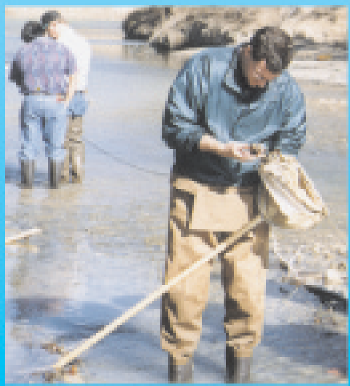
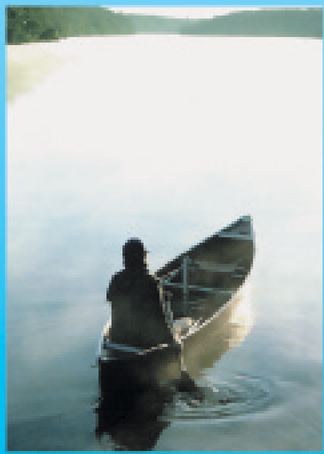
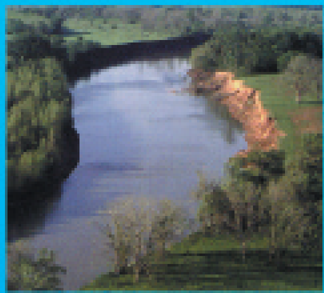
Palo Pinto Reservoir Watershed
Brush Control Assessment and Feasibility Study

Prepared for the

Texas State Soil and Water Conservation Board

Brazos River Authority

Striving for Excellence

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1.0 Executive Summary

Streamflow in the Brazos River and its tributaries, along with reservoirs in the Brazos River basin, comprise a vast supply of surface water to Texas. Diversions and use of this surface water occurs throughout the entire basin with over 1,500 water rights currently issued. However, the supply of surface water varies greatly throughout the basin due to large variations in rainfall and evaporation rates. The upper part of the basin is heavily dependent on surface water sources. Palo Pinto Reservoir, operated by the Palo Pinto County Municipal Water District, is a water supply reservoir in North-Central Texas.

The upper part of the Brazos River basin ranges from desert-like conditions to semi-arid with minimal rainfall. Water availability is a critical factor as the population in the urban areas of the region grows. In an effort to guarantee adequate water supply for the future of this region, a variety of options are being considered by the State. One of the options is brush control. Brush control is the selective control, removal, or reduction of noxious brush such as mesquite and cedar, which consume large quantities of water. Brush control can have positive results in increasing stream flow, aquifer levels, and water availability. In watersheds where the vegetation is dominated by noxious brush, replacing the brush with native grasses that use less water may yield greater quantities of available water. The goal of this study is to evaluate the climate, vegetation, soil, topography, geology and hydrology of the Palo Pinto watershed with respect to the feasibility of implementing brush control programs in the watershed.

Climate data have been collected in the region since 1950. This data reveals no major changes in temperature or precipitation levels between 1950 and 2000. While the climate has not changed, it appears that various changes in stream flow, spring discharge, and vegetation have occurred since the first European settlers began to arrive in the area in the 19th century. The first-hand accounts of the early settlers document ample water supplied through perennial springs and streams and a lush grassland with little mesquite and juniper. In contrast to historical accounts, today the area is dominated by mesquite and juniper brush, springs are intermittent, and the water supply in the watershed is inadequate to meet demand without inputs of water from other watersheds.

Brush removal simulations reveal that rates of evapotranspiration will be reduced as a result of brush control, grass cover will increase, and their will be higher runoff and groundwater flows in the Palo Pinto Reservoir watershed. Simulations of brush control implementation estimate average annual water yield increases in the Palo Pinto reservoir watershed to be about 178,000 gallons per treated acre.

An assessment of the economic feasibility of brush control in the Palo Pinto Reservoir watershed revealed the following results: the total cost of added water was determined to average $24.09 per acre foot if all eligible acreage is treated; present value of total control costs per acre range from $35.57 for herbicide control of moderate mesquite to $173.17 for mechanical control of heavy mixed brush; benefits to landowners range from $17.09 per acre for control of moderate mesquite to $37.20 per acre for the control of heavy mixed brush; and state cost share per acre is estimated to be $18.48 for moderate mesquite control to $143/63 for heavy cedar control.

2.0 Introduction

The Brazos River Authority is participating in a study coordinated by the Texas State Soil and Water Conservation Board (TSSWCB) to assess the feasibility of instituting brush control measures in the Palo Pinto Reservoir watershed. In 1985, the Texas Legislature created the Texas Brush Control Program. The goal of this legislation is to enhance the State's water resources through selective control of brush species. The TSSWCB was given jurisdiction over the program. Brush control, as defined in the legislation, means the selective control, removal, or reduction of noxious brush such as mesquite, prickly pear, salt cedar, or other deep-rooted plants that consume large amounts of water.

Water will likely be the most limiting natural resource in Texas in the future. The ability to meet future water needs will significantly impact growth and economic well being of this State. The United States Department of Agriculture-Natural Resources Conservation Service (NRCS) estimated that brush in Texas uses over 3.5 trillion gallons of water annually. Control of brush presents a viable option for increasing the availability of water allowing the State to meet its future needs.

Since the European settlement of Texas, overgrazing by livestock, fire suppression and droughts have led to the increase and dominance of noxious brush species over the native grasses and trees. The continuous livestock grazing of the State’s rangeland has reduced the ability of grasses to suppress seedling tree establishment and have led to the establishment of invasive woody species, such as juniper and mesquite. This noxious brush utilizes much of the available water resources with little return to the watershed and reduced production capabilities of the region.

This project aims to increase stream flow and water availability in the watershed that drains into Palo Pinto Reservoir. This reservoir and several smaller reservoirs in the watershed, Lake Hagaman, Lake Thurber, Lake Tucker, Lake C.B. Long, James Lake and Lake Mingus, are used as a water supply for industrial, agricultural, and municipal uses. This report will assess the feasibility of brush management to meet the project goals by developing a historical profile of the vegetation in the watershed, developing a hydrological profile of the watershed, and evaluating historical climatic data in the watershed.

3.0 Watershed Description

The boundary of United States Geological Survey (USGS) hydrologic unit 12060201 was used to define the Palo Pinto Reservoir watershed for this study. The study area includes 471 square miles of North-Central Texas, within Palo Pinto, Stephens, Eastland and Erath Counties. Major tributaries to the reservoir include: Palo Pinto Creek, Lake Creek, Barton Creek, North Fork Palo Pinto Creek and South Fork Palo Pinto Creek (Figure 3.1).

Topography and Drainage

The Palo Pinto Reservoir is located within the Osage Plains section of the Central Lowlands physiographic province. Topographic elevations range from about 800 to 1,450 feet above sea level for a total relief of 650 feet. The land surface is in general gently rolling to semi-level. Prominent northeast sloping escarpments are formed by Permian limestones.

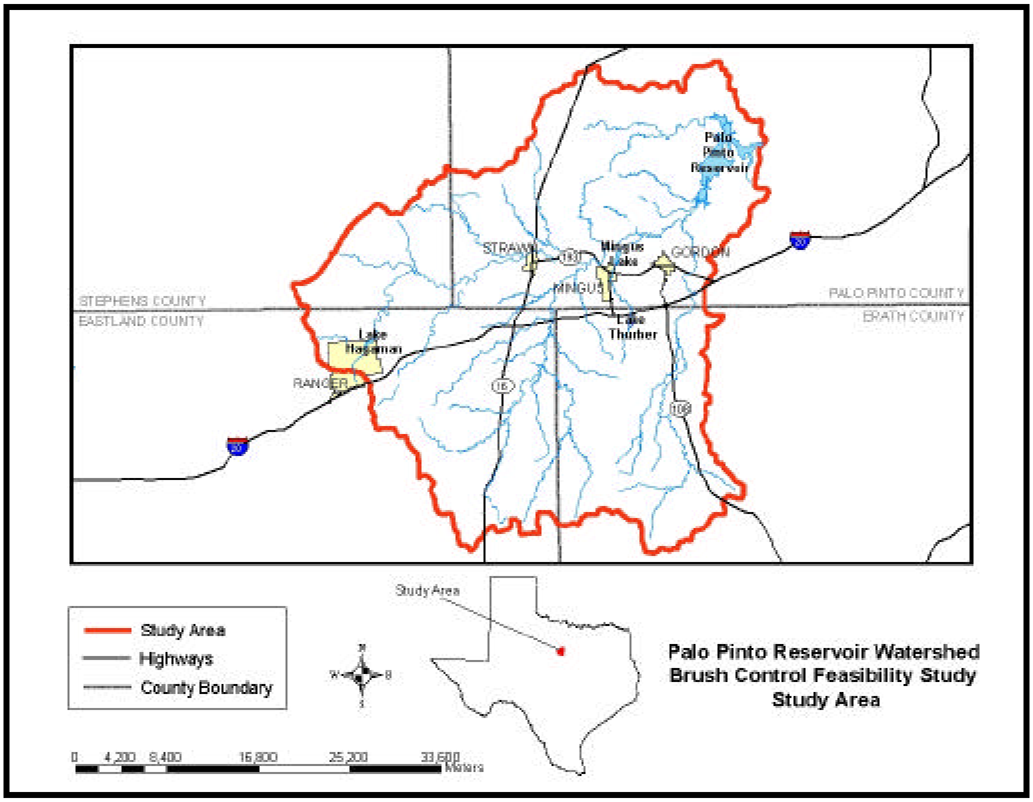


Figure 3.1 Palo Pinto Reservoir Watershed

The watershed is located entirely within the Brazos River drainage system. The Palo Pinto Reservoir discharges to the Brazos River through Palo Pinto Creek in Palo Pinto Coutny.

In addition to Palo Pinto Reservoir there are several smaller reservoirs in the Palo Pinto Reservoir watershed. Palo Pinto Reservoir is the largest of these and from where the Cities of Mingus, Strawn, and Gordon receive much of their water supply. The reservoir is in the southwestern portion of Palo Pinto County and impounds approximately 34,250 acre-feet of water on Palo Pinto Creek. Mingus Lake and Thurber Lake are formed by a dams on Gibson Creek, Hagaman Lake is formed by a dam on the North Fork of Palo Pinto Creek, Lake C. B. Long is formed by a dam on Panther Creek, and James Lake is formed by a dam on an unnamed creek.

A portion of Trinity Aquifer extends into the watershed. The Trinity Aquifer is classified as major aquifers by the Texas Water Development Board and supplies large amounts of water to large areas of the State (Figure 3.2).

The Trinity Aquifer is widespread and furnishes small to moderate amounts of groundwater to entities in 17 counties. In the artesian portions of the aquifer development has resulted in significant declines in the water table.

Geology

The surface of the watershed is comprised of geological formations of primarily Permian rock with some interspersed Quaternary rock (Bureau of Economic Geology 1972). The gently northeast trending belts of Permian rock are exposed in narrow, successively younger belts from west to east across the watershed. Unconsolidated sands and gravels of the Quaternary System are found as alluvium and terrace deposits along and between the tributaries of the watershed.

Climate

The climate of the watershed is a Modified Marine climate which is classified as subtropical sub humid. The marine climate is caused by the predominant onshore flow of tropical maritime air from the Gulf of Mexico. The onshore flow is modified by a decrease in moisture and by intermittent seasonal intrusions of continental air. The climate of the watershed is characterized by hot summers and dry winters.

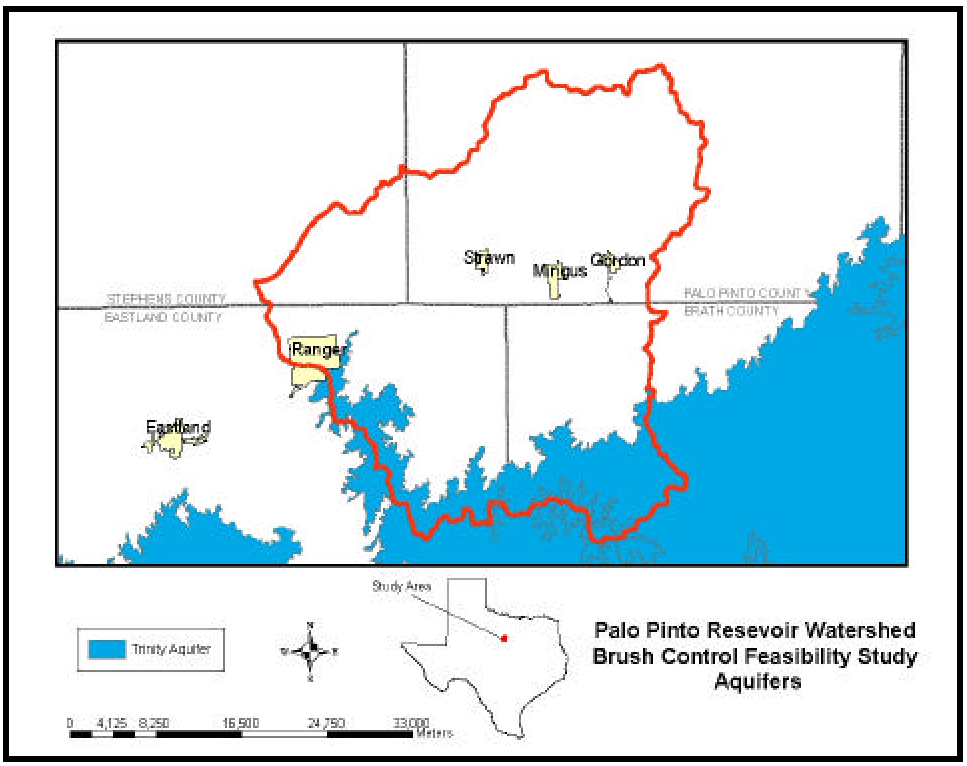


Figure 3.2 Aquifers in the Palo Pinto Reservoir Watershed.

The rainfall pattern in the watershed is typical of the Rolling Plains Natural Region (Figure 3.3). The amount of rainfall in the watershed varies considerably from year to year, but the average annual rainfall is approximately 29.5 inches (Table 3.1). In exceptionally wet years, much of the rain comes within short periods and causes excessive runoff. The rainfall distribution in the watershed has two peaks. Spring is typically the wettest season, with a peak occurring in May. These spring rains are caused by convective thunderstorms, which produce high intensity, short-duration storm events. The second peak which is generated by the tropical cyclone season is usually in October. Snow in the watershed is infrequent. When snow storms occur they are frequently of little to no consequence, with little moisture gained by the watershed from snowfall. The watershed also exhibits high evaporative rates in the summer months due to high temperatures, high light intensities, low humidity, and high wind speeds.

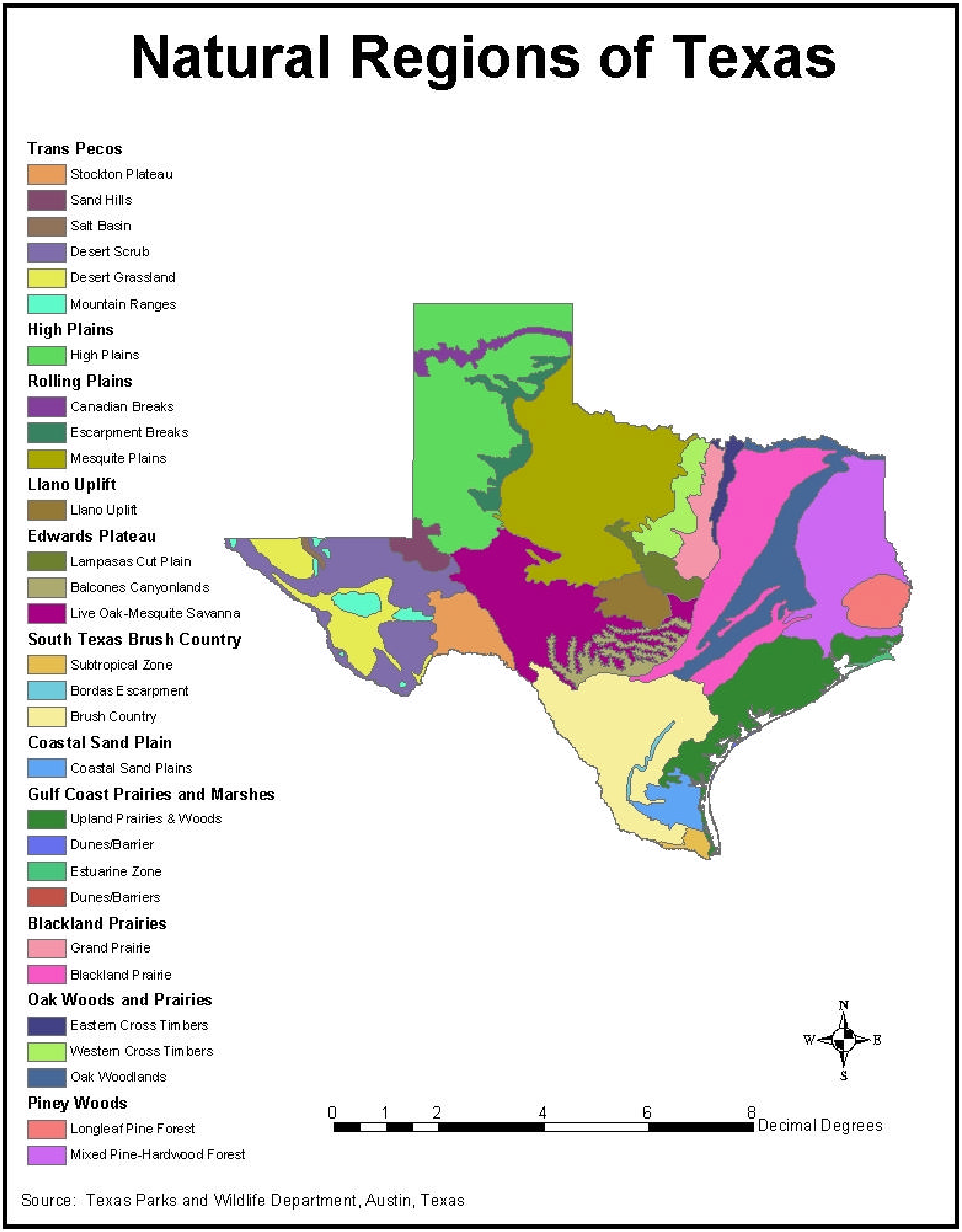


Figure 3.3 Natural Regions of Texas

Table 3.1. Monthly Temperatures, Precipitation, and Evaporation of the Palo Pinto Reservoir Watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature Data (1950-2001)													
Mean Minimum Temperature (°F)	32.9	36.9	43.6	53.3	61.5	69.3	72.8	71.7	65.6	54.4	42.9	35.4	53.4
Mean Maximum Temperature (°F)	56.6	61.9	69.2	78.1	84.6	92.7	97.1	96.5	89.4	79.7	67.0	59.7	77.7
Mean Temperature (°F)	44.8	49.5	56.4	65.7	73.1	81.1	85.0	84.2	77.5	67.1	55.0	47.6	65.6
Precipitation Data (1950-2001)													
Minimum Total Precipitation (inches)	0.00	0.00	0.11	0.35	0.79	0.15	0.00	0.00	0.00	0.05	0.00	0.00	17.60
Maximum Total Precipitation (inches)	7.61	8.34	6.66	10.54	14.09	6.91	10.81	7.2	10.57	10.34	5.40	6.23	48.27
MeanTotal Precipitation (inches)	1.50	1.74	2.19	3.10	4.28	2.62	2.72	1.98	2.91	3.17	1.84	1.48	29.53
Evaporation (1954-2000)													
Minimum Total Evaporation (inches)	1.24	1.25	2.47	2.94	3.06	4.79	5.01	5.50	4.10	3.52	2.24	1.54	46.93
Maximum Total Evaporation (inches)	3.94	4.69	6.39	7.21	7.49	8.95	11.54	10.52	8.66	7.00	4.52	4.14	73.59
Mean Total Evaporation (inches)	2.28	2.67	4.33	5.22	5.26	7.08	8.41	7.70	5.93	4.87	3.32	2.45	59.65

Source: Temperature and Precipitation—National Climatic Data Center, Ashville, North Carolina; Evaporation—Texas Water Development Board, Austin, Texas

The wide range between maximum and minimum temperatures in the watershed is characteristic of the Rolling Plains. Temperature changes are rapid, especially in winter and early spring when cold, dry polar air replaces the warm, moist tropical air. Periods of very cold weather are short and occur mostly in January; fair, mild weather is frequent. High daytime temperatures prevail for a long period in the summer when the maximum temperature reaches or exceeds 90° F daily. July is the hottest month with an average daily maximum temperature of 97° F. The high temperatures of summer are associated with fair skies, westerly winds and low humidity.

In late spring and early summer severe winds and hailstorms can accompany thunderstorms. Tornados can accompany the thunderstorms in the watershed but they are infrequent.

Population

Table 3.2 presents population data for Palo Pinto, Stephens, Erath and Eastland Counties from 1880 to 1990 and population projections from 2000 to 2050. The populations of the counties are not expected to increase significantly between 2000 to 2050. A 0.80% increase is projected for Erath County, a 0.53% increase is projected for Palo Pinto County, a 0.32% increase is projected for Stephens County and a –0.36% decrease is projected for Eastland County.

Table 3.2 Population Trends for Palo Pinto, Stephens, Erath and Eastland Counties.

Year	Palo Pinto	Stephens	Erath	Eastland	Total
1880	5,882	4,725	11,796	4,855	27,260
1890	8,320	4,926	20,998	11,413	45,657
1900	12,291	6,466	30,000	17,971	66,728
1910	19,506	7,701	32,095	23,421	82,723
1920	23,431	15,403	28,385	58,508	125,727
1930	17,576	13,879	20,804	34,156	86,415
1940	18,356	12,356	19,619	29,049	79,380
1950	17,154	10,597	18,434	23,942	70,127
1960	20,516	8,885	16,236	19,526	65,163
1970	28,962	8,414	18,141	18,092	73,609
1980	24,062	9,926	23,500	18,290	75,778
1990	25,055	9,010	27,991	18,488	80,544
2000	26,661	9,240	32,828	17,940	86,669
2010	28,449	9,840	38,290	17,546	94,125
2020	30,123	10,184	42,059	17,256	99,624
2030	31,886	10,441	45,065	16,557	103,949
2040	33,052	10,670	47,362	15,792	106,876
2050	34,741	10,854	48,872	14,952	109,419

Sources: 1880-1980 (Leffler 2002, Leffler 2002, Young 2001, Leffler 2002)

1990-2050 (Brazos G Regional Water Planning Group)

Land Use

The land use in the watershed is dominated by agribusiness including rangeland and row-crop agriculture (Figure 3.4). Rangeland is used mainly for livestock: cattle, goats, and sheep and accounts for 90% of the watersheds agricultural yield. Crop production is largely dominated by pecans, peaches, vegetables, grains and hay.

Urban land use is limited to the towns of Ranger, Gordon, Mingus and Strawn.

Wildlife

The ecology of the watershed reflects a history negative disturbances including improper grazing procedures, soil erosion, lowered water tables in some areas, declining native grasslands, and altered river ecosystems. The historic tall and mid-grass prairies have become a mesquite-short grass savanna.

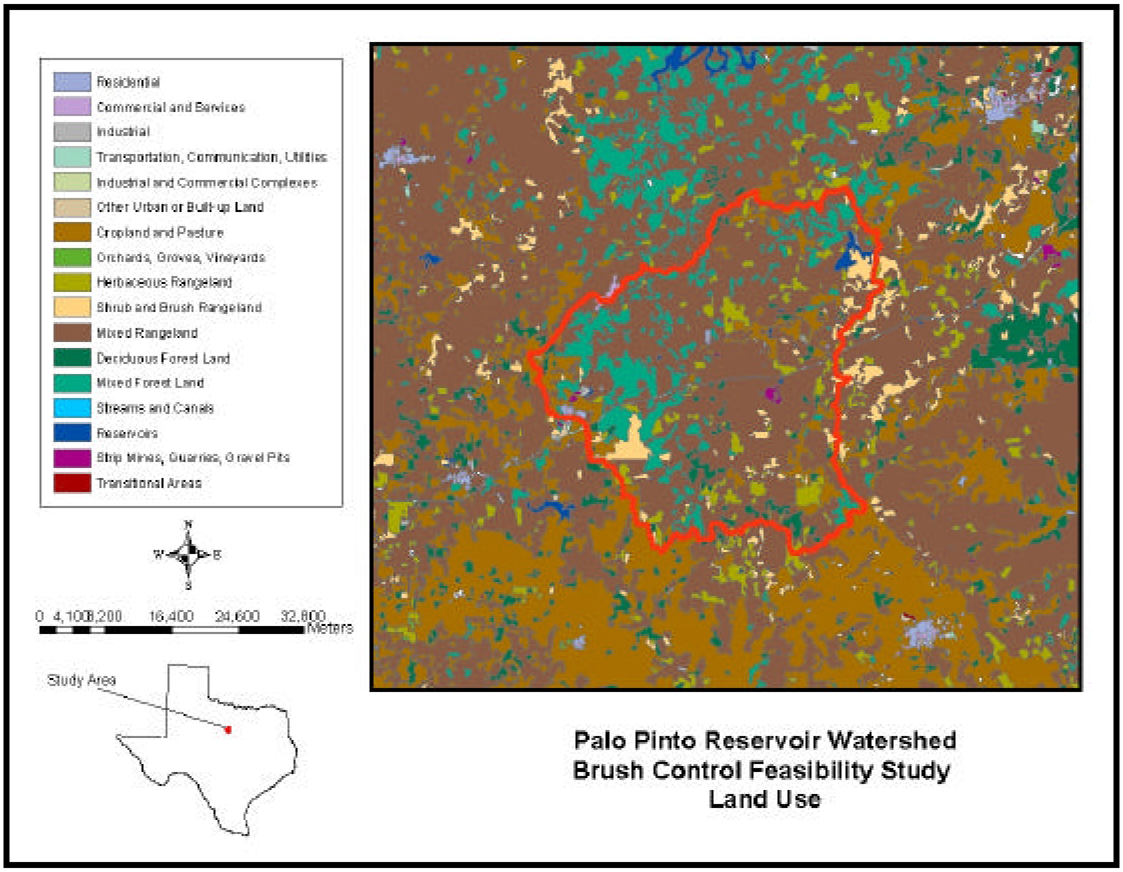


Figure 3.4 Palo Pinto Reservoir watershed land use.

The upper Brazos River basin has fish fauna that include endemic species. All rivers and streams in the Palo Pinto Reservoir watershed are typical prairie stream ecosystems characterized by extreme fluctuations in water level. The native fish fauna in the watershed are adapted to the variable flow regimes and extremes.

The reservoirs of the watershed support fish species not typical of streams, including: common carp, gizzard shad, warmouth, bluegill sunfish, longear sunfish, largemouth bass, white bass, white crappie, flathead catfish, striped bass and walleye.

The watershed, in addition to the remainder of the Rolling Plains, is important to migratory and winter waterfowl. Ducks and coots are distributed widely throughout the watershed wherever there are ponds or natural wetlands. The Texas Parks and Wildlife Department reports that the most abundant ducks are mallard, gadwall, and American wigeon (Moulton 1998). Large numbers of sandhill cranes winter in and migrate through the watershed utilizing the same wetland habitats as waterfowl. Many species of migrating shorebirds, raptors, Neotropical songbirds and other birds stopover in the watershed to feed and rest. The trees and shrubs that grow along the rivers and streams are of special importance to migrating songbirds and raptors.

At least 34 species of amphibians, reptiles and mammals are known to inhabit the watershed. Many of these species are aquatic or semi-aquatic. All toads require aquatic habitats to reproduce. A number of snakes known in the watershed are restricted to riparian habitats including: the copperhead, the western ribbon snake and the eastern coral snake.

The Golden-cheeked Warbler (*Dendroica chrysoparia*) is currently on the Federal list of endangered or threatened species and its known range includes the Palo Pinto Reservoir watershed. The most significant threat to the existence of the warbler is the loss of habitat and fragmentation due to clearing of oak-juniper woodlands, and brood parasitism by brown-headed cowbirds (*Molothrus ater*). The golden-cheeked warbler breeds exclusively in Texas, is present from early March to late August and winters from southern Mexico to Nicaragua.

Golden-cheeked Warbler

Woodlands with mature Ashe juniper in a natural mix with oaks, elms and other hardwoods, in relatively moist areas such as steep canyons and slopes are considered habitat types that are highly likely to be used by warblers. These areas generally will have a nearly continuous cover with 50 to 100 percent canopy cover. The United States Fish and Wildlife Service (USFWS) assumes the presence of the warbler in the above described areas and indicates that the habitat should be retained wherever they occur, especially along creeks and draws and on steep slopes and generally rough terrain. Additionally, the USFWS indicates that the following habitats should be treated as occupied habitat until technical assistance is obtained to determine whether or not specific areas support warblers:

- Stands of mature Ashe juniper, over 10 feet in height, with scattered live oaks (at least 10% total canopy cover), where the total canopy cover exceeds 35 percent.
- Bottomlands along creeks and drainages which support at least 35 percent canopy of deciduous trees, with mature Ashe juniper growing either in the bottom or nearby slopes.
- Mixed stands of post oak and/or blackjack oaks with scattered mature Ashe juniper (10-30% canopy cover), where total canopy covet of trees exceeds 35 percent.
- Mixed stands of shinoak with scattered mature Ashe juniper (10-30% canopy cover), where the total canopy cover of the trees exceeds 35 percent.

Best management practices for retention of habitat for the warbler include maintenance of tree canopy when planning improvements or maintenance to land in Golden-cheeked warbler habitat.

The Black-capped Vireo (*Vireo atricapillus*) is currently on the Federal list of endangered or threatened species and its known range includes the Palo Pinto Reservoir watershed. The most significant threat to the existence of the vireo is the loss of habitat and fragmentation due to clearing of oak-juniper woodlands, and brood parasitism by brown-headed cowbirds. The vireo breeds from central Oklahoma south through the Edward's Plateau in Texas to Coahuila, Mexico, is present from early March to late August and winters in southern Mexico.

Black-capped Vireo

Vegetation

In many areas of the State, historical records show that higher levels of spring flow and stream base flow occurred in the past. Brush encroachment may be an important factor in declining flows. This phenomenon is apparent in the Palo Pinto Reservoir watershed. The watershed sustained minimal brush and tree cover before European settlers came to the watershed. While springs occurred and are documented in historical accounts, there is little quantitative information, historical or current, about them.

Historical accounts provide a general picture of the vegetation of the Western Cross Timbers and the area of Palo Pinto Reservoir watershed as an area of mixed prairie dominated by grasses one to three feet tall with strips of woodland dissecting the prairie.

The paleoenvironment of the area sees a transition from woodlands during a mesic period existing from 7,000 to 3,000 BC to grasslands and oak savannahs during a period of gradual warming and drying from 3,000 to 500 BC (Skinner 1998). The region has been continuously inhabited by Native Americans since approximately 7,000 BC (Skinner 2001). Numerous prehistoric sites have been identified along river and creek valleys and on the bluffs overlooking the valleys in the region. These Native Americans utilized the megafaunal populations for subsistence.

The termination of the Paleoindian period coincided with a trend towards increasingly arid conditions and the collapse of the megafaunal populations. Following the Paleoindian period, the Archaic period emerged with people maintaining a mobile lifestyle to exploit seasonal and spatial resources, which had adapted to a prairie oriented behavioral patterns. People during the Archaic period subsisted on hunting and gathering. These grasslands were populated by grasses, such as bluestem, grama, wildrye, wheatgrass, switchgrass, and Indian grass.

European explorers began arriving in the area during the 16th century beginning with Coronado in 1540. The exploration of the area continued by the Europeans through the 18th century. This era of exploration resulted in the introduction of the horse to the region and the development of an indigenous horse culture. In the 18th century the Comanche Indians acquired horses and became the dominant occupant of the area, which is now the Fort Phantom Hill Reservoir watershed.

In the 19th century European settlers began to arrive in the area which is now the Palo Pinto Reservoir watershed. William A. A. (Bigfoot) Wallace arrived in 1837 to survey the area that is now Palo Pinto County (Leffler 2001). The earliest European settlers came to the region in 1850 and established cattle ranches in the region. Early accounts of the region note the presence of oak, mesquite, red cedar, and Bois d' Arc trees in the bottomlands (McMinn 1986). Uplands were reported to be prairies with an absence of trees. The absence of trees was attributed to burning by the Indians. According to Chief Jose Maria of the Anadarkos, the Indians burned the prairies every three years to keep young tree growth to a minimum (McMinn 1986).

By 1860 ranching, cattle and sheep, and farming were the dominant activity in the watershed; however, frequent Indian raids made survival difficult. With removal of the Indian threat in the 1870s, agricultural development in the watershed continued almost uninterrupted into the 1910s. Between 1880 and 1900 thousands of acres were cultivated for cotton, corn, and wheat and thousands of acres were used for grazing of livestock; the native prairie grasses were entirely consumed and their roots trampled by improper grazing practices or removed and replaced by cultivated crops. As the prairie was developed for agriculture, a pattern of fire suppression developed on the range. This fire suppression reduced the ability of the grass to compete and unpalatable brush such as mesquite and juniper began to invade the range.

Diversity, size, and natural productivity of most of the native mixed grass prairie in the region had been drastically reduced by the processes of agriculture by 1900. As the grass was removed through improper grazing practices and increased cultivation, mesquite, juniper, and prickly pear spread from the bottomlands to the uplands. Records of the vegetation document post oak and blackjack oak on the uplands; cedar and live oak moving up the hills; pecan, walnut, elm, hackberry, cottonwood and willow along the streams; and mesquite in the glades (Langston 1904). A 1950 description of the region notes that cedar is a recent inhabitant to the area but is rapidly increasing its coverage and has grown dominant on the rough limestone formations (Cox 1950).

Today much of the land in the watershed is used for rangeland, the dominant vegetation assemblage is Oak-Mesquite-Juniper Parks/Woods (Figure 3.5). The other vegetation assemblages present in the watershed are the Live Oak-Ashe Juniper Parks assemblage, the Live Oak-Mesquite-Ashe Juniper Parks assemblage, Crops, and the Ashe Juniper Parks/Woods assemblage. These assemblages are disturbance types resulting from improper grazing techniques, soil erosion, lowered groundwater tables, and the decline of native grasses.

The Oak-Mesquite-Juniper Parks/Woods assemblage occurs extensively throughout the watershed. Species associated with this assemblage include: Post oak, Ashe juniper, shin oak, Texas oak, blackjack oak, live oak, cedar elm, agarito, soapberry, sumac, hackberry, Texas pricklypear, Mexican persimmon, purple three-awn, hairy grama, Texas grama, sideoats gramma, curly mesquite, and Texas wintergrass are commonly associated with this assemblage. This assemblage occurs as associations or as a mixture of individual species on uplands.

The Live Oak-Ashe Juniper Parks assemblage is scattered throughout the central portion of the watershed while the Live Oak-Mesquite-Ashe Juniper Parks assemblage occurs in the northern portion of the watershed. Plants commonly associated with the assemblages include: Texas oak, shin oak, cedar elm, flameleaf

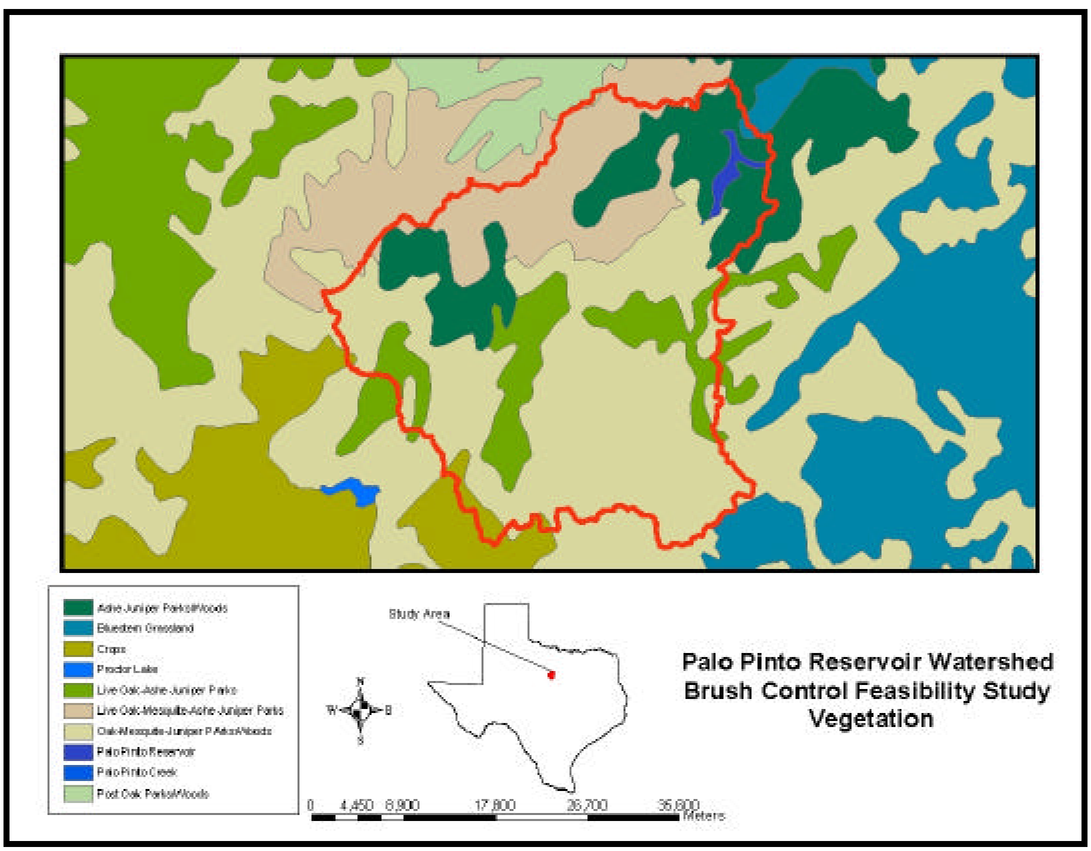


Figure 3.5 Palo Pinto Reservoir Watershed Vegetation

sumac, netleaf hackberry, Texas pricklypear, agarito, Mexican persimmon, kidneywood, saw greenbriar, Texas wintergrass, little bluestem, curly mesquite, Texas grama, Halls panicum, purple three-awn, hairy tridens, cedar sedge, two-leaved senna, mat euporbia and rabbit tobacco. These assemblages are chiefly located on level to gently rolling uplands and ridge tops.

The Ashe Juniper Parks/Woods assemblage occurs in the northern half of the watershed principally on the slopes of hills in Stephens and Palo Pinto counties. Commonly associated plants include: Live oak, Texas oak, cedar elm, mesquite, agarito, tasajillo, western ragweed, scurfpea, little bluestem, sideoats grama, Texas wintergrass, silver bluestem, hairy tridens, tumblegrass, and red three-awn.

4.0 Hydrology

Water yield in a watershed can be calculated using the following equation:

Runoff + Deep Drainage = Precipitation—Evapotranspiration.

Where:

Evapotranspiration is the sum of water loss to the atmosphere by transpiration and evaporation. Transpiration is the loss of water vapor from the inside of a leaf to the atmosphere. Evaporation is the physical process by which water changes from a liquid to a gas. Evaporation in nature requires heat drawn from the immediate environment as an energy source.

Precipitation is the physical process by which water changes from a gas in the atmosphere and falls to Earth as a liquid.

Runoff is the overland flow of water, usually from precipitation, to streams and reservoirs.

Deep Drainage is water that infiltrates the ground and moves through pore spaces of rocks and soil.

This equation implies that water yield can be increased if evapotranspiration can be decreased (Thurow 1998). One method of decreasing evapotranspiration is through reducing transpiration rates by vegetation management. An analysis of climate, evapotranspiration, and runoff in the western United States indicated that sites with tree and shrub communities need to receive over 18 inches of precipitation per year and need to have an evapotranspiration rate of 15 inches per year to yield significantly more water if converted to grassland (Hibbert 1983). All ecoregions in Texas have a potential evapotranspiration rate of over 15 inches per year, suggesting that a reasonable criteria for deciding where brush control is likely to increase water yield, is to concentrate on areas, which receive at least 18 inches of rain per year. The Palo Pinto Reservoir watershed is in the region that the TSSWCB (2002) has defined as generally suitable for brush control projects, based on rainfall and brush infestation.

There are no current or historical United States Geological Survey flow-monitoring stations within the Palo Pinto Reservoir watershed. Most historical accounts of stream flow in the watershed are qualitative, a pattern of alternating normal to severe drought conditions is apparent. While perennial streams have been documented in historical accounts of the region, there is no quantitative data documenting the current status of these springs (Eastland 1989). Little groundwater is present in the Palo Pinto Reservoir watershed except for in the southeastern portion of the watershed.

In response to the declining water supply the Palo Pinto Municipal Water District began construction of Palo Pinto Reservoir in 1963. Palo Pinto Reservoir impounds 34,250 acre-feet of water annually for municipal and industrial use, has a conservation storage capacity of 42,200 acre-feet and a surface area of 2,661 acres at the spillway crest elevation of 876 feet.

Surface Water

There is no reservoir water level data recorded for Palo Pinto Reservoir. Additionally, there is a lack of flow data for the tributaries to the Palo Pinto Reservoir with no active or historical USGS Gauging Station in the watershed. The USGS operated a streamflow gauging station near the City of Santo on Palo Pinto Creek (08090500) between May 1951 and September 1976. The drainage area above the gauge is 573 square miles. However, streamflows at this gauge have been largely controlled by Palo Pinto Reservoir since its completion in 1964.

In 2001, the Palo Pinto County Municipal Water District No. 1 contracted HDR Engineering, Inc. to complete a yield study for Palo Pinto Reservoir and the proposed Turkey Peak Reservoir. Because historical monthly release records or inflow records had not been maintained for Palo Pinto Reservoir, HDR reconstructed streamflows into Palo Pinto Reservoir. To reconstruct inflows into Palo Pinto Reservoir, HDR utilized data from the USGS gauge at Santo, hydrological data from the nearby Paluxy River, and historical permitted diversions from between Palo Pinto Reservoir dam and the USGS gauge at Santo. This reconstructed data reveals no significant change in stream flow over time since the completion of Palo Pinto Reservoir dam (Figure 4.1).

Predictable trends exist between water levels and climatic parameters such as temperature and precipitation in the Palo Pinto Reservoir watershed from 1950 to 2001, including significant relationships between reservoir inflow and precipitation and evaporation and temperature (Figures 4.2 and 4.3).

Due to the watershed's strong correlation between reservoir inflow and precipitation indicates that there is little groundwater discharge

Figure 4.1
Palo Pinto Reservoir Inflow

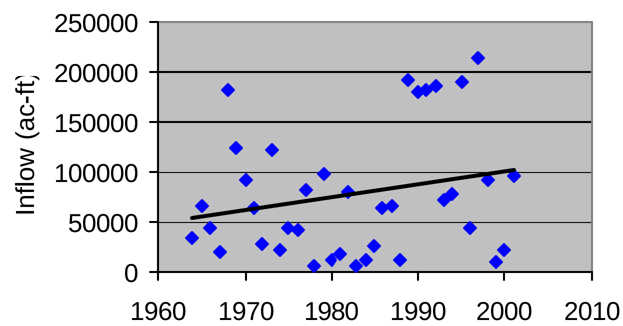


Figure 4.2
Palo Pinto Reservoir Inflow vs. Precipitation

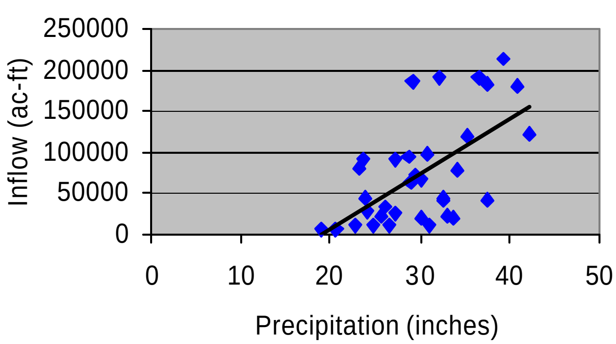
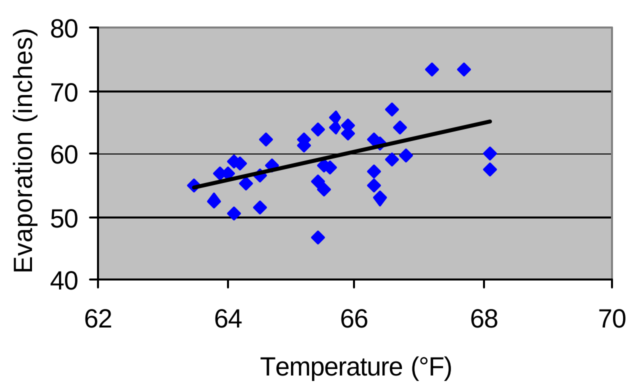


Figure 4.3
Palo Pinto Reservoir Evaporation vs. Temperature



into the watershed. Analysis of existing stream flow data does not provide a strong indication that brush infestation has significantly reduced basin yields; however, this conclusion is tenuous because of the lack of quantitative streamflow and reservoir level data.

Springs

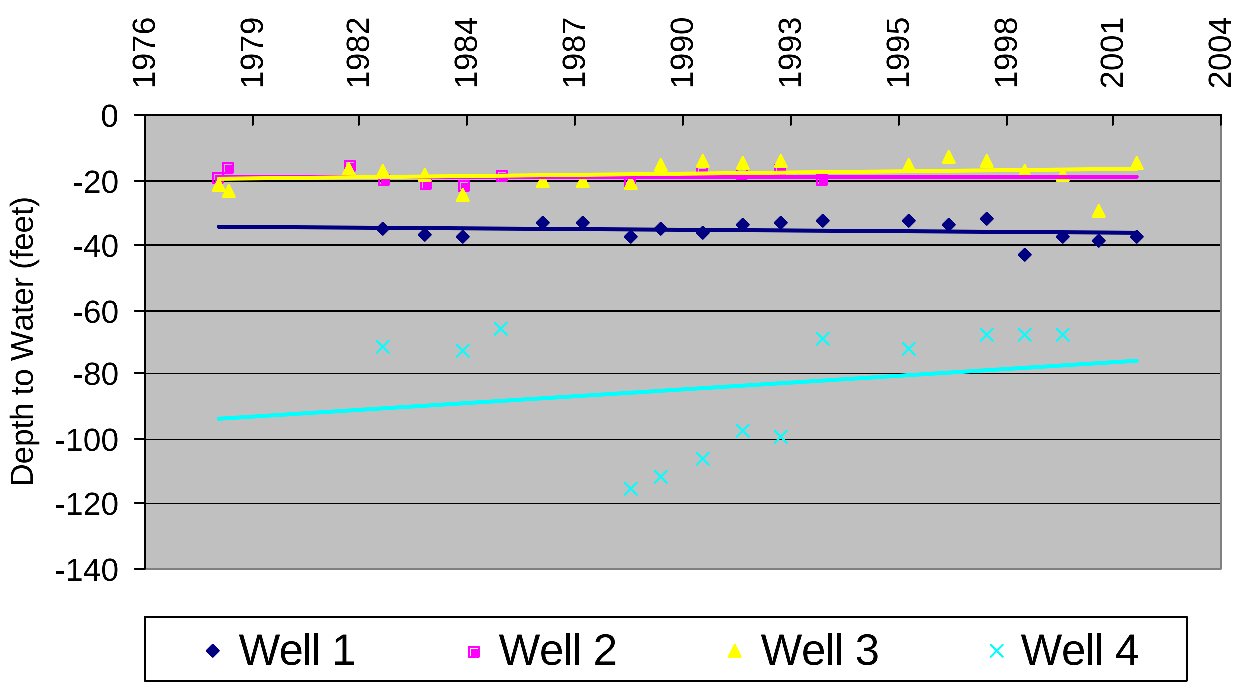
Early explorers of the watershed mentioned springs but no quantitative historical information on spring flow exists. Currently, no major springs are currently known to be discharging in the watershed. While data on springs in Palo Pinto, Erath, Eastland and Stephens Counties is limited, reports on springs from nearby Haskell County document that the drought of 1948 through 1957 resulted in the exhaustion of most of the springs in the county (Brune 1980).

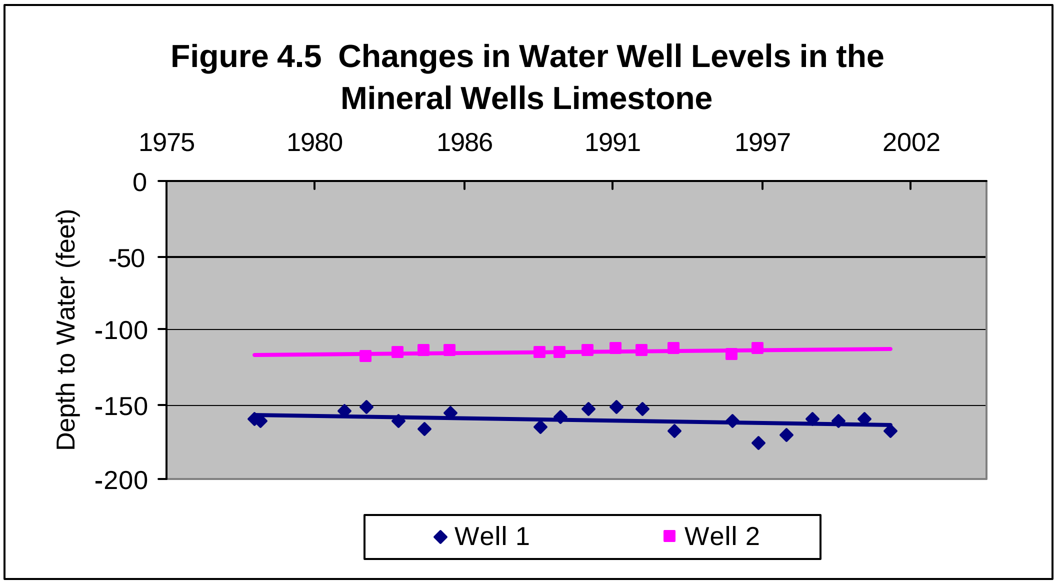
Groundwater Levels

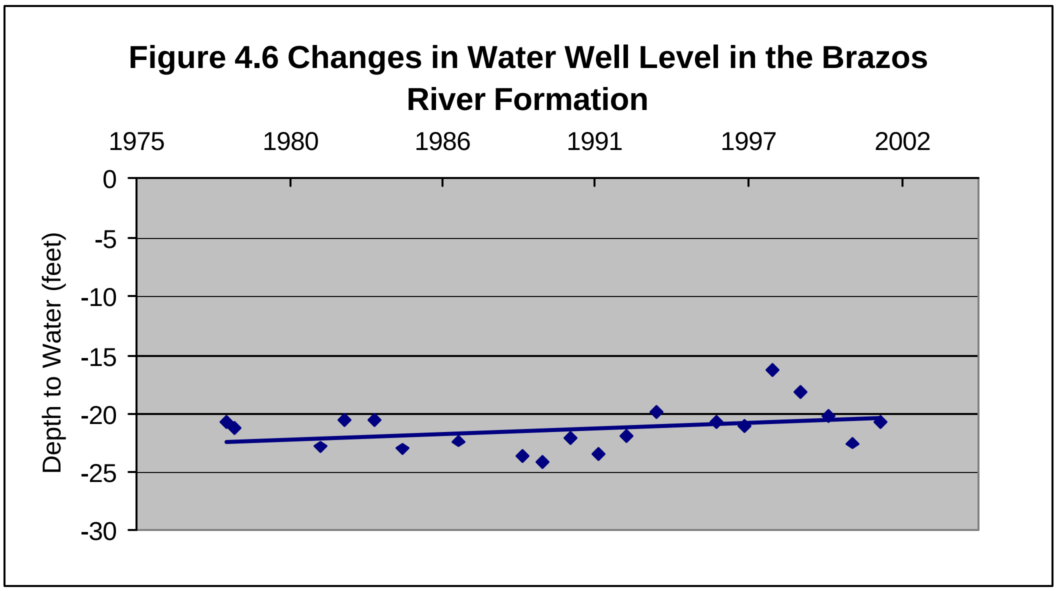
Groundwater does not contribute significantly to the available water supply in the watershed. Water well level data in Erath, Eastland, Stephens and Palo Pinto Counties were examined to identify any significant changes in water level over time. The TWDB maintains a database of water level records for hundreds of water wells in the counties. A total of 7 water wells having 20 or more years of data available were identified in the geologic formations which transect the watershed. These wells were examined to determine if net water level changes have occurred for the individual wells.

Four wells in the Palo Pinto Formation showed no significant change in water levels over time, while two wells in the Mineral Wells Limestone also revealed no significant changes in water levels over time (Figure 4.4 and 4.5). One well was identified in the Brazos River Formation, and it has experienced a significant increase in water level over time (Figure 4.6).

Figure 4.4 Changes in Water Well Levels in the Palo Pinto Formation







Geology

Underlying rocks representing six different Pennsylvanian geologic systems are present in the watershed. In the watershed, rocks of the Pennsylvanian Period are dominant and are composed primarily of limestone, sandstone, and shale. The Quarternary sediments contain mostly gravel, sand, and pebbles. (Barnes 1972).

Pennsylvanian sediments of the Winchell Limestone, Palo Pinto, Brazos River, Mineral Wells, Wolf Mountain Shales and Mingus Formations occur at the surface of the watershed. None of the above formations is known to contain significant quantities of potable water.

The Quaternary deposits of the watershed are composed of alluvium and fluvial terrace deposits. Alluvial deposits composed of fine sand, silt, clay, and gravel occur in and border many of the streambeds in the watershed. These alluvial deposits may possess a thickness of up to 25 feet. Fluvial terrace deposits are mostly undivided gravel, sand, and silt. Along streams gravel, sand and pebbles originate from quartz, igneous rock, and metamorphic rock from distant sources intermingled with local bedrock fragments. Sands in the alluvium is mostly fine to coarse-grained quartz and is reddish brown to gray. Silt is clayey, bedded to lenticular and commonly cross-bedded.

The Winchell Limestone Formation is formed of alternating layers of limestone and shale, varies in thickness across the formation from 25 to 75 feet and is located in the western portion of the watershed The uppermost layer of limestone is fine grained. This bed is thick in the southern portion of the watershed and thins as the bed trends northward, thicknesses range from 4 to 10 feet. The Lower Limestone possesses a thickness of 15 to 50 feet and is fine grained to coarsely bioclastic with calcareous shale between beds. This Lower Limestone is thin to medium bedded with marine megafossils.

The Wolf Mountain Shale formation is predominantly composed of shale containing small portions of limestone and sandstone in channel fill bodies. The formation is located on the western boundary of the watershed.

The Palo Pinto formation, which occurs in the central to western half of the watershed, is dominantly formed by limestone and marl with some sandstone and shale.

The Mineral Wells formation occurs in the central to western half of the watershed. The Mineral Wells formation is composed of shale, sandstone, conglomerate and limestone.

The Brazos River formation occurs around the Palo Pinto Reservoir and along the South Fork of Palo Pinto Creek. The formation is composed of sandstone and mudstone that is fine to medium grained, calcareous and thin bedded. The formation grades laterally into interbedded thin sandstone and shale beds.

The Mingus Formation occurs predominantly in the eastern half of the watershed and is composed of shale, sandstone and limestone.

The formations in the watershed are dominated by thin beds of alternating shale and limestone and do not contain a significant supply of groundwater for the population in the watershed.

Existing Surface Water Hydrology

The hydrologic characteristics of the Palo Pinto Reservoir watershed are closely linked to precipitation patterns in the river basin, especially the cycles of floods and droughts. Major flood and drought events are those recurrence intervals longer than 25 years and 10 years respectively. Reservoir inflow measurements have been calculated for the reservoir since 1950, and show that there has been a drought in almost every decade since then. Average monthly inflows into the reservoir range from approximately 17,457 ac-ft in May to about 2,416 in November and January. The watershed has varying topography with steep channels in the southern, western and eastern portions of the watershed and flat slopping channels in the north, which results in rapid runoff and flash floods during intense rain events. The average annual runoff into Palo Pinto Reservoir from 1950 through 2001 was 69,000 acre-feet.

The tributaries and reservoirs of the watershed are classified by the Texas Commission on Environmental Qulaity (TCEQ) as suitable for contact recreation, aquatic life, and public water supply. Overall, the quality of he water in the watershed is high and supports a diversity of aquatic life.

The primary water quality issue for the reservoir, excluding water quantity, is the increasing potential for water contamination from nonpoint source pollution from agricultural activities. Due to the watershed's high dependency on precipitation for surface water supply and a negligible groundwater supply, protecting the watershed from nonpoint source pollution is imperative.

Existing Groundwater Hydrology

The only major aquifer within the watershed is the Trinity Aquifer in the south. The Trinity Aquifer is in interbedded sandstone, sand, limestone, and shale of Cretaceous age and underlies an area of about 41,000 square-miles, which extends from southeastern Oklahoma to south-central Texas.

The Palo Pinto and Mineral Wells formations in the watershed are the aquifers from which the most water is withdrawn in the watershed. A total of 23 wells in the Palo Pinto Formation and a total of 20 wells in Mineral Wells formation, which produce or have produced, from this aquifer were identified in Palo Pinto County. These formations are found in the central and western portion of the watershed and located in flood plains of the western tributaries to Palo Pinto Reservoir.

While artesian springs were reported by the early settlers to the area, currently water wells are the only known means of groundwater discharge in the watershed. Small amounts of water are withdrawn from aquifers throughout the watershed for use by individuals for domestic, livestock, and irrigation use.

Description of the Hydrologic System

The hydrologic system of the Palo Pinto Reservoir watershed is greatly changed from that encountered by the first European settlers to the region. Four reservoirs have been constructed in the watershed and springs, which were abundant and provided a significant volume of water are now intermittent to non-existent and the yield is insignificant.

Precipitation enters the watersheds hydrologic system as runoff or infiltrates surface soil or bedrock and recharges the underlying aquifers. Additionally, some water may enter the system from groundwater flow from outside the watershed boundary; however, water may also be removed from the system in the same manner. With insignificant amounts of groundwater contained between impervious layers of shale and intermittent springs it is unlikely that a significant amount of surface water in the Palo Pinto Reservoir watershed is derived from groundwater. Nearly all of the initial flow in the tributaries to Palo Pinto Reservoir is derived from precipitation. With no significant change in precipitation patterns occurring since the European settlers began recording data, losses in baseflow and reservoir capacity are principally due to evaporation and withdrawals. Discharge from the watershed occurs as streamflow into the Brazos River basin, as artificial surface water and groundwater withdrawals, and as returns to the atmosphere through evapotranspiration. Additionally, water may flow from the streams and reservoirs into the alluvial deposits.

The watershed is part of the Brazos G Regional Water Planning Area, which encompasses all or part of 37 central Texas counties primarily within the Brazos River watershed. TWDB reports on the planning area state that Eastland, Erath, Stephens and Palo Pinto Counties now consume approximately 57,000 acre-feet of water each year, with 35 percent used for municipal uses, 5 percent used industrial uses, and 60 percent used for agricultural uses. Water demand in the four counties is not expected to increase significantly by 2050. Current groundwater and surface water supplies in the counties are sufficient to meet current needs. The water supply is projected to be adequate to meet demands in the future.

As the demand for water increases throughout the Brazos River basin, the Counties may experience water supply problems due to competition for water and infrastructure limitations. Currently the communities of Cisco in Eastland County and Stephenville in Erath County are water short due to limited surface water availability and conveyance capacity and Erath County is water short for agricultural supply. Erath County is projected to continue to experience a county wide shortage of water for agricultural uses through 2050. Palo Pinto County is projected to see shortages for manufacturing use by 2030. The City of Palo Pinto is projected to see shortages in supply by 2010 due to lack of surface water and lack of infrastructure. Eastland County is projected to see shortages for irrigation by 2030 and the Cities of Eastland and Ranger are projected to see shortages in municipal water supply by 2050. Stephens County is projected to see shortages for manufacturing and irrigation by 2030. Possible solutions to the water shortages in the four counties include:

- Wastewater reuse;
- Reservoir construction at Breckenridge;
- Diversion of water from Battle Creek Reservoir to Lake Cisco;
- Redistribution of water supply from communities with surplus to communities with shortages;
- Additional water conservation;
- Bring water to the area from Possum Kingdom Reservoir through the Kerr-McGee pipeline; and
- Brush control in the watershed.

5.0 SUMMARY AND CONCLUSIONS

This evaluation of the hydrology of the Palo Pinto Reservoir watershed has included a review and analysis of available data on climate, vegetation, geology, surface hydrology and groundwater hydrology. The following conclusions summarize the findings:

- No significant changes have occurred in the historical climate patterns within the watershed, including precipitation frequency, duration, and intensity.
- Changes in the historical vegetation of the watershed have been dramatic. Based on first-hand accounts of the vegetation during the 19th century, the area was predominantly mixed grass prairie, with little to no stands of juniper or mesquite. There is a great indication that brush cover in the watershed is significantly more extensive today than it was historically.
- Good quality data on stream flow in the watershed has not been collected.
- The available, calculated reservoir inflow data reveal no major changes have occurred in inflow volumes during the period of record; however, the current intermittent nature of springs in the watershed is in direct opposition to the first-hand accounts of water availability during the 19th century.
- Water levels in aquifers in the watershed have historically risen and fallen in response to rainfall patterns and artificial withdrawals. No systematic declines in aquifer water levels are indicated.
- Water supply shortages are a current problem for the some of the communities in the area and these shortages are projected to increase as demand increases. Brush management could help offset supply deficits in the watershed by reducing water losses in the streams.
- Hydrological studies reveal that brush control in the Palo Pinto Reservoir watershed is estimated to increase annual average water yields by 178,000 gallons per treated acre. The cost of control is moderate at $24.09 per acre-foot generated. With some of the communities in the watershed currently experiencing water shortages and with shortages projected to increase, an organized brush control program could prove greatly beneficial to the watershed.
- It is recommended that the Texas Legislature commit to appropriate $14,332,239 to implement brush control practices in the Palo Pinto Reservoir watershed. Implementation should begin within the next five to ten years, with maintenance occurring throughout the ten-year period following implementation.

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APPENDIX A

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).

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

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

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

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

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

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

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

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

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

Table 1-2. Watershed area, number of subbasins, and average annual precipitation.

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

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

Model Inputs

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

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

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

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

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

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

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

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

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

Model Calibration

The calibration period was based on the available period of record for stream gauge flow and reservoir volumes within each watershed. Measured stream flow was obtained from

USGS. Measured monthly reservoir storage and reservoir withdrawals were obtained from USGS, Texas Water Development Board (TWDB), river authorities, water districts, reservoir managers, and other water users. A base flow filter (Arnold et al., 1995a) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

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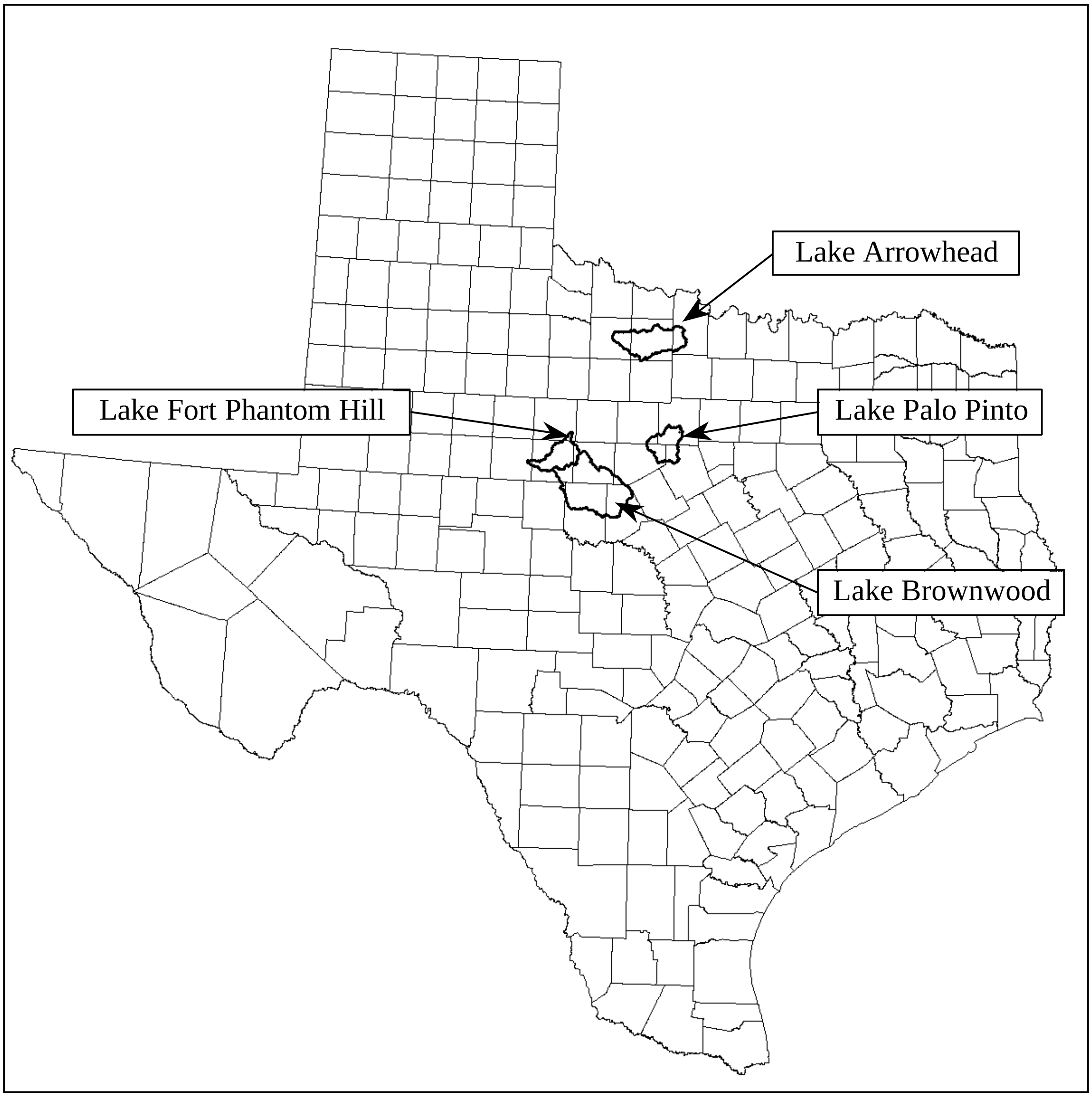

Figure 1-1. Watersheds included in the study area.

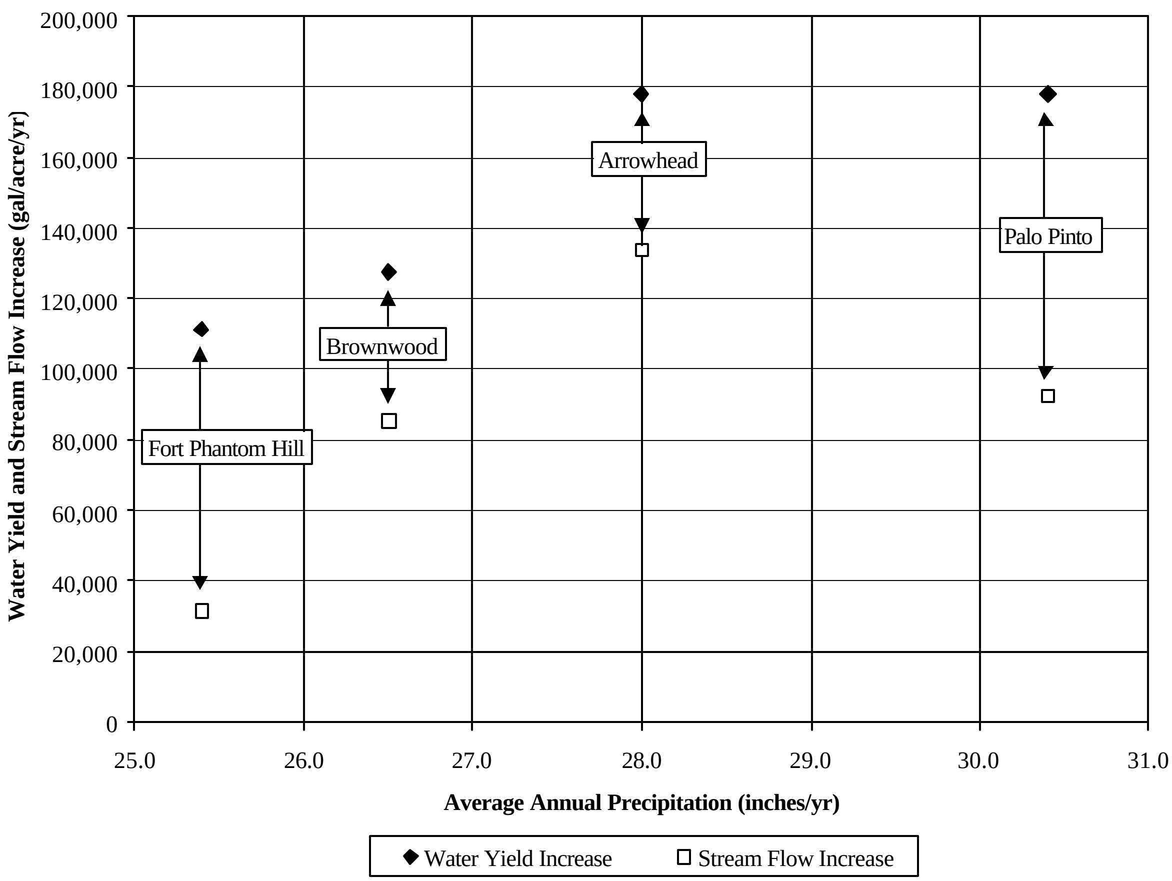

Figure 1-2. Average annual water yield and stream flow increases per treated acre versus average annual precipitation for watersheds in this study, 1960 through 1999.

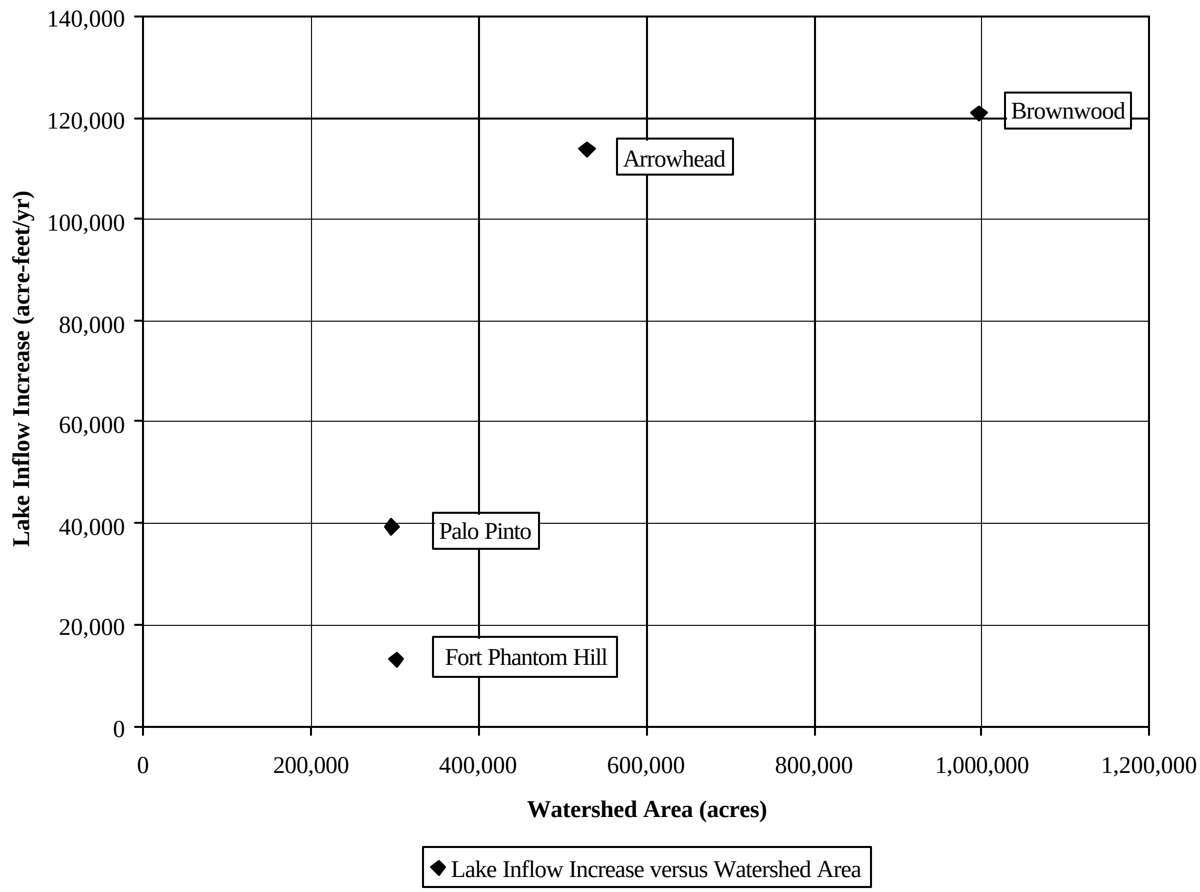

Figure 1-3. Average annual lake inflow increase resulting from brush removal versus watershed drainage area for watersheds in this study, 1960 through 1999.

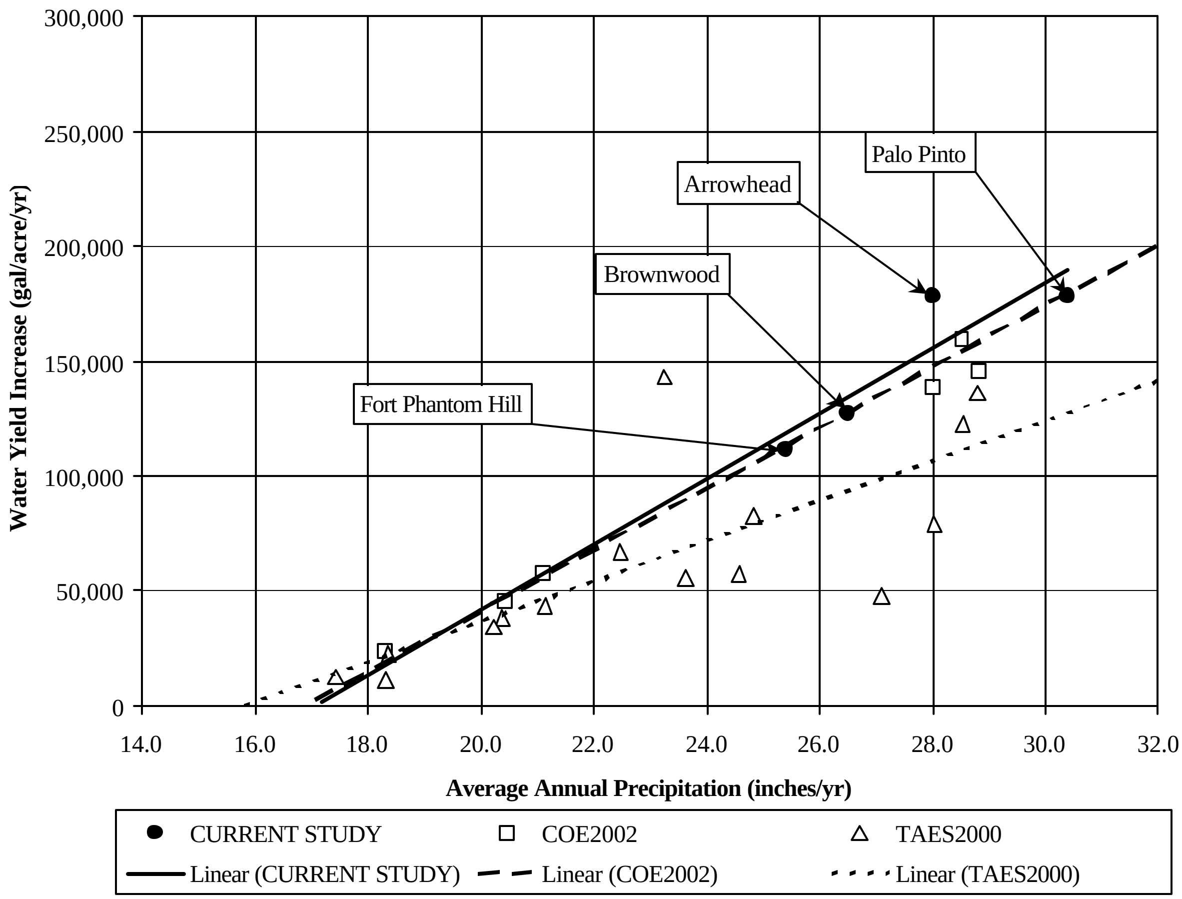

Figure 1-4. Water yield increase versus average annual precipitation - current study, COE (2002), and TAES (2000). Points are labeled for watersheds in current study.

APPENDIX B

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 sometime 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 20^{th} 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.

<u>Soils</u>

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.

Set (5.22%): 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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Table 9-1. SWAT input variables used in modeling the hydrology of the 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. Water yield changes in the Lake Palo Pinto watershed from brush control.

SUBBASIN DATA - PALO PINTO WATERSHED					
Subbasin	**Total Area**	**Brush Area**	**Brush Fraction**	**Increase in**	**Increase in**
		(Treated)	**(Treated)**	**Water Yield**	**Water Yield**
	(acres)	**(acres)**		**(gal/acre/year)**	**(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***

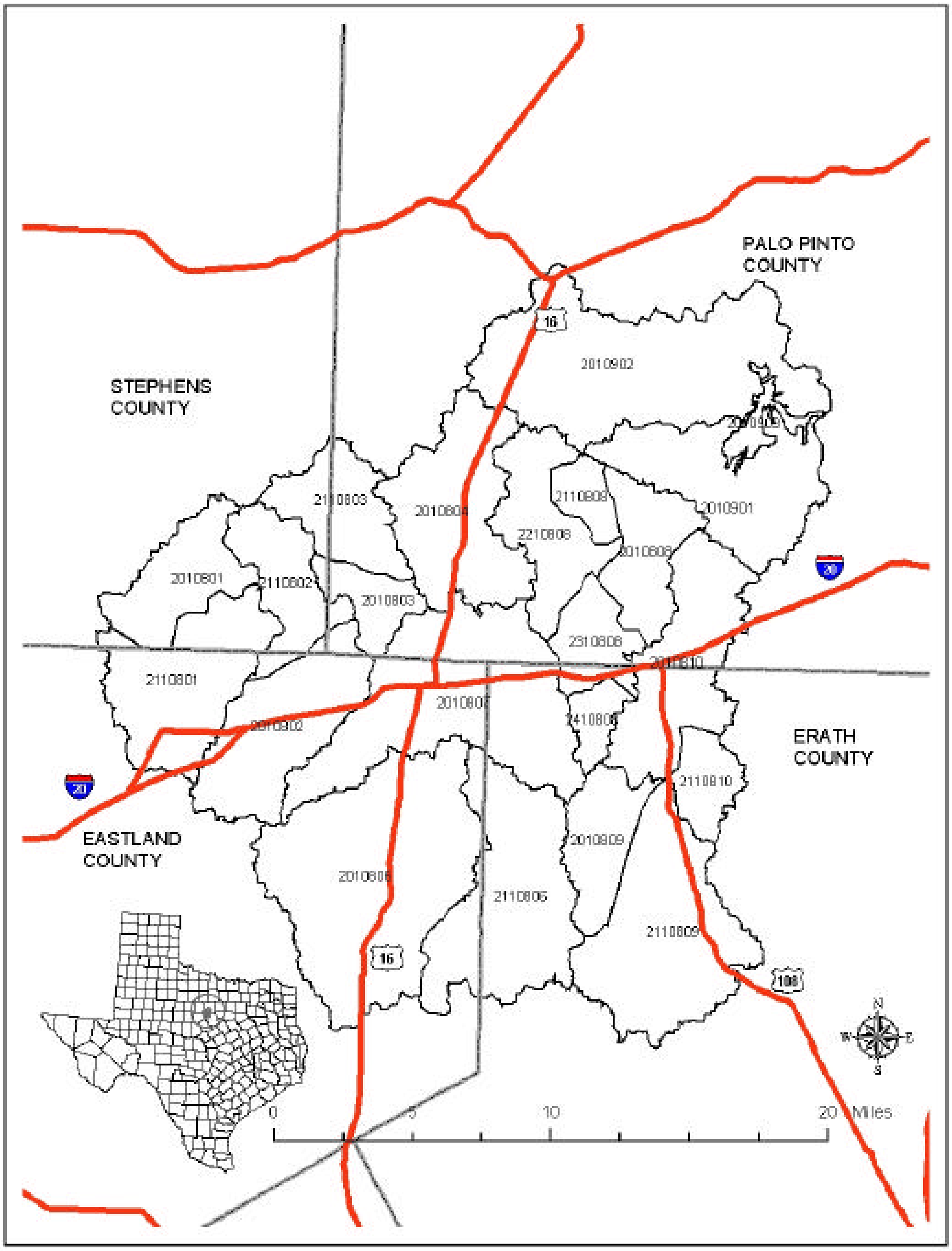

Figure 9-1. Lake Palo Pinto watershed sub-basin map with major roads.

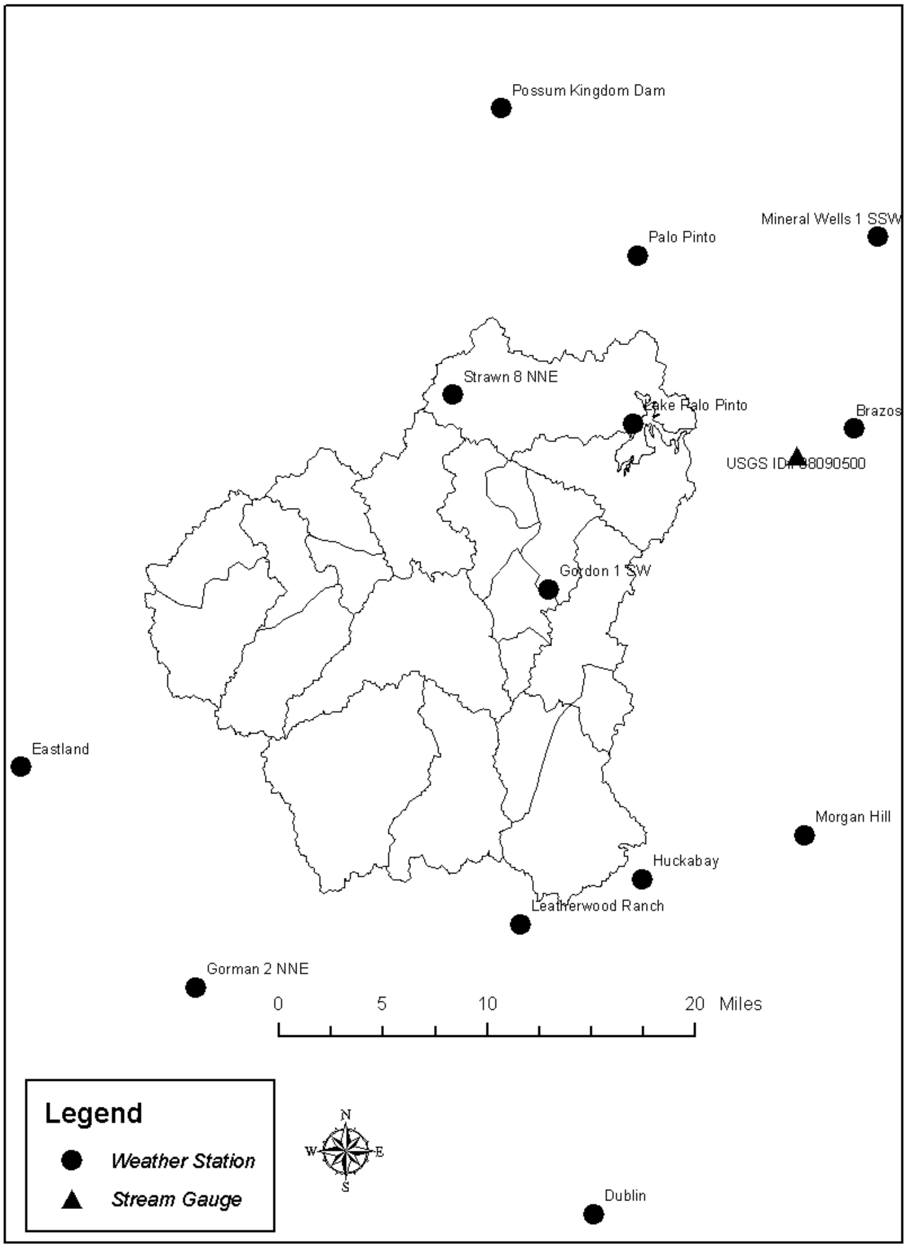

Figure 9-2. Climate and stream gauging stations in the Palo Pinto watershed.

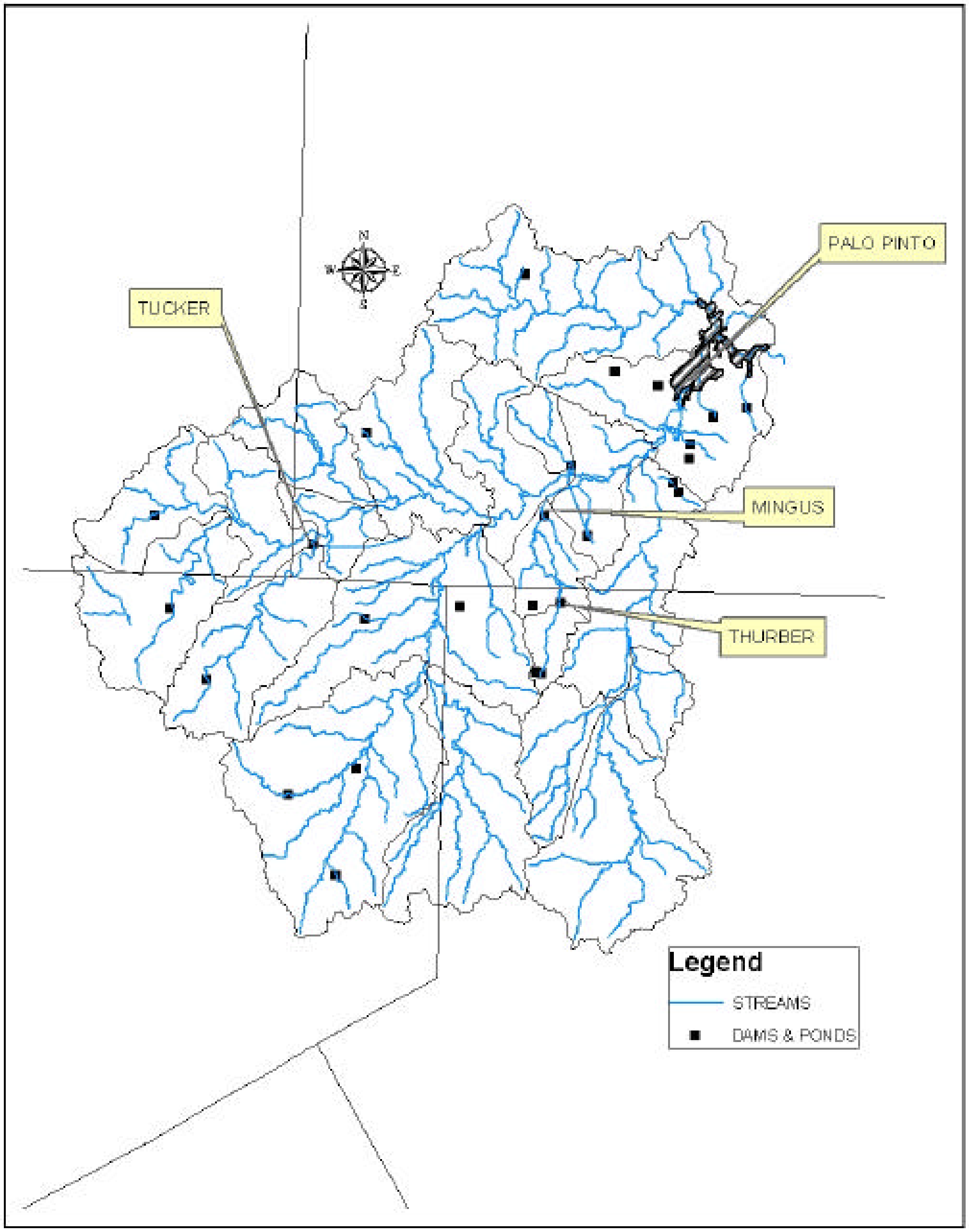

Figure 9-3. Inventory-sized ponds and reservoirs (labeled) in the Palo Pinto watershed.

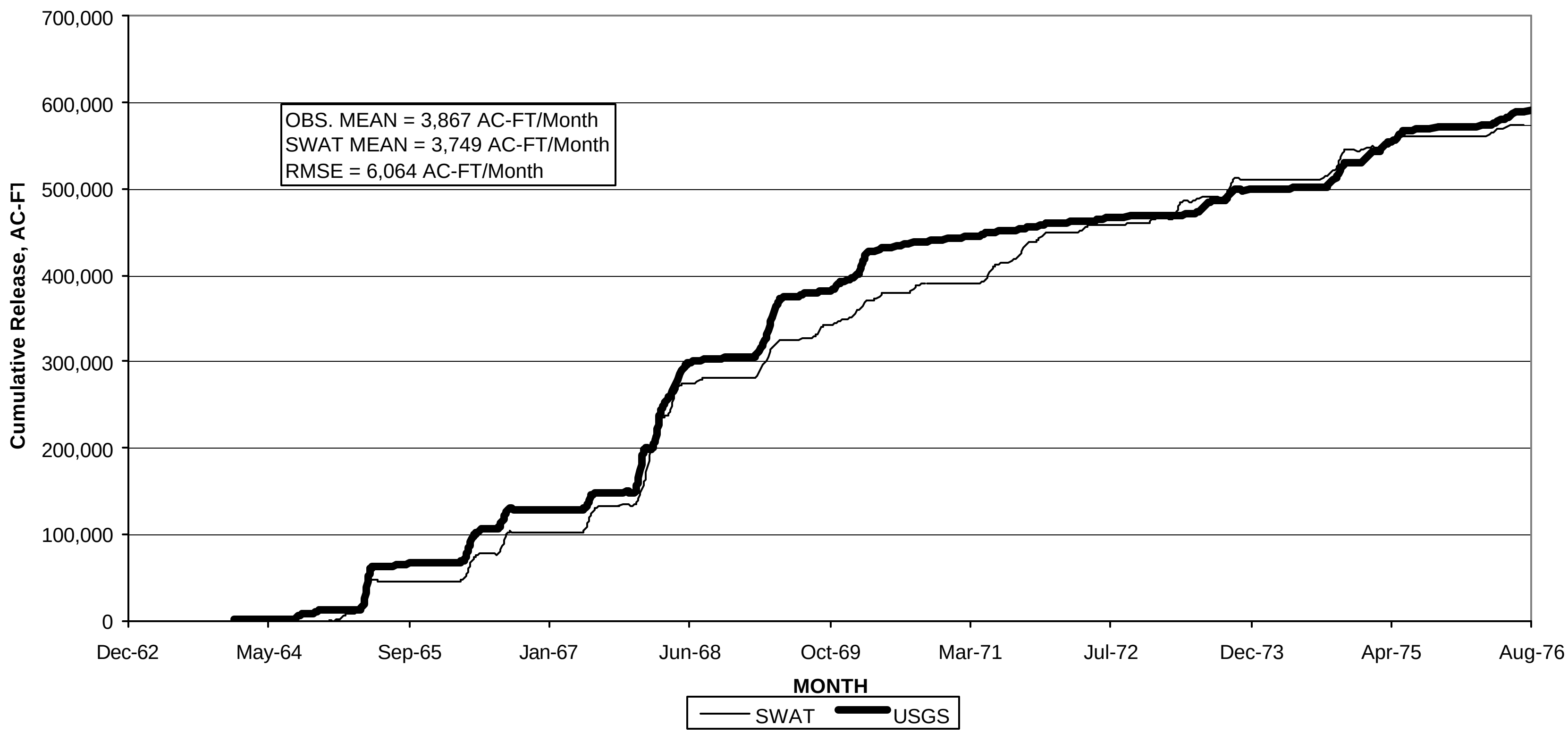

Figure 9-4. Calibration curve for SWAT (thin line) against measured USGS flows at the Santo gauge No. 08090500 about 10 miles downstream of Lake Palo Pinto. Note that the flows are through 1976.

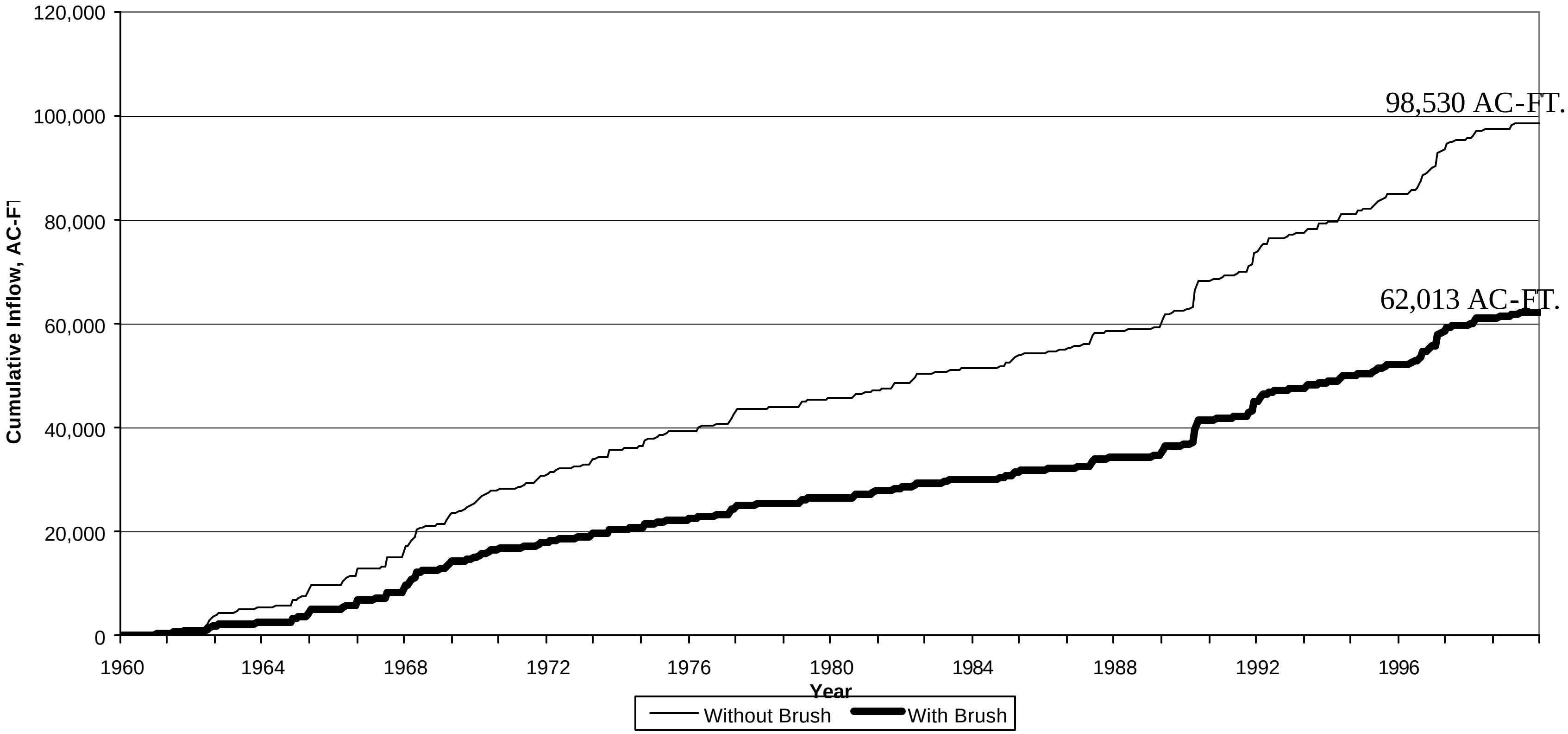

Figure 9-5. Flow into Lake Mingus with and without brush during 1960-1999.

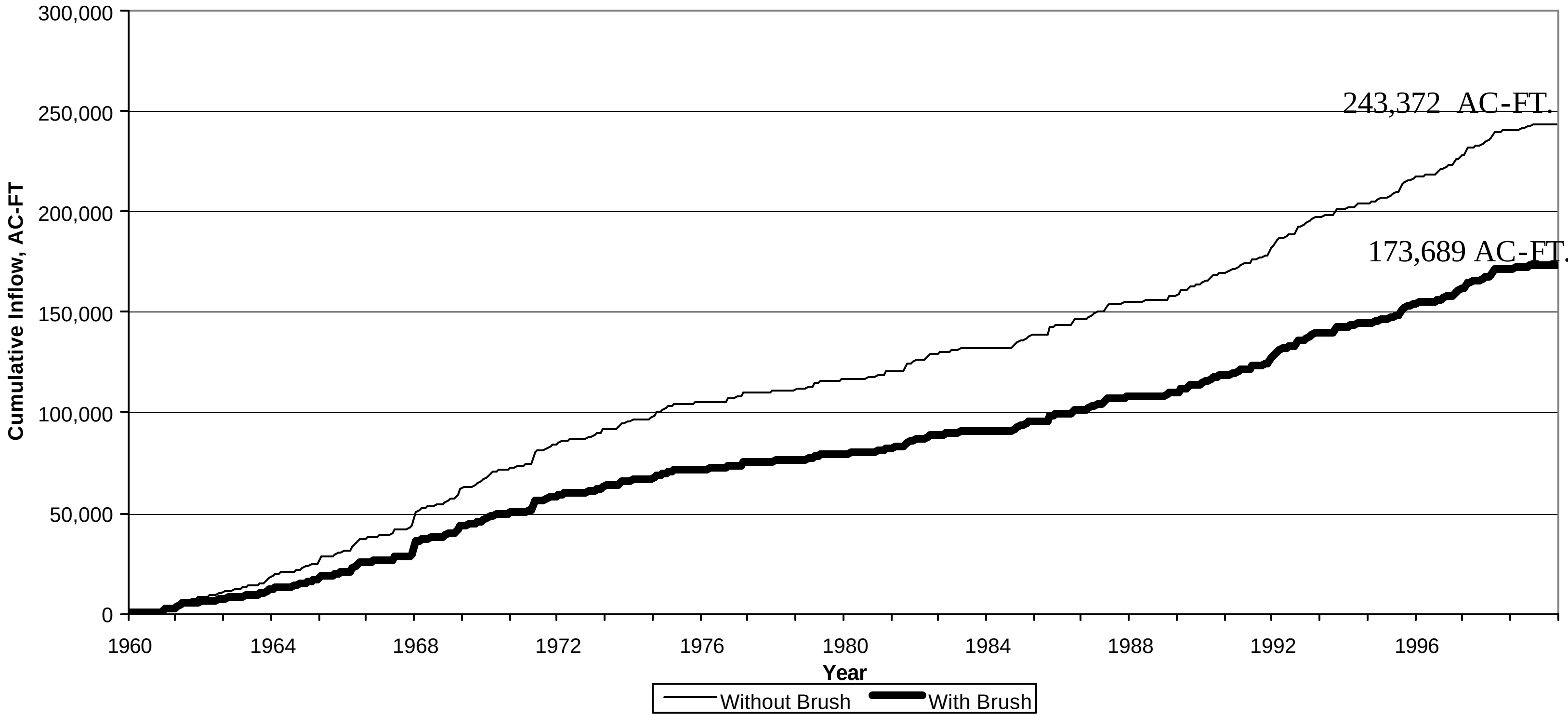

Figure 9-6. Flow into Lake Tucker with and without brush during 1960-1999.

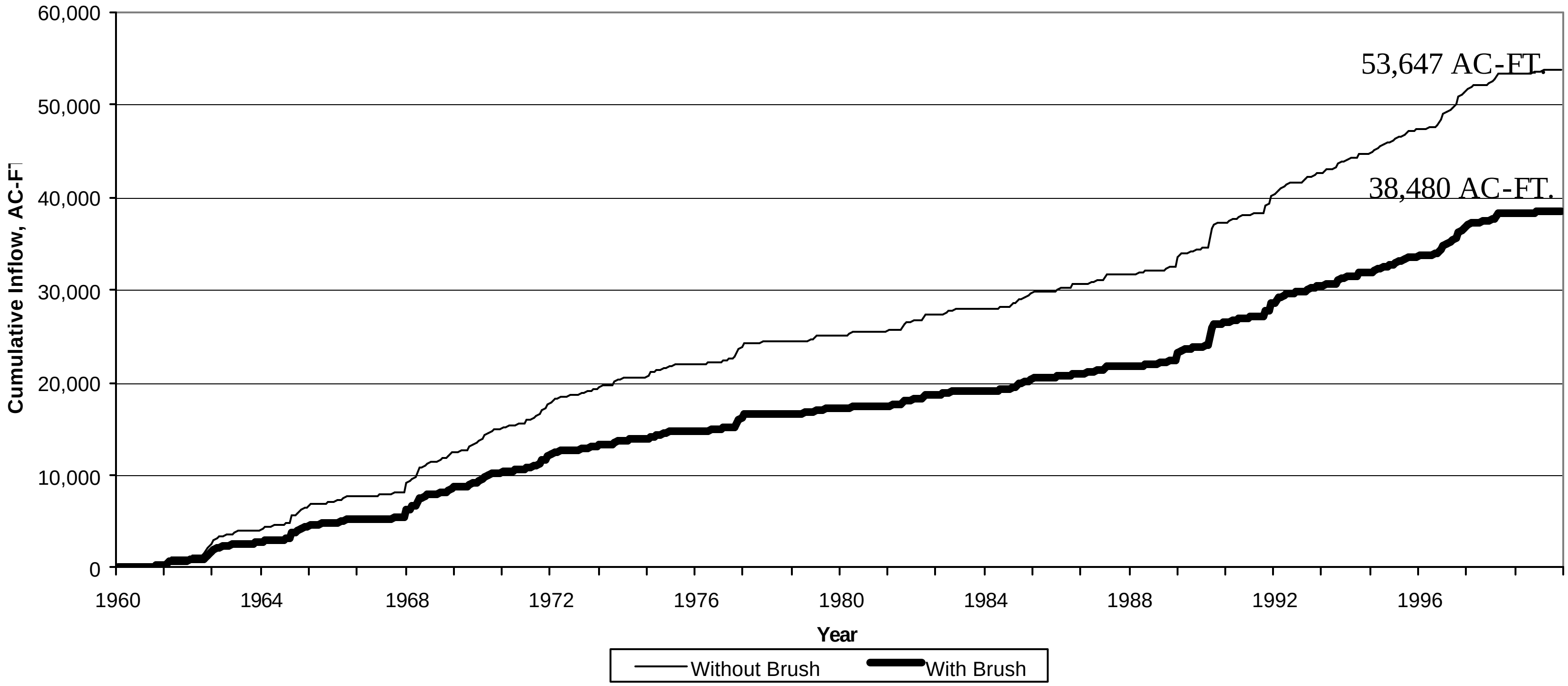

Figure 9-7. Flow into Lake Thurber with and without brush during 1960-1999.

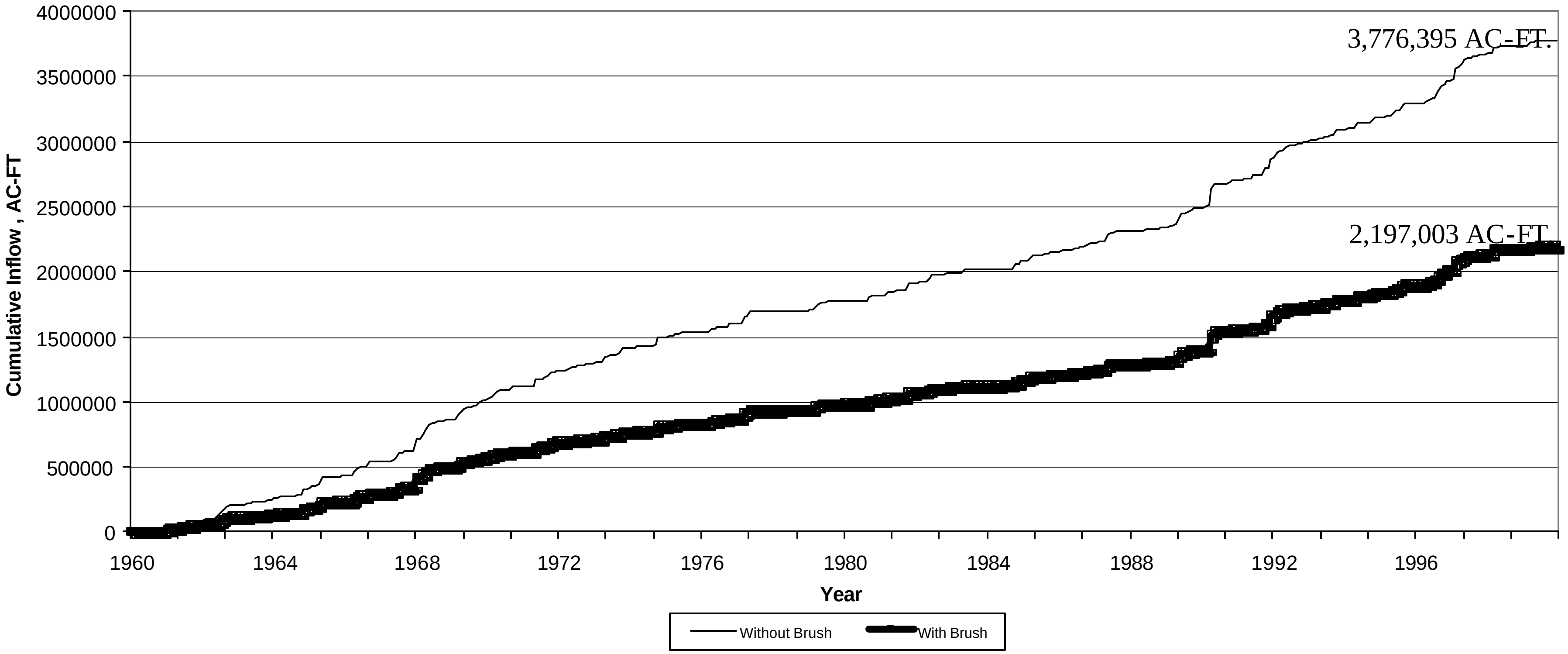

Figure 9-8. Flow into Lake Palo Pinto with and without brush control during 1960-1999.

APPENDIX C

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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Thurow, A., J.R. Conner, T. Thurow and M. Garriga. 2001. Modeling Texas ranchers' willingness to participate in a brush control cost-sharing program to improve off-site water yields. *Ecological Economics*: 37(Apr. 2001):137-150.

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

Heavy Mesquite – Chemical

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

Heavy Mesquite - Mechanical Choice

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

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

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

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

Year	Animal Units	Total Increase in Sales	Total Added Investment	Increased Variable Costs	Additional Revenues	Cash Flow	Annual NPV	Accumulate NPV
0	50	0	0	0	0	0	0	-
1	53.3	1292	2100	417	1000	-225	-212	-212
2	57.1	3015	2800	973	1000	242	215	3
3	61.5	4737	2800	1529	1000	1408	1182	1185
4	66.7	6890	5000	2224	1000	666	528	1713
5	66.7	6890	0	2224	1000	5666	4234	5947
6	66.7	6890	0	2224	1000	5666	3995	9942
7	66.7	6890	0	2224	1000	5666	3768	13710
8	66.7	6890	0	2224	1000	5666	3555	17265
9	66.7	6890	0	2224	1000	5666	3354	20619
				Salvage Value		12700	7517	28136

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

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

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

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

APPENDIX D

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**

Table 10-1. Cost of Water Yield Brush Control Programs by Type-Density Category, Continued

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**

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**

Table 10-1. Cost of Water Yield Brush Control Programs by Type-Density Category, Continued

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**

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**

Table 10-1. Cost of Water Yield Brush Control Programs by Type-Density Category, Continued

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 10-2. 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	Control	25.00	23.25	21.50	19.75	18.00	18.00	18.00	18.00	18.00	18.00
	No Control	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Heavy Cedar	Control	45.00	40.00	35.00	30.00	25.00	25.00	25.00	25.00	25.00	25.00
	No Control	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
Heavy Mixed-Brush	Control	35.0	31.3	27.5	23.8	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Heavy Post/Shimmery Oak	Control	40.0	35.0	30.0	25.0	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Moderate Mesquite	Control	20.0	19.5	19.0	18.5	18.0	18.0	18.0	18.0	18.0	18.0
	No Control	20.0	20.2	20.4	20.7	20.9	21.1	21.3	21.6	21.8	22.0
Moderate Cedar	Control	35.0	32.5	30.0	27.5	25.0	25.0	25.0	25.0	25.0	25.0
	No Control	35.0	35.4	35.8	36.2	36.6	36.9	37.3	37.7	38.1	38.5
Moderate Mixed-Brush	Control	28.0	26.0	24.0	22.0	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	28.0	28.3	28.6	28.9	29.2	29.6	29.9	30.2	30.5	30.8
Moderate Post/Shimmery Oak	Control	25.0	23.8	22.5	21.3	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	25.0	25.3	25.6	25.8	26.1	26.4	26.7	26.9	27.2	27.5

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