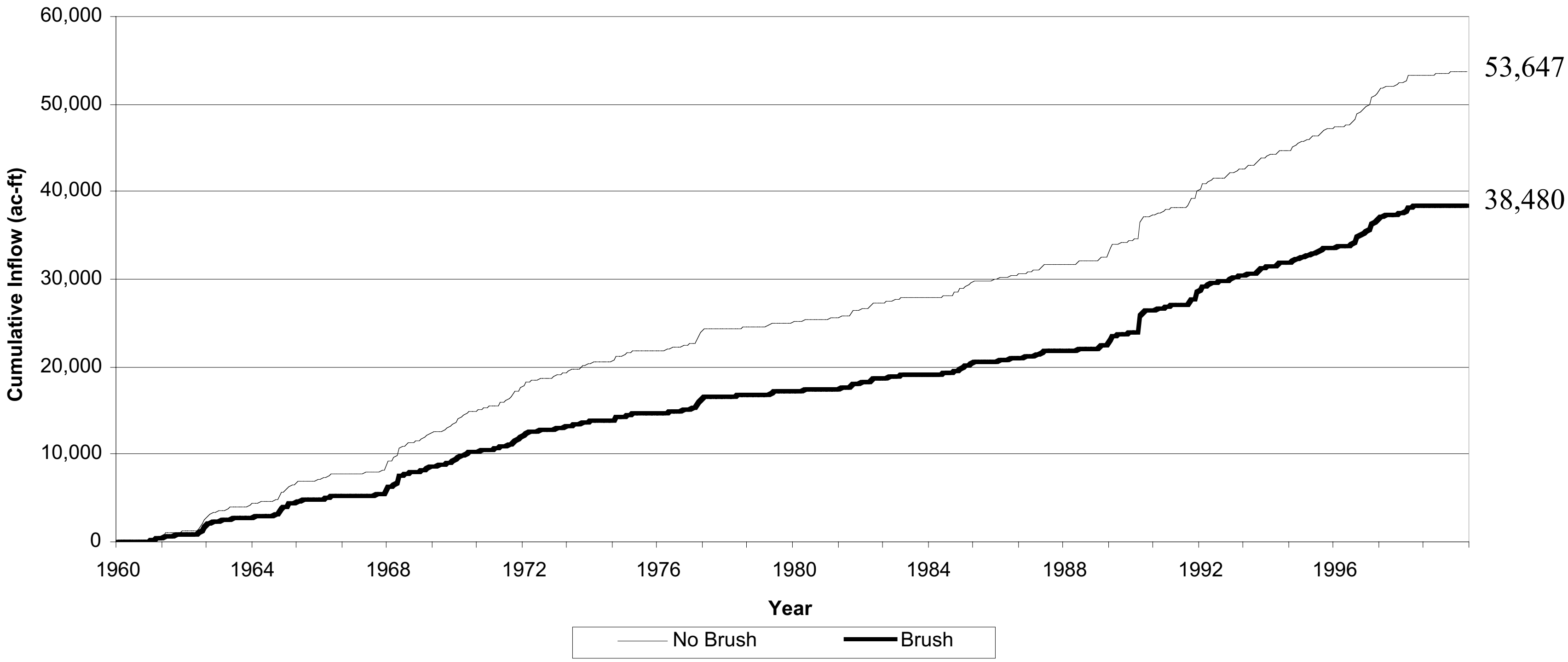

Figure 9-7. Predicted cumulative monthly stream flow into Lake Thurber for brush and no brush conditions.

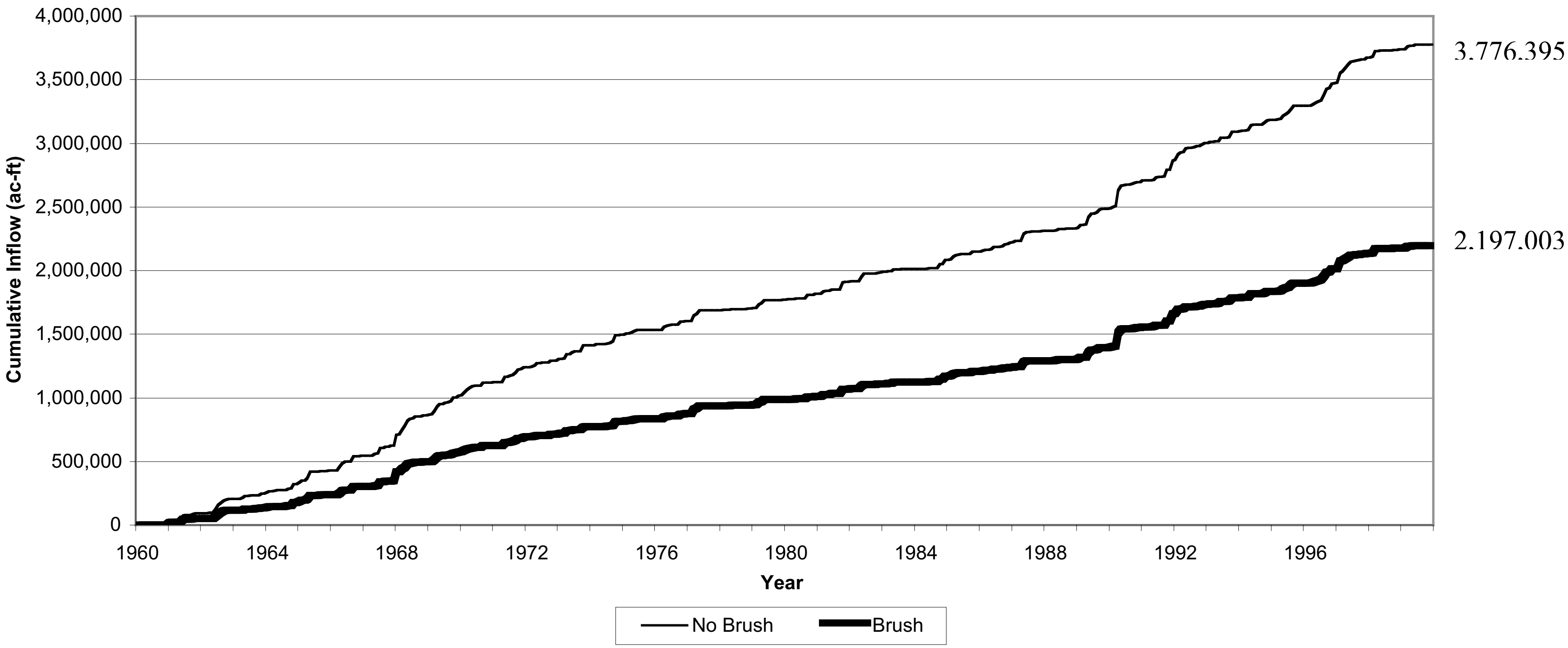

Figure 9-8. Predicted cumulative monthly stream flow into Lake Palo Pinto for brush and no brush conditions.

CHAPTER 10

PALO PINTO 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 9. 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 Palo Pinto watershed.

BRUSH CONTROL COSTS

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5% or less and maintain it at the reduced level for at least 10 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% 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 6 or 7. 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 $173.17 for mechanical control of heavy mixed brush. Costs of treatments and year those treatments are needed for each brush type - density category are detailed in Table 10-1.

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 Palo Pinto are shown in Table 10-2. 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 10-3. 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 was 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 $17.09 per acre for control of moderate mesquite to $37.20 per acre for the control of heavy mixed brush (Table 10-4).

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 $11.35 for control of heavy cedar with roller chop to $143.63 for control of heavy cedar 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 10-4.

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% discount rate).

The cost of added water was determined to average $24.09 per acre-foot for the entire Palo Pinto Watershed (Table 10-5). Subbasins range from costs per added acre-foot of $18.17 to $34.98.

Table 10-1. Cost of water yield brush control programs by type-density category.

Heavy Mesquite - Chemical			
Year	Treatment Description	Treatment Cost ($)/Acre	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
		TOTAL	**$54.78**

Heavy Mesquite - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Doze/Root Plow, Rake, Stack and Burn	150.00	150.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$160.57**

Heavy Cedar - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Tree Doze/Grub, Rake, Stack and Burn	150.00	150.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**$172.57**

Heavy Cedar - Mechanical/Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Skid Steer with Shears	70.00	70.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**$92.57**

Heavy Cedar - Chain & Burn

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	2-Way Chain and Burn	32.00	32.00
3	Choice Type IPT or Burn	15.00	12.59
7	Choice Type IPT or Burn	15.00	9.98
		TOTAL	**$54.57**

Heavy Cedar - Roller Chop			
Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Roller Chop	25.00	25.00
3	Burn	7.00	5.88
8	Choice Type IPT or Burn	15.00	9.41
		TOTAL	**$40.29**

Table 10-1. Cost of water yield brush control programs by type-density category, continued.

Heavy Mixed Brush - Mechanical Choice

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Doze/Grub, Rake, Stack and Burn	150.00	150.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$173.17**

Heavy Mixed Brush - Mechanical/Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Skid Steer with Shears and Herbicide	70.00	70.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$93.17**

Heavy Mixed Brush - Chain & Burn

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	2-Way Chain and Burn	32.00	32.00
3	Choice Type IPT or Burn	15.00	12.59
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$55.17**

Heavy Oak and/or Elm - Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Aerial Spray Spike	70.00	70.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$80.57**

Moderate Mesquite - Chemical

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

Moderate Mesquite - Chemical/Shears

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Skid Steer w/Shears and Herbicide	40.00	40.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$50.57**

Moderate Mesquite - Mechanical/Grub

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Grub, Rake, Stack and Burn	120.00	120.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$130.57**

Table 10-1. Cost of water yield brush control programs by type-density category, continued.

Moderate Cedar - Mechanical/Grub			
Year	**Treatment Description**	**Treatment Cost ($)/Acre**	**Present Value**
0	Grub, Rake, Stack and Burn	120.00	120.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$130.57**
Moderate Cedar - Mechanical/Shears			
Year	**Treatment Description**	**Treatment Cost ($)/Acre**	**Present Value**
0	Skid Steer with Shears	35.00	35.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$45.57**
Moderate Cedar - Roller Chop			
Year	**Treatment Description**	**Treatment Cost ($)/Acre**	**Present Value**
0	Roller Chop	25.00	25.00
3	Burn	7.00	5.88
8	Choice Type IPT or Burn	15.00	9.41
		TOTAL	**$40.29**

Moderate Mixed Brush - Mechanical/Grub

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Grub, Rake, Stack and Burn	120.00	120.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$130.57**

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

Moderate Oak and/or Elm - Chemical

Year	Treatment Description	Treatment Cost ($)/Acre	Present Value
0	Aerial Spray Spike	70.00	70.00
6	Choice Type IPT or Burn	15.00	10.57
		TOTAL	**$80.57**

Table 10-3. Investment analysis budget, cow-calf production.

Partial Revenues:					
Revenue Item Desription	**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	60.00	60.00
Cattle Marketing - All Cattle		----------	Head	----------	15.00
Vitamin/Salt/Minerals		60	Pound	0.10	6.00
Veterinary Medicine		1	Head	14.00	14.00
Miscellaneous		1	Head	12.00	12.00
Net Cost for Replacement Cows		----------	Head	700.00	40.00
Net Cost for Replacement Bulls		----------	Head	1500.00	4.00
				TOTAL	**151.00**

Table 10-4. Landowner/State cost-shares of brush control.

Brush Type & Density	Control Practice	PV of Total Cost ($/acre)	Rancher Share ($/acre)	Rancher %	State Share ($/acre)	State %
Heavy Mesquite	Chemical	54.78	26.00	47.46	28.78	52.54
	Grub or Doze	160.57	26.00	16.19	134.57	83.81
Heavy Cedar	Grub or Doze	172.57	28.94	16.77	143.63	83.23
	Shears	92.57	28.94	31.26	63.63	68.74
	Chain & Burn	54.57	28.94	53.03	25.63	46.97
	Roller Chop	40.29	28.94	71.83	11.35	28.17
Heavy Mixed Brush	Grub or Doze	173.17	34.18	19.74	138.99	80.26
	Shears	93.17	34.18	36.69	58.99	63.31
	Chain & Burn	55.17	34.18	61.95	20.99	38.05
Heavy Post/Shimmery Oak	Chemical	80.57	37.20	46.17	43.37	53.83
Moderate Mesquite	Chemical	35.57	17.09	48.05	18.48	51.95
	Shears	50.57	17.09	33.79	33.48	66.21
	Grub or Doze	130.57	17.09	13.09	113.48	86.91
Moderate Cedar	Mechanical Choice	130.57	24.04	18.41	106.53	81.59
	Shears	45.57	24.04	52.75	21.53	47.25
Moderate Mixed Brush	Grub or Doze	130.57	27.11	20.76	103.46	79.24
	Shears	45.57	27.11	59.49	18.46	40.51
	Roller Chop	40.29	27.11	67.29	13.18	32.71
Moderate Post/Shimmery Oak	Chemical	80.57	22.74	28.22	57.83	71.77

Table 10-5. Cost of added water from brush control by subbasin (acre-foot).

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
2010801	402,622.17	480,749,115.20	1,475.36	11,510.34	34.98
2010802	890,541.61	1,268,882,407.00	3,894.06	30,380.24	29.31
2010803	281,254.07	547,897,399.50	1,681.44	13,118.04	21.44
2010804	707,572.60	1,626,742,164.00	4,992.29	38,948.30	18.17
2010806	1,953,171.62	3,079,537,933.00	9,450.75	73,731.88	26.49
2010807	1,551,395.33	2,510,125,319.00	7,703.29	60,098.71	25.81
2010808	341,540.79	657,582,181.90	2,018.05	15,744.17	21.69
2010809	367,689.31	610,470,018.60	1,873.46	14,616.19	25.16
2010810	679,520.82	1,220,221,283.00	3,744.72	29,215.17	23.26
2010901	831,096.15	1,332,094,232.00	4,088.05	31,893.69	26.06
2010902	1,588,452.40	3,531,425,395.00	10,837.55	84,551.20	18.79
2010903	7,513.25	12,638,350.20	38.79	302.59	24.83
2110801	727,638.57	1,134,515,066.00	3,481.70	27,163.14	26.79
2110802	549,744.11	838,948,577.90	2,574.64	20,086.54	27.37
2110803	488,598.44	720,684,060.00	2,211.70	17,254.99	28.32
2110806	1,011,164.74	1,648,131,456.00	5,057.93	39,460.41	25.62
2110808	172,253.80	365,073,605.70	1,120.37	8,740.78	19.71
2110809	796,708.14	1,383,675,725.00	4,246.34	33,128.68	24.05
2110810	171,993.03	316,773,663.10	972.14	7,584.36	22.68
2210808	444,408.91	914,193,891.50	2,805.56	21,888.10	20.30
2310808	234,171.89	420,458,162.80	1,290.34	10,066.83	23.26
2410808	133,187.75	231,312,171.40	709.87	5,538.20	24.05
Total	14,332,239.50			595,022.55	
Average					24.09