Fort Phantom Hill 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. The western part of the basin is heavily dependent on surface water sources. Fort Phantom Hill Reservoir, operated by the West Central Texas Municipal Water District, is one of the major water supply reservoirs in the western part of the region.

The western 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, prickly pear, salt cedar, or other deep-rooted plants, 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 Fort Phantom Hill Reservoir 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 void of mesquite and juniper infestation. 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 Fort Phantom Hill Reservoir watershed. Simulations of brush control implementation estimate average annual water yield increases in the Fort Phantom Hill reservoir watershed to be about 111,000 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 $29.45 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 $143.17 for mechanical control of heavy mixed brush; benefits to landowners range from $21.37 per acre for control of moderate mesquite to $35.50 per acre for the control of heavy mixed brush; and state cost share per acre is estimated to be $14.20 for moderate mesquite control to $112.53 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 Fort Phantom Hill 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, improper livestock grazing practices, fire suppression and droughts have led to the increase and dominance of noxious brush species over the native grasses and trees. The improper livestock grazing of the watershed's rangeland in the late 19th century and early 20th century reduced the ability of grasses to suppress seedling tree establishment and 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 Fort Phantom Hill Reservoir. This reservoir and three smaller reservoirs in the watershed, Lake Abilene, Lake Kirby, and Lake Lytle, 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 12060102 was used to define the Fort Phantom Hill Reservoir watershed for this study. The study area includes 470 square miles of West-Central Texas, mostly within Jones and Taylor counties, but includes small portions of Callahan and Nolan Counties. Major tributaries to the reservoir include: Cedar Creek, Cat Claw Creek, Elm Creek, Indian Creek, Little Elm Creek and Lytle Creek (Figure 3.1).

Topography and Drainage

The Fort Phantom Hill Reservoir is located within the Osage Plains section of the Central Lowlands physiographic province. Topographic elevations range from about 1,600 to 2,400 feet for a total relief of 800 feet. The land surface is in general gently rolling to semi-level. Prominent northeast sloping escarpments are formed by Permian limestones and dolomites (Price 1978).

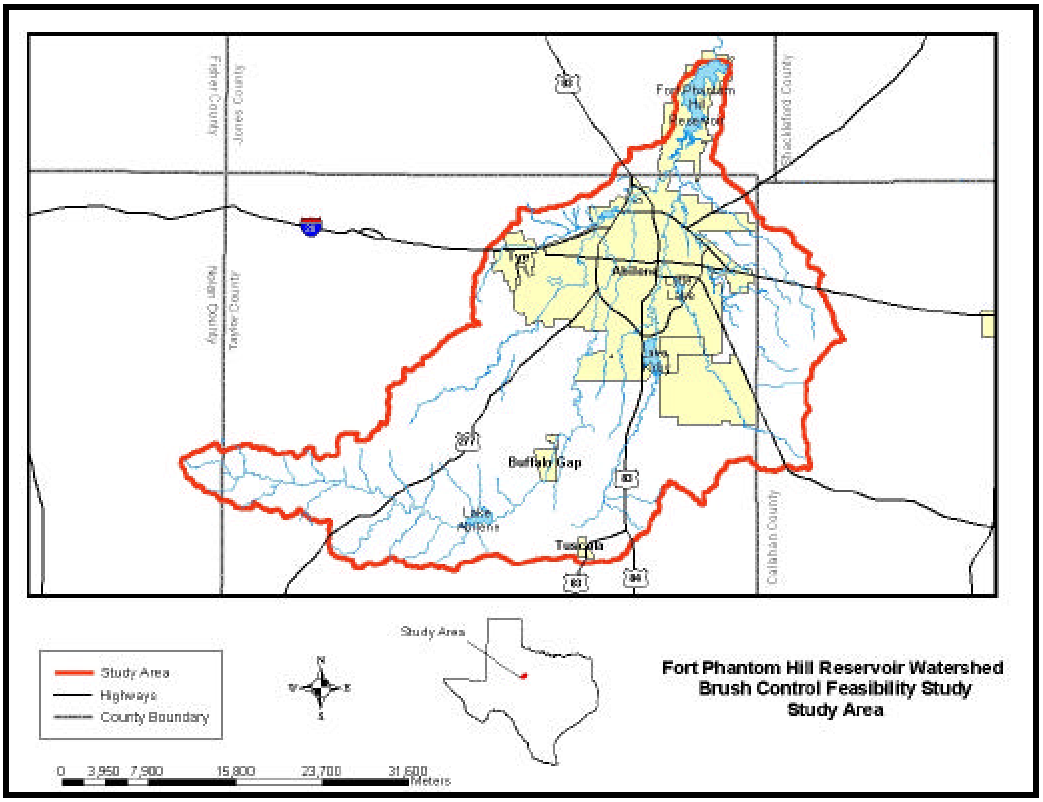


Figure 3.1 Forth Phantom Hill Reservoir Watershed

The watershed is located entirely within the Brazos River drainage system. The Fort Phantom Hill Reservoir discharges to the Clear Fork of the Brazos River through Elm Creek. The Clear Fork of the Brazos River then discharges into the Brazos River in Young County southwest of the City of Graham.

In addition to Fort Phantom Hill Reservoir there are three other reservoirs in the Fort Phantom Hill Reservoir watershed, Lake Abilene, Lake Kirby and Lytle Lake. Fort Phantom Hill Reservoir is the largest of these and from where the City of Abilene receives much of its water supply. The reservoir is in the southeastern portion of Jones County and impounds approximately 74,310 acre-feet of water on Elm Creek. Lake Abilene is in the southwest corner of Taylor County and impounds approximately 7,900 acre-feet of water and is a source of water for the City of Abilene. Lytle Lake is located in the southeastern part of the City of Abilene and impounds approximately 1,200 acre-feet of water and is also a source of water for the City of Abilene.

Portions of two aquifers extend into the watershed; the Edwards-Trinity and the Trinity. Both are classified as major aquifers by the Texas Water Development Board and supply large amounts of water to large areas of the State (Figure 3.2). The Edwards-Trinity Aquifer offers little room for further development.

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 the Permian, Cretaceous, and Quaternary systems and are exposed at the surface (Price 1978, Taylor 1978). The gently west-northwest dipping Permian rocks are exposed in narrow, successively younger belts from east to west across the watershed. Cretaceous sedimentary units, dip to the southwest forming northward facing steep-walled mesas in the southern portion of 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.

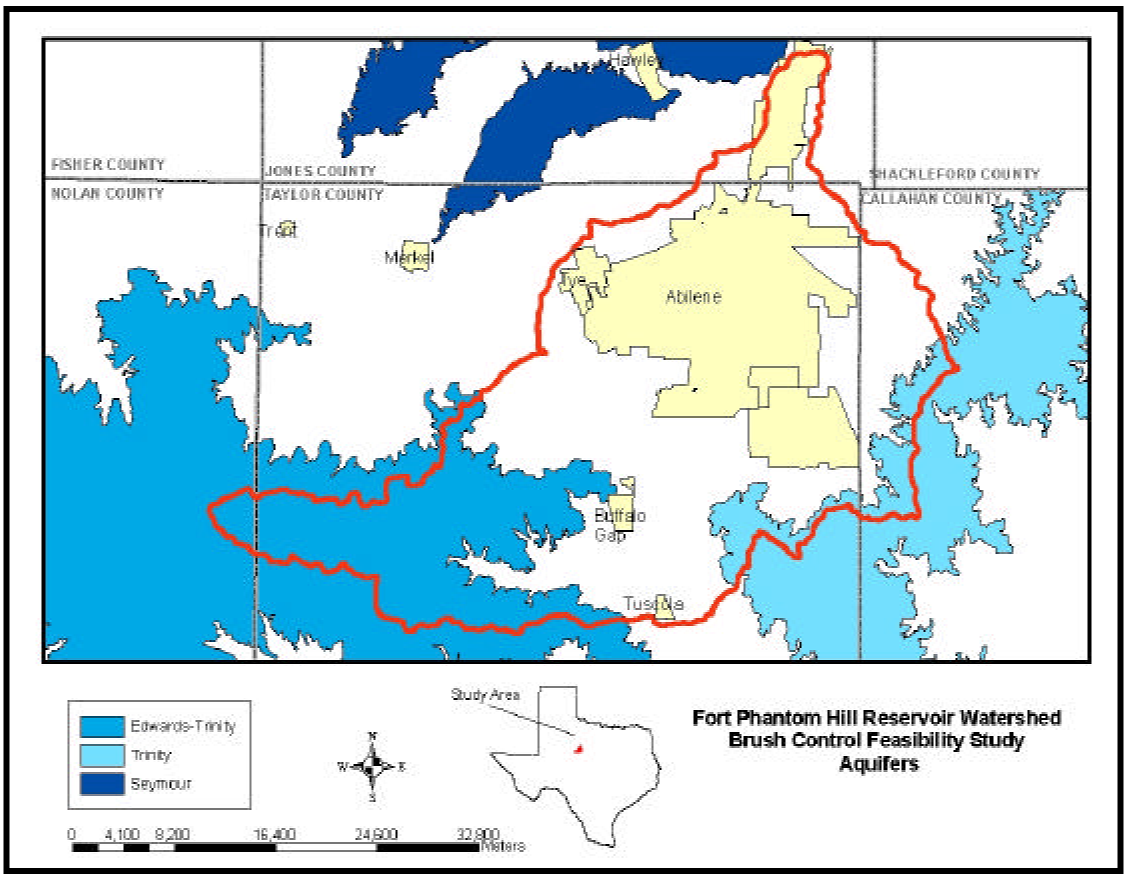


Figure 3.2 Aquifers in the Fort Phantom Hill Reservoir Watershed.

Population

Table 3.1 presents population data for Taylor and Jones Counties from 1880 to 1990 and population projections from 2000 to 2050. The populations of the two counties are not expected to increase significantly between 2000 to 2050. A 0.75% increase is projected for Taylor County and a 0.48% increase for Jones County.

Climate

Table 3.1 Population Trends for Jones and Taylor Counties.

Year	Jones County	Taylor County	Total
1880	542	917	1,459
1890	3,797	6,957	10,754
1900	7,049	6,957	14,006
1910	24,499	26,293	50792
1920	22,323	24,081	46,404
1930	24,233	41,023	65,256
1940	23,378	44,147	67,525
1950	21,338	63,101	84,439
1960	19,299	101,078	120,377
1970	16,106	97,853	113,959
1980	17,268	110,932	128,200
1990	16,490	122,797	139,287
2000	17,392	138,592	155,984
2010	18,791	151,965	170,747
2020	19,788	167,058	186,846
2030	20,642	179,239	199,881
2040	21,427	191,876	213,303
2050	22,120	200,872	222,992

Sources: 1880-1990 (Odintz 2001, Leffler 2001)

2000-2050 (Brazos G Regional Water Planning Group)

The climate of the watershed has 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.

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 24 inches (Table 3.2). 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 September. Snow in the watershed is infrequent. When snow storms occur they are frequently severe. Little moisture is gained by the watershed from snowfall due to high winds and frequently rising temperatures which make the coverage uneven and retention times short.

The watershed also exhibits high evaporative rates in the summer months due to high temperatures, high light intensities, low humidity, and high wind speeds.

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 even in January; fair, mild weather is frequent. High daytime temperatures prevail for a long period in the summer but rapid cooling occurs after nightfall and most nights have a minimum temperature in the upper or lower 70s.

Winds are strongest during intense thunderstorms but these storms usually do not last long. The

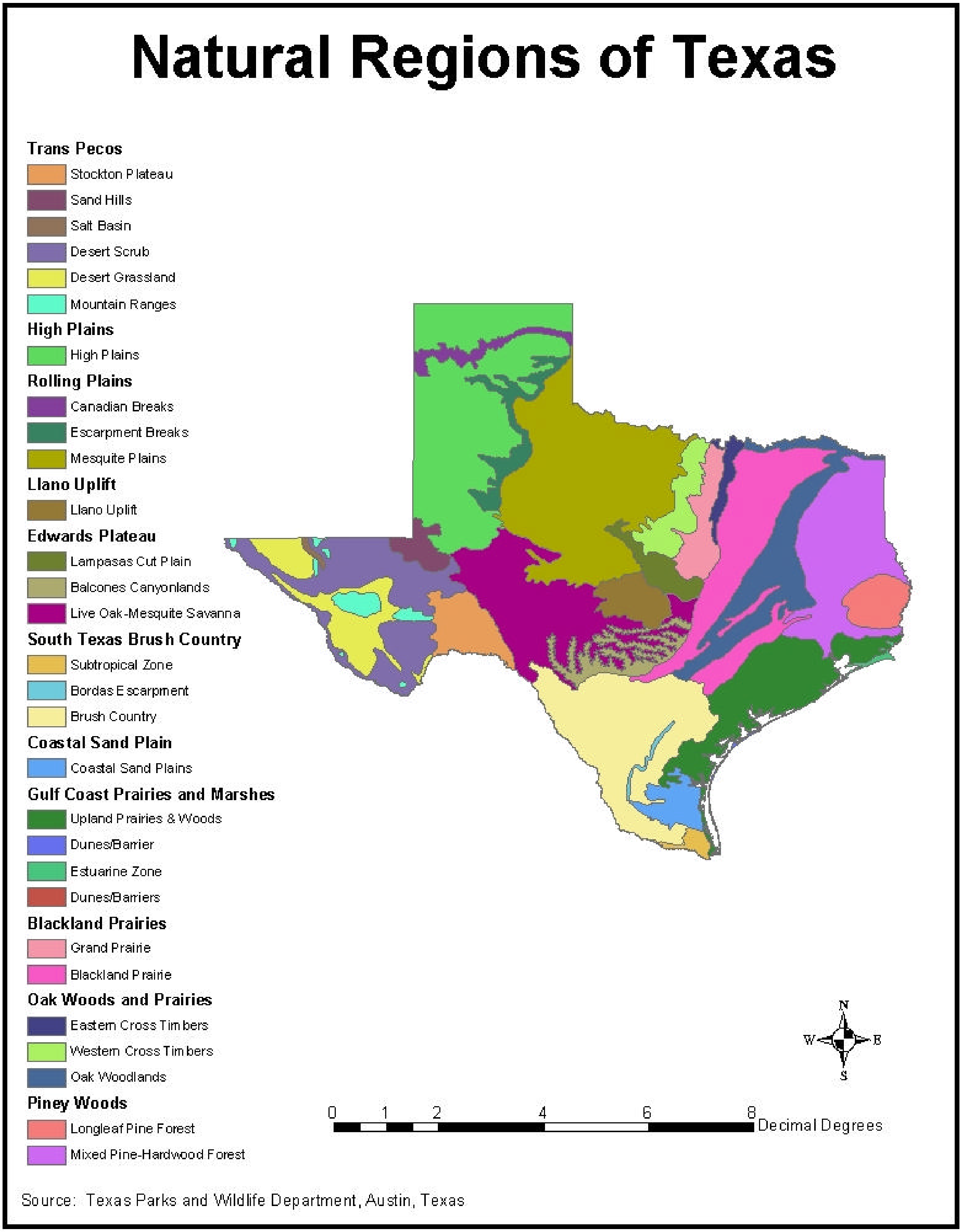


Figure 3.3 Natural Regions of Texas

Table 3.2. Monthly Temperatures, Precipitation, and Evaporation of the Fort Phantom Hill Reservoir Watershed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Temperature Data (1950-2001)													
Mean Minimum Temperature (°F)	31.9	36.3	43.0	52.9	61.1	68.8	72.6	84.0	64.7	54.4	42.3	34.0	52.8
Mean Maximum Temperature (°F)	55.5	60.3	66.6	77.1	84.1	90.9	94.7	93.9	86.6	77.4	65.1	57.1	75.9
Mean Temperature (°F)	43.9	48.4	55.7	64.9	72.8	80.0	83.8	82.9	75.8	66.0	53.9	45.7	64.5
Precipitation Data (1950-2001)													
Minimum Total Precipitation (inches)	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.78
Maximum Total Precipitation (inches)	4.35	3.60	5.16	6.80	13.19	9.60	7.15	8.18	11.03	10.68	4.60	6.28	36.84
MeanTotal Precipitation (inches)	1.01	1.13	1.21	2.04	3.25	2.92	1.98	2.46	2.79	2.50	1.38	1.07	23.90
Evaporation (1954-2000)													
Minimum Total Evaporation (inches)	1.26	1.49	2.32	4.10	3.92	5.35	5.00	5.10	3.69	3.37	2.40	1.08	52.33
Maximum Total Evaporation (inches)	3.78	5.01	7.15	7.78	7.85	10.04	11.41	11.10	9.57	8.16	4.80	3.86	80.91
Mean Total Evaporation (inches)	2.31	2.78	4.66	5.83	5.78	7.45	8.53	7.90	6.06	5.11	3.45	2.52	62.51

Source: Temperature and Precipitation—National Climatic Data Center, Ashville, North Carolina; Evaporation—Texas Water Development Board, Austin, Texas strongest continuous winds occur during March and April and the prevailing direction of the winds is from the south to southeast.

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.

Land Use

The land use in the watershed is dominated by agribusiness including: feedlots, rangeland, and row-crop agriculture (Figure 3.4). Rangeland is used mainly for livestock: cattle, goats, and sheep. Crop production is largely dominated by wheat, cotton, sorghum, and hay.

Urban land use is limited to the City of Abilene and the towns of Potosi, Buffalo Gap, and Tye. Dyess Air Force Base lies west of the City of Abilene in the watershed and the oil industry is prominent in the watershed with exploration, drilling, refining, and oil field service industries.

Wildlife

The ecology of the watershed reflects negative impacts from improper grazing practices, 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.

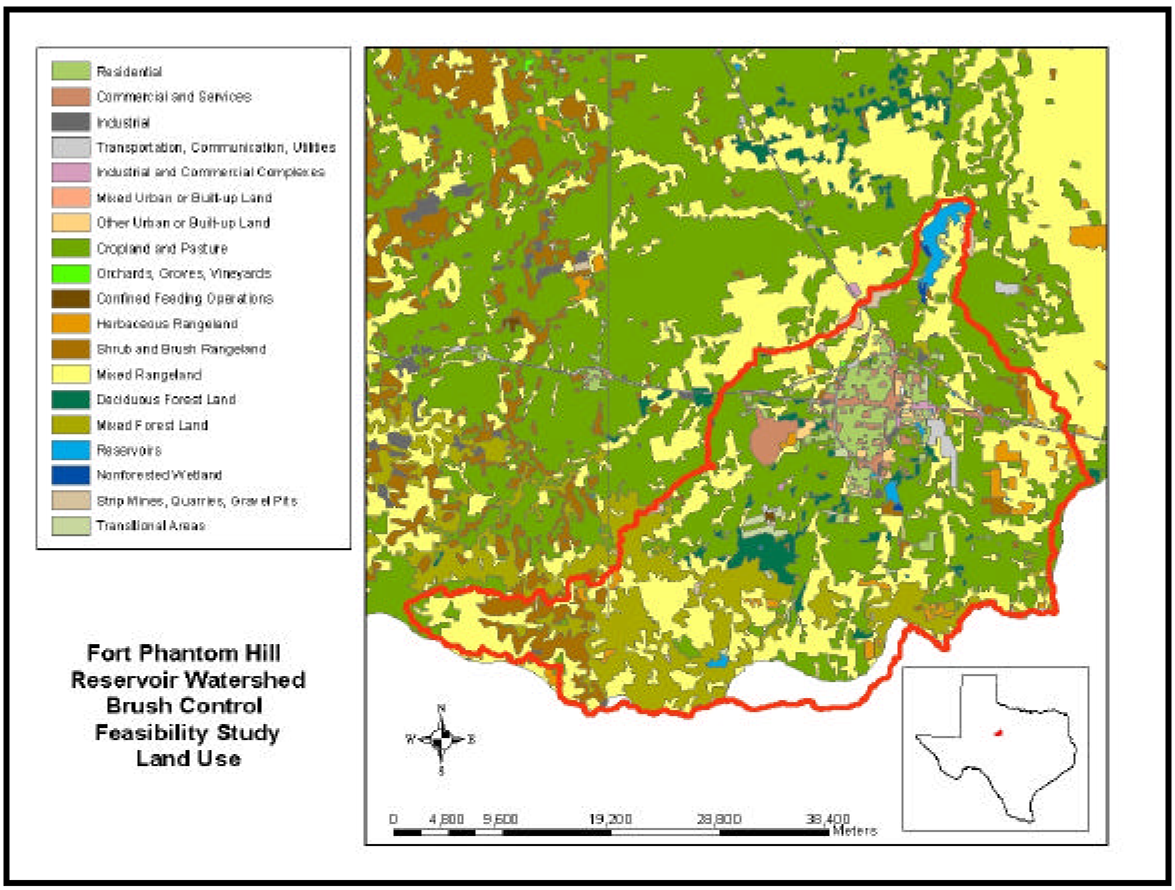


Figure 3.4 Fort Phantom Hill Reservoir watershed land use.

The upper Brazos River basin has fish fauna that include endemic species. All rivers and streams in the Fort Phantom Hill 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 smalleye shiner (*Notropis buccula*) is endemic to the Brazos River basin in Texas. The population of smalleye shiners above Possum Kingdom Reservoir is stable. The shiner has not been collected downstream of Possum Kingdom Reservoir in several decades and most likely has been extirpated from this region of the Brazos River basin. The smalleye shiner is currently on the United States Fish and Wildlife Service's Candidate List for listing as endangered or threatened. The most significant threat to the existence of the smalleye shiner is the present and continued modification of its habitat by reservoir construction, irrigation and water diversion, sedimentation, industrial and municipal discharges, and agricultural activities. The current limited distribution of the smalleye shiner within the Upper Region of the Brazos River basin make it vulnerable to catastrophic events such as the introduction of competitive species or prolonged drought.

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 45 species of amphibians, reptiles and mammals are known to inhabit the watershed. Many of these species are aquatic, semi-aquatic, or dependent on wetlands in some way. 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.


Texas Horned Lizard.

The Texas Horned Lizard (*Phyrnosoma cornutum*) is currently on the State of Texas' list of endangered or threatened species. The most significant threat to the existence of the horned lizard is the increasing large population of fire ants, insecticides used to control the fire ants, loss of habitat, reduction in population of harvester ants, and over collecting. While the horned lizard is widespread and relatively common in some areas of the south-central United States and northern Mexico, it is apparently declining in the eastern portions of its range in Texas, Oklahoma, and Kansas.

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 Fort Phantom Hill Reservoir watershed. The watershed did not sustain extensive 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 Rolling Plains and the area of Forth Phantom Hill Reservoir watershed as an area of mixed prairie dominated by grasses one to three feet tall.

The Paleoindian and Archaic periods see the first peopling phase to the area which is now the Fort Phantom Hill Reservoir watershed. The Paleoindian period, dating from 10,000+ to 6,000 BC, spanned a time of more mesic conditions than the present. Springs were more abundant and playa lakes were likely important loci of hunting and occupation. People of the Paleoindian period subsided largely on Pleistocene megafauna (Carpenter 2001).

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 dating from 6,000 BC to 500 AD. People of the Archaic period maintained a mobile lifestyle to exploit seasonal and spatial resources and subsided on hunting and gathering. This hunter/gatherer lifestyle was apparently caused by a decrease in the buffalo population in the present day watershed area from 5,000 to 1,000 BC (Carpenter 2001).

Buffalo returned to the area during the cyclical mesic periods of the Late Prehistoric Period (500 to 1500 AD) and resumed their prominence in subsistence patterns. The grasslands of the Prehistoric Period supported a wide variety of animal life including: bison, deer, antelope, rodents, and other small mammals (Turpin 1997). 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 Fort Phantom Hill Reservoir watershed. The earliest European settlement came to the region in 1851 when Fort Phantom Hill was established to guard the frontier and protect gold miners traveling to the West Coast on the Randolph B. Marcy Trail (Odintz 2001). Early accounts of the region note the presence of oak, elm, pecan, and hackberry trees growing along stream banks with only scattered, stunted mesquite trees in the area (Shelton 1978).

Buffalo hunters moved into the area in the 1860s and 70s after the Indian threat had been removed by the United States Army. Soon after the buffalo hunters arrived, cattle ranchers followed to take advantage of the grasslands. These earlier ranchers have reported grasses one to three feet high and sometimes as high as a cow's back, mesquite trees were few and present near streams, and ranges could carry three hundred head of cattle per square mile (1 head of stock per 2 acres). Common varieties of plants documented by these early ranchers include: little blue stem, big blue stem, Indian grass, buffalo grass, and several varieties of gramma grass. Additionally, frontier doctors have recorded the presence of the following plants, used in folk medicines, including: poke weed, redroot weed, liveoak, horehound weed, balmony plant, mayapple, saffarila, Mullien plant, houselake plant, and prickly pear (Zachary).

Hardships abounded for the early ranchers including drought and prairie fires. Many prairie fires are reported to have been started by the Indians who believed that burning the range lands restored the grasses. Reports that grasses were plenty and mesquite trees few lend credibility to this belief. By 1880 farmers had moved into the area. The 1880 census for Jones County counts 1,191 acres in cultivation (Odintz 2001). In Taylor County 107 farms and ranches were identified encompassing 30,120 acres (Leffler 2001).

By the late 1890s significant impacts from cattle grazing were beginning to be observed in the region. The carrying capacity of the range had decreased from 1 head of stock per 2 acres to 1 head of stock per 10 acres (Bentley 1898). Between 1880 and 1900 thousands of cattle and sheep were crowded on ranges where the grasses were entirely consumed, the roots trampled and destroyed. As the range was overgrazed and fire pattern of the range suppressed, reducing the ability of the grass to compete, unpalatable brush such as mesquite and juniper began to invade the range.

By 1900, the diversity, size, and natural productivity of most of the native mixed grass prairie in the region had been drastically reduced by the improper grazing practices in the livestock industry of the time. As the grass was removed through overgrazing, mesquite, juniper, and prickly pear spread on the mismanaged range. In the late 1910s mesquite had become so prevalent on the range that ranchers used the tree’s leaves and seed pods as a feed supplement during the winter months (Smith 1918). A 1939 description of the region notes the increasing prevalence of mesquite and other thorny brush and notes the rising population of juniper (Tharp 1939).

Today much of the land in the watershed is used for cultivated fields or urban expansion, the dominant vegetation assemblage non-cultivated, non-urban areas is Mesquite-Lotebush Shrub Brush (Figure 3.5). The other vegetation assemblages present in the watershed are the Mesquite-Juniper-Live Oak Brush assemblage and the Mesquite-Juniper Shrub assemblage. These assemblages are disturbance types resulting from overgrazing, soil erosion, lowered groundwater tables, and the decline of native grasses.

The Mesquite-Lotebush Shrub assemblage occurs extensively in the northeast portion of the watershed. Species associated with this assemblage include: yucca, agarito, elbowbush, juniper, tasajillo, bluestem grasses, sand dropseed, grama grasses, buffalograss, three-awn grasses, tobosa, Texas wintergrass, bitterweed, broom snakeweed, and Englemann daisy.

The Mesquite-Juniper-Live Oak Brush assemblage and the Mesquite-Juniper Shrub assemblage occur in the southwest portion of the watershed and includes the following associated species: Lotebush, shin oak, sumac, Texas pricklypear, tasajillo, kidneywood, agarito, redbud, yucca, Lindheimer silktassel, stool, catclaw, Mexican persimmion, gramma grasses, three-awn, curly mesquite, buffalograss, and hairy tridens.

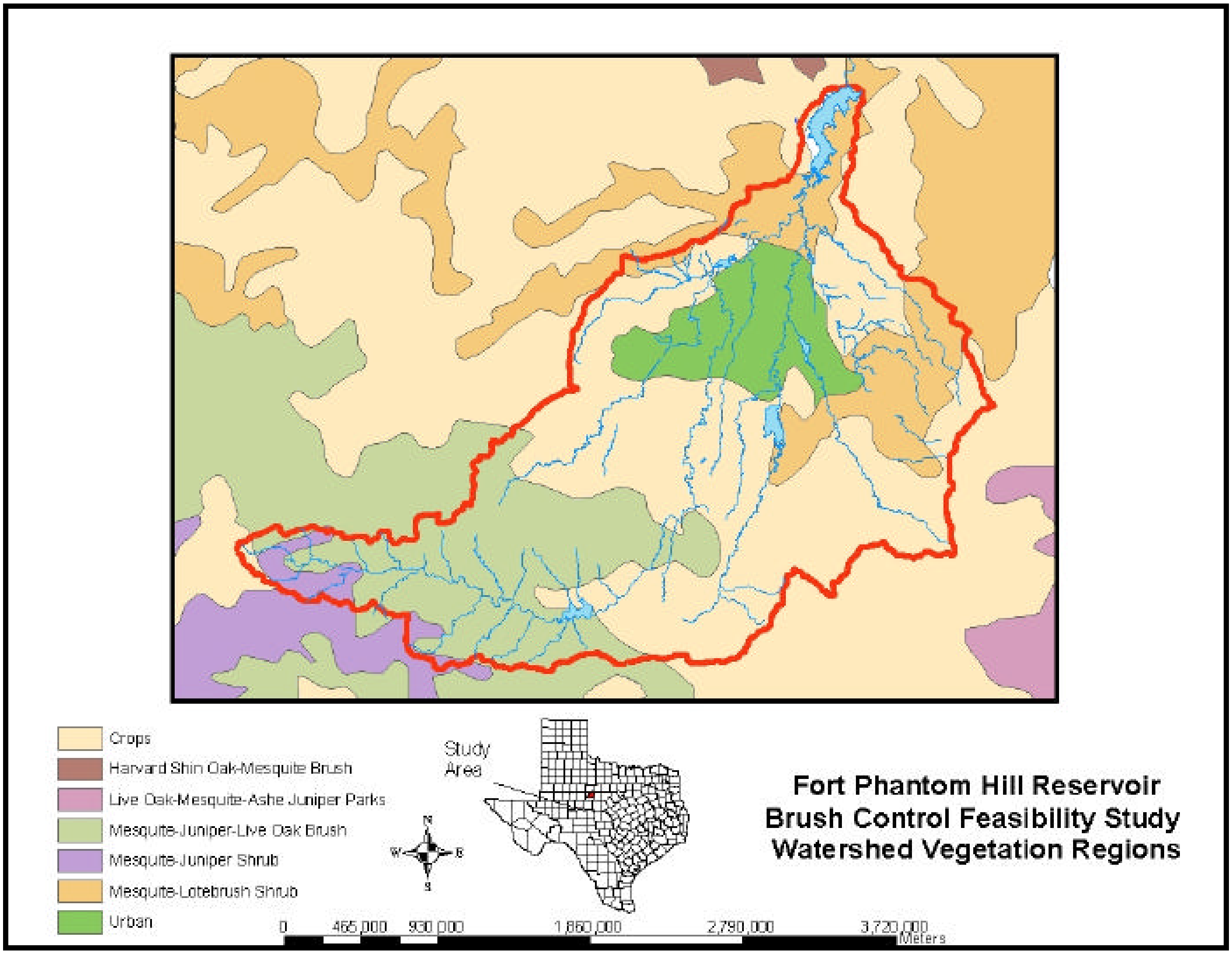


Figure 3.5 Fort Phantom Hill Reservoir Watershed Vegetation

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 Fort Phantom Hill 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.

Currently, there are no United States Geological Survey flow-monitoring stations within the Fort Phantom Hill Reservoir watershed. Most historical accounts of stream flow are qualitative, a pattern of alternating normal to severe drought conditions is apparent. The United States Weather Bureau opened a station at Abilene in October 1885. The new weather station immediately began collecting data on one of the most severe droughts the region has experienced, the drought of 1885-1886. In the beginning months of 1885 rainfall was ample but by fall rain was in much need. In 1886, 18.14 inches of rain was recorded in Taylor County and significant rains did not return to the region until late 1887 (Zachry). In response to the drought of 1885-1886 the City of Abilene began excavating Lake Lytle in 1897. However, in 1898, the presence of numerous streams supplying an abundance of water for livestock was documented by the Grass Station (Bentley 1898).

By 1918 an overall decline in water supply can be observed. It is documented that few permanent streams remain, springs are scarce, and deep bored wells delivering good water are rare (Smith 1918).

In response to the declining water supply the City of Abilene began a period of reservoir and diversion construction in the watershed beginning in 1918 and ending in 1954. The first reservoir to be constructed was Lake Abilene, a 11,868 acre-feet capacity reservoir begun in 1918. Next came Lake Kirby, constructed in 1927, the lake impounds 8,500 acre-feet of water. The final reservoir constructed in the watershed is Fort Phantom Hill. Construction on the dam began in 1937. This reservoir has a capacity of 73,690 acre-feet. To supply additional water to the City, diversions discharging into Fort Phantom Hill Reservoir were built from the Clear Fork of the Brazos River in 1954 and Deadman's Creek in 1954.

Surface Water

Several predictable trends exist between water levels and climatic parameters such as temperature and precipitation in the Fort Phantom Hill Reservoir watershed from 1950 to 2001, including: significant relationships between reservoir capacity and precipitation, stream flow and precipitation and evaporation and temperature (Figures 4.1, 4.2, and 4.3).

Figure 4.1. Fort Phantom Hill Reservoir Capacity vs. Precipitation

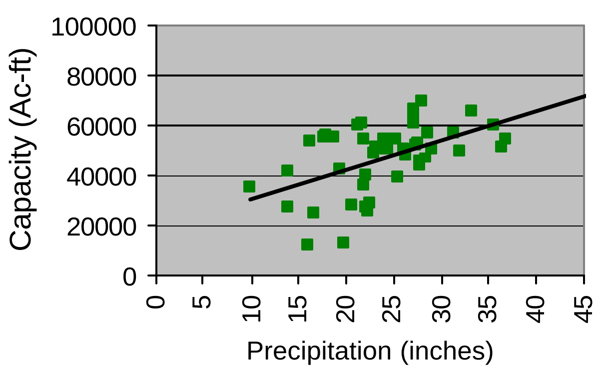
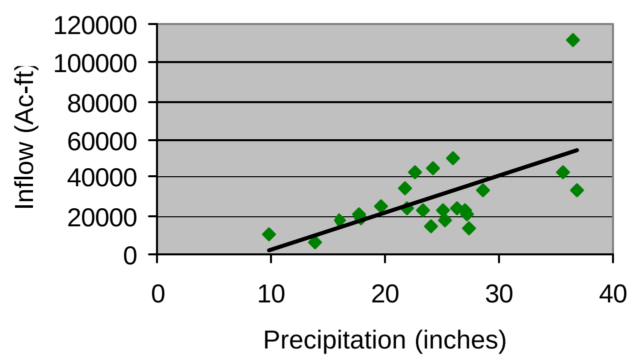
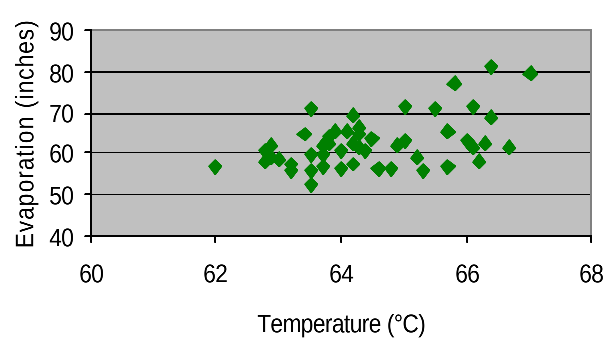


Figure 4.2. Fort Phantom Hill Reservoir Inflow vs. Precipitation



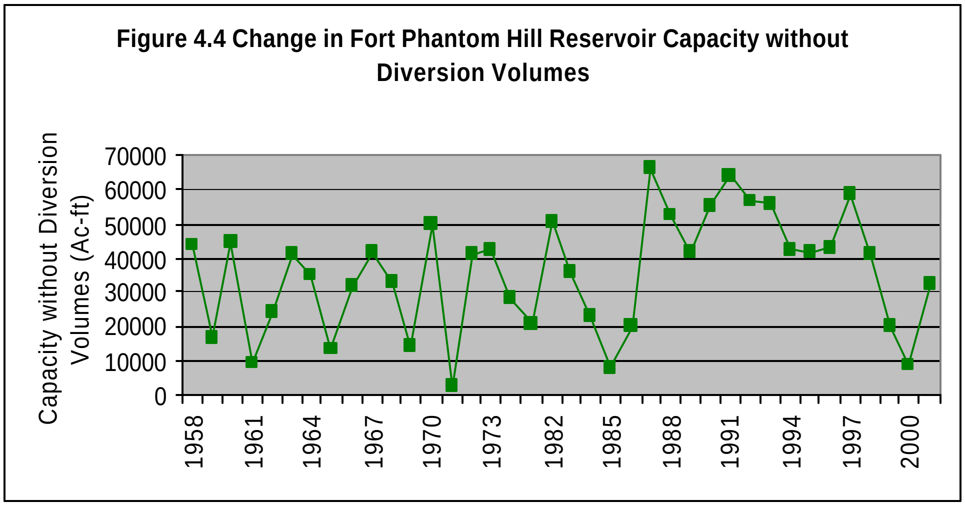
Historical capacity levels of the Fort Phantom Hill Reservoir were determined from records of lake levels, diversions, and estimated evaporation losses. To determine changes in natural inflow to reservoir, diversions made from Deadman's Creek and the Clear Fork of the Brazos River were deducted from the capacity. No significant change in reservoir capacity over time from 1958 to 2001 was identified when diversion volumes were removed from consideration (Figure 4.4). Data from 1950 through 1957 were removed from this evaluation due to the record drought that oc-

Figure 4.3. Fort Phantom Hill Reservoir Evaporation vs. Temperature



curred during this time period and skewed the data.

There is a lack of recent flow data for the tributaries to the Fort Phantom Hill Reservoir with no active USGS Gauging Station in the watershed. However, there is some historical flow data on several tributaries in the watershed.



Flow in Cat Claw Creek (USGS Station 08083420) was monitored daily by the USGS from October 1970 through September 1979. During this time period the minimum flow measured in Cat Claw Creek was 0.0 cfs, the maximum flow measured was 480 cfs, with an average measured flow of 2.5 cfs. No significant trend towards increasing or decreasing flows was observed in the creek during the period of measurement. Analysis of the flow pattern of the creek at this location reveals that the creek flow is intermittent with flow occurring approximately 24 percent of the time. The remaining 76 percent of the time the creek experienced no flow conditions.

Flow in Cedar Creek (USGS Station 08083470) was monitored daily by the USGS from October 1970 to October 1984. During this time period the minimum flow measured in Cedar Creek was 0.0 cfs, the maximum flow measured was 7,820 cfs, with an average measured flow of 7.1 cfs. Again, no significant trend towards increasing or decreasing flows was observed in the creek during the period of measurement. There is flow in Elm Creek at this location approximately 84 percent of the time. The remaining 16 percent of the time the creek experienced no flow conditions. The majority of the flow of Elm Creek at this location is between 10 cfs and 100 cfs, with values within this range being measured approximately 75% of the time.

Flow in Cedar Creek at IH-20 in Abilene (USGS Station 08083480) was monitored for four months in 2001 between June and September. During this time period the minimum flow measured at this station was 0.0 cfs, the maximum flow measured was 67.0 cfs, with an average measured flow of 1.68 cfs. Analysis of the flow pattern of the creek at this location reveals that the creek flow is intermittent with flow occurring approximately 32 percent of the time. The remaining 68 percent of the time this station experienced no flow conditions.

Flow in Little Elm Creek (USGS Station 08083400) was monitored daily by the USGS from October 1963 through September 1979. During this time period the minimum flow measured in Little Elm Creek was 0.0 cfs, the maximum flow measured was 948 cfs, with an average measured flow of 2.1 cfs. Again, no significant trend towards increasing or decreasing flows was observed in the creek during the period of measurement. Analysis of the flow pattern of the creek at this location reveals that the creek flow is intermittent with flow occurring approximately 20 percent of the time. The remaining 80 percent of the time the creek experienced no flow conditions.

Flow in Elm Creek has been monitored daily at two locations: Elm Creek near Abilene (USGS Station 08083300) and Elm Creek at Abilene, TX (USGS Station08083430). Elm Creek near Abilene was monitored by the USGS from October 1963 through September 1979. During this time period the minimum flow measured in Elm Creek at this location was 0.0 cfs, the maximum flow measured was 1,630 cfs, with an average measured flow of 9.8 cfs. No significant trend towards increasing or decreasing flows was observed in the creek during the period of measurement. Analysis of the flow pattern of the creek at this location reveals that the creek flow is intermittent with flow occurring approximately 55 percent of the time. The remaining 45 percent of the time the creek experienced no flow conditions. The majority of the flow of Elm Creek at this location is between 10 cfs and 100 cfs, with values within this range being measured 40% of the time.

Elm Creek at Abilene, TX was monitored by the USGS from October 1979 through September 83. During this time period the minimum flow measured in Elm Creek at this location was 0.0 cfs, the maximum flow measured was 3,980 cfs, with an average measured flow of 18.9 cfs. No significant trend towards increasing or decreasing flows was observed in the creek during the period of measurement. There is flow in Elm Creek at this location approximately 98 percent of the time. The remaining 2 percent of the time the creek experienced no flow conditions. The majority of the flow of Elm Creek at this location is between 10 cfs and 100 cfs, with values within this range being measured approximately 85% of the time.

Due to the highly intermittent nature of stream flow in the watershed, the watershed's strong correlation between reservoir capacity and precipitation, and the watershed's dependence on diversions of water from other watersheds indicate that there is little groundwater discharge into the watershed. The short duration for which quantitative stream flow data is available inhibits the ability to determine if a significant correlation exists between brush infestation and reduced basin yields.

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 Jones and Taylor 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

Since groundwater contributes to the available water supply in the watershed, water level data in Taylor and Jones 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 Taylor and Jones Counties. A total of 11 water wells having 20 or more years of data available were identified in four of the geologic formations which transect the watershed. These wells were examined to determine if net water level changes have occurred for the individual wells.

One well in the Choza Formation showed no net change in water levels, while one well showed a net water level gain, with a gain of approximately 1.35 feet (Figure 4.5). Two wells in the Antlers

Sand formation revealed no net changes in water levels and two wells showed significant water declines, with an average loss per well of 8.5 feet (Figure 4.6 and 4.7). Of two wells identified in the Seymour Formation one experienced no net change in water level and one experienced a significant decline in water level of approximately 7.0 feet (Figure 4.8). Three wells were identified in the Quaternary Alluvium. All three wells in the Quaternary Alluvium have experienced significant declines in water level with an average loss per well of 3.0 feet (Figure 4.9).

Natural water level changes in an aquifer are mainly due to changes in the groundwater recharge/discharge conditions of the aquifer. Figures 4.5, 4.6, 4.7 and 4.8 show water level fluctuations in the individual wells over time. Decreasing water levels in some of the wells may be attributed to increased demand for ground water and increased urbanization around the City of Abilene, which reduces

Figure 4.5 Change in Water Well Levels in the Choza Formation

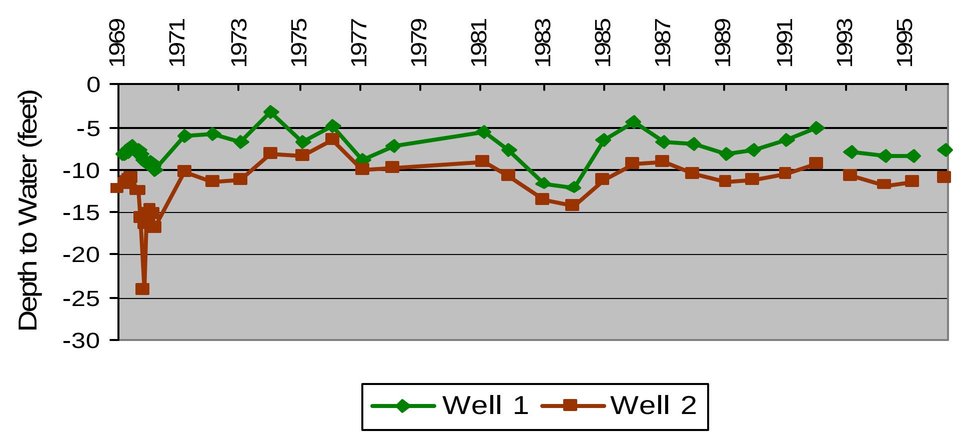


Figure 4.6 Changes in Water Well Levels in the Antlers Sand Formation

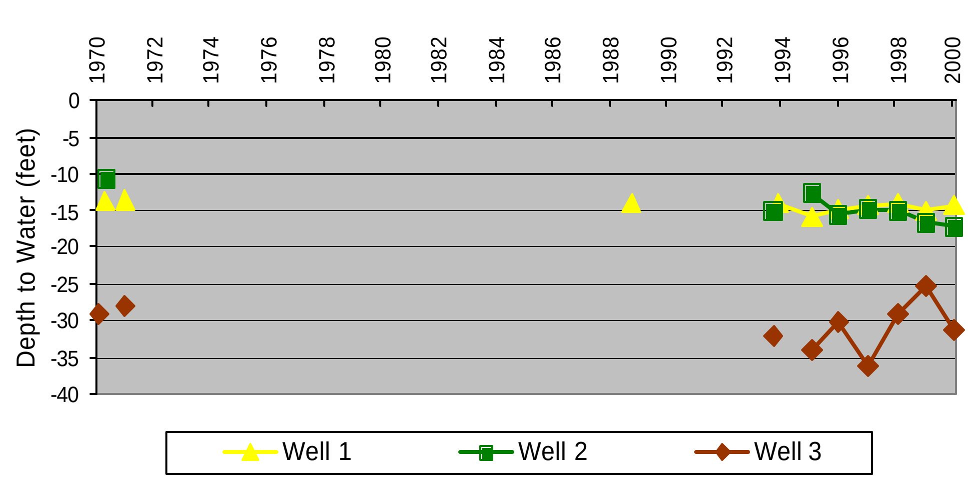
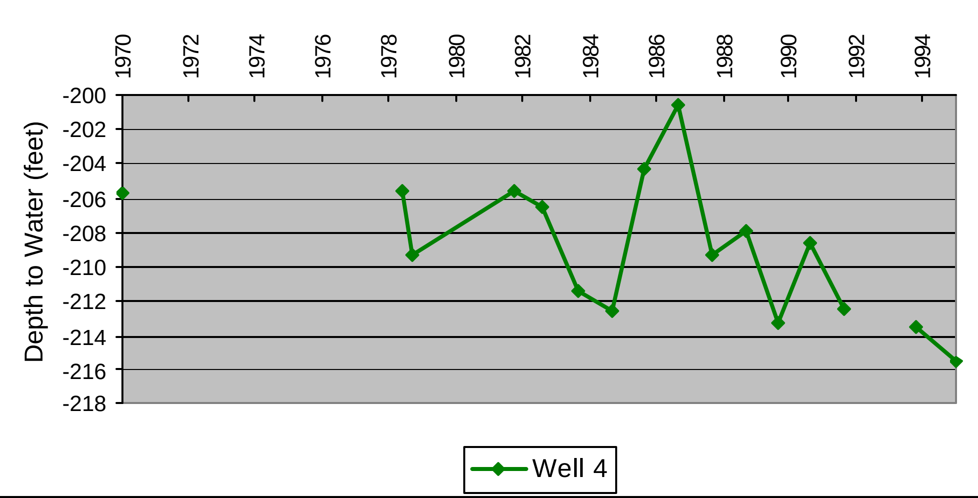


Figure 4.7 Changes in Water Well Levels in the Antlers Sand Formation



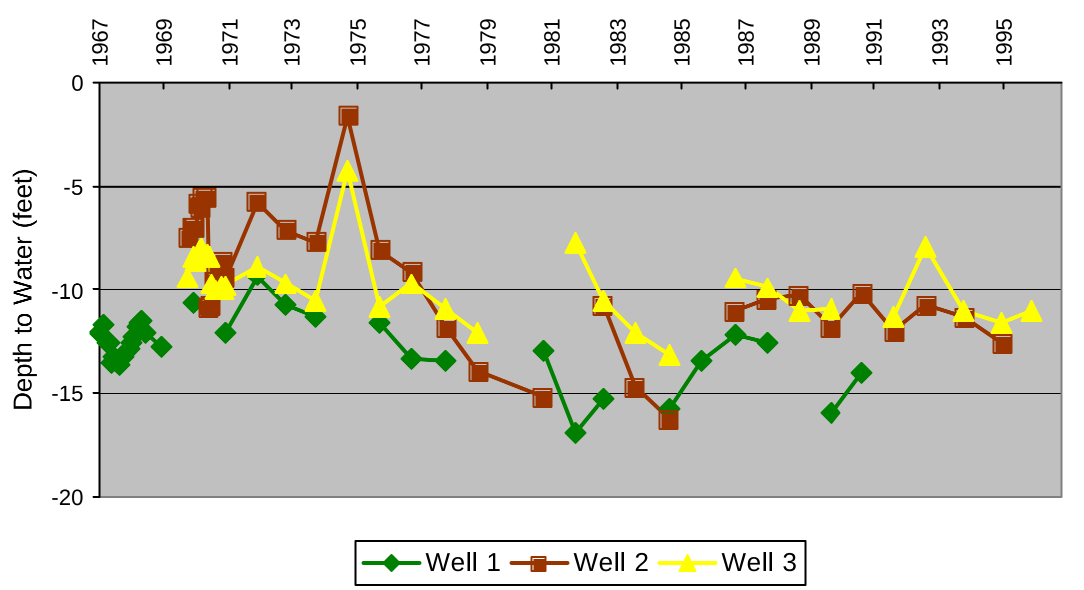
the available recharge zone surface area.

Geology

Underlying rocks representing various geologic systems are present in the watershed. In ascending order, rocks of the Precambrian, Cambrian, Ordovician, Mississippian, and Pennsylvanian Systems are present in the watershed; sediments of the Permian, Cretaceous, and Quarternary are exposed at the surface (Price 1978, Taylor 1978).

Figure 4.8 Change in Water Well Levels in the Seymour Formation

Figure 4.9 Changes in Water Well Levels in the Quarternary Alluvium



In the watershed rocks of the Precambrian age are composed primarily of granite, schist, and gneiss. The Cambrian sediments contain mostly dolomitic limestone with some sandstone. Deposits of Ordovician and Mississippian consists mostly of dolomite, dolomitic limestone, and limestone, with some chert and shale. The Pennsylvanian contains sands, limestone and thick sequences of shale (Price 1978, Taylor 1978).

All water in the rocks from the Cambrian to the Upper Permian contain only brine (Price 1978, Taylor 1978).

Permian sediments of the Lueders, Arroyo, Vale, and Choza Formations occur at the surface of the watershed. These rocks attain a total thickness of about 1,600 feet and form part or all of the

Clear Fork River Group. The Lueders Formation contains the only known potable water in this group and outcrops in the eastern part of the watershed (Price 1978, Taylor 1978).

The Cretaceous deposits of the watershed are composed of the Fredericksburg Group. The-Group yields fresh water in small quantities to scattered wells in the southern portion of the watershed (Price 1978, Taylor 1978).

Sand, silt, and gravel, with varying amounts of clay, form a thin mantle which rests unconformably on Permian beds in much of the northern half of the watershed. Many of these deposits are assigned to the Seymour Formation, whereas others are believed to be younger Pleistocene (Price 1978, Taylor 1978).

Alluvial deposits composed of fine sand, silt, clay, and gravel occur in and border many of the streambeds in the watershed. These stream deposits are derived from older Pleistocene sediments as well as Cretaceous and Permian rocks. These rocks yield fresh to moderately saline water in small to moderate quantities to wells in the watershed (Price 1978, Taylor 1978).

Existing Surface Water Hydrology

The hydrologic characteristics of the Fort Phantom Hill 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. Stream flow measurements began in the river basin in 1950, and show that there has been a drought in almost every decade since then. Average monthly inflows into the reservoir range from approximately 51,450 ac-ft in June to about 45,500 in February and March. The watershed has varying topography with steep channels in the southern and western portions of the watershed and flat slopping channels in the northeast, which results in rapid runoff and flash floods during intense rain events. The average annual runoff into Fort Phantom Hill Reservoir from 1950 through 1973 was 28,800 acre-feet.

The tributaries and reservoirs of the watershed are classified by the Texas Commission on Environmental Quality (TCEQ) as suitable for contact recreation, aquatic life, and public water supply. Overall, the quality of 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. With row crop agriculture and urban expansion from the City of Abilene, the potential for increased levels of anthropogenic compounds entering the streams and reservoirs increases. Due to the watershed's high dependency on precipitation for surface water supply and declining groundwater well quantities, protecting the watershed from nonpoint source pollution is imperative.

Existing Groundwater Hydrology

The three important aquifers within the watershed are the Edwards-Trinity Aquifer in the west, the Trinity Aquifer in the east, and the alluvial aquifer in the lower central portion of the watershed. The Edwards-Trinity Aquifer is in carbonate and clastic rocks of Cretaceous age in a 77,000 square-mile area, which extends from southeastern Oklahoma to western Texas. 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 Edwards-Trinity and the Trinity aquifers are stratigraphically equivalent in part and are hydraulically connected in some places; however, the groundwater flow systems and permeability of the two aquifers are sufficiently different to allow them to be separately described.

The alluvial deposits in the watershed are the aquifer from which the most water is withdrawn in the watershed. A total of 219 wells, which produce or have produced, from this aquifer were identified in Taylor County. Deposits of alluvium are found in the channels and small flood plains of most of the tributaries to Fort Phantom Hill Reservoir. The maximum thickness of this aquifer is believed to be about 30 feet (Taylor 1978). The alluvium derives its water through direct rainfall, runoff, and seepage from lakes and streams. Groundwater occurs in the alluvium of most of the drainage tributaries to Fort Phantom Hill Reservoir. Elm Creek alluvium, found in coarse-grained sands and gravel, yield is sufficient to be the high demand required for irrigation of crops.

The general direction of movement of groundwater in the watershed is northerly towards Fort Phantom Hill Reservoir. The slope of the water table in the alluvium in the watershed is directly correlated to the slope of the land. However, localized pumping can cause the water in the immediate area of the pumping to move towards these points of artificial discharge instead of towards Fort Phantom Hill Reservoir. The main sources of recharge to the aquifer is precipitation falling directly on the outcrop and surface runoff; however, in areas of irrigation the water used can also serve as a source of recharge if it infiltrates the alluvium. Because natural discharge through springs is not known in the watershed, groundwater discharge from the alluvium is a result of pumping.

Use of ground water from wells and springs is reported as early as the 1880s in Taylor County. The earliest known irrigation with alluvium groundwater was the mid-1940s along Elm Creek (Taylor 1978). In the watershed, irrigation pumping has increased steadily since the mid-1940s.

Water level fluctuations in the alluvial aquifer follow a general pattern of declining levels through summer, a stasis point through winter, and a period of recharge and increasing levels in the spring. As indicated previously, it appears that the water level in the alluvium of the watershed is experiencing a gradual decline with time. This is most likely a result of the increased pumping volume in the area.

In the watershed, both the Edwards-Trinity and Trinity Aquifers consist of the Fredericksburg Group and the Antlers Formation. The Cretaceous rock of the Edwards-Trinity and Trinity Aquifers were once connected and covered all of the Nolan, Taylor, and Callahan Counties along with all of the area to the south and east to the Llano Uplift. Erosion has separated these rocks into two areas: the Cretaceous rocks to the west of Buffalo Gap are part of the Edwards-Trinity Aquifer and the Cretaceous rocks to the east of Buffalo Gap are part of the Trinity Aquifer. The Antlers Formation is believed to attain a thickness of approximately 200 feet in Taylor County (Taylor 1978).

The Antlers Formation is considered to be the most important aquifer in the watershed, after the alluvium, due to its large area and reliability as a source for potable water.

The source of groundwater and recharge to the aquifer is precipitation falling directly onto the Createaceous rocks. The water table in this formation is highest in the Edwards-Trinity Aquifer portion of the formation. The water movement in this formation in both aquifers is outward from the central parts of the outlying rock towards streams. Some discharge from the formation is lost to the Permian rocks on which it sits and to the alluvium. Additionally, many wells located on both aquifers represent points of artificial discharge.

Fluctuations in water level occur in the Antlers Formation in both the Edwards-Trinity and Trinity Aquifers with no apparent pattern, while the use of this water has remained fairly constant. In above-average rainfall calendar years additional groundwater may be available in this formation but its dependency on precipitation does not make the additional yield a reliable water source.

The Fredericksburg Group rocks make up the "cap rock" for the mesas and buttes in the southern part of the watershed and its reliability as a water supply is considered poor. The main source of recharge for this group is precipitation on the outcrop. Groundwater in the group is held in solution channels within the limestone and to a lesser extent in the thin layers of interbedded soft shales (Taylor 1978). Discharge of ground water from the group occurs naturally, through intermittent springs, and artificially through wells.

The Choza Formation, formed of Permian rock, is present only in the Edwards-Trinity Aquifer and yields a limited amount of groundwater for irrigation. It has been reported that some wells used for public in Merkel pumped mud during the drought of the early 1950s. This indicates that the Choza is not dependable for continued heavy withdrawals during periods of drought (Taylor 1978). Precipitation on the outcrop is the major source of groundwater for the formation. Discharge from the overlying Antlers formation and alluvium are other sources of recharge for the formation. Groundwater occurs in the formation in solution channels and fractures of dolomitic limestone and in sandstone lenses. The water in the formation moves down gradient to areas of natural discharge and to points of artificial discharge. Insufficient data is available regarding changes in water levels over time in this formation.

The Arroyo Formation is a water bearing formation of Permian rocks, which is independent on both aquifers, in the northeast portion of the watershed. The primary source of recharge to the formation is precipitation on the outcrop area and some discharge from overlying Cretaceaous rocks and alluvium. Groundwater occurs in solution cavities and fractures within the thin limestone beds. Movement of the groundwater is down gradient to points of discharge. The yield of this formation is believed to be too small for even irrigation use (Taylor 1978).

The Vale formation is another water bearing Permian formation independent of the two aquifers. The Vale formation runs through the central portion of the watershed. The source of recharge for the formation is primarily precipitation on its outcrop. In localized areas, recharge may be contributed from overlying Cretaceous and Quaternary rocks. Groundwater occurs in dolomitic limestone in solution fractures and in lenses in sandstone. Movement of the groundwater is down gradient to discharge areas. The only known method of discharge from the Vale Formation is through well pumping (Taylor 1978).

Annual groundwater discharge in the Fort Phantom Hill Reservoir watershed can vary considerably depending on the amount, frequency, and distribution of precipitation. Groundwater levels, storage, and natural discharge increase during periods of high recharge. Conversely, during periods of low recharge, groundwater levels decline, storage is reduced, and natural discharge ceases. When groundwater levels and the land surface are at equal elevations, groundwater in the watershed can discharge at seeps and springs.

Water wells are the only means of artificial discharge in the watershed. Significant amounts of water are withdrawn from the Cretaceous and Paleozoic aquifers throughout the watershed for use by rural subdivisions, unincorporated communities, and individuals for domestic, livestock, and irrigation use.

Description of the Hydrologic System

The hydrologic system of the Fort Phantom Hill Reservoir watershed is greatly changed from that encountered by the first European settlers to the region. Four reservoirs have been constructed in the watershed, diversion of water into the watershed occur frequently, 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 declining alluvial aquifer levels and intermittent springs it is unlikely that a significant amount of surface water in the Fort Phantom Hill Reservoir watershed is derived from groundwater. Nearly all of the initial flow in the tributaries to Fort Phantom Hill 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 irrigation withdrawals. Discharge from the watershed occurs as streamflow into the Clear Fork of the Brazos River basin, as artificial surface water and groundwater withdrawals, as groundwater crossing the downgradient boundary of the watershed, and as returns to the atmosphere through evapotranspiration. Additionally, as alluvial water levels decline, water may flow from the streams and reservoirs into the alluvial deposits. Diversions of water from other watersheds into Fort Phantom Hill Reservoir help keep the capacity of the reservoir relatively static.

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 Jones and Taylor Counties now consume approximately 34,000 acre-feet of water each year, with 82 percent used for municipal uses, 8 percent used industrial uses, and 10 percent used for agricultural uses. Water demand in Jones and Taylor Counties is expected to increase by approximately 36,000 acre-feet by 2050. Current groundwater and surface water supplies in the Fort Phantom Hill Reservoir watershed are insufficient to meet current needs without diversions of water from other watersheds. The watersheds and area groundwater yields will be grossly inadequate to meet projected demands in the future. About 80 percent of the Jones and Taylor Counties 136,000 people are currently concentrated in the growing Abilene area. By 2050, the population of the area as a whole is expected to increase by 61 percent.

As the demand for water increases throughout the Brazos River basin, Jones and Taylor Counties may experience water supply problems due to competition for water and infrastructure limitations. Currently the communities of Merkel and Tye in Taylor County and Hamlin in Jones County are water short due to limited surface water availability and conveyance capacity. Jones County is projected to experience a county wide shortage of water for municipal and industrial uses as early as 2010. The City of Abilene is projected to see shortages in supply by 2020 due to lack of surface water and lack of infrastructure to Lake O.H. Ivie. Additionally, Taylor County is expected to see both short- and long-term shortages for manufacturing, mining, and irrigation. Possible solutions to the water shortages in the two counties include:

- Wastewater reuse;
- Reservoir construction at Breckenridge;
- Redistribution of water supply from communities with surplus to communities with shortages;
- Construct pipeline from O.H. Ivie Reservoir to City of Abilene;
- Bring water to the area from Possum Kingdom Reservoir through the Kerr-McGee pipeline;
- Develop an Aquifer Storage and Recovery System for the Seymour Aquifer in Jones County; and
- Brush control in the watershed.

5.0 SUMMARY AND CONCLUSIONS

This evaluation of the hydrology of the Fort Phantom Hill 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 pattens 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 for an extended period of time. USGS gauging stations have been operated at many locations in the watershed but gauging at any one location has been limited to a maximum duration of 16 years.
- The available stream flow data reveal no major changes have occurred in stream characteristics during the period of record; however, the current intermittent nature of the streams 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, except for the alluvial aquifer in the watershed.
- The watershed is dependent on diversions of water from other stream systems. Without diversions from Deadman's Creek and the Clear Fork of the Brazos River, Fort Phantom Hill Reservoir would not be able to meet the current demands of the population of the watershed.
- Soils in the watershed are typically thin, formed of large particles, and conducive to groundwater recharge.
- Water supply shortages are a current problem for 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 both the streams and alluvial aquifer.
- While hydrological studies reveal that brush control in the Fort Phantom Hill Reservoir watershed is estimated to increase annual average water yields by only 111,000 gallons per treated acre, the cost of control is moderate and the need for water in this region is immediate. An organized brush control program will provide great benefit to this water poor region.
- It is recommended that the Texas Legislature commit to appropriate $10,189,417 to implement brush control practices in the Fort Phantom Hill watershed. Implementation should occur as soon as funding is available, 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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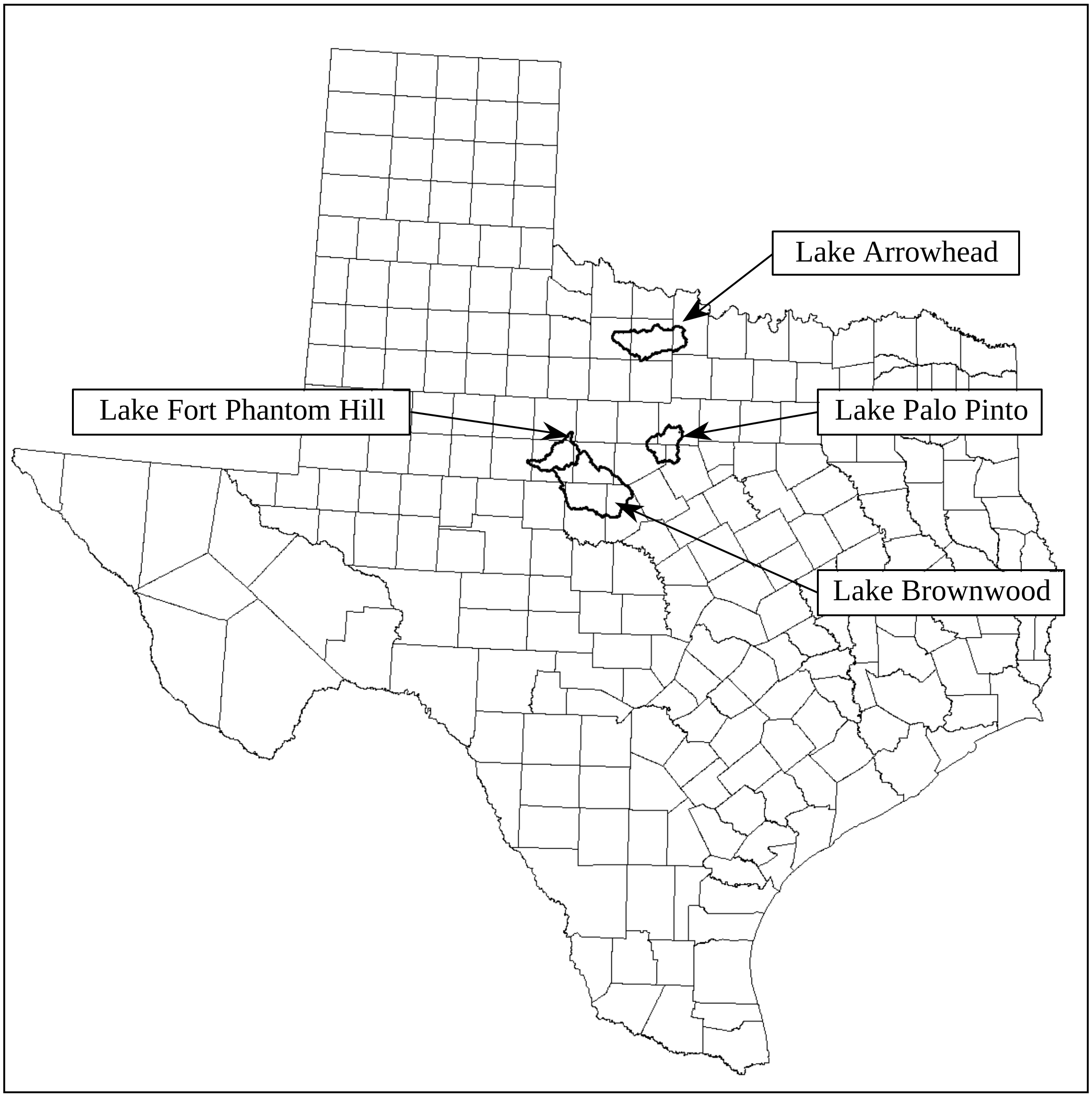

Figure 1-1. Watersheds included in the study area.

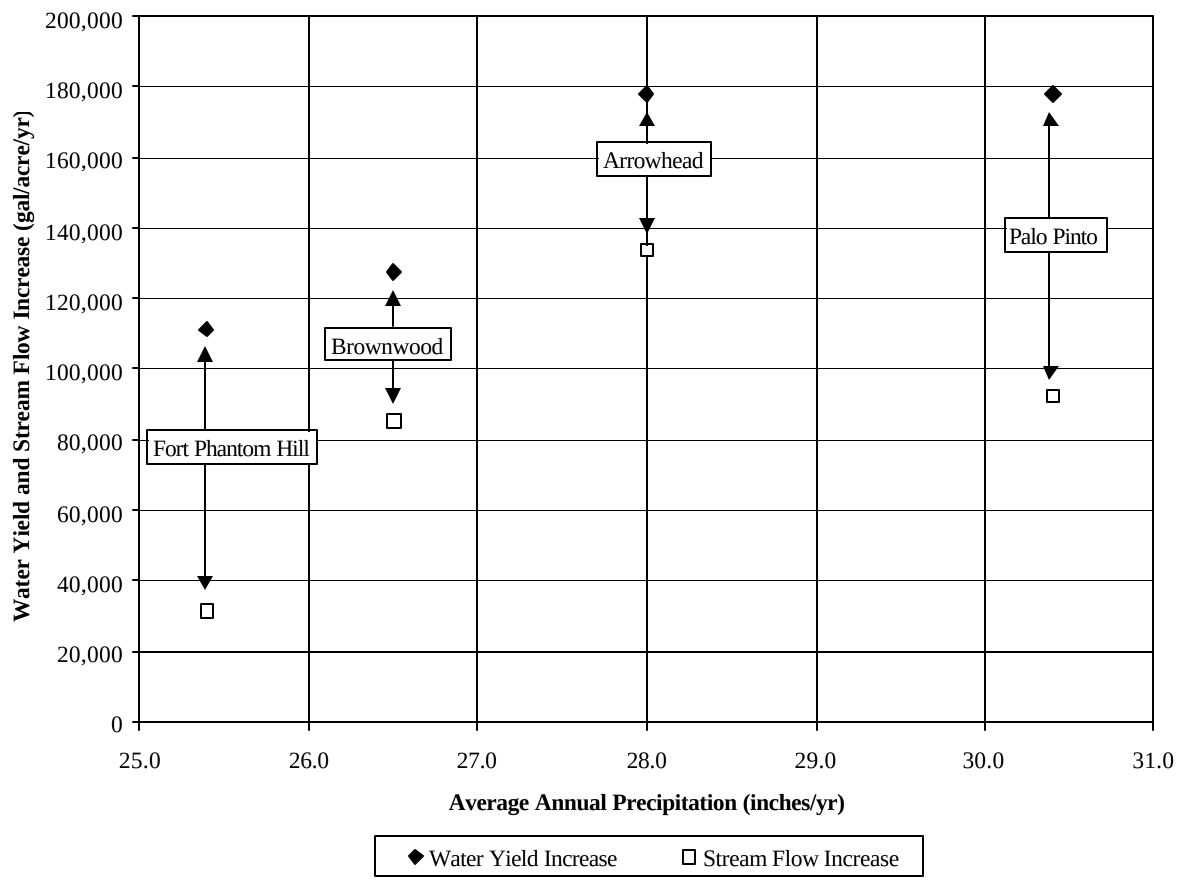

Figure 1-2. Average annual water yield and stream flow increases per treated acre versus average annual precipitation for watersheds in this study, 1960 through 1999.

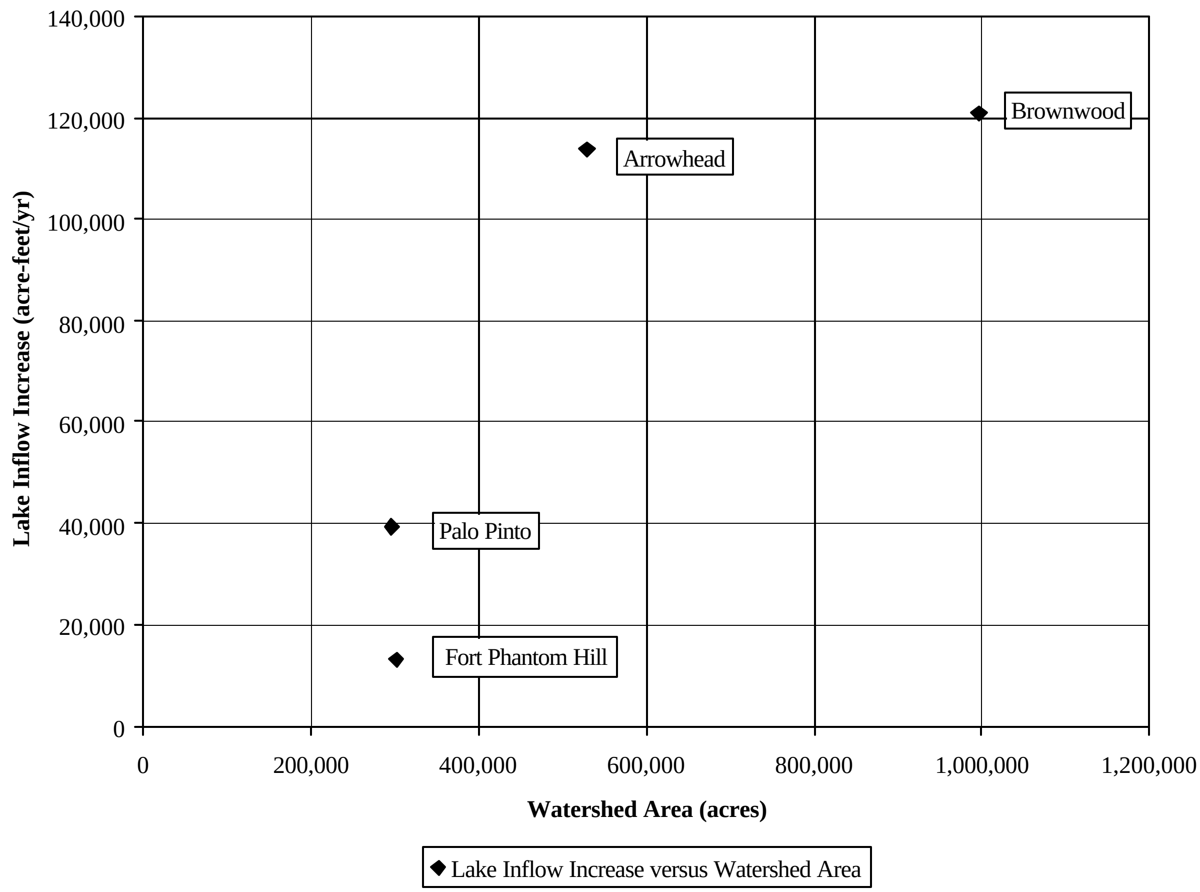

Figure 1-3. Average annual lake inflow increase resulting from brush removal versus watershed drainage area for watersheds in this study, 1960 through 1999.

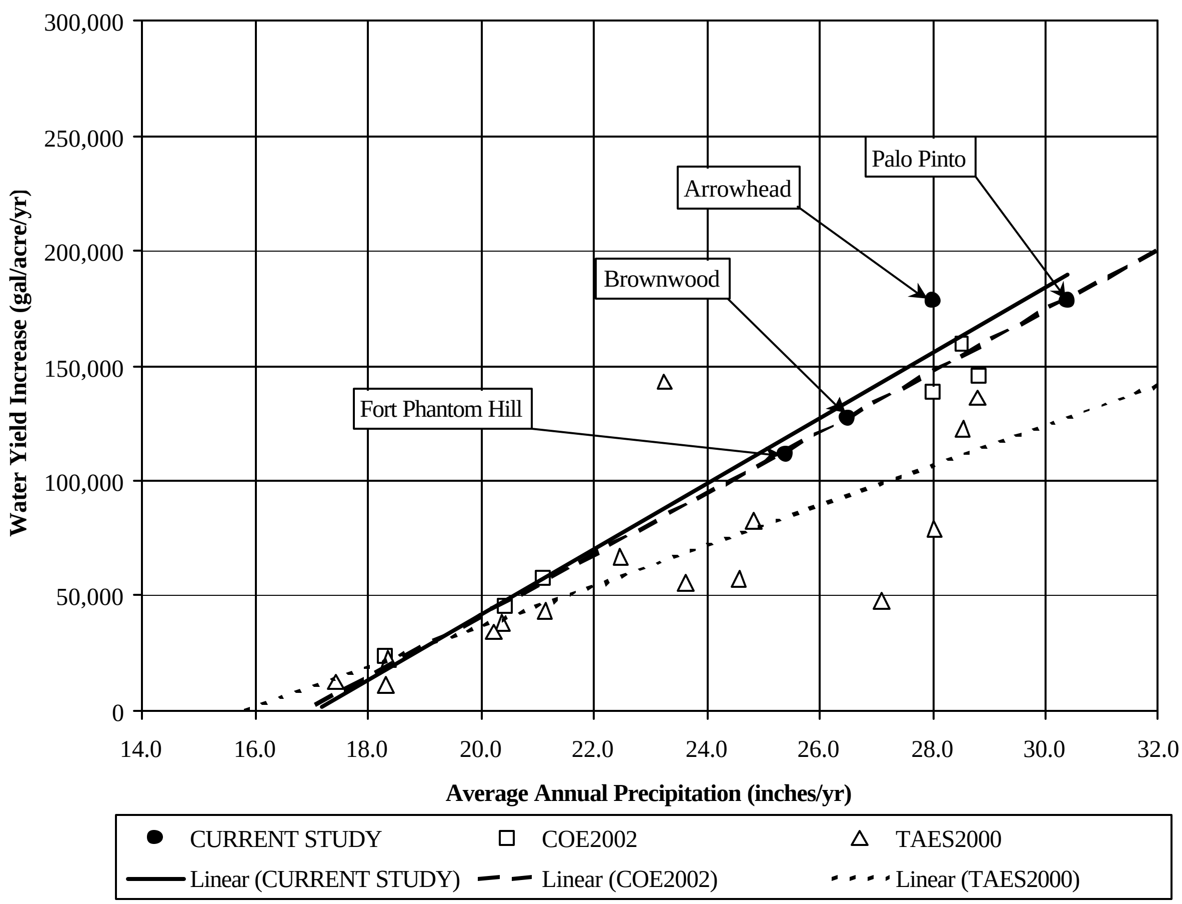

Figure 1-4. Water yield increase versus average annual precipitation - current study, COE (2002), and TAES (2000). Points are labeled for watersheds in current study.

APPENDIX B

FORT PHANTOM HILL RESERVOIR WATERSHED--HYDROLOGIC SIMULATION

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WATERSHED DATA

Physical Data

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

METHODS

Land Use/Land Cover

The land use map for the Ft. Phantom Hill and Lake Brownwood watersheds was derived from the classification of Landsat 7 imagery utilizing ground control points collected by local NRCS personnel. Software accuracy assessment based on ground control points was approximately 75%. Over 75% is in some type of rangeland or pasture cover. The amount of treatable brush (medium and heavy mesquite, cedar, and mixed brush) is 138,396 ac (216 mi^2) or 46.0% of the watershed (Table 7-2). The majority of the brush is located in the western and southern areas of the watershed. Some cultivated cropland is located in the eastern part of the watershed. Urban areas represent approximately 10% of the watershed area.

Soils

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

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

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

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

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

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

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

Topography

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

Geology

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

Climate

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

Ponds/Reservoirs

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

Model Inputs

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

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

Model Calibration

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

Brush Removal Simulation

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

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

RESULTS

Model Calibration

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

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

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

Brush Removal Simulation

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

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

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Table 7-1. SWAT Input Variables for Lake Fort Phantom Hill Watershed.

VARIABLE		ADJUSTMENT or VALUE
Runoff Curve Number Adjustment	(subbasins 1-8,10-13)	-7
	(subbasin 14, 15, 16)	-12
	(subbasin 9, 17)	-2
	(urban landuse--subbasins 1-17)	set 92
Soil Available Water Capacity (in H_20/in soil)	Tarrant	+ 0.05 (first layer)
	Miles	+ 0.05 (first layer)
	Tobosa	+ 0.05 (all layers)
	Shep	+ 0.02 (second layer)
Soil Crack Volume Factor	Tarrant	0.1
	Oplin	0.3
Soil Saturated Conductivity		None (default)
Soil Evaporation Compensation Factor		0.85
Minimum Shallow Aquifer Storage for Groundwater Flow (inches)		0.1
Minimum Shallow Aquifer Storage for Re-Evap (inches)		0.08
Shallow Aquifer Re-evaporation Coefficient	Brush	0.4
	All Others	0.1
Transmission Losses (inches/hour)	Subbasin	0.39
	Channel	1.0
Bank Coefficient		0
Reservoir ET coefficient		1.0
Reservoir seepage (inches/hour)		0.0039
Discharge Rate (cfs)	Lake Fort Phantom Hill	177
	Lake Abilene	706
	Like Kirby	247
Potential Heat Units for Land Cover (^{o}C-days)	Heavy Juniper	4300
	Heavy Mixed Brush	4000
	Heavy Mesquite, Heavy Oak, Moderate Juniper	3741
	Moderate Mesquite, Moderate Oak	3311
	Moderate Mixed Brush	3526
	Light Brush &Open Range	2974
Plant Rooting Depth (feet)	Heavy and Moderate Brush	6.5
	Light Brush and Open Range/Pasture	3.3
Maximum Leaf Area Index	Heavy Juniper	6
	Moderate Juniper	5
	Heavy Mesquite, Mixed Brush, Oak	4
	Moderate Mixed Brush, Oak	3
	Moderate Mesquite, Light Brush	2
	Open Range/Pasture	1

Table 7-2. Subbasin Data—Lake Ft. Phantom Hill Watershed.

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

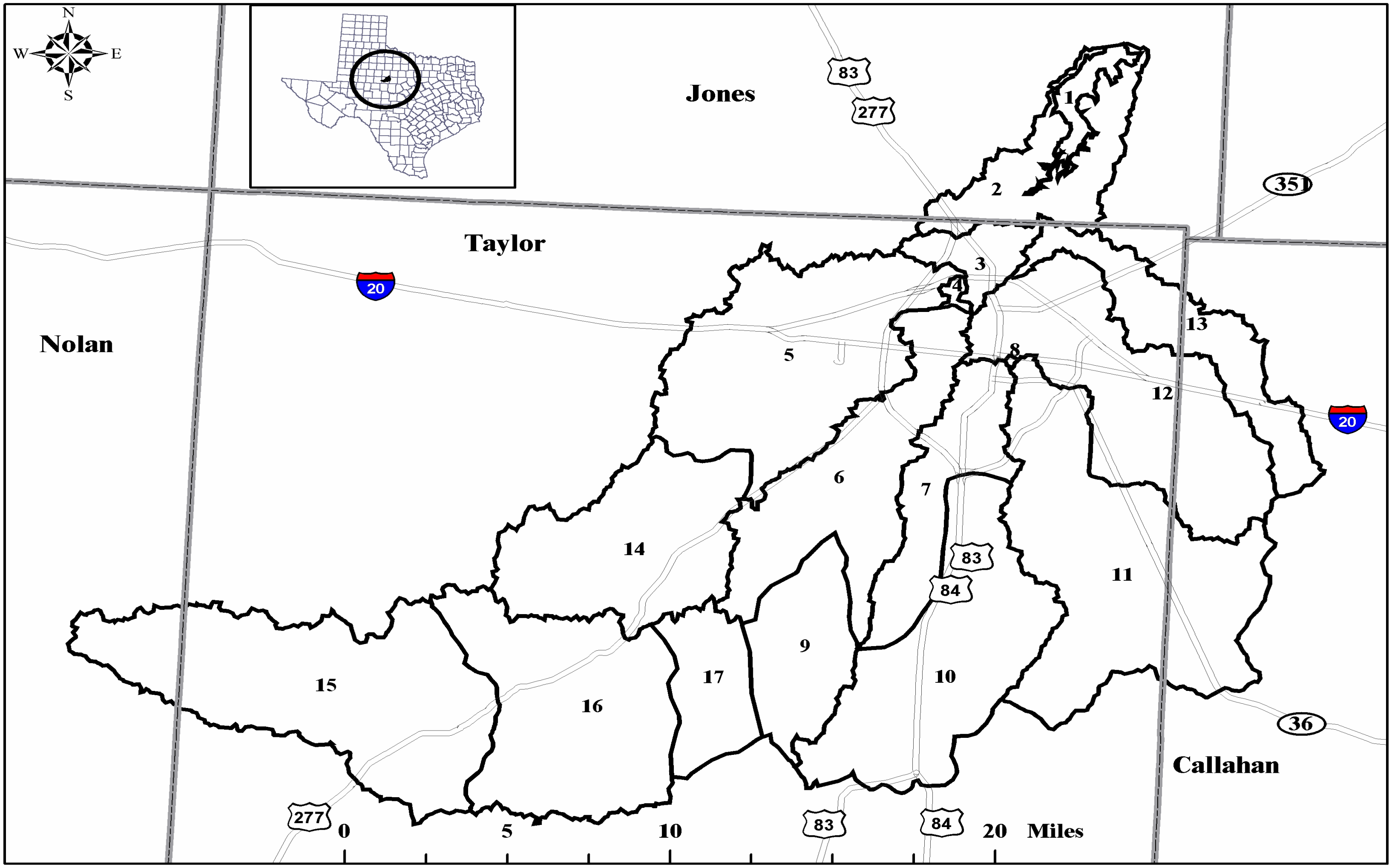

Figure 7-1. Subbasin map of the Lake Ft. Phantom Hill Watershed with major roads.

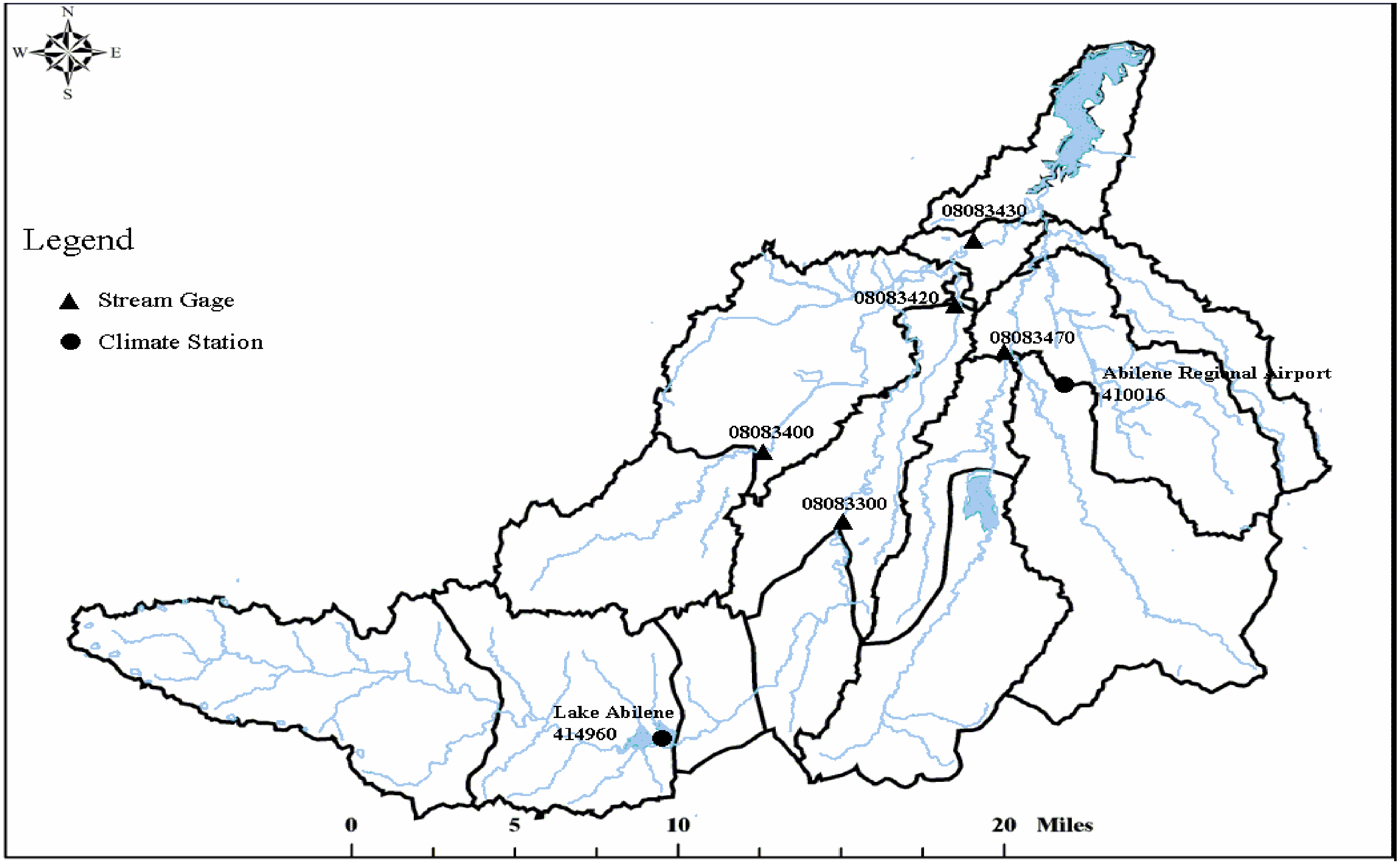

Figure 7-2. Climatic and Stream Gauge Station Locations in the Lake Ft. Phantom Hill watershed.

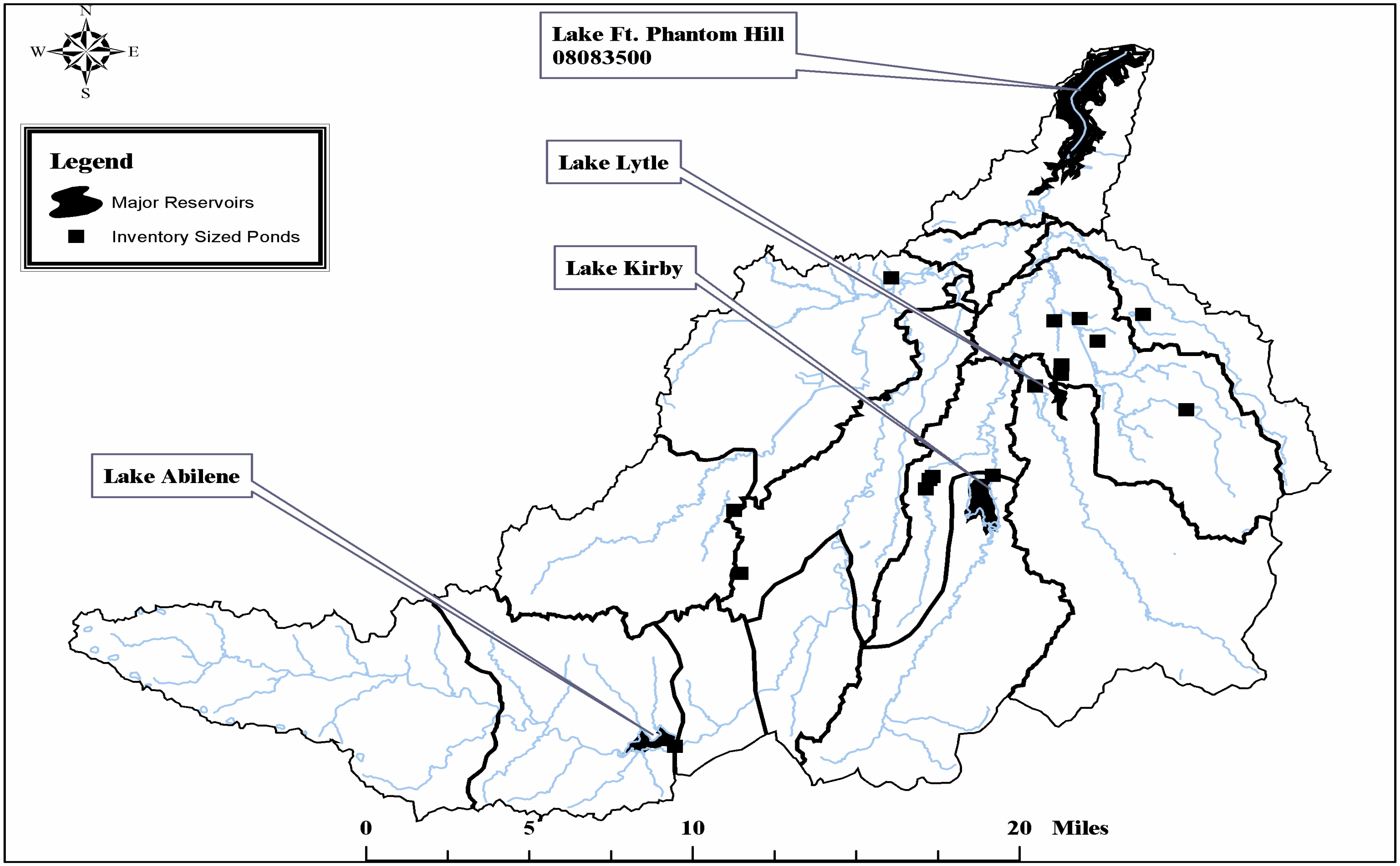

Figure 7-3. Inventory-Sized Ponds and Reservoirs in the Ft. Phantom Hill watershed.

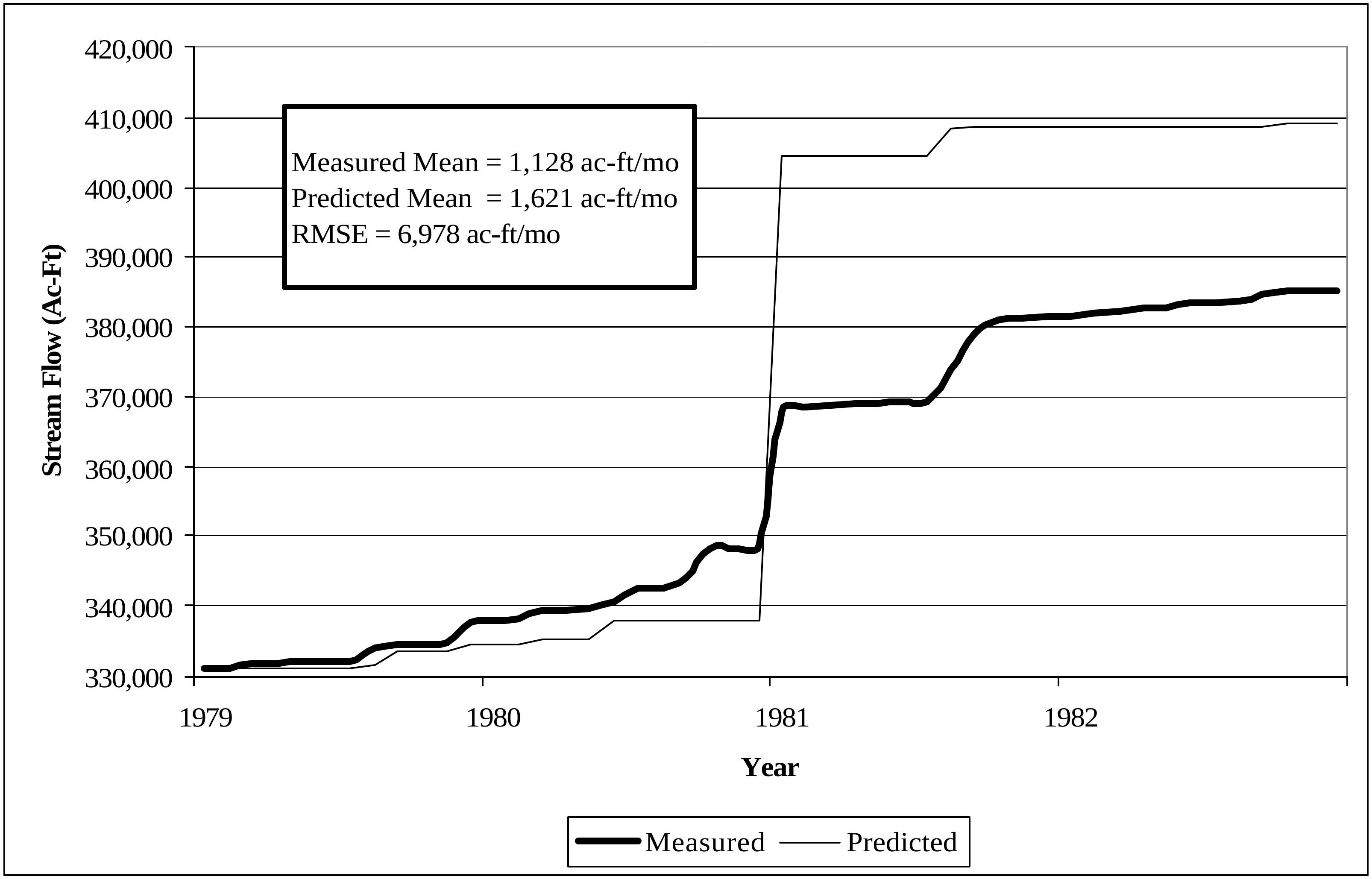

Figure 7-4. Cumulative monthly measured and predicted stream flow at gage 08083430 (Elm Creek), Lake Fort Phantom Hill Watershed, 1979 through 1983. Monthly statistics are shown in box.

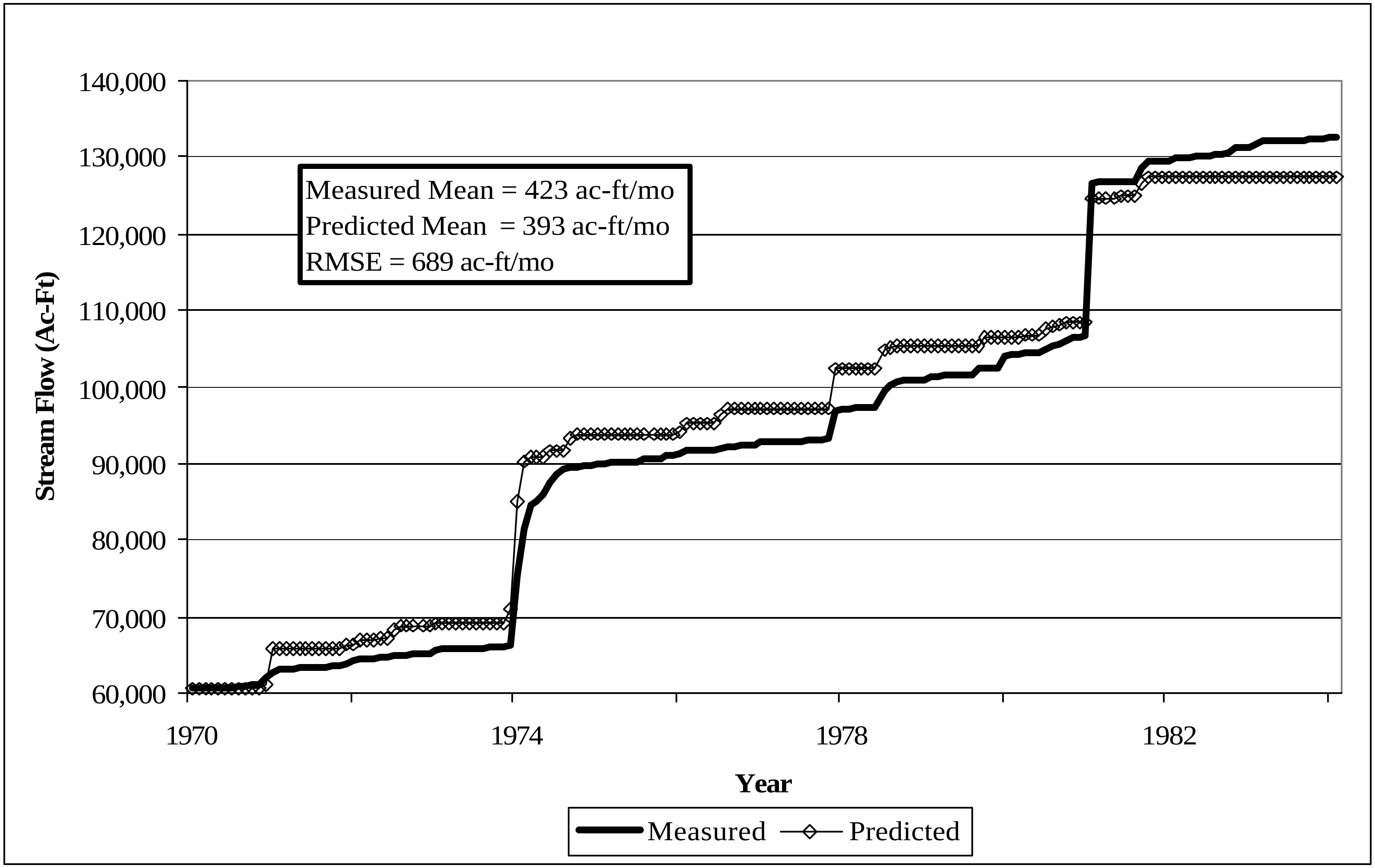

Figure 7-5. Cumulative monthly measured and predicted stream flow at gauge 08083470 (Cedar Creek), Lake Fort Phantom Hill Watershed, 1970 through1984. Monthly statistics are shown in box.

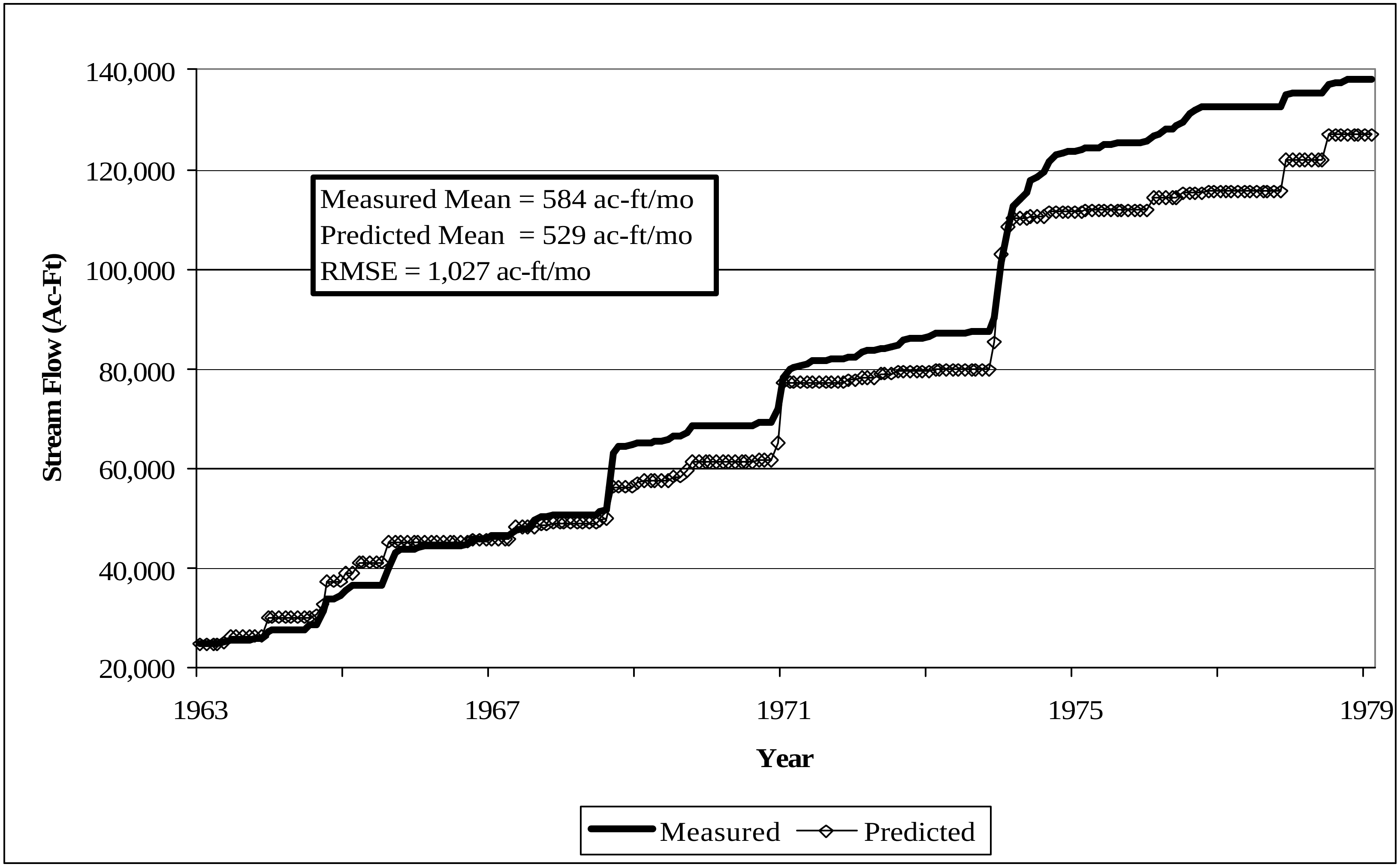

Figure 7-6. Cumulative monthly measured and predicted stream flow at gauge 08083300 (Elm Creek), Lake Fort Phantom Hill Watershed, 1963 through 1979. Monthly statistics are shown in box.

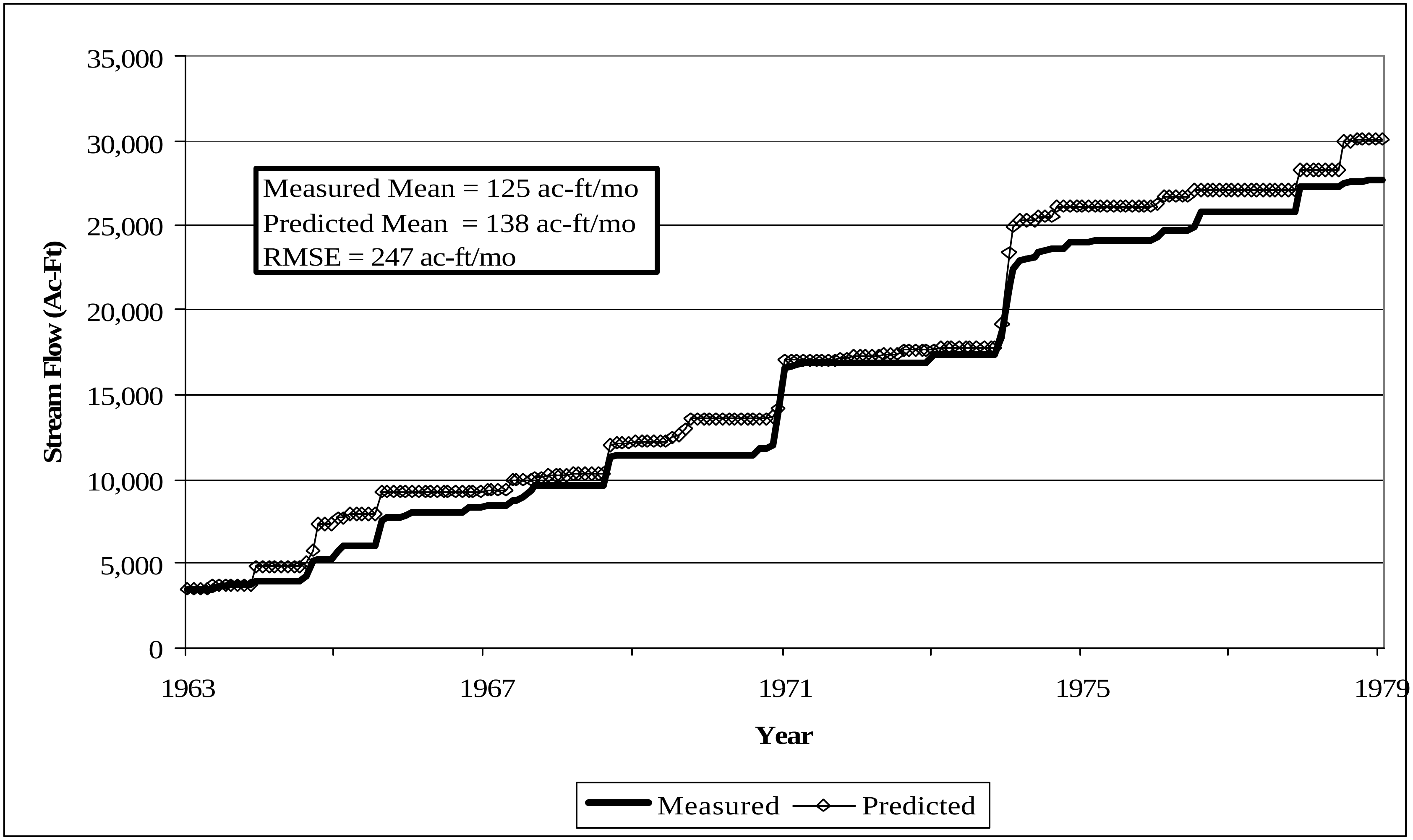

Figure 7-7. Cumulative monthly measured and predicted stream flow at gauge 08083400 (Little Elm Creek), Lake Fort Phantom Hill Watershed, 1963 through 1979. Monthly statistics are shown in box.

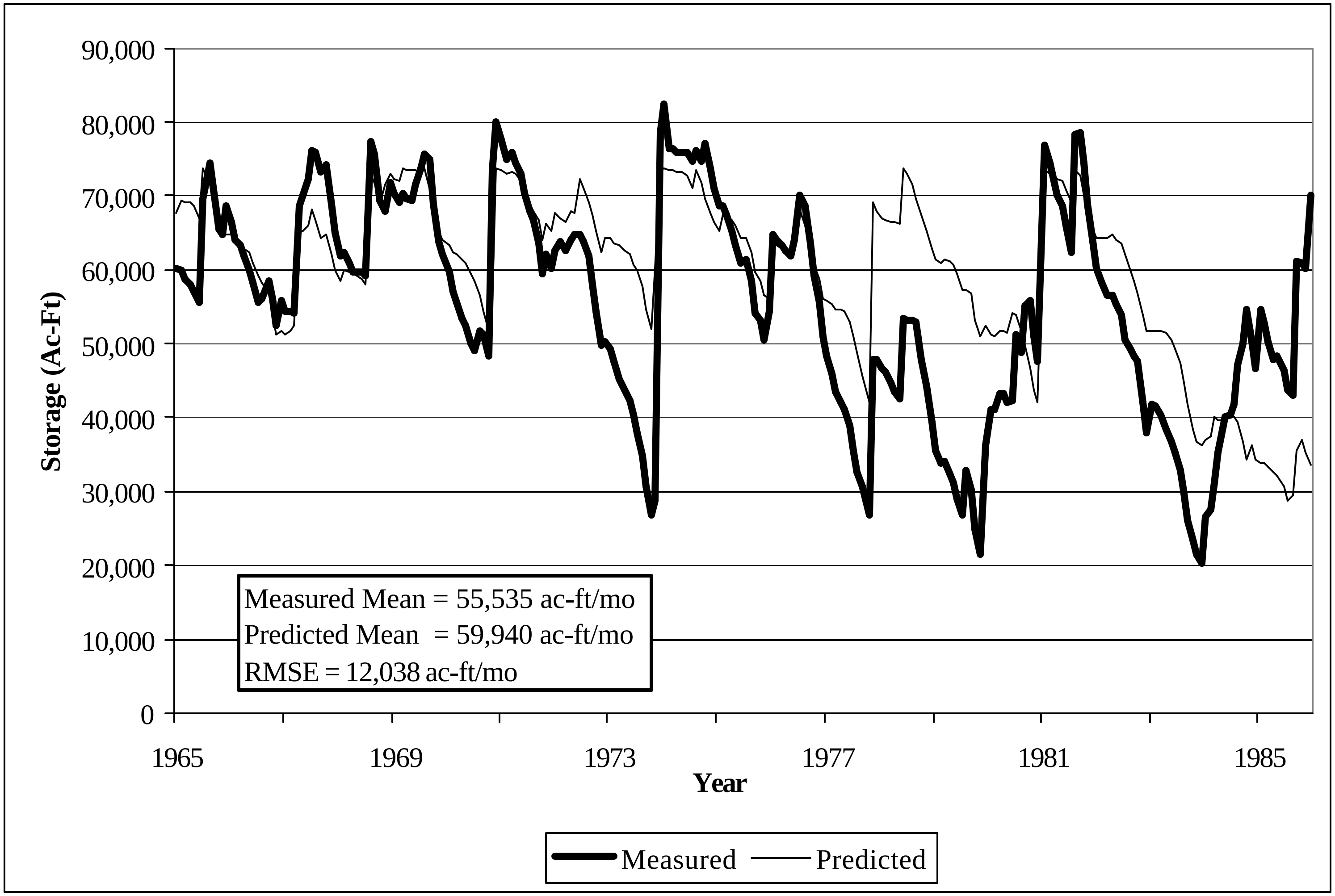

Figure 7-8. Monthly measured and predicted lake storage levels for Lake Ft. Phantom Hill (the recording period was from 1965-1986). Monthly statistics are in the box.

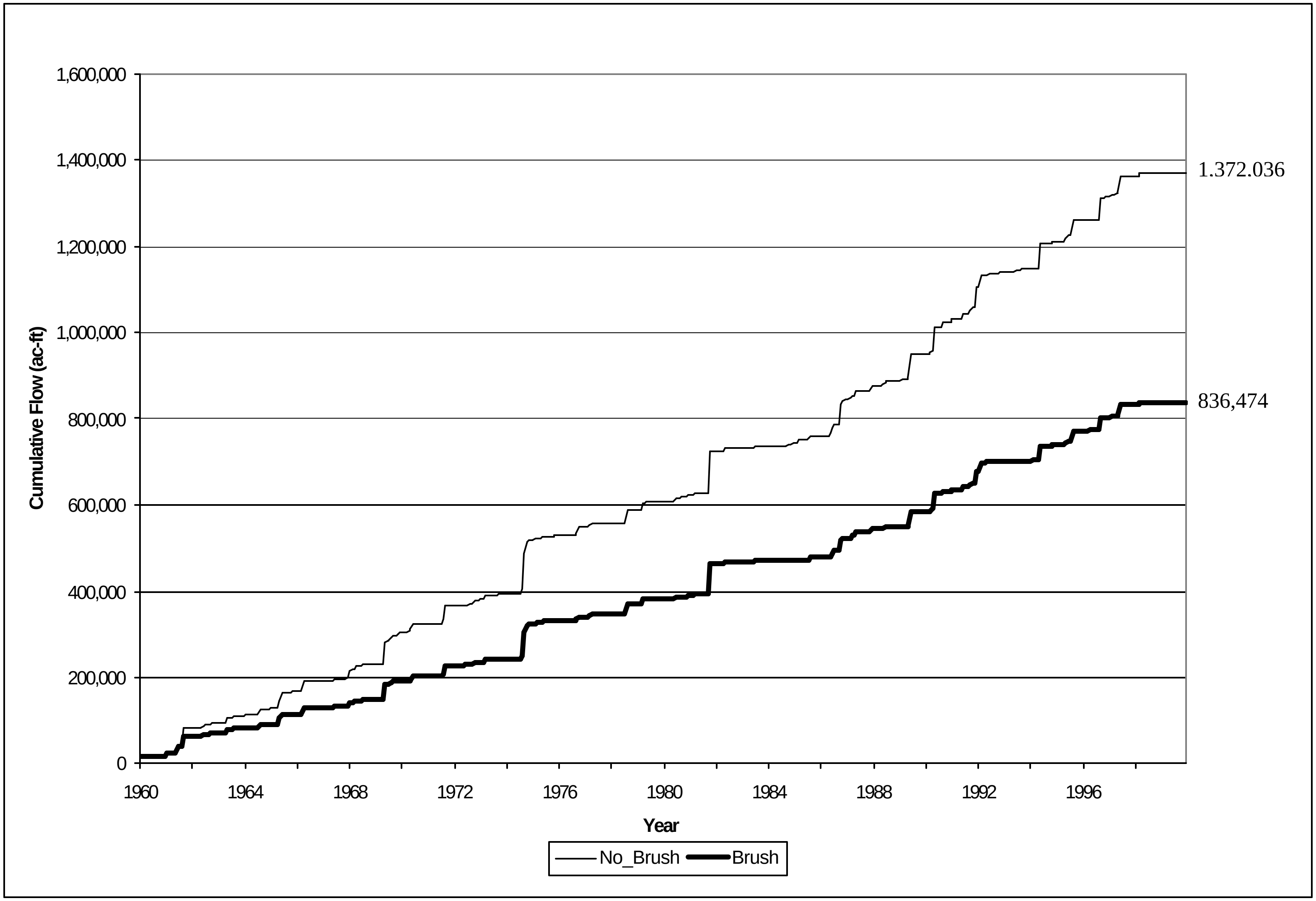

Figure 7-9. Predicted cumulative monthly stream flow into Lake Ft. Phantom Hill for brush and no-brush conditions.

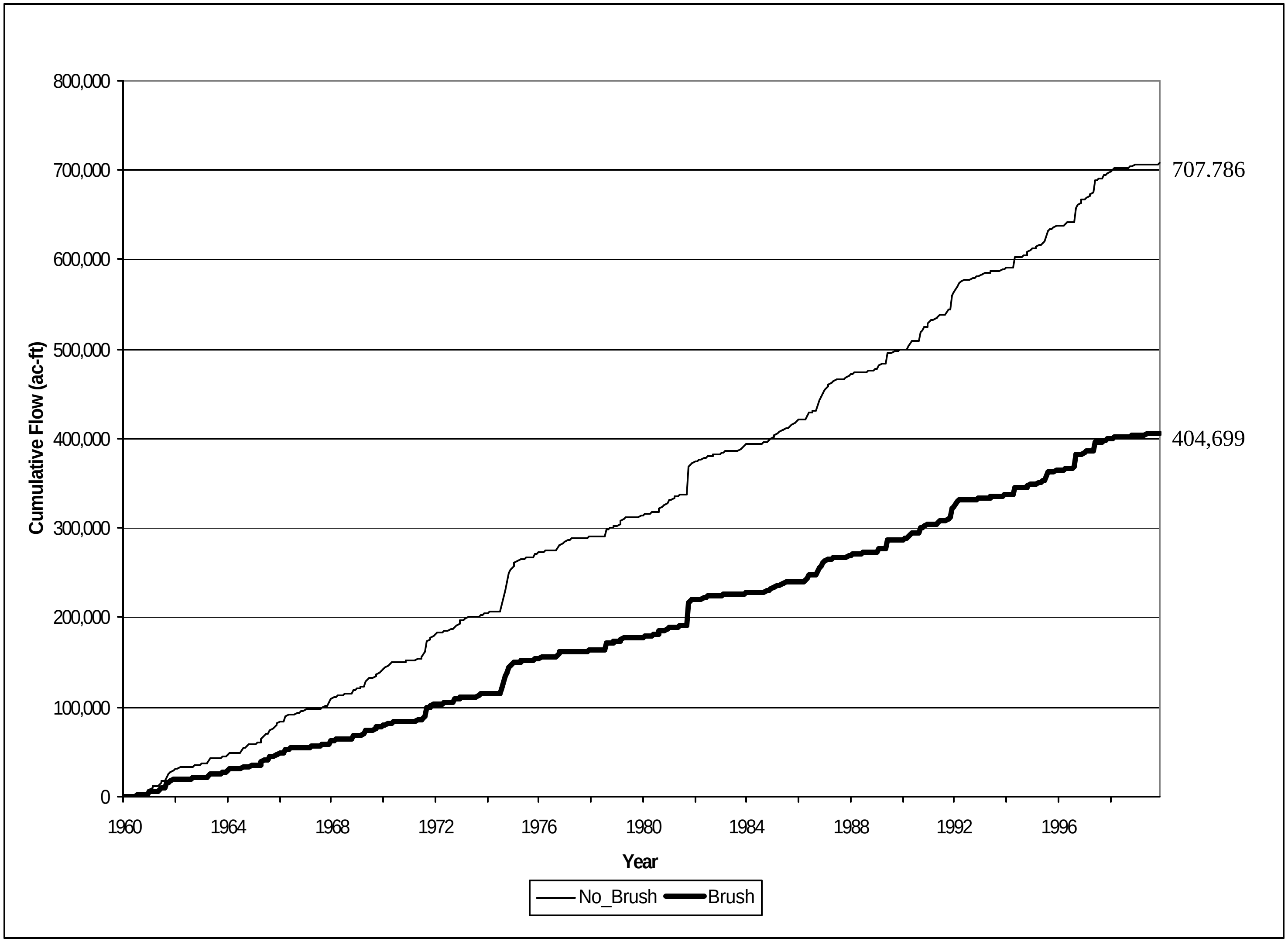

Figure 7-10. Predicted cumulative stream flow into Lake Abilene for brush and no-brush conditions.

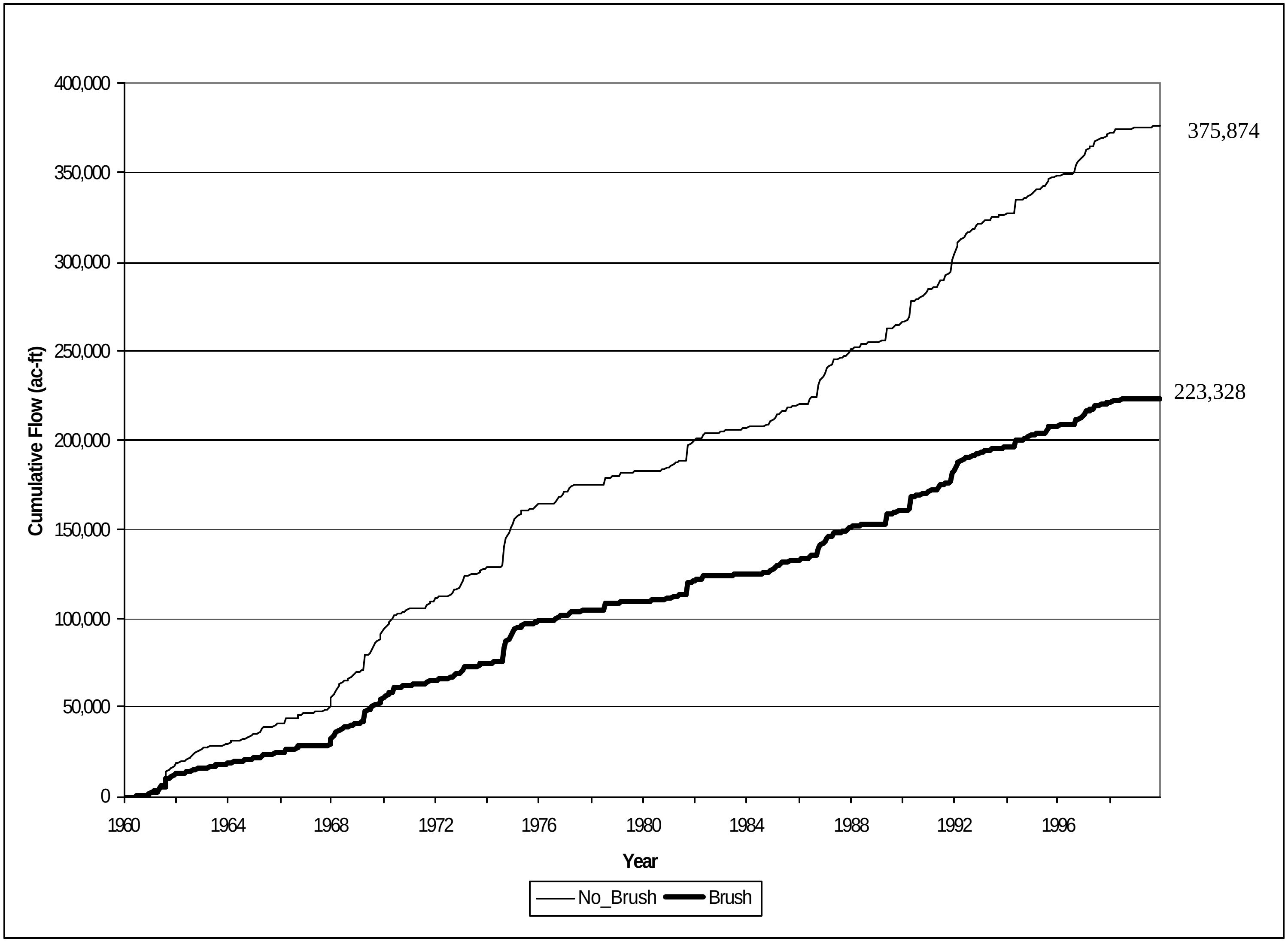

Figure 7-11. Predicted cumulative stream flow into Lake Lytle for brush and no-brush conditions.

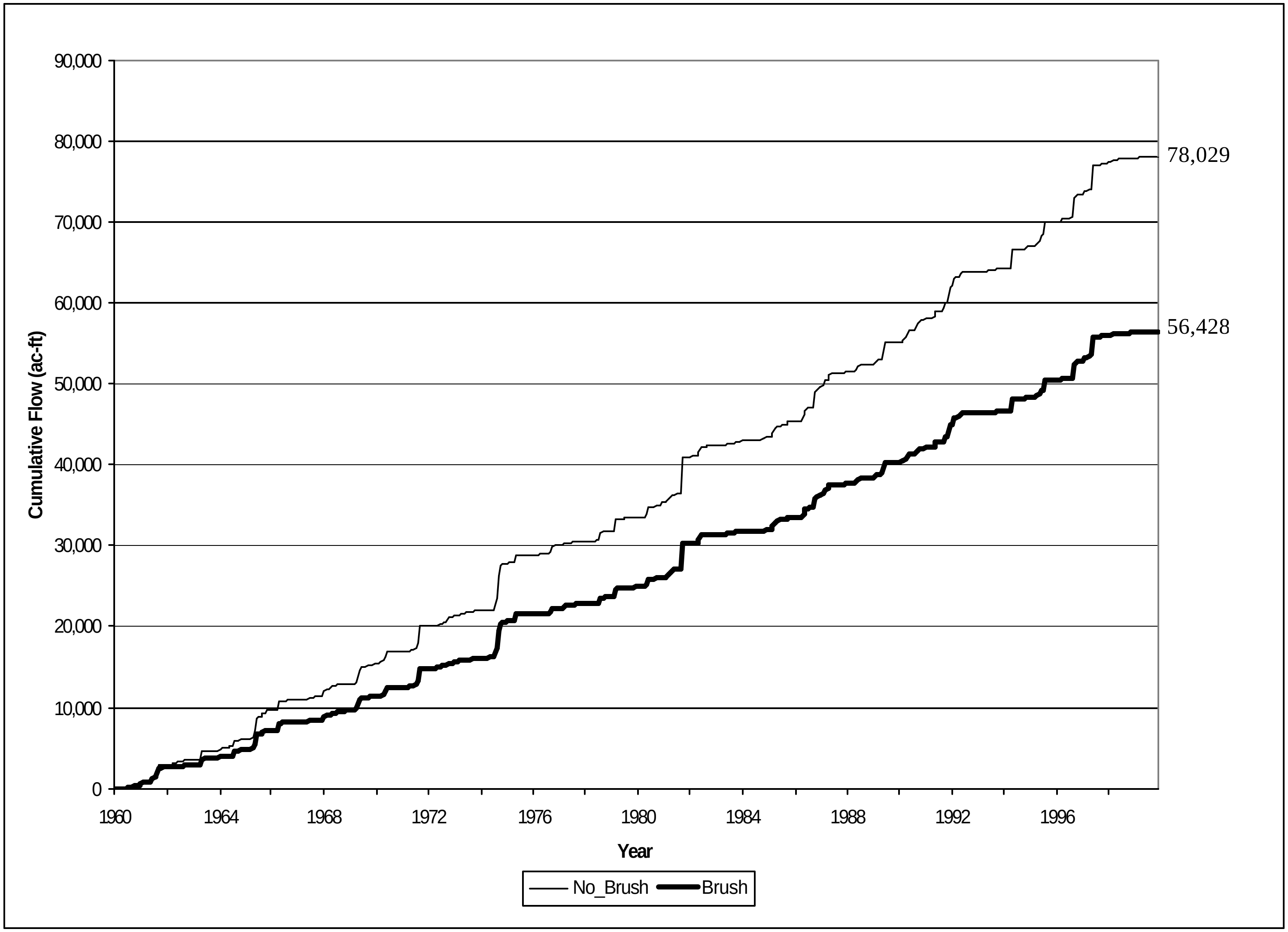

Figure 7-12. Predicted cumulative stream flow into Lake Kirby for brush and no-brush conditions.

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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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

LAKE FORT PHANTOM HILL WATERSHED – ECONOMIC ANALYSIS

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INTRODUCTION

Amounts of the various types and densities of brush cover in the watershed were detailed in Chapter 7. Changes in water yield (runoff and percolation) resulting from control of specified brush type-density categories were estimated using the SWAT hydrologic model. This economic analysis utilizes brush control processes and their costs, production economics for livestock and wildlife enterprises in the watershed and the previously described, hydrological-based, water yield data to determine the per acre-foot costs of a brush control program for water yield for the Lake Fort Phantom Hill watershed.

BRUSH CONTROL COSTS

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5% or less and maintain it at the reduced level for at least 10 years. Both the types of treatments and their costs were obtained from meetings with landowners and Range Specialists of the Texas Agriculture Experiment Station and Cooperative Extension, and USDA-NRCS with brush control experience in the project areas. All current information available (such as costs from recently contracted control work) was used to formulate an average cost for the various treatments for each brush type-density category.

Obviously, the costs of control will vary among brush type-density categories. Present values (using a 6% discount rate) of control programs are used for comparison since some of the treatments will be required in the first and second years of the program while others will not be needed until year 6 or 7. Present values of total control costs in the project area (per acre) range from $35.57 for moderate mesquite that can be initially controlled with herbicide treatments to $143.17 for mechanical control of heavy mixed brush. Costs of treatments and year those treatments are needed for each brush type - density category are detailed in Table 8-1.

LANDOWNER AND STATE COST SHARES

Rancher benefits are the total benefits that will accrue to the rancher as a result of the brush control program. These total benefits are based on the present value of the improved net returns to the ranching operation through typical cattle, sheep, goat and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, an improvement in net returns would result from increased amounts of usable forage produced by controlling the brush and thus eliminating much of the competition for water and nutrients within the plant communities on which the enterprise is based. The differences in grazing capacity with and without brush control for each of the brush type-density categories in the watersheds draining to Lake Fort Phantom Hill are shown in Table 8-2. Data relating to grazing capacity was entered into the investment analysis model (see Chapter 2).

Livestock production practices, revenues, and costs representative of the watershed were obtained from personal interviews with a focus group of local ranchers. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into livestock production investment analysis budgets. This information for the livestock enterprises (cattle) in the project areas is shown in Table 8-3. It is important to note once again (refer to Chapter 2) that the investment analysis budgets are for analytical purposes only, as they do not include all revenues nor all costs associated with a production enterprise. The data are reported per animal unit for each of the livestock enterprises. From these budgets, data was entered into the investment analysis model, which was also described in Chapter 2.

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

With the above information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $21.37 per acre for control of moderate mesquite to $35.55 per acre for the control of heavy mixed brush (Table 8- 4).

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state per acre cost share of brush control in the project area range from $14.20 for control of moderate mesquite with chemical treatments to $112.53 for control of heavy cedar by mechanical methods. Total treatment costs and landowner and state cost shares for all brush type-density categories are shown by both cost-share percentage and actual costs in Table 8-4.

COST OF ADDITIONAL WATER

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program. The brush control program water yields and the estimated acreage by brush type-density category by subbasin were supplied by the Blacklands Research Center, Texas Agricultural Experiment Station in Temple, Texas (see previous Chapter). The total state cost share for each subbasin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the subbasin. The cost of added water resulting from the control of the eligible brush in each subbasin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the 10-year period using a 6% discount rate).

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

Table 8-1. Cost of Water Yield Brush Control Programs by Type-Density Category

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

Heavy Mesquite - Mechanical Choice

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

Heavy Cedar - Mechanical Choice

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

Heavy Cedar - Shears

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

Heavy Mixed Brush - Mechanical Choice

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

Table 8-1. Cost of Water Yield Brush Control Programs by Type-Density Category, Continued

Heavy Mixed Brush - Shears

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

Moderate Mesquite - Chemical

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

Moderate Mesquite - Shears

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

Moderate Mesquite - Mechanical/Grub

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

Moderate Cedar - Mechanical/Grub

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

Table 8-1. Cost of Water Yield Brush Control Programs by Type-Density Category, Continued

Moderate Cedar - Mechanical/Shears

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

Moderate Mixed Brush – Mechanical/Grub

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

Moderate Mixed Brush – Mechanical/Shears

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

Table 8-2. 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	20.00	18.75	17.50	16.25	15.00	15.00	15.00	15.00	15.00	15.00
	No Control	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
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
Moderate Mesquite	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 Cedar	Control	17.0	16.5	16.0	15.5	15.0	15.0	15.0	15.0	15.0	15.0
	No Control	17.0	17.2	17.4	17.6	17.8	17.9	18.1	18.3	18.5	18.7
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

Table 8-3. Investment Analysis Budget, Cow-Calf Production

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

Partial Variable Costs:

Variable Cost Item Description		**Quantity**	**Unit**	**$ Per Unit**	**Cost**
Supplemental Feed		1	1	48.00	48.00
Cattle Marketing - All Cattle		----------	Head	----------	15.00
Vitamin/Salt/Minerals		60	Pound	0.10	6.00
Veterinary Medicine		1	Head	14.00	14.00
Miscellaneous		1	Head	12.00	12.00
Net Cost for Replacement Cows		----------	Head	700.00	40.00
Net Cost for Replacement Bulls		----------	Head	1500.00	4.00
				TOTAL	**139.00**

Table 8-4. Landowner/State Cost-Shares of Brush Control

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

Table 8-5. Cost of Added Water From Brush Control by Subbasin (Acre Foot)

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