Lake Brownwood Watershed

Brush Control Assessment and Feasibility Study

Lower Colorado River Authority

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ACKNOWLEDGEMENTS

This report is the result of a collaborative effort between the Lower Colorado River Authority, the Texas State Soil and Water Conservation Board (TSSWCB), the Coleman County Soil & Water Conservation District (SWCD), the Pecan Bayou SWCD, the U. S. Department of Agriculture's Natural Resources Conservation Service (NRCS), and the Texas A&M University System (TAMU). Professionals from each of these entities provided valuable input, which, in turn, resulted in the creation of a document that reflects the views of various interests from local landowners to government agencies. A debt of gratitude goes out to all who gave their time and effort.

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1.0 INTRODUCTION

In 1985, the Texas Legislature established a brush control program for the state. As defined in the enabling legislation, brush control means 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. The Texas State Soil and Water Conservation Board (TSSWCB) was given jurisdiction of the program and was directed to prepare and adopt a brush control plan that includes a strategy for managing brush in areas where brush is contributing to a substantial water conservation problem. In addition, the plan is to designate areas of critical need in which to implement brush control programs. In designating critical areas under the plan, TSSWCB is required to consider:

- the locations of brush infestations;
- the type and severity of brush infestations;
- the management methods that may be used to control brush; and
- any other criteria that the Board considers relevant to ensure that the brush control program can be most effectively, efficiently and economically implemented.

In designating critical areas, the TSSWCB shall give priority to areas with the most critical water conservation needs and those in which brush control and revegetation projects will be most likely to produce a substantial increase in the amount of available and usable water.

In 2001, the Texas Legislature provided appropriations through the TSSWCB for feasibility studies for four watersheds on the effects of brush management on water yields. The studies will focus on the changing water yields associated with brush management and the related economic aspects. The Lake Brownwood watershed is one of the four watersheds that was funded for study.

The overall goal of this project is to increase the streamflow and water availability of Pecan Bayou and Jim Ned Creek into Lake Brownwood and other reservoirs in the watershed for use as a supply of industrial, agricultural, municipal and other water use. The first stage of the project is the goal of this report; to plan and assess the feasibility of brush management to meet the project's goals. The objectives of this study are to:

- develop a historical profile of the vegetation in the Lake Brownwood watershed.
- develop a hydrological profile of the Lake Brownwood Watershed.

evaluate climatic data throughout the past century and its relative effects on the current hydrological conditions in the Lake Brownwood watershed.

The Lower Colorado River Authority (LCRA) was contracted by the TSSWCB to investigate and produce the following portion of this report on the Lake Brownwood watershed:
the watershed's location, climate, geology, soils, current water use and projected water needs.
the current and historical landuse/land cover (brush type, density and canopy cover) and observable trends.
the current and historical surface and groundwater hydrology and observable trends.
the potential impacts of a brush control program on wildlife, especially endangered species, are also addressed.

The overall study has been a cooperative ecosystem-level approach that involved LCRA, the TSSWCB, Coleman Soil and Water Conservation District (SWCD), Pecan Bayou SWCD, NRCS, and Texas A&M University (TAMU). The reports produced by the NRCS and TAMU are included in this document as Appendices 1-4.

2.0 EXECUTIVE SUMMARY

As Texas seeks to secure additional water supplies to sustain it in the 21st century, policy makers will consider a variety of options including brush control to meet future water needs. Where it is environmentally and ecologically sound, replacing brush with grasses that use less water could supply Texas with additional amounts of relatively inexpensive water. The goal of this study was to evaluate the climate, vegetation, soil, topography, geology, and hydrology of the Lake Brownwood River watershed with regard to the feasibility of implementing brush control programs in the watershed.

Based on historical evidence and more recent regional descriptions, it is apparent that the vegetational landscape of the Lake Brownwood watershed has changed considerably over the past 150 years. The early European settlers who migrated to the area by the mid to late 1800s found a vast expanse of midgrass to tallgrass prairies typical of the Rolling Plains. Distinct land use changes brought on by settlement and an extensive drought precipitated a widespread transformation of the landscape by the end of the nineteenth century. This change included a great increase in the amount and distribution of woody species, particularly honey mesquite (*Prosopis glandulosa*). The once distinct boundaries among the various habitat types have become blurred, as each community assemblage has become more homogenous and grasslands have almost disappeared.

Meteorological data collected in the vicinity of the Lake Brownwood watershed since the late 1800s indicate that climatic conditions have not changed significantly over the past century. The exception is reduced precipitation during the record drought from 1946 to 1957. The average annual temperature in the watershed is approximately 64.4° F, and the average annual rainfall is approximately 25.9 inches. Segments of Pecan Bayou, Jim Ned Creek and Hords Creek were gauged at various times between 1923 and 1990, but the periods of record for the gauges are different, and nearly all of the gauges are located downstream of surface reservoirs with controlled release.

There is no evidence to suggest that groundwater levels have declined systematically in the aquifers beneath the watershed within the evaluation period. A decrease in water levels would be expected if aquifer recharge had declined due to increased evapotranspiration caused by brush infestation. Observed changes in water levels in watershed aquifers are more likely due to variations in natural rainfall and groundwater withdrawals.

Although the hydrologic data available for this study were not adequate for determining if water yields in the Lake Brownwood watershed have been affected by brush infestation, geologic and hydrologic conditions in the watershed are very conducive to enhancement of water yields through brush management. Analysis found in Appendices 1-4 are based on the period of 1960-1999. Further evaluations that include the drought of record may prove to be useful in predicting water availability for future water supplies.

Current and projected water demands in the watershed are expected to result in water shortages in the future, especially in the rural areas of Brown County that depend heavily on groundwater resources. In addition, larger water supply shortages are projected to occur in the lower Colorado River basin downstream of Lake Brownwood. Brush management may be an effective means of improving surface water and groundwater supplies in the watershed. However, it should be noted that modeling of such scenarios is dependent on input variables that are subject to interpretation..

3.0 HYDROLOGIC EVALUATION

The following water balance equation can be used to estimate water yield (i.e., runoff and deep drainage) in a watershed:

Runoff + Deep Drainage = Precipitation – Evapotranspiration.

Runoff = water exiting the watershed via overland flow.

Deep drainage = water exiting the watershed via soil percolation below the plant root zone.

Precipitation = water that falls in the watershed as rain or snow.

Evapotranspiration = water returned to the atmosphere through the processes of evaporation and transpiration. Evaporation is the process by which surface water, water in soil, and water adhered to plants returns to the atmosphere as water vapor. Transpiration is the process by which water vapor passes through plant tissue

The above relationship suggests water yield can be increased by reducing evapotranspiration through vegetation management (Thurow, 1998), and a significant amount of research supports that premise. Field studies conducted at the Texas A&M University (TAMU) Agricultural Research Station at Sonora found that significant increases in water yield can be obtained by converting brush to grassland on sites with the following characteristics: more than 18 inches of rain per year, thin soils with high infiltration rates overlying fractured limestone, and dense juniper oak woodland cleared and replaced with shortgrass and midgrass species. These results corroborate the findings of brush management studies conducted in the western United States and other parts of the world.

The Lake Brownwood watershed is in the region that TSSWCB (2002) has defined as generally suitable for brush control projects, based on rainfall and brush infestation (Figure 3-1). In addition, the Lake Brownwood watershed has been designated as a brush control priority, because the City of Clyde, which gets its water from Lake Clyde, had to implement severe water use restrictions due to recent drought. The restrictions affected 3,002 residents in Clyde. Other water supplies that may be enhanced by brush control in the watershed include Lake Coleman on Jim Ned Creek and Hords Creek Lake. The following hydrologic evaluation describes the climate, vegetation, soil, topography, geology and hydrology of the watershed. This baseline information can help assess the feasibility of brush management in the watershed and develop strategies for implementing brush management.

3.1 DESCRIPTION OF THE WATERSHED

The Lake Brownwood watershed encompasses approximately 982,400 acres (1,558 square miles) of the Colorado River basin in north central Texas. It is mostly within Brown, Callahan and Coleman counties, but includes small portions of Eastland, Runnels and Taylor counties (Figure 3-2). The watershed is drained by Pecan Bayou and Jim Ned Creek, which empty into Lake Brownwood at the southeast end of the watershed. The dam that created Lake Brownwood was completed in 1932.

Physiography and Topography

The study area is within the North-Central Plains physiographic province of Texas (Bureau of Economic Geology, 1996), which represents the southernmost extent of the Great Plains province of the United States (Thornberry, 1965). The North-Central Plains has a gently-rolling to moderately-rough topography that is dissected by narrow intermittent stream valleys flowing east to southeast.

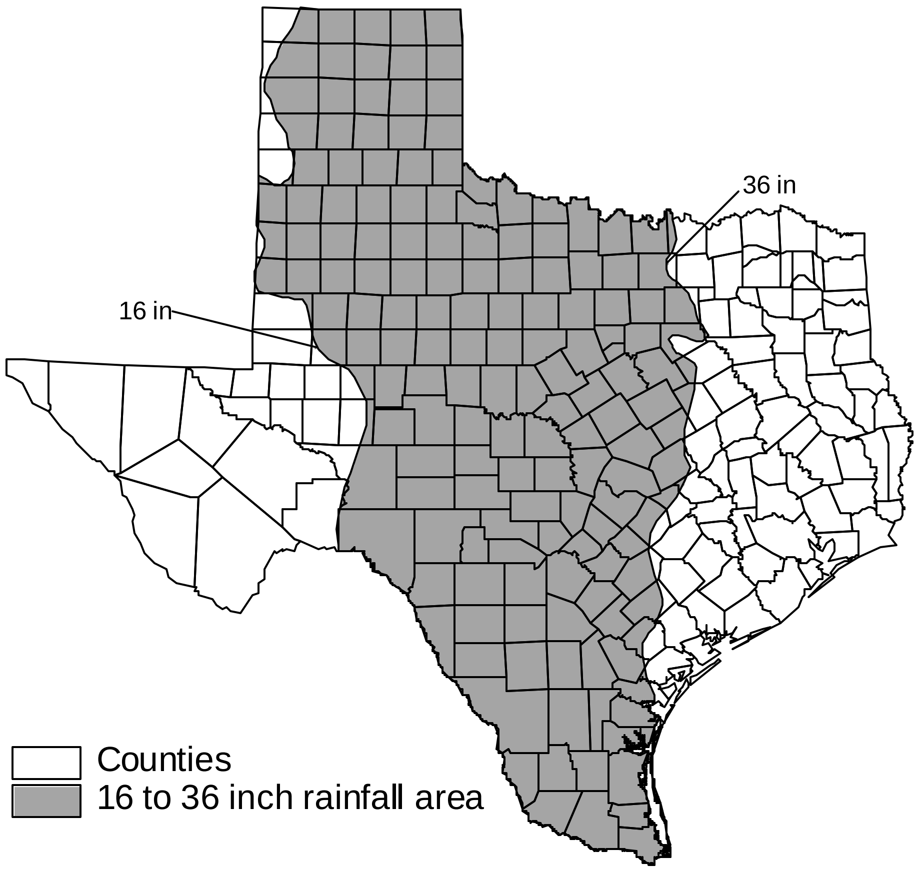

Figure 3-1

GENERAL BRUSH CONTROL ZONE

The western and southern portions of the study area are within the Mesquite Plains natural subregion of Texas (LBJ School of Public Affairs, 1978), a gently rolling plain of mesquite-short grass savanna formed on sandstone, shale and limestone substrate (Figure 3-3). The eastern margin of the watershed is included in the Lampasas Cut Plain natural subregion, which is characterized by grassland and scattered mesquite woods on low rolling hills underlain by limestone.

Surface elevations in the watershed vary from approximately 1,380 feet above mean sea level (msl) along Pecan Bayou immediately downstream of Lake Brownwood to approximately 2,200 feet msl in the upper reaches of the watershed. The northern boundary of the watershed is marked by a low range of hills known as the Callahan Divide, which separates the Colorado River basin on the south from the Brazos River basin on the north.

Geology

The Lake Brownwood watershed is underlain by approximately 4,000 feet of Paleozoic (Permian and Pennsylvanian) rock strata comprised of limestone, dolomite, shale and clastics that dip to the northwest at an average rate of 50 feet per mile. Up to 100 feet of Cretaceous rock strata unconformably overlie the Paleozoic rocks, in portions of the watershed. The Cretaceous rocks consist of sandstone, shaly limestone and limestone and are exposed at the surface mainly along the eastern margin of the study area. However, they also occur as erosional remnants, or outliers, in the localized areas in the western part of the watershed. In contrast to the Paleozoic rocks, the Cretaceous beds dip gently southeastward. Thin deposits of Quaternary age sand, silt, clay and caliche unconformably overlie the Paleozoic rocks in the western portions of the watershed, and recent (Holocene) alluvium deposits occur throughout the watershed in the floodplains of the larger streams. The Paleozoic rocks, the lowermost Cretaceous rocks, and the alluvium are sources of small to moderate amounts of fresh to saline groundwater in the watershed.

Climate

The Lake Brownwood watershed has a subtropical, subhumid to semiarid climate, with typically dry winters and hot humid summers. The distribution of monthly rainfall has two peaks. Spring is typically the wettest season, with a peak occurring in May. The second peak is usually in September, coinciding with the tropical cyclone season in the late summer/early fall. Spring rains are typified by convective thunderstorms that produce high intensity, short duration rainfall events and rapid runoff. Fall rains are primarily governed by tropical storms and hurricanes that originate in the Caribbean Sea or the Gulf of Mexico and make landfall on the coast from Louisiana to Mexico. For the past century, annual precipitation in the watershed has varied from approximately 10.7 to 50.6 inches and averaged 25.9 inches. From 1940 to 1997, monthly gross evaporation in the watershed varied from approximately 2.5 to 9.2 inches. The average annual gross evaporation was approximately 67.3 inches.

Land Use

The six-county area in which the watershed is located is primarily rural, with approximately 56 percent of the land used for ranching and 29 percent for farming. Animal production is dominated by cattle, but includes sheep, hogs and poultry. Wheat and hay are the dominant crops, followed by cotton and sorghum. Foods crops include peaches, pecans and peanuts. The largest surface water body in the watershed is Lake Brownwood, which has a usable conservation storage capacity of 131,430 acre-feet. The second largest water supply reservoir in the watershed is Lake Coleman (40,000 acre-feet) on Jim Ned Creek approximately 14 miles north of Coleman. Additional reservoirs include Hords Creek Lake (8,110 acre-feet) approximately 13 miles west of Coleman and Lake Clyde (5,748 acre-feet) approximately six miles south of Clyde. Recreation in the watershed centers on the Lake Brownwood State Park.

Population

The Lake Brownwood watershed is primarily rural, but contains numerous small communities that serve the rural population. Abilene, which has a population of approximately 120,000, is in Taylor County immediately northwest of the watershed.

Figure 3-2
Study Area Location

Lake Brownwood Watershed Brush Control Planning Assessment and Feasibility

N
W E
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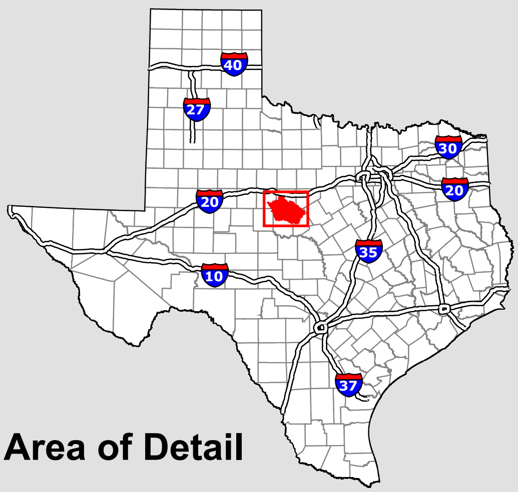
0 5 10 Miles



Area of Detail

Lake Brownwood Watershed Boundary

County Boundary

Highways

Lakes

Major Streams

Minor Streams

Cities

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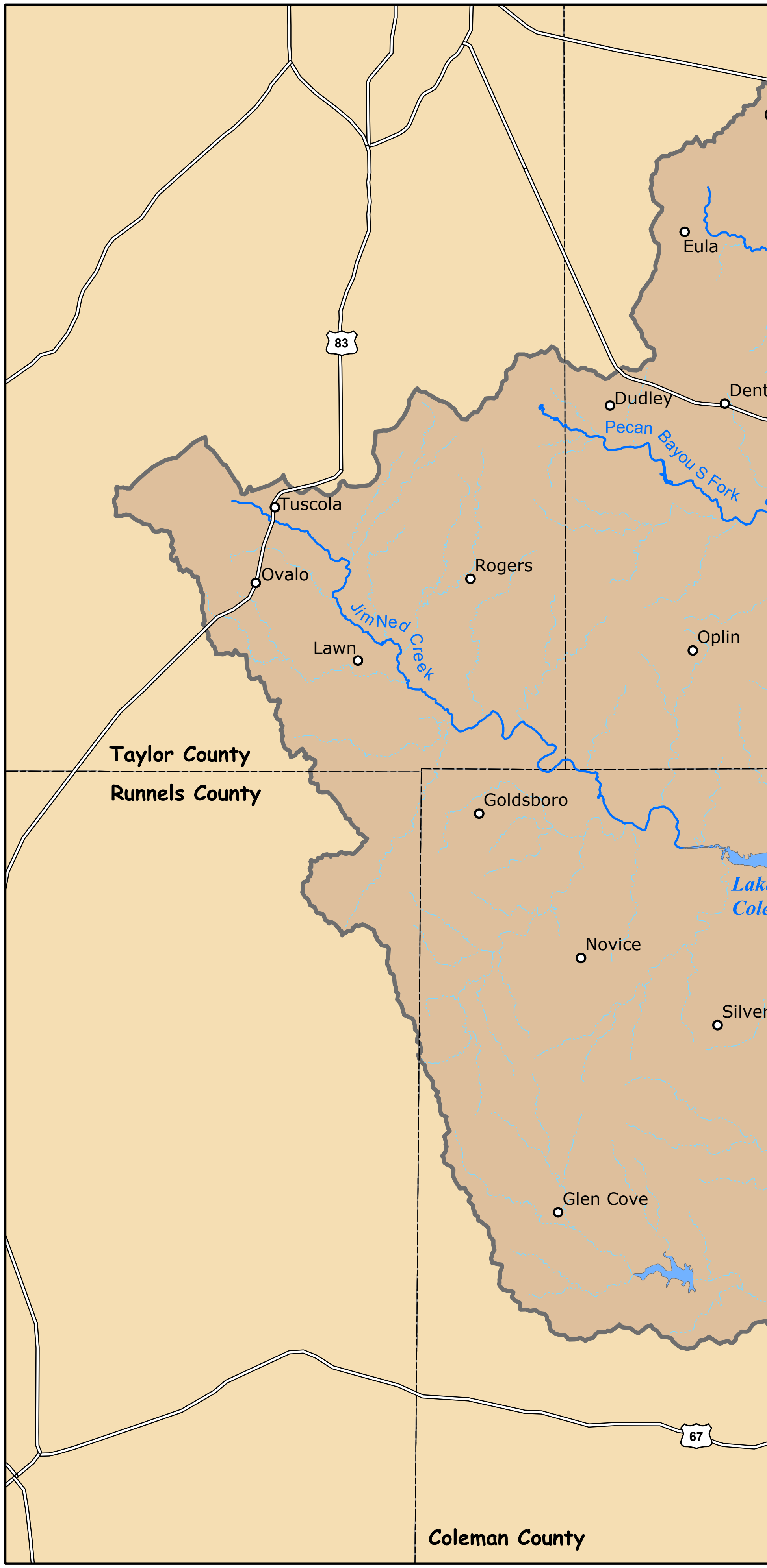
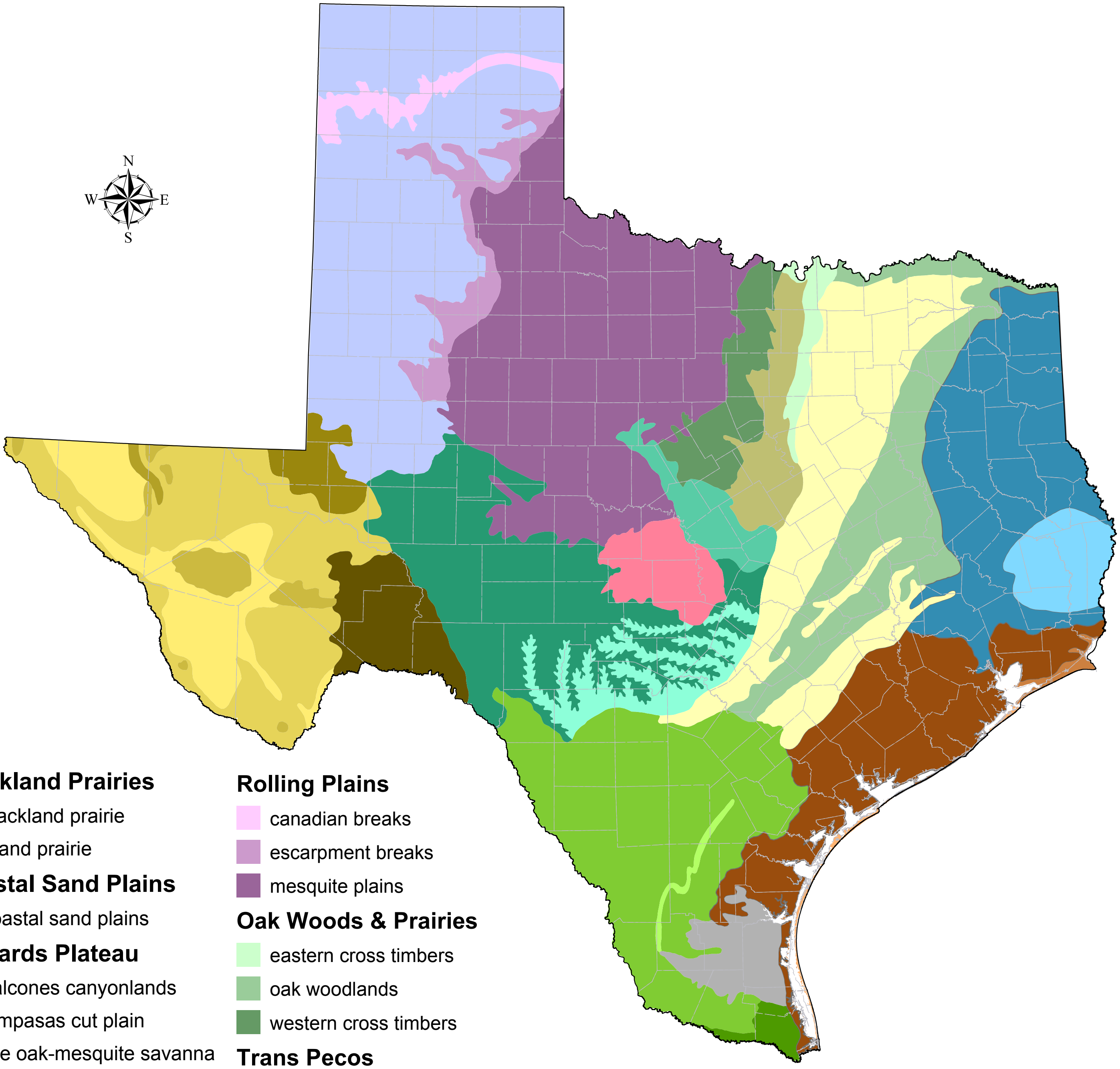
Source:
Roads - Texas Department of Transportation
Counties - Texas Department of Transportation
Cities - Texas Natural Resources Information System
Streams - United States Geological Survey
Lakes - Environmental Protection Agency



Callahan County
Eastland County
Comanche County
Brown County
Clyde
20
283
183
206
Pecan Bayou N Fork
Rowden
Cottonwood
36
Cross Plains
Pioneer
Cross Cut
Williams
Webbville
Pecan Bayou
Burkett
May
Jim Ned Creek
Echo
Byrds
Holder
279
Grosvenor
Hamrick
Blackwell Crossing
Lake Brownwood
Lake Shore
Coleman
Shamrock Shores
Thrifty
Buffalo
67
Valley

3-4



Source: Texas Parks and Wildlife Department, Austin, Texas, 1975

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FIGURE 3-3
NATURAL REGIONS AND SUBREGIONS OF TEXAS

LAKE BROWNWOOD WATERSHED BRUSH CONTROL PLANNING ASSESSMENT AND FEASIBILITY

Brownwood lies a few miles downstream of Lake Brownwood in Brown County and has a population of approximately 20,000. Table 3-1 presents population data for the six counties partially within the watershed. In addition to historical information for the counties, the data include municipal and rural population projections through 2050.

The six counties that are partially within the watershed began to be settled by white Europeans in the 1850s and experienced moderate growth until the early 1900s. Droughts, a drop in cotton production due to the boll weevil, and the Great Depression were major factors that caused all of the counties except Taylor to lose population from 1930 through 1960 or 1970. Since 1970, the population has grown at a low to moderate rate. Taylor County, or rather Abilene, grew rapidly until 1960 when its growth stabilized at a much lower rate. Brown, Coleman, Runnels and Taylor counties are expected to experience low to moderate growth through 2050. In Brown and Runnels counties, the growth is expected to occur primarily in rural areas. In contrast, Eastland and Callahan counties are expected to see their populations decrease during the first half of this century.

Wildlife

The flora and fauna of the watershed are typical of north central Texas; species are mostly western, but some eastern plants and animals can be found. The flora consists of three natural types: mesquite-grassland savanna, upland scrub, and bottomland woodland along the creeks. The Texas poppy-mallow is a federally listed endangered plant species that may occur in the study area (U.S. Fish and Wildlife Service, 2001). The fauna of the area includes such reptiles as yellow mud turtles, Texas map turtles, western cottonmouth snakes, hognose snakes, western diamond-backed rattlesnakes, coachwhips, horned toads, and the eastern tree lizard; birds such as turkeys, screech owls, wood ducks, turkey vultures and red-tailed hawks; and such mammals as white-tailed deer, black-tailed jackrabbits, opossums and ringtails. Federally listed, threatened or endangered animal species that may occur in the study area include four bird species (golden-cheeked warbler, black-capped vireo, whooping crane and bald eagle) and one reptile (Concho water snake).

White-tailed deer provide an important resource to landowners and land managers within the Lake Brownwood watershed. Their presence adds aesthetic as well as economic value to farms and ranches throughout the region. The demand for lease hunting recreation for white-tailed deer creates an economic incentive for landowners to manage land and habitat resources to meet the biological needs of white-tailed deer. Increasing demands for the space that white-tailed deer and their habitat occupies in the Cross Timbers and Prairies introduces a serious management problem (Poor, 1997).

3.2 HISTORICAL CONSIDERATIONS

In many areas of the state, historical records show that higher levels of spring-flow and streambase-flow occurred in the past and that brush encroachment in watersheds has been an important factor in the declining flows. A great increase in the amount and distribution of woody species, particularly honey mesquite, in the Lake Brownwood watershed over the past century suggests that surface water flows in the area may have been affected. Unfortunately, the hydrological data that have been collected in the watershed are not well suited to assessing whether reduced streambase-flow or spring-flow have occurred.

3.2.1 Vegetation History

Based largely on anecdotal evidence and recent regional descriptions, the vegetation of the Lake Brownwood watershed appears to have changed considerably over the past 150 years. Distinct land use changes brought on by European settlement and an extensive drought precipitated a widespread transformation of the landscape by the end of the nineteenth century. This change included a great increase in the amount and distribution of woody species, particularly honey mesquite (*Prosopis glandulosa*). The once distinct boundaries among the various habitat types have blurred, as each community assemblage has become more homogenous and grasslands have almost disappeared.

Early travelers knew the location of the Western Cross Timbers and used them as points of reference in travel. In 1772, De Mezieres (Dyksterhuis 1948) stated that from the Brazos River north "…one sees on the right a forest that the native appropriately call the Grand Forest…Since it contains some large hills, and because of the great quantity of oaks, walnuts, and other large trees, it is a place difficult to cross…On the farther edge of this range, or forest, one crosses plains having plentiful pasturage…" and in 1778 "…I crossed the Colorado and Brazos, where there are…an incredible number of Castilian cattle, and herds of mustangs that never leave the banks of these streams. The region from one river to the other, is no less bountifully supplied with buffalo, bear, deer, antelope, wild boars, partridges, and turkeys."

Nineteenth Century Historical Vegetation Descriptions

Little is known about the vegetational landscape of the Lake Brownwood watershed prior to about 1858 when each of the counties in the study area was being organized. Before this time, the U.S. west of the 98th meridian had been touted as "The Great American Desert" (Zachry, 1980). Due to an absence of trees and a lack of persistent streams, early surveyors decided that this land must be poor for cultivation (Berry, 1949; Duff, 1969; Zachry, 1980). Another barrier to European explorers, and thus written record, was the danger of encounters with early Native American inhabitants such as the Comanche, Lipan Apache, and Jumano peoples.

Situated at the juncture of the Western Cross Timbers, Rolling Plains and Edwards Plateau vegetational areas as described by Dyksterhuis (1948), Gould (1975), and Hatch et al. (1990), the floral landscape of the Lake Brownwood watershed was once a mosaic of prairies, bottomland woodlands and upland forests.

In 1840, Col. Stiff (Dyksterhuis 1948), upon approaching the Cross Timbers of Texas from the western prairies, stated, "In turning to the northeast, something much resembling an irregular cloud is dimly seen. This is a skirt of woodland…called the Cross Timbers…Whether this was once a beach of a mighty lake or a sea we must leave to the geologist to determine." On July 21, 1841, Kendall (1841) stated, "We are now fairly within the limits of the Cross Timbers…The immense western prairies are bordered, for hundreds of miles on their eastern side, by a narrow belt of forest land, well known to hunters and trappers under the above name." He stated, "The growth of timber is principally small, gnarled post oaks and black jacks, and in many places the traveler will find an almost impenetrable undergrowth of briers and other thorny bushes."

The early European settlers who migrated this far west by the mid to late 1800s found a vast expanse of mid to tallgrass prairies typical of the Rolling Plains (Gay, 1936; Berry, 1949; Havins, 1958; Mitchell, 1949; Duff, 1969; Zachry, 1980). Berry (1949) described grass so tall, it "brushed your stirrups as you rode." Abundant prairie grasses observed during this period included mesquite grass (*Muhlenbergia porteri*), little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), curly mesquite (*Hilaria belangeri*), yellow indiangrass (*Sorghastrum nutans*), buffalograss (*Buchloe dactyloides*), switchgrass (*Panicum virgatum*), sand dropseed (*Sporobolus cryptandrus*), sideoats grama (*Bouteloua curtipendula*), hairy grama (*Bouteloua hirsuta*), blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), green sprangletop (*Leptochloa dubia*), Texas cupgrass (*Eriochloa sericea*), and timothy (*Phleum pratense*) (Gay, 1936; Mitchell, 1949; Havins, 1958; Lyndon B. Johnson (LBJ) School of Public Affairs, 1978; Zachry, 1980). These expanses of prairie were broken only by a few scrub oaks (Quercus sp.) and blackjack oaks (*Quercus marilandica*) (Zachry, 1980) and, toward the western part of the study area, scattered mesquites (Marcy, 1849, as cited in Dyksterhuis, 1948).

Within these prairies, the primary source of timber for the European settlers was found along the various water courses (Gay, 1936; Lindsey, 1940; Dyksterhuis, 1948; Mitchell, 1949; Havins, 1958). According to Lindsey (1940), bottomlands approximately one-eighth to three-quarters of a mile wide meandered through the region. The most common bottomland species described were pecan (*Carya illinoinensis*), elms (*Ulmus spp.*), and cottonwood (*Populus deltoides*). Cedar (*Juniperus sp.*) breaks also lined some upland riparian edges (Gay, 1936).

The third vegetation type found by early settlers in the Lake Brownwood watershed is forest. The Western Cross Timbers, found in pockets of sandy soils within the Lake Brownwood watershed and east of the study area, were described by Kennedy in 1841 as an abrupt "wall of woods stretching from south to north" along the adjacent prairie (as cited in Dyksterhuis, 1948). Although post oak (*Quercus stellata*), and blackjack oak dominated the upland woodlands, minor species included hackberry (*Celtis sp.*), cedar elm (*Ulmus crassifolia*), hickory (*Carya sp.*), holly (*Ilex sp.*), and white oak (*Quercus alba*). Some descriptions of these woods depict an understory of thorny shrubs; other descriptions note an understory of only tall- and midgrasses open enough to allow “a man on horseback to ride beneath their crowns” (Dyksterhuis, 1948). The Western Cross Timbers likely included Dugan’s woods, a twenty-acre block of woods in Callahan County described as “a forest primeval with a wide, well-beaten path winding through it” (Berry, 1949). Northwestern Coleman County was described as open post oak woodlands filled with plentiful wildflowers (Gay, 1936). Brown County, on the other hand, was described as having more underbrush (Gay, 1936).

Other woodlands within the area were found on the shallow soils of topographic features and rocky outcrops, representative of Edwards Plateau regional vegetation. The slopes of Santa Anna Mountain in Coleman County were “sparsely covered by a scrubby growth of juniper (*Juniperus sp.*), shinry (possibly Havard oak, also called sand shinnery oak, (*Quercus havardii*)), and other trees of like nature, but a few live oaks (*Quercus fusiformis*) have found a foothold in the fertile soil between the rocks” (Gay, 1936).

Land Use Changes at the Turn of the Century

The end of the nineteenth century saw many changes in land use and a severe drought that would lead to remarkable changes in the landscape of the Lake Brownwood watershed and the region as a whole. The first farmer settled in the study area in Brown County in 1857 (Havins, 1958). The land was purchased inexpensively and hastily cleared for new farms (Lindsey, 1940). Cotton was the primary crop grown in the area during the last half of the nineteenth century, although peanuts and forage crops were becoming more abundant. By 1881, landowners began to enclose the lands they claimed with barbed wire fencing. Coleman County was quickly divided into small farms and large ranches over a ten-year period (Mitchell, 1949). The year 1886 saw the introduction of the railroad to the area allowing for a more diverse market for cultivated goods such as cotton.

The land use changes that most affected the floral composition of the study area, however, were grazing and the cessation of a fire regime. The first herd of cattle was driven into the study area to Brown County in 1856 (Havins, 1958). Over the next 25 years, the land remained largely unclaimed by European settlers, while cattle were driven to the area, branded, and released to graze on the vast, open range (Gay, 1936). The abundant open rangeland was attractive to early cowboys, resulting in a rapid increase in the local stocking rate. In fact, within the first 20 years of grazing in Eastland County, there was an estimated 159 head of cattle per resident within the county’s borders (Jordan, 1981). Moreover, Mitchell (1949) reports that by 1900, 200 to 300 cattle were confined to 640 acres of grassland in Coleman County. Mitchell further states that as grazing pressure increased on the prairie, the area of grassland required to support livestock rose from early stocking rates as low as three acres per animal unit to 15 to 25 acres per animal by the early 1900s.

Early European settlers were distraught to find that the region surrounding the watershed was regularly burned by the Native Americans who lived in the area (Fernandez, 1788; Fortune, 1835, both as cited in Weniger, 1984). Each fall after setting fire to the grasslands, the Native Americans would follow the buffalo north of the Arkansas River, then return the following spring when the grass was lush again (Fortune, 1835, as cited in Weniger, 1984; Mitchell, 1949; Havins, 1958). This cycle allowed the suppression of woody brush in both prairie and forest communities while ensuring the regeneration of tall- and midgrasses in the landscape. As the Native American people were driven from the land, their methods of land management were maintained by early ranchers until farmers settled among them, erecting wooden structures that were vulnerable to such large-scale burning (Dyksterhuis, 1948).

Twentieth Century Vegetation Descriptions

As a result of the rapid changes in land use as well as extensive drought in 1886 and 1887 (Dyksterhuis, 1948), habitat descriptions from the early part of the twentieth century alluded to a distinct transformation of the landscape. Early residents soon recognized that the region’s tall- and midgrasses were disappearing and being replaced by shorter species more tolerant to grazing pressure and dry climatic conditions (Dyksterhuis, 1948; Berry, 1949; Mitchell, 1949). By mid-century, pure stands of the native mid- and tallgrasses only remained as relicts in areas out of reach for grazers, such as rough, rocky outcrops or wetter sites (Tharp, 1939; Mitchell, 1949).

Some of the native grasses that continued to be widespread by the early to mid-1900s were the mid-grasses sideoats grama and sand dropseed and the short grasses blue grama, hairy grama, buffalograss and curly mesquite. Several of these species would continue to decrease under extensive grazing pressure, while some, such as curly mesquite, would become more prevalent (Johnson, 1931; Allred, 1956). The midgrass and shortgrass species that increased under intensive grazing could not suppress the invasion of woody species. Soon mesquite, Havard oak, sand sage (*Artemisia filifolia*), soapweed (*Yucca glauca*), and skunkbush (*Rhus aromatica*) became established in mottes throughout the prairies (Allred, 1956).

Of all the invasive woody species, mesquite was the most widespread. Once established, mesquite could compete with the adjacent grasses, and the prairies of the Rolling Plains now supported a mesquite savannah (Allred, 1956). Mesquite, once sparse, now grew so dense it "must be ridden closely to gather stock" (Berry, 1949). Mitchell (1949) noted that, in Coleman County, mesquite covered almost all land not in cultivation by 1949. According to Havins (1958), Brown County was covered almost entirely by mesquite and oak savannahs. Mesquite woods were typically found with other xeric species including pencil cactus (Opuntia leptcaulis) and lotebush (Zizyphus obtusifolia) and species of Acacia and Condalia (Tharp, 1939; Dyksterhuis, 1948). These dryland species thrived on steeper sloped areas with shallow soils as well as deeper clay prairie soils, that do not readily release water (Johnson, 1931; Dyksterhuis, 1948).

Riparian vegetation remained relatively unchanged, still dominated by elms, oaks, cottonwood, walnut (Juglans sp.), hackberry, sycamore (Platanus occidentalis), and pecan (Cox, 1950; Havins, 1958). Shin oak (Quercus sinuata var. breviloba) became more frequent along the water courses (Cox, 1950). Havins (1958) indicated that nearly 3,000 acres of timber, primarily oak, pecan and cottonwood, were removed upstream of the Brownwood Dam in creation of the Lake Brownwood Reservoir in 1930.

Woody species once confined to the riparian zone began to spread to the upland prairies (Havins, 1958). Cox (1950) noted the presence of cedar on limestone outcrops, "a relatively recent inhabitant of this part of the country…rapidly increasing its coverage." Mitchell (1949) stated that post oak, live oak and blackjack oak had increased in the eastern half of Coleman County as well.

By mid-twentieth century, the woodlands of the Western Cross Timbers supported only young trees, having been harvested of all mature vegetation outside of the floodplains. Although clear-cutting for lumber in the region was rare, clearing large tracts for agricultural land uses was not uncommon (Dyksterhuis, 1948). The exposed underlying sandy soils of the Western Cross Timbers became vulnerable to wind erosion, forming deep, extensive gullies and forcing some farmers to abandon their land. These fallow fields either were absorbed by neighboring ranches to be grazed, or they were left to naturally rebound, now dominated by annual threeawns (*Aristida spp.*) (Dyksterhuis, 1948).

Post oaks and blackjack oaks still dominated the canopy of the Western Cross Timbers and were supported by a midstory of mesquite, other shrubs, and greenbriar. The understory became dominated by shortgrasses, primarily buffalograss, some mid-grasses, including sideoats grama and Texas wintergrass (*Stipa leucotricha*), and rarely tallgrass species (Dyksterhuis, 1948). The prairie-woodland interface, however, was now characterized by thickets of dense shrubs (Tharp, 1939).

By the mid-twentieth century vast tracts of land that once supported prairie or forest were now in cultivation (Johnson, 1931; Dyksterhuis, 1948). Forage crops, such as small grains and Johnsongrass (*Sorghum halepense*), as well as cash crops, such as peanuts, fruits and vegetables, were now widespread. Tame pastures, typically of bermudagrass (*Cynodon dactylon*) and Johnsongrass, also were abundant by this period, although livestock was still grazed on tracts of native grasses (Dyksterhuis, 1948).

Figure 3-4
General Vegetation Mapping of the Study Area

Lake Brownwood Watershed Brush Control Planning Assessment and Feasibility

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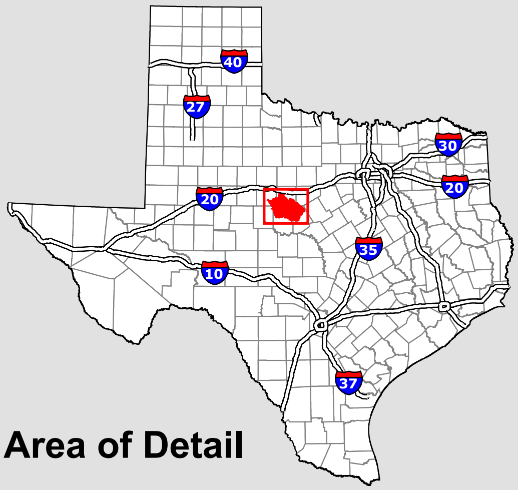

Area of Detail

Lake Brownwood Vegetation

- Crops
- Live Oak - Mesquite - Ashe Juniper Parks
- Mesquite - Juniper - Live Oak Brush
- Oak - Mesquite - Juniper Parks/Woods
- Water Body
- Lake Brownwood Watershed Boundary
- County Boundary
- Highways
- Lakes
- Major Streams
- Minor Streams
- Cities

LCRA
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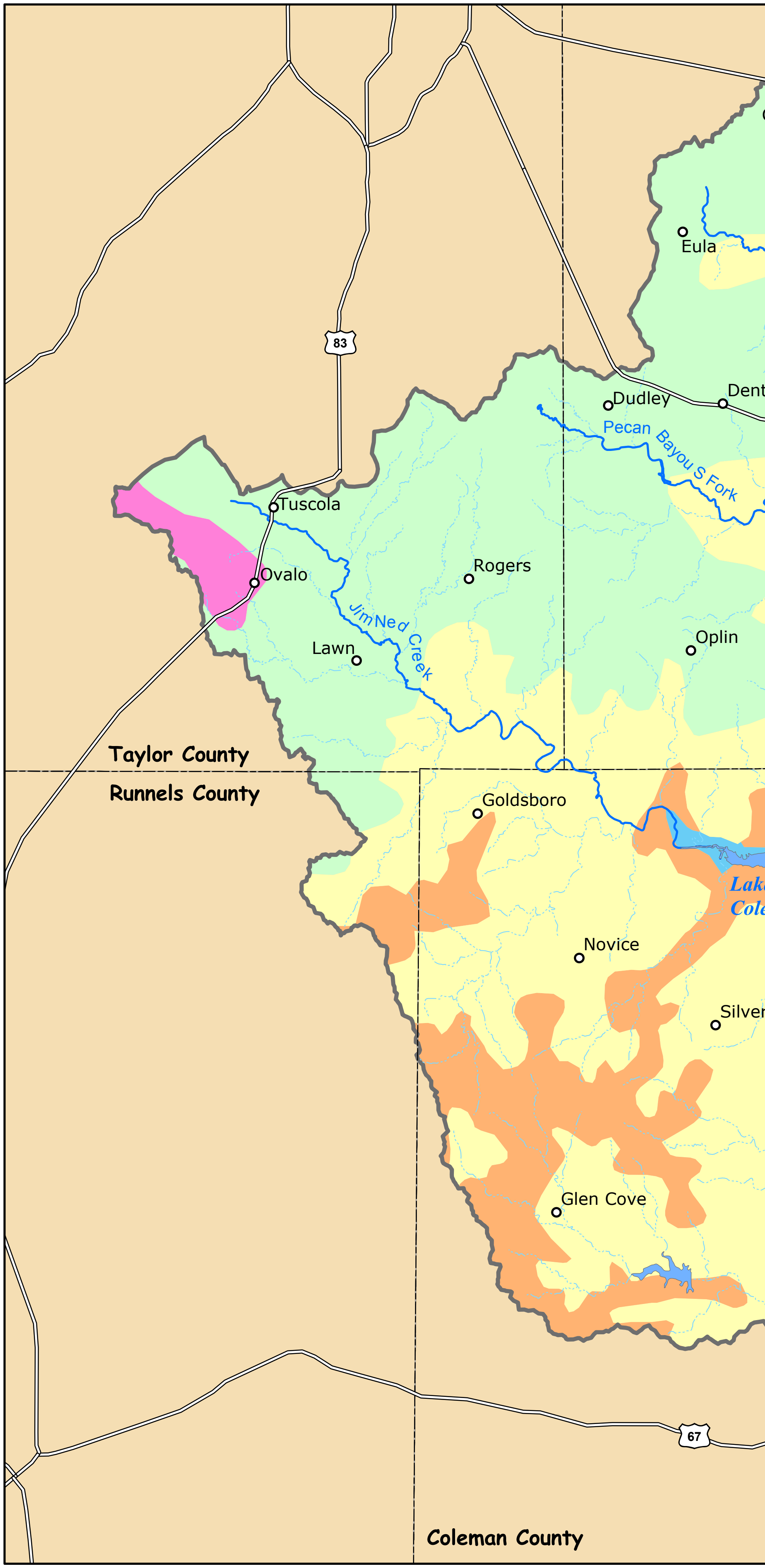
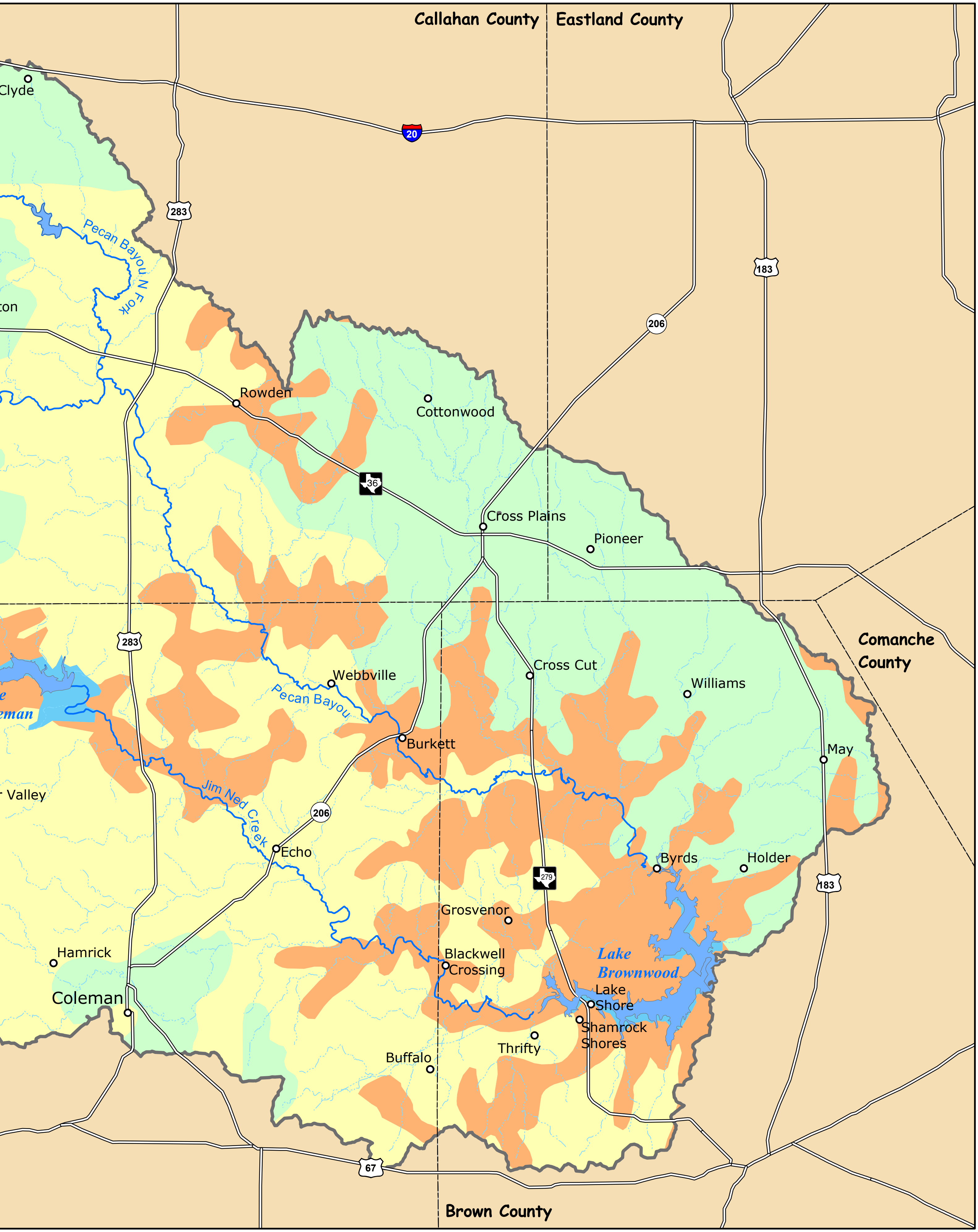
Source:
Roads - Texas Department of Transportation
Counties - Texas Department of Transportation
Cities - Texas Natural Resources Information System
Streams - United States Geological Survey
Lakes - Environmental Protection Agency
Vegetation - Texas Parks and Wildlife




Callahan County
Eastland County
Comanche County
Brown County
Clyde
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283
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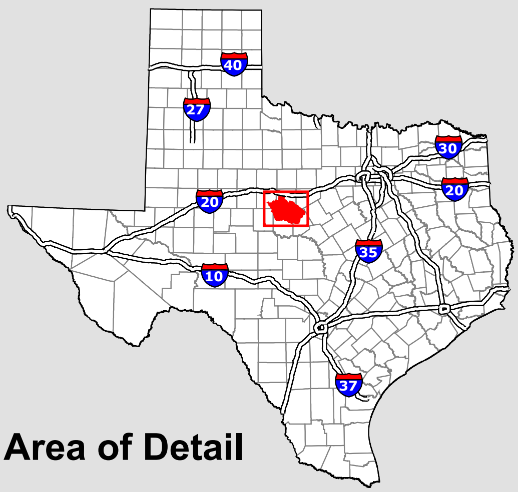
206
36
279
67
Pecan Bayou N Fork
Rowden
Cottonwood
Cross Plains
Pioneer
Cross Cut
Williams
Webbville
Pecan Bayou
Burkett
May
Jim Ned Creek
Echo
Byrds
Holder
Grosvenor
Blackwell Crossing
Lake Brownwood
Lake Shore
Shamrock Shores
Thrifty
Buffalo
Hamrick
Coleman
Valley

3-10

Figure 3-5
2000 Watershed Vegetation Map

Lake Brownwood Watershed Brush Control Planning Assessment and Feasibility

0 5 10 Miles



Area of Detail

Legend

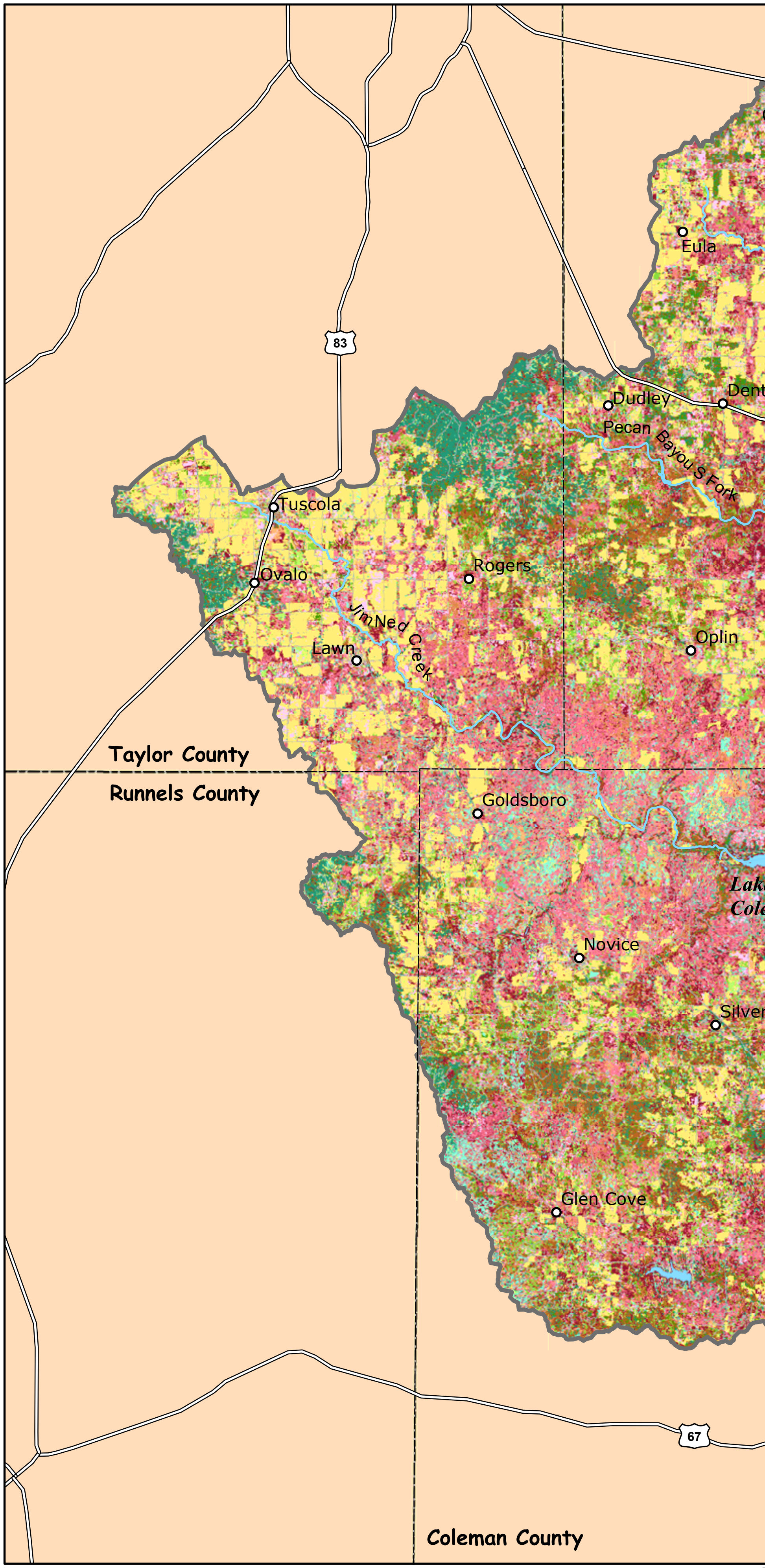
- Highways
- County Boundary
- Cities

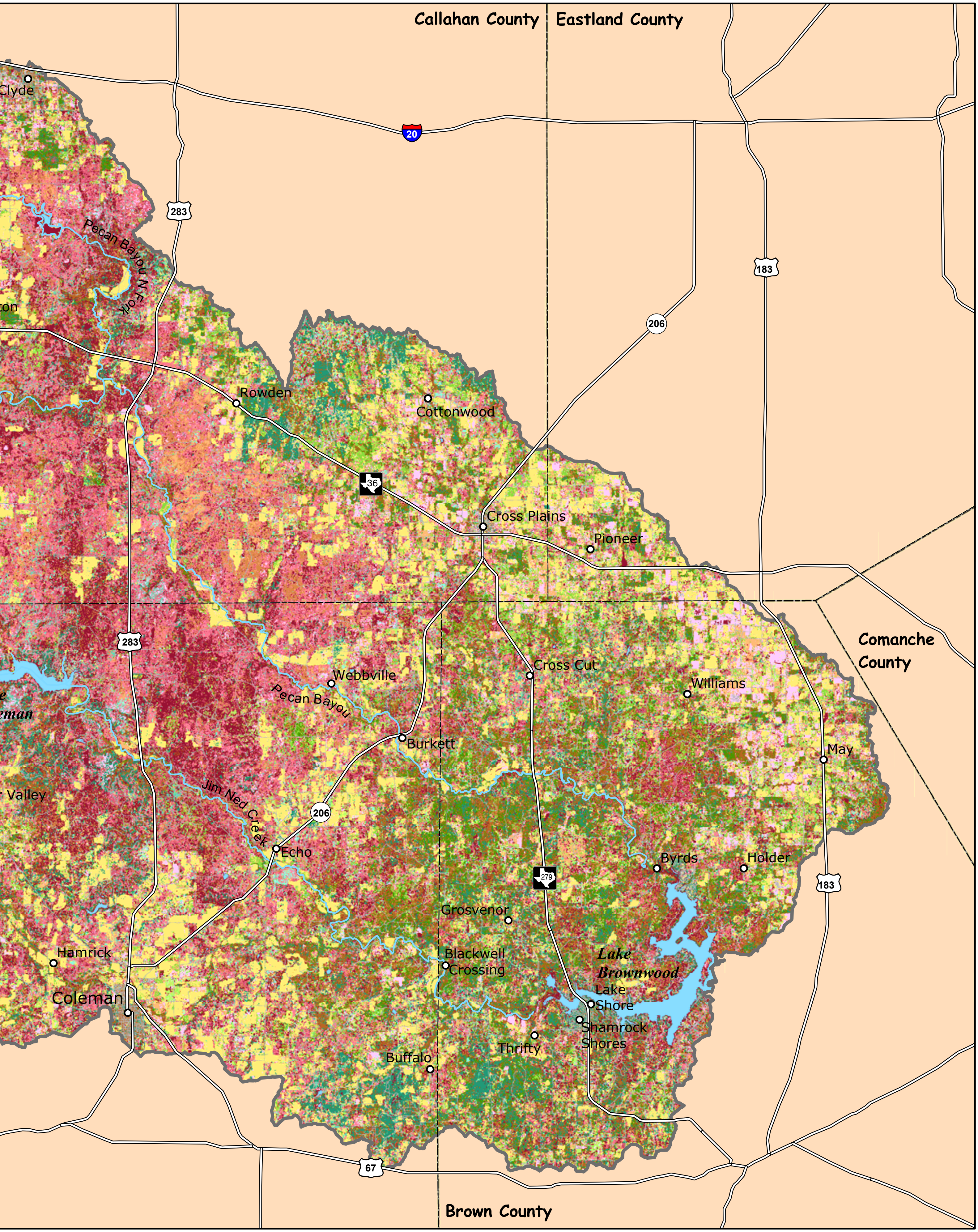
Land Cover

- Agriculture
- Pasture Land
- Urban
- Water
- Light Oak
- Medium Oak
- Heavy Oak
- Light Mixed Brush
- Medium Mixed Brush
- Heavy Mixed Brush
- Light Juniper
- Medium Juniper
- Heavy Juniper
- Light Mesquite
- Medium Mesquite
- Heavy Mesquite

ENERGY • WATER • COMMUNITY SERVICES

Source:
Roads - Texas Department of Transportation
Counties - Texas Department of Transportation
Cities - Texas Naturar Resources Information System
Land Cover - Texas A&M University Blacklands Research Center





Callahan County
Eastland County
Comanche County
Brown County
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Rowden
Cottonwood
Cross Plains
Pioneer
Cross Cut
Webbville
Williams
Burkett
May
Echo
Byrds
Holder
Grosvenor
Blackwell Crossing
Lake Brownwood
Lake Shore
Shamrock Shores
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Buffalo
Hamrick
Coleman
Pecan Bayou N Fork
Pecan Bayou
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Late Twentieth Century Vegetation Descriptions

Descriptions of the vegetation in the Lake Brownwood watershed from the late 1900s did not fail to mention mesquite as a prevalent component of every community as it even had invaded the bottomland riparian zone for the first time. Other invasive woody species found in the bottomlands included saltcedar (*Tamarix sp.*), willow (*Salix sp.*), and eastern red cedar (*Juniperus virginiana*) (Scifres, 1980; LBJ School of Public Affairs, 1978).

Both the Edwards Plateau and Rolling Plains regions were generally described at the time as a mesquite-shortgrass savannah with varying densities of woody species. Important components of the shrub stratum included oaks, junipers and species of Acacia and Mimosa (LBJ School of Public Affairs, 1978). The native tall- and midgrasses had given way to stands of Texas wintergrass, threeawns, short gramas, buffalograss, curly mesquite, tobosa (*Hilaria mutica*), dropseeds (*Sporobolus spp.*) and hooded windmillgrass (*Chloris cucullata*) (Scifres, 1980).

The Western Cross Timbers still supported post oak and blackjack oak woodlands; however, this community had an almost impenetrable understory of yaupon (*Ilex vomitoria*), winged elm (*Ulmus alata*), common persimmon (*Diospyros virginiana*), and other spiny brush species as well as numerous low-growing shrubs and vines. Willow baccharis (*Baccharis salicina*) was a common invader in the post oak savannahs in this region as well (Scifres, 1980).

The region continued to be predominantly locked in agricultural land uses through the end of the twentieth century with vast ranching operations and a number of smaller farms. By the end of the twentieth century, the predominant crops grown in the region were sorghum, cotton, and wheat (Scifres, 1980).

HYDROLOGICAL HISTORY

Temperature and precipitation data were obtained from the National Climatic Data Center for three cooperative stations at Albany (410120), Balinger (410493), and Brownwood (411138), which are located north, southwest and southeast of the study area, respectively (Figure 3-2). Due to their similarity, simple averaging of the data from these stations was used to estimate temperatures and precipitation for the entire watershed. Table 3-2 presents a summary of the mean monthly and mean annual temperatures and precipitation for the station and watershed. Except for a record drought in the 1950s, meteorological data indicate that temperature precipitation patterns in the Lake Brownwood watershed has been rather stable for the past century. The average annual temperature in the watershed is approximately 64.4° F, and the average annual rainfall is approximately 25.9 inches. Data from the Texas Water Development Board (TWDB) indicate that the average annual gross evaporation in the watershed is approximately 67.3 inches.

The U.S. Geological Survey (USGS) has operated gauges at four stream sites in the Lake Brownwood watershed and one on Pecan Bayou several miles downstream of Lake Brownwood (Figure 3-2): The locations of the gauges are shown on Figure 3-2 and their periods of records are as follows.

- 08143500 - Pecan Bayou at Brownwood, Texas (1923-1983)
- 08140700 - Pecan Bayou near Cross Cut, Texas (1968-1978)
- 08140800 - Jim Ned Creek near Coleman, Texas (1965-1980)
- 08142000 - Hords Creek near Coleman, Texas (1940-1970)
- 08141500 - Hords Creek near Valera, Texas (1947-1990)

The gauge at Brownwood has the longest period of record and is reasonably well positioned to assess the discharge characteristics of the overall watershed. However, the flow data for this gauge is heavily influenced by the operation of Lake Brownwood, which was constructed approximately eight miles upstream of the gauge in 1933. Similarly, the gauge on Hords Creek near Valera is affected by the operation of Hords Creek Dam, which was constructed immediately upstream of the gauge in 1948. The gauge on Hords Creek near Coleman is approximately 15 miles downstream of Hords Creek Lake, but is also influenced by operation of Hords Creek Dam. Lastly, the gauge on Jim Ned Creek near Coleman is not strongly affected by reservoir releases, but it only has a 15-year period of record.

Assessing the natural flow characteristics of gauged streams in the watershed requires accounting for diversions for municipal, irrigation and other uses; return flows to the stream; reservoir storage changes, and reservoir evaporation. This type of analysis was beyond the resources of this feasibility study. However, R. J. Brandes Company recently conducted this analysis for Pecan Bayou at Brownwood, in an effort to develop the water availability model for the Colorado River basin. At the time of the completion of this report, the modeling is not yet complete, and the naturalized flows from that study were unavailable. However, the information is believed to be reasonably accurate, recognizing there are limitations on the estimation of naturalized streamflow. Such limitations include not considering changes in the runoff characteristics of the watershed, which are greatly influenced by vegetation. Consequently, even though the naturalized streamflows for Pecan Bayou were estimated for the period 1940 to 1998, they cannot be used to assess impacts of vegetation or other land use changes in the watershed. In addition, average monthly flows were estimated instead of daily flows, which makes examination of base flow data for the Pecan Bayou untenable.

Streamflow

Figure 3-5 is a plot of total annual precipitation in the watershed and total annual discharge of Pecan Bayou at Brownwood. The plot shows the discharge based on daily gauge readings from 1930 to 1982 and the naturalized streamflow estimates discussed above. The naturalized flows show the expected relationship between discharge and precipitation (i.e., increased discharge with increased precipitation). In contrast, the gauge measurements show several years when discharge has been low despite normal to high amounts of precipitation. The precipitation and discharge data are tabulated in Table 3-3. Mean annual discharge measured at the USGS gauge on Pecan Bayou at Brownwood was 95,949 acre-feet for the period 1930-1982. The mean annual discharge at the same location based on naturalized streamflow for 1940 to 1998 was 145,331 acre-feet. Mean annual precipitation between 1930 and 1998 was 26.2 inches.

A flow-duration curve is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. The naturalized streamflow estimates for Pecan Bayou at Brownwood were used to prepare a flow-duration curve of monthly discharge from 1940 through 1998 (Figure 3-6). The curve shows that the naturalized discharge varies widely. There is flow in the river during the month approximately 99 percent of the time, and approximately 90 percent of the time the monthly discharge is 377 acre-feet or more.

Groundwater Levels

Since groundwater discharge presumably contributes to streamflow in the watershed, water level data from wells in the watershed were examined for indications of whether the amount of groundwater discharged to the river had changed over time. TWDB maintains a database that contains water level readings for approximately 885 wells in or very near the watershed. Fifty-four of the wells have water level data available for 20 or more years. Of these, nine wells were completed in alluvium, 36 in aquifers of the Trinity Group aquifers (mostly Antlers Formation), four in Permian formations, four in the Pennsylvanian Canyon and Cisco groups, and one in older Paleozoic rocks. Table 3-4 presents a summary of the approximate net water level changes for these wells.

Three of the nine wells completed in the alluvium showed net water level declines, with an average loss per well of 3.5 feet. Net water level gains were recorded in the other alluvium wells, with an average gain per well of 6.3 feet. Fourteen of 36 wells in the Trinity Group showed net water level declines, averaging 4.5 feet per well. The remaining 22 Trinity wells showed net water level increases, with an average gain of 5.3 feet per well. Of four wells completed in water bearing Permian formations showed a net water level decline of 12.0 feet. The other three Permian wells showed net water level gains that averaged 2.6 feet. Three of four wells completed in Pennsylvanian aquifers showed net water level declines, with one reporting a decline of 157 feet and the other two an average of 7.5 feet. The remaining Pennsylvanian well had a net water level increase of 2 feet. The one well completed in older Paleozoic rock had a net water decrease of 3.3 feet.

Natural water level changes in an aquifer are mainly due to changes in the groundwater recharge/discharge conditions of the aquifer. Variation in atmospheric pressure and rate of evapotranspiration also may have a lesser effect on water levels in wells. When natural groundwater recharge is reduced during dry periods, water is discharged naturally from storage and groundwater levels decline accordingly. As the aquifer is recharged by rainfall, the groundwater lost from storage is replenished and water levels begin to rise. Groundwater withdrawals from wells disrupt these natural conditions and artificially cause water level changes.

Hhydrographs for water levels in selected water wells in the watershed show the fluctuation of water level that occurs over time. Overall, the water level fluctuations are likely the result of variations in rainfall. Localized concentrated groundwater withdrawals and, to a lesser extent, the rates of evapotranspiration are likely causes of any long-term water level declines.

Springs

No quantitative information on spring flows in the watershed was found for this study, and little information appears to be published on the existence of springs in the area. Thompson (1967) inventoried 11 springs in Brown County, but he did not describe them beyond identifying the geologic unit from which they discharged. Two of the springs reportedly issue from the Trinity Group, five from Permian formations, and four from Pennsylvanian strata. The locations of these springs are shown on Figure 3-10. Price et al. (1983), Taylor (1976), and Walker (1967) mention the occurrence of numerous spring in Callahan, Coleman and Taylor counties but did not identify any that discharge within the Lake Brownwood watershed. Many of the springs appear to discharge along slopes where permeable, water bearing rocks rest on less permeable rocks. An excellent example of this is where strata of the Fredericksburg Group (including the Edwards Formation) occur at the tops of the hills that form the Callahan Divide. Water that infiltrates the surface of the Fredericksburg percolates downward until it encounters less permeable rocks and flows laterally and by gravity to discharge points along hillsides.

3.3 GEOLOGICAL CONSIDERATIONS

Geologic units at the surface within the study area are delineated on the geologic map in Figure 3-8. Generally, streams in the watershed flow across Permian and Pennsylvanian sedimentary rocks that extend to a depth of approximately 4,000 feet. The rocks are composed of limestone, dolomite, shale and clastics that dip to the northwest at an average rate of 50 feet per mile. Cretaceous rocks consisting of sandstone, shaly limestone and limestone are exposed at the surface mainly along the eastern margin of the study area. However, they also occur as erosional remnants, or outliers, in the localized areas in the western part of the watershed. The Cretaceous rocks unconformably overlie the Pennsylvanian strata and dip gently to the southeast in the study area. The Cretaceous rocks form the larger hills and mesa-type landforms in the area. Thin deposits of Quaternary age sand, silt, clay and caliche unconformably overlie the Paleozoic rocks in the western portions of the watershed, and recent (Holocene) alluvium deposits occur throughout the watershed in the floodplains of the larger streams. The Qauternary deposits are not depicted in Figure 3-8. An east-west geologic cross-section that illustrates the subsurface geology within the watershed is presented in Figure 3-9. Table 3-5 identifies the stratigraphic units, and corresponding aquifers that occur in the study area. The table also summarizes the lithologic character and water-bearing properties of each significant unit.

Figure 3-6
Geologic Map of the Study Area

Lake Brownwood Watershed Brush Control Planning Assessment and Feasibility

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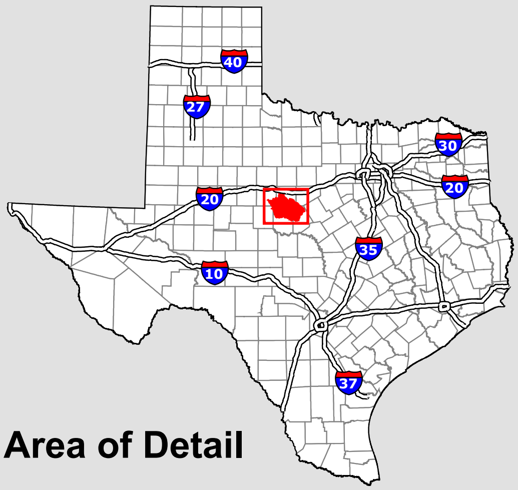
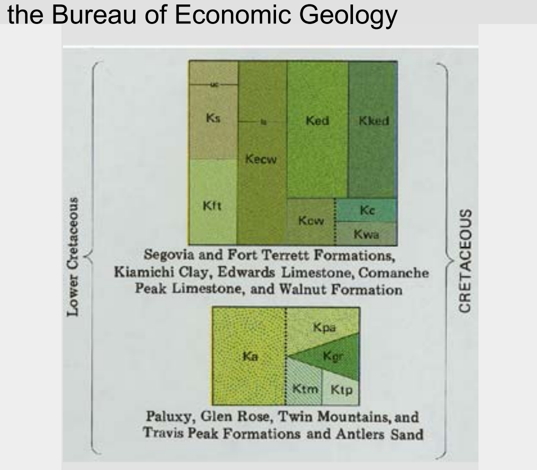


Area of Detail

Subset of Geologic Legend:
Complete legend information available from the Bureau of Economic Geology



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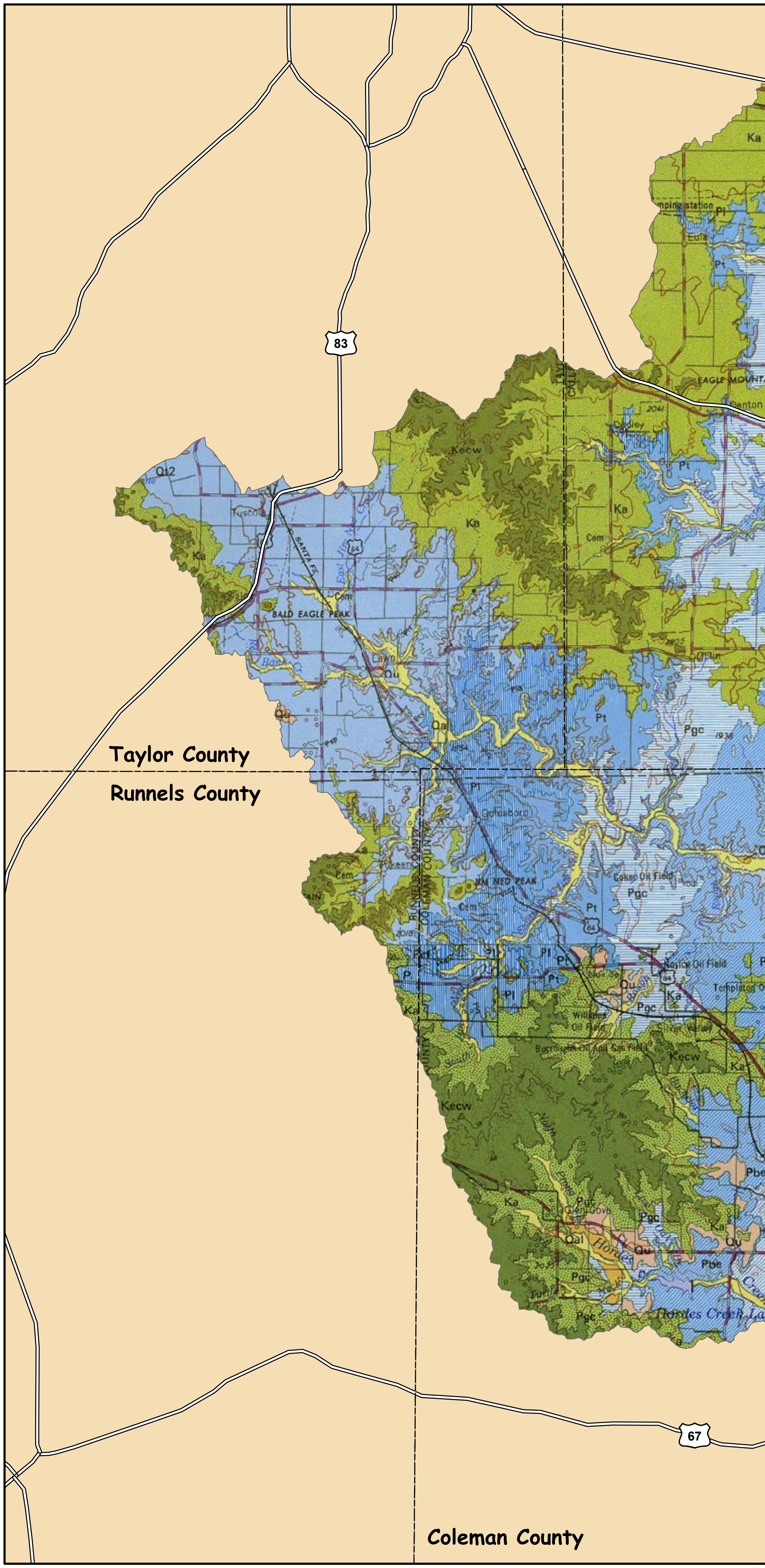
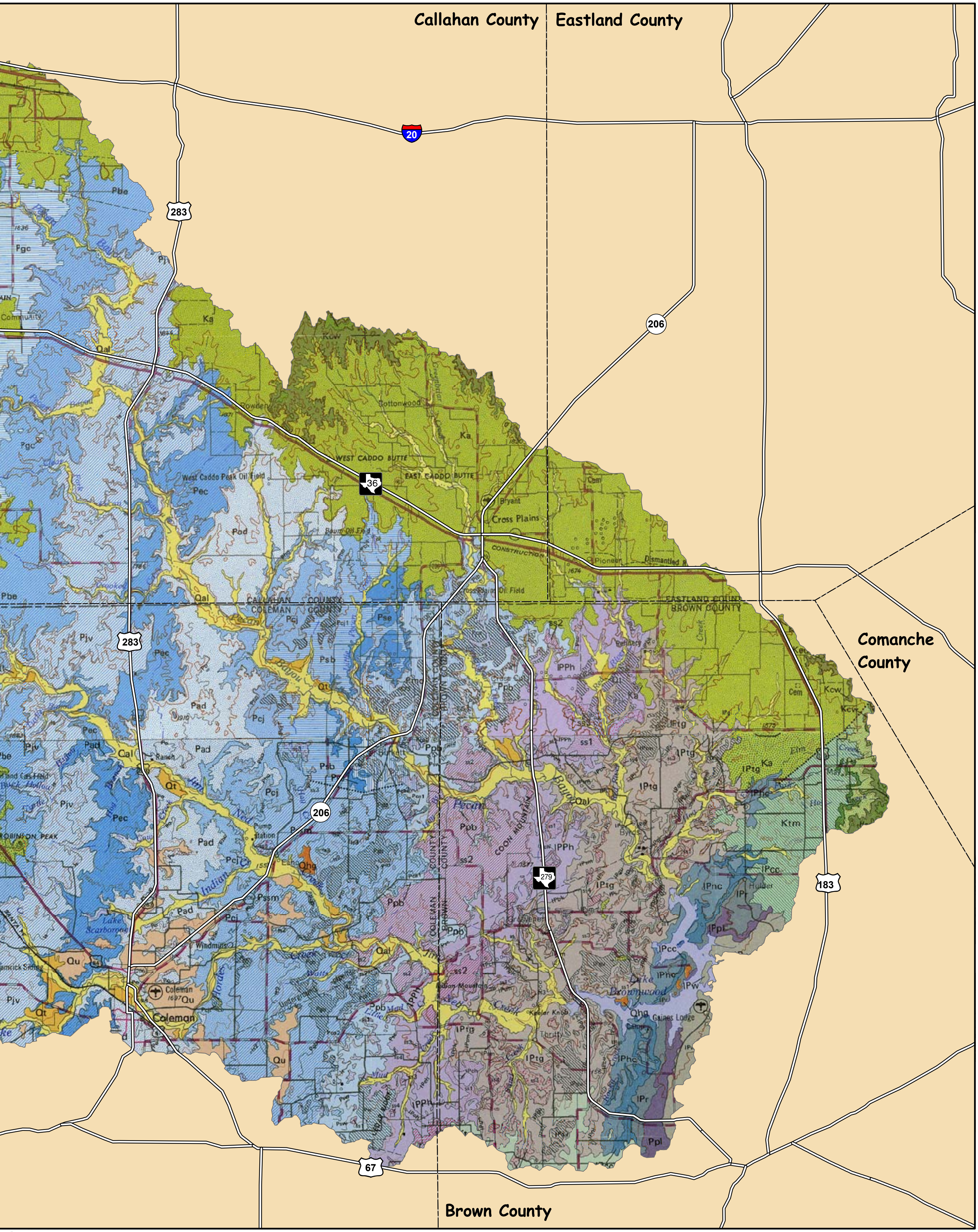
Source:
Roads - Texas Department of Transportation
Counties - Texas Department of Transportation
Geology - Bureau of Economic Geology




Callahan County
Eastland County
Comanche County
Brown County
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36
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183
67
West Caddo Butte
East Caddo Butte
Cross Plains
Coleman
Lake Brownwood
Coon Mountain

3.4 EXISTING SURFACE WATER HYDROLOGY

The hydrologic characteristics of the Lake Brownwood watershed are closely linked to precipitation patterns in the watershed, especially the cycles of floods and droughts, which are common in Texas. Major flood and drought events are those with statistical recurrence intervals longer than 25 years and 10 years, respectively. Streamflow measurements began in the river basin in 1923, and the data show there has been a significant or major drought in almost every decade since then. Based on naturalized streamflow estimates, the average monthly discharge of Pecan Bayou at Brownwood ranges from about 4,500 acre-feet in November to about 31,000 acre-feet in May. The average annual runoff from 1940 to 1998 was 145,331 acre-feet at Brownwood. No major water quality issues have been identified in the watershed, but contamination from non-point sources of pollution are probably the most likely way that surface water quality may be impacted. Non-point source pollution is runoff that, as it flows over the land, picks up pollutants that adhere to plants, soils and man-made objects and eventually infiltrates to the groundwater table or flows into a surface stream. Another source of non-point pollution is an accidental spill of toxic chemicals near streams or over recharge zones that will send a concentrated pulse of contaminated water through stream segments or aquifers. Public water supply wells that only use chlorination water treatment and domestic groundwater wells that may not treat water before consumption are especially vulnerable to sources of non-point pollution, as are the habitats of threatened and endangered species that live in and near springs and certain stream segments.

3.5 EXISTING GROUNDWATER HYDROLOGY

The most productive water-bearing unit in the study area is the Trinity Group, which consists mainly of the Antlers Formation. More wells are completed in the Trinity than other water-bearing units, and the water is of better quality. The water-bearing portions of the Trinity Group consist of fine- to coarse-grained sand, gravel and shaly limestone. The maximum thickness of the Trinity in the study area is probably less than 100 feet.

In the western portion of the study area and along the watershed's northern margin, younger Cretaceous strata of the Fredericksburg Group, including the Edwards, Comanche Peak and Walnut formations, overlie the Trinity Group. The Edwards is the most permeable of the Fredericksburg units and is more permeable than the Trinity Group aquifers. However, it occurs only as thin remnants capping hilltops in portions of the study area, and is not sufficiently saturated to produce much groundwater. However, the quality of water in the Fredericksburg Group is generally good.

Permian and Pennsylvanian rocks that underlie the watershed produce small amounts of fresh to very saline water from highly interbedded and laterally discontinuous sandstone and limestone strata. Water is also produced to a limited degree from older Paleozoic rocks that underlie the Pennsylvanian system, including limestones of the Ellenburger Group and Hickory Sandstone. Groundwater in the deeper Paleozoics occurs under artesian conditions and the water is slightly saline to saline. Thin deposits of alluvium along the major streams consist of unconsolidated sand, silt, clay and gravel and yield small amounts of generally good quality water.

All of the aquifers in the watershed, except the deep Paleozoic aquifers, receive recharge from precipitation in outcrop areas. The Permian and Pennsylvanian rocks and the alluvium also receive recharge as seepage from surface water bodies. The deep Paleozoic rocks receive their recharge from areas outside the watershed.

Groundwater in all of the aquifers moves slowly under the force of gravity from areas with relatively high groundwater elevations to areas with low groundwater elevations, and generally from areas of recharge to areas of discharge. The direction and rate of groundwater movement in these aquifers are controlled by the hydraulic gradient, aquifer permeability and structural dip of the rock units comprising the aquifer. Some of the groundwater in the aquifers is discharged naturally through springs, by channel seeps associated with base flow of effluent streams, by subsurface underflow, and by evapotranspiration.

Artificial discharge of groundwater is by water wells in the region. Figure 3-10 presents a location map of water wells and springs within the Lake Brownwood watershed. The wells are those for which records exist in the TWDB groundwater database, and they represent only a small portion, perhaps 20 percent, of the wells that probably exist in the area. Nonetheless, they are generally representative of groundwater usage in the watershed. Of 1,450 wells, 599 are used for domestic water supply, 271 for irrigation, 266 for livestock, 50 for public water supply, and 19 for industrial purposes. Approximately 231 are reported as being unused. Use of the remaining wells is unspecified or for other minor uses.

3.6 DESCRIPTION OF THE WATERSHED HYDROLOGIC SYSTEM

The hydrologic system of the Lake Brownwood watershed is generally unchanged from that encountered by the first European settlers to the region. Water enters the hydrologic system as precipitation in the watershed. Precipitation either enters surface streams as runoff or infiltrates surface soil or bedrock and recharges the underlying aquifers. Some water may enter the hydrologic system as groundwater flow from outside the watershed boundary. Streams in the watershed receive their base flow from groundwater that is naturally discharged from the near surface aquifers. The streams generally gain in flow from springs and seeps issuing along their course. Losses in base flow are principally due to evaporation and diversions for water supply. Discharge from the system includes surface water releases from Lake Brownwood, artificial surface water and groundwater withdrawals, groundwater flow crossing the downgradient boundary of the watershed, and returns to the atmosphere through evapotranspiration.

Brown, Coleman and Runnels counties are within the Region F Water Planning Group established by the State Legislature in Senate Bill 1, while Taylor, Callahan and Eastland counties fall within the Brazos G Regional Water Planning Area. Approximate current and future water demands in the counties are summarized in Table 3-6. The region is heavily dependent on surface water to meet its water needs, due to the generally low yields available from area aquifers. Rural areas in Brown and Runnels counties are expected to experience some water deficit in the future because of population growth. Future demands by other sectors of the watershed are expected to be met by existing surface reservoirs.

3.7 SUMMARY AND CONCLUSIONS

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

No significant changes have occurred in the historical climate patterns within the watershed, including precipitation frequency, duration and intensity.

Changes in the historical vegetation of the watershed have been substantial. Distinct land use changes brought on by European settlement and an extensive drought precipitated a widespread transformation of the landscape by the end of the nineteenth century. This change included a great increase in the amount and distribution of woody species, particularly honey mesquite (*Prosopis glandulosa*). The once distinct boundaries among the various habitat types have become blurred, as each community assemblage has become more homogenous and grasslands have almost disappeared.

Data on streamflow were collected from the USGS gauging stations on Pecan Bayou, Jim Ned Creek and Hords Creek, but the data cannot be used to determine whether vegetation changes have affected surface water yields in the watershed. This is primarily due to the location of the gauges downstream of controlled release reservoirs.

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 evident.

The streams in the watershed are naturally “gaining” streams (i.e., flow increases downstream). The river generally gains flow by the discharge of groundwater to the river. Groundwater contributions come from springs and seeps along major streams and their tributaries.

The aquifers in the study area generally yield only small amounts of water, and they receive comparatively low recharge. Accordingly most precipitation becomes runoff to local streams.

Limited water supply shortages are projected to occur in the watershed because of increased water demand. Water availability in rural areas of Brown and Runnels counties is a particular concern. Brush management may be an effective means of improving surface water and groundwater supplies in the watershed. Further, the population in the lower Colorado River basin is projected to more than double over the next 50 years. This projected increase in population is the principal factor behind a projected increase in total water demand in the basin from approximately 1.1 million acre-feet in 2000 to 1.4 million acre-feet in 2050.

Although the hydrologic data available for this study were not adequate for determining if water yields in the Lake Brownwood watershed have been affected by brush infestation, geologic and hydrologic conditions in the watershed are very conducive to enhancement of water yields through brush management. Analysis found in Appendices 1-4 are based on the period of 1960-1999. Further evaluations that include the drought of record may prove to be useful in predicting water availability for future water supplies. It should also be noted that modeling of such scenarios is dependent on input variables that are subject to interpretation.

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APPENDIX 1

BRUSH / WATER YIELD FEASIBILITY STUDIES II

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Abstract*:* The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in four watersheds in Texas for 1960 through 1999. Methods used in this study were similar to methods used in a previous study (TAES, 2000) in which 8 watersheds were analyzed. Landsat 7 satellite imagery was used to classify land use, and the 1:24,000 scale digital elevation model (DEM) was used to delineate watershed boundaries and subbasins. SWAT was calibrated to measured stream gauge flow and reservoir storage. Brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Simulated changes in water yield due to brush treatment varied by subbasin, with all subbasins showing increased water yield as a result of removing brush. Average annual water yield increases ranged from about 111,000 gallons per treated acre in the Fort Phantom Hill watershed to about 178,000 gallons per treated acre in the Palo Pinto watershed. Water yield increases per treated acre were similar to a previous study (COE, 2002), but higher than TAES (2000). As in previous studies, there was a strong, positive correlation between water yield increase and precipitation.

BACKGROUND

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

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

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

METHODS

SWAT Model Description

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

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

SWAT was used to simulate water yield (equal to the sum of surface runoff + shallow aquifer flow + lateral soil flow – subbasin transmission losses) and streamflow 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:

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).

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.

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

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:

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.

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.

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

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

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

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

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**

<u>Climate.</u> 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 streamflow 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 streamflow 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 streamflow 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.

Streamflow 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 streamflow 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. Streamflow 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 streamflow.

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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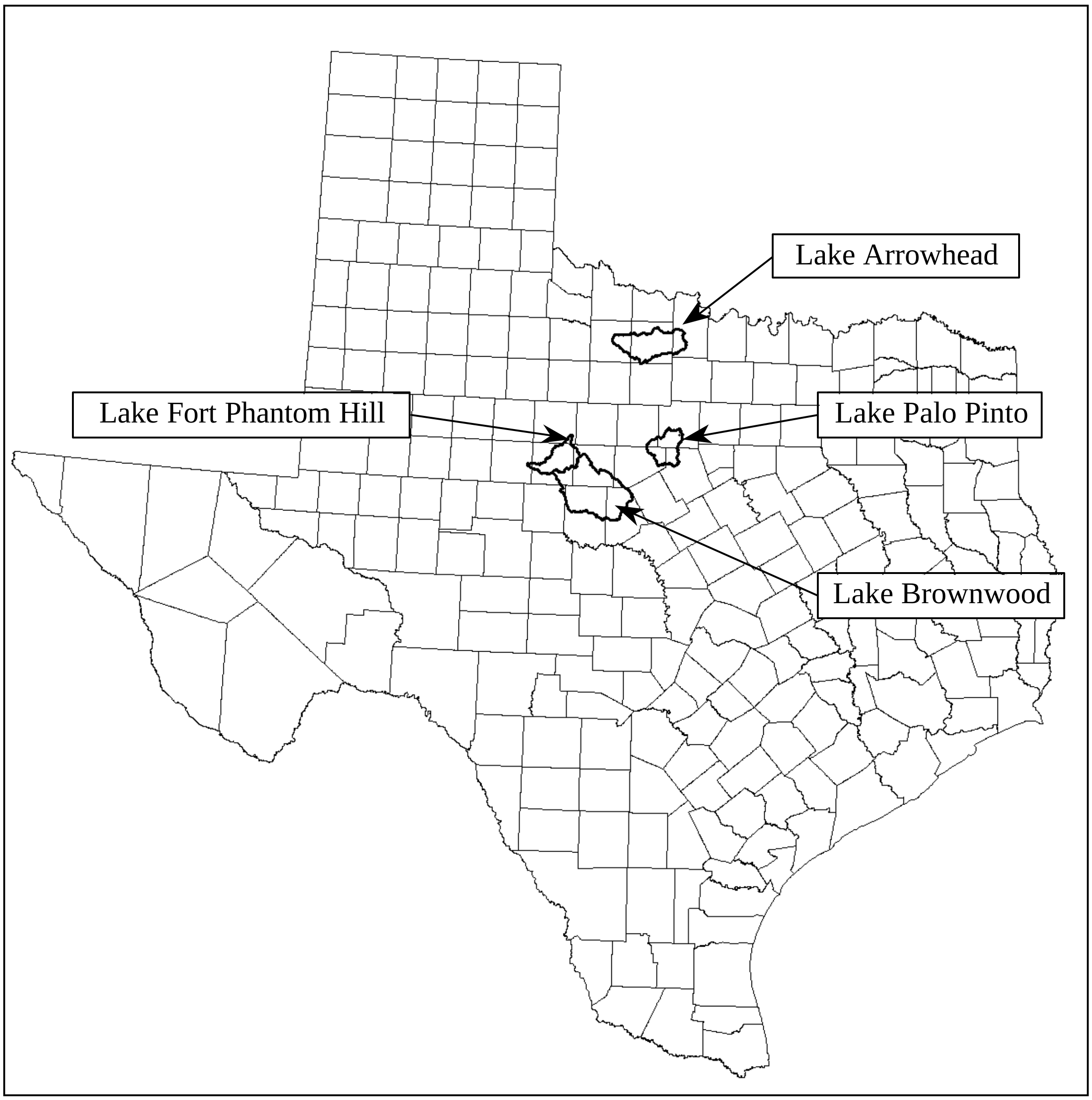

Figure 1-1. Watersheds included in the study area.

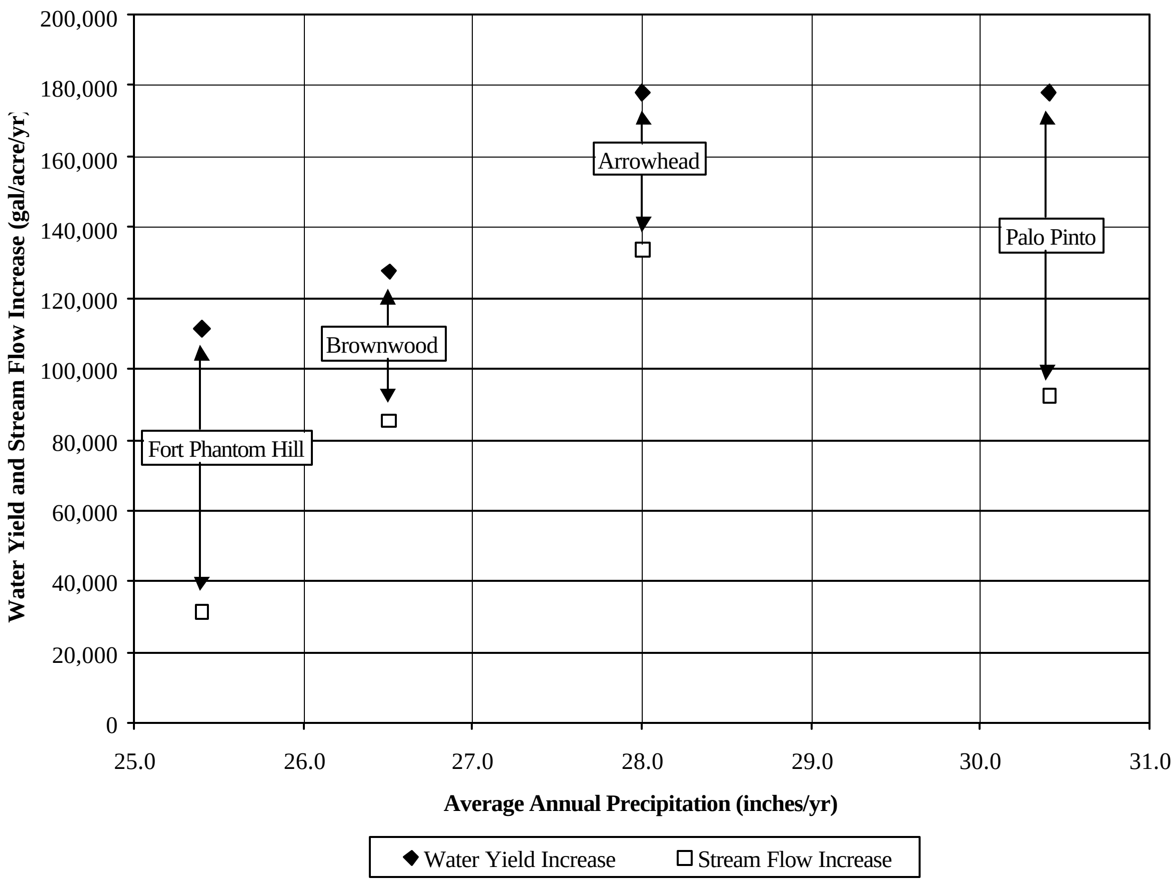

Figure 1-2. Average annual water yield and streamflow increases per treated acre versus average annual precipitation for watersheds in this study, 1960 through 1999.

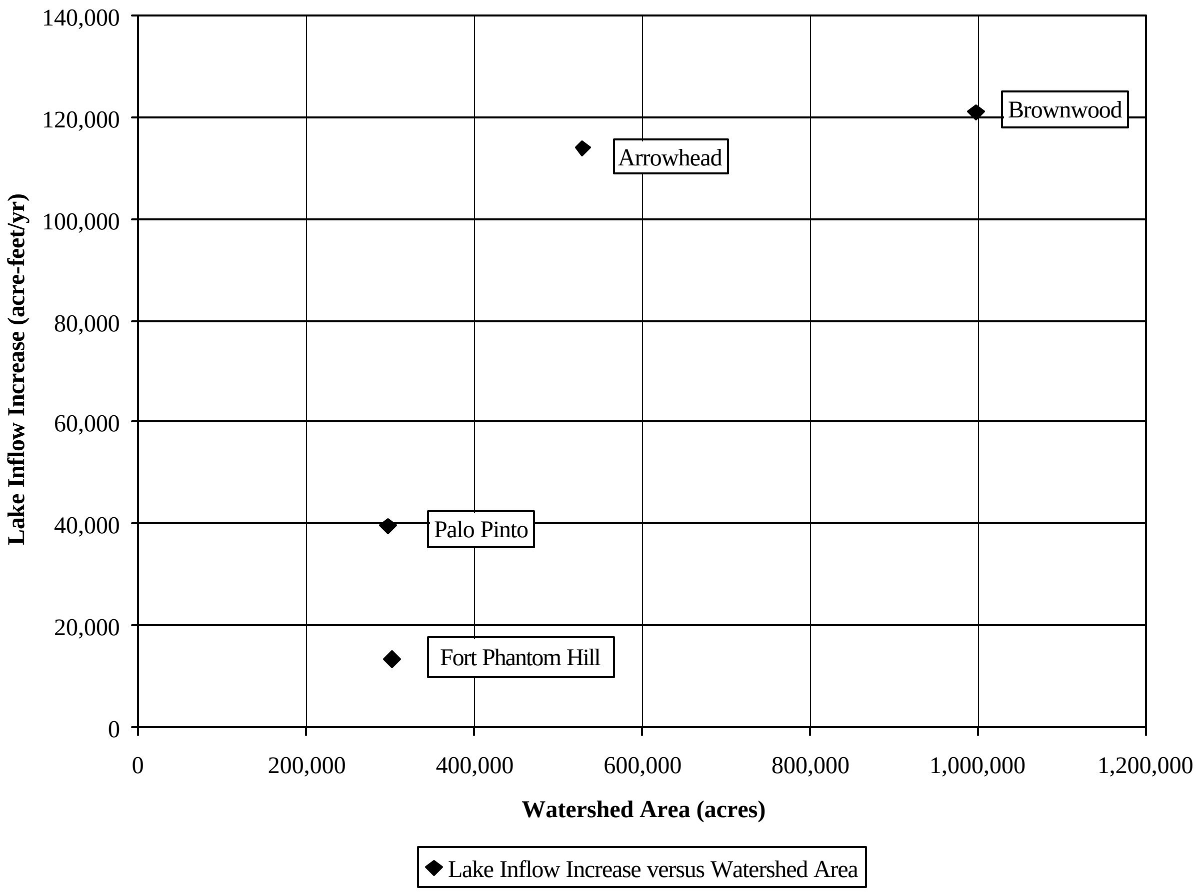

Figure 1-3. Average annual lake inflow increase resulting from brush removal versus watershed drainage area for watersheds in this study, 1960 through 1999.

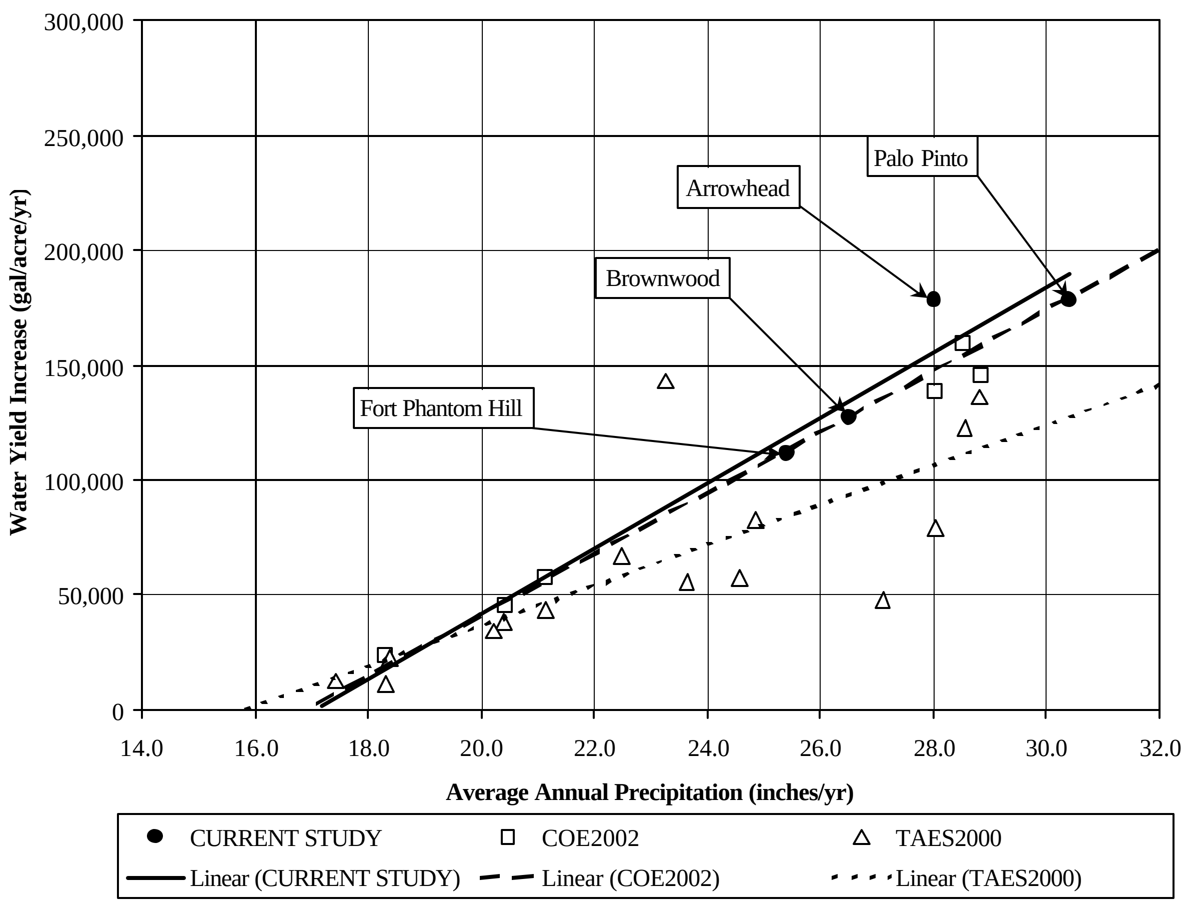

Figure 1-4. Water yield increase versus average annual precipitation - current study, COE

(2002), and TAES (2000). Points are labeled for watersheds in current study.

APPENDIX 2

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

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Abstract: A feasibility study of brush control for off-site water yield was undertaken in 1998 on the North Concho River near San Angelo, Texas. In 2000, feasibility studies were conducted on eight additional Texas watersheds. This year, studies of four additional Texas watersheds were completed and the results reported herein. Economic analysis was based on estimated control costs of the different options compared to the estimated landowner benefits from brush control. Control costs included initial and follow-up treatments required to reduce brush canopy to between 8% and 3% and maintain it at the reduced level for 10 years. The state cost share was estimated by subtracting the present value of landowner benefits from the present value of the total cost of the control program. The total cost of additional water was determined by dividing the total state cost share if all eligible acreage were enrolled by the total added water estimated to result from the brush control program. This procedure resulted in present values of total control costs per acre ranging from $35.57 to $203.17. Rancher benefits, based on the present value of the improved net returns to typical cattle, sheep, goat and wildlife enterprises, ranged from $37.20 per acre to $17.09. Present values of the state cost share per acre ranged from $140.62 to $39.20. The cost of added water estimated for the four watersheds ranged from $14.90 to $37.95 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) and in eight additional watersheds across Texas (Conner and Bach). 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 Appendix 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 1. Year 0 in Table 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. In the larger watersheds two focus groups were used where it was deemed necessary because of significant climatic and/or terrestrial differences.

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 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.).

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). The ECON model yields net present values 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 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 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 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 Pala Pinto Watershed to $37.20 per acre for control of heavy Shinnery Oak in the Lake Pala Pinto Watershed.

<u>State Cost Share</u>

If ranchers are not to benefit from the state's portion of the control cost, they must invest in the implementation of the brush control program an amount equal to their total net benefits. 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 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 sub-basin were supplied by the Blacklands Research Center, Texas Agricultural Experiment Station in Temple, Texas (see Appendix 1). The total state cost share for each sub-basin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the sub-basin. The cost of added water resulting from the control of the eligible brush in each sub-basin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the 10-year period using a 6% discount rate). Table 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 $14.90 per acre-foot for the entire watershed. Sub-basin 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 eight 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. 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	-	-	-	-	-	-	26	22	-	-	-	-	-	-
Lake Brownwood	40	25	20	15	35	20	37	25	18	15	29	20	30	20	29	20
Fort Phantom Hill	45	25	20	15	35	20	18	15	37	25	29	20	-	-	-	-
Palo Pinto	45	25	25	18	35	20	37	25	21	18	29	20	40	20	27	20

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

Year	Animal Units	Total Increase in Sales	Total Added Investment	Increased Variable Costs	Additional Revenues	Cash Flow	Annual NPV	Accumulated NPV
0	50	0	0	0	0	0	0	-
1	53.3	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 2-5. Cost of Added Water From Brush Control by Sub-Basin (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	890,835.69	2,154,658,197.03	6,612.40	51,587.94	17.27
2	792,839.56	1,603,971,605.12	4,922.41	38,403.11	20.65
3	1,193,772.24	2,645,021,025.03	8,117.27	63,328.45	18.85
4	645,032.32	1,149,475,605.35	3,527.61	27,521.34	23.44
5	330,284.29	523,014,767.61	1,605.07	12,522.29	26.38
6	385,074.33	1,060,752,122.04	3,255.33	25,397.07	15.16
7	451,240.14	1,246,555,855.56	3,825.54	29,845.68	15.12
8	893,199.99	2,508,188,911.38	7,697.35	60,052.35	14.87
9	789,409.91	1,724,107,666.62	5,291.09	41,279.47	19.12
10	1,390,116.97	4,128,213,443.23	12,669.02	98,839.81	14.06
11	1,304,918.20	4,175,057,884.49	12,812.78	99,961.38	13.05
12	87,872.64	382,626,356.77	1,174.24	9,161.04	9.59
13	1,164,934.45	3,449,892,862.07	10,587.33	82,599.11	14.10
14	855,343.01	2,714,347,320.33	8,330.03	64,988.30	13.16
15	326,603.70	1,188,731,222.13	3,648.08	28,461.21	11.48
16	257,684.25	981,314,990.05	3,011.55	23,495.15	10.97
17	177,614.54	655,942,859.17	2,013.01	15,704.92	11.31
18	166,110.60	556,785,852.99	1,708.71	13,330.85	12.46
19	1,029,797.78	2,823,542,988.67	8,665.14	67,602.72	15.23
20	886,216.09	2,440,216,220.39	7,488.75	58,424.91	15.17
21	364,992.01	1,015,478,003.63	3,116.39	24,313.10	15.01
22	75,349.90	272,324,895.18	835.73	6,520.14	11.56
23	905,677.75	3,239,088,907.36	9,940.40	77,551.93	11.68
24	946,411.68	3,019,716,470.06	9,267.17	72,299.61	13.09
25	293,211.92	893,809,938.15	2,743.00	21,400.06	13.70
26	546,610.84	1,745,624,225.02	5,357.12	41,794.63	13.08
27	318,222.59	640,949,626.80	1,967.00	15,345.95	20.74
28	76,455.03	466,961,686.53	1,433.05	11,180.24	6.84
Total	17,545,832.44			1,182,912.76	
Average					14.90

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

APPENDIX 3

LAKE BROWNWOOD WATERSHED – HYDROLOGIC SIMULATION

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WATERSHED DATA

Physical Data

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

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

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

The outlet or "catchment" for the watershed simulated in this study is Lake Brownwood labeled subbasin number 48. The subbasin delineation, numbers, county boundaries, and major roads (obtained from the Census Bureau) are shown in Figure 3-1.

METHODS

Land Use/Land Cover

The land use map was derived from the classification of Landsat 7 imagery utilizing ground control points collected by local NRCS personnel. Software accuracy assessment based on ground control points was approximately 75 percent. Over 75 percent of the watershed is in some type of rangeland or pasture cover. Approximately 46 percent of the watershed is moderate or heavy brush that was converted to open rangeland in the SWAT simulation.

Soils

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

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

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

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

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

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

Frio. The Frio series consists of very deep, well-drained, moderately slowly permeable soils that formed in loamy and clayey calcareous alluvium. These flood plain soils have slopes ranging from 0 to 2 percent.
Tobosa. The Tobosa series consists of very deep, well-drained, very slowly permeable soils formed in calcareous clayey materials. These nearly level to gently sloping soils are on uplands. Slopes range from 0 to 3 percent.
Bonti. The Bonti series consists of moderately deep, well-drained, moderately slowly permeable soils formed in residuum of interbedded sandstone and clayey materials. These upland soils have slopes ranging from 1 to 40 percent.
Sagerton. The Sagerton series consists of very deep, well-drained, moderately slowly permeable soils that formed in calcareous clayey and loamy sediments. These nearly level to gently sloping soils are on uplands. Slopes range from 0 to 5 percent.
Callahan. The Callahan series consists of moderately deep, well drained, very slowly permeable soils that formed in clayey shale interbedded with thin sandstone strata. These soils are on gently to strongly sloping uplands. Slopes range from 1 to 12 percent.

Topography

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

Geology

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

Climate

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

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

Ponds and Reservoirs

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

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

Model Inputs

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

Model Calibration

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

Brush Removal Simulation

The input variables for the no-brush condition, with one exception, were the same as the calibration variables, with the change in landuse being the only difference between the two simulations. The exception is that we assumed the shallow aquifer re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and the opportunity for re-evaporation from the shallow aquifer is higher. The re-evaporation coefficient for all brush hydrologic response units (HRU – combinations of soil and land use/cover) is 0.4, and for non-brush HRU's is 0.1.

RESULTS

Model Calibration

The results of reservoir storage calibrations are shown on Figures 3-4 and 3-5. Measured and predicted mean monthly volumes were within 4.9% (Hords Creek Reservoir) and 3.5% (Lake Brownwood). The calculated difference between measured and predicted values expressed as a residual of the means squared is the root mean square error (RMSE). One way to gage the accuracy of the calibration is to divide the RMSE by the mean measured monthly value. The lower the result of this calculation, the more precise the comparison. The RSME/actual storage values were very low (0.3 and 0.1 respectively, for Hords Creek and Brownwood) which indicate that the model did a good job simulating actual storage volumes.

The results of calibration are shown for the stream gages on Figures 3-6 through 3-9. The calibration period for each stream gage varied but all fell within the range from 1960 through 1990. Comparisons of measured flow versus predicted flow (cumulative average monthly flow) yielded the following differences: 24.7% (08141500; 1960-1990), 3.5% (08142000; 1960 - 1970), 0.2%(08140800; 1965 - 1980), and 6.1% (08140700; 1968 - 1979). The RSME/actual flow values for different calibration points in the watershed are as follows: 3.3 (08141500), 1.6 (08142000), 2.2 (08140800), and 0.5 (08140700). The calibration for stream gage 08141500 (immediately downstream of Hords Creek reservoir) showed the poorest agreement for measured and predicted flow and RMSE. This particular calibration was considered acceptable only because it fell closely between two other calibration points (08140100 and 08142000) that demonstrated a good correlation.

Brush Removal Simulation

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

Figures 3-10 through 3-12 shows the cumulative monthly total flow to Lake Clyde, Lake Coleman, and Lake Brownwood for the brush and no-brush conditions from 1960 through 1999.

The total subbasin area, area of brush treated, fraction of subbasin treated, water yield increase per acre of brush treated, and total water yield increase for each subbasin are shown in Table 3-2. The amount of annual increase varied among the subbasins and ranged from 82,525 gallons per acre of brush removed per year in subbasin number 38, to 195,281 gallons per acre in subbasin number 48. The large increase in water yield for the subbasin containing Lake Brownwood (subbasin 48) was most likely due to the presence of predominantly muck soils (high runoff potential) associated with water bodies and heavy brush. Variations in the amount of increased water yield were expected and were influenced by brush type, brush density, soil type, and average annual rainfall. The larger water yields were most likely due to greater rainfall volumes as well as increased density and canopy of brush.

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

For the entire simulated watershed, the average annual water yield increased by about 68% or 180,782 acre-feet, and flow at the watershed outlet (Lake Brownwood) increased by 120,885 acre-feet per year.

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Table 3-1. SWAT input variables for Lake Brownwood watershed.

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

Table 3-2. Subbasin data, Lake Brownwood watershed.

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

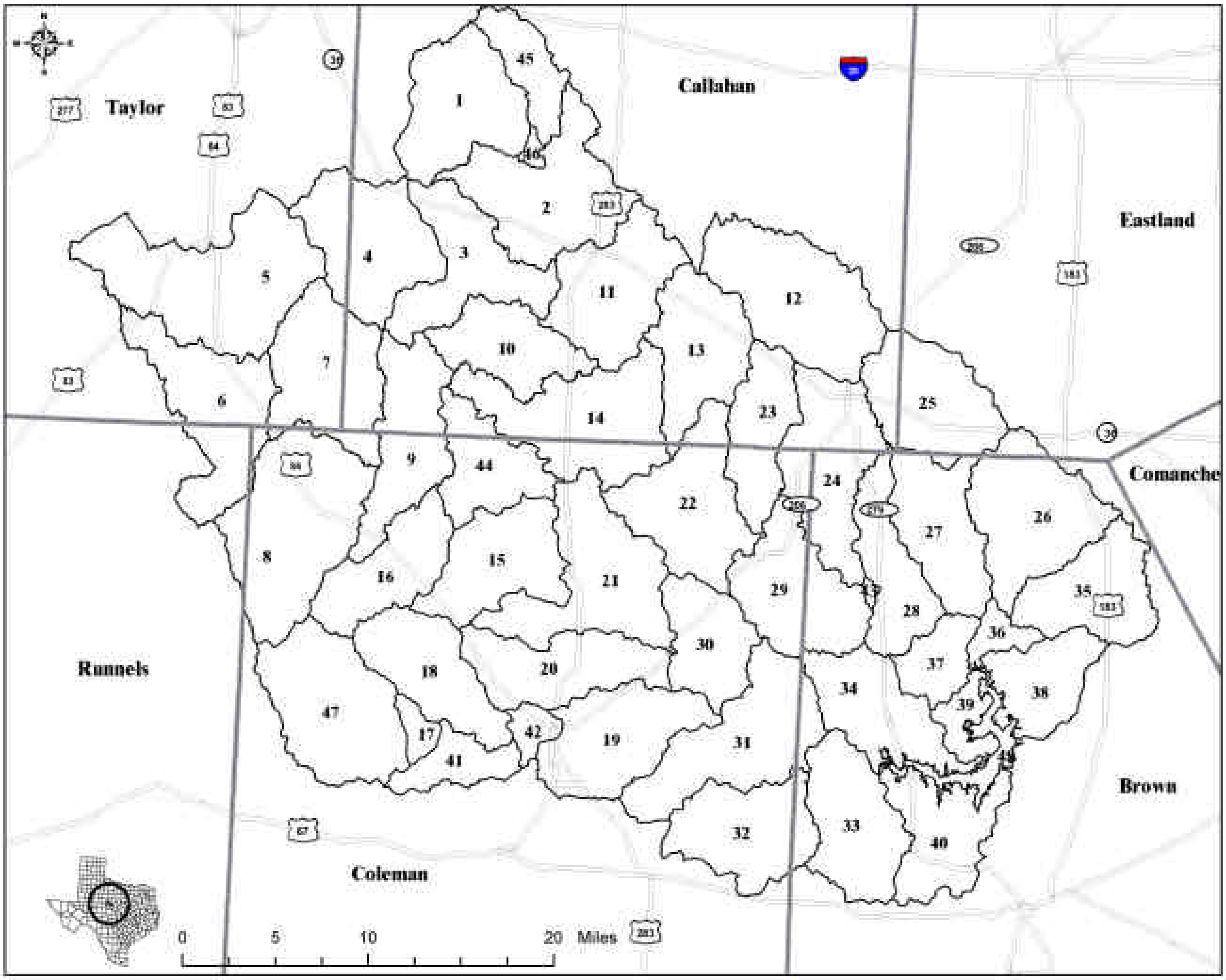


Figure 3-1. Lake Brownwood watershed subbasin map with roads.

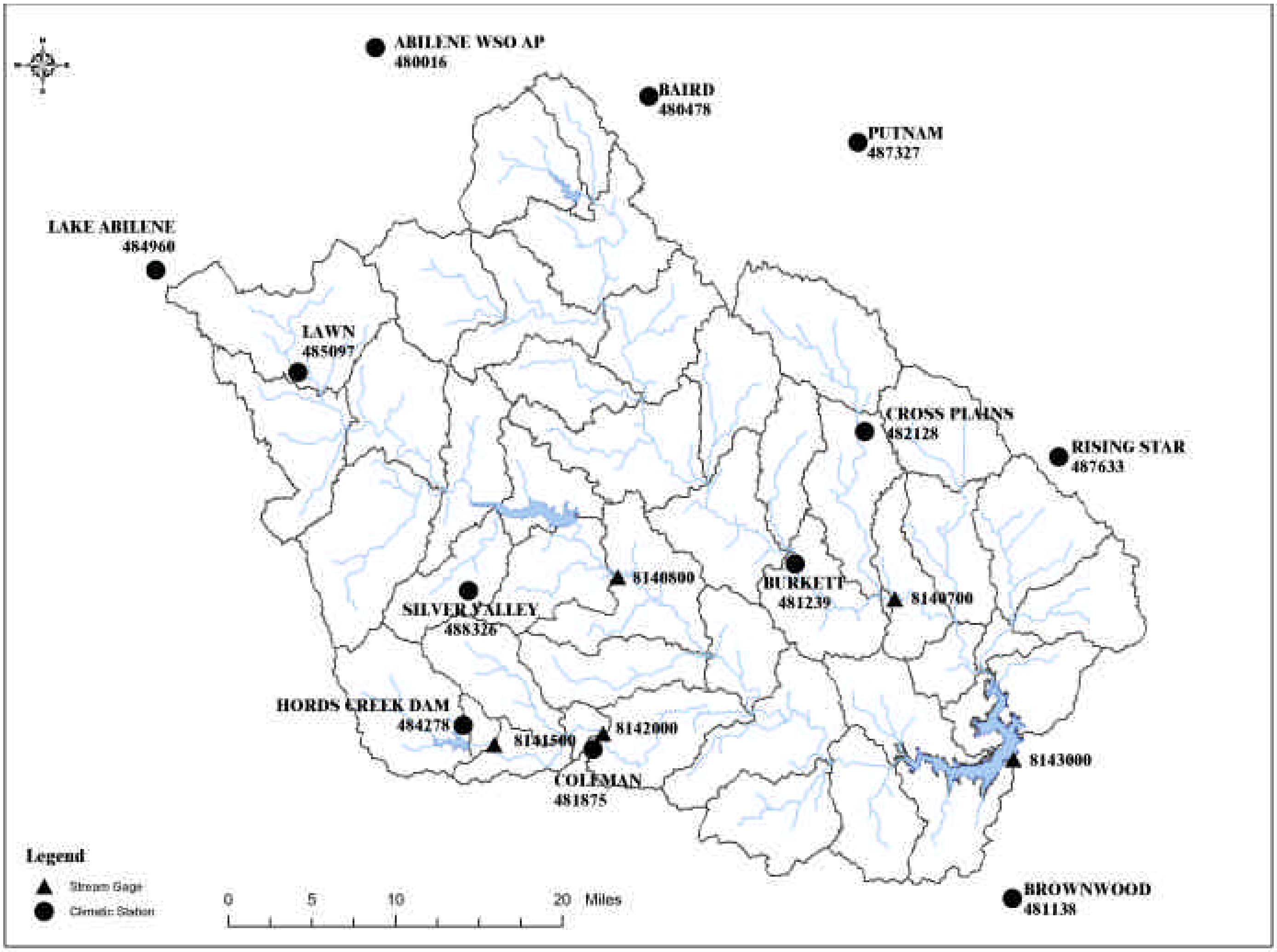


Figure 3-2. Climate and stream gage stations in the Lake Brownwood watershed.

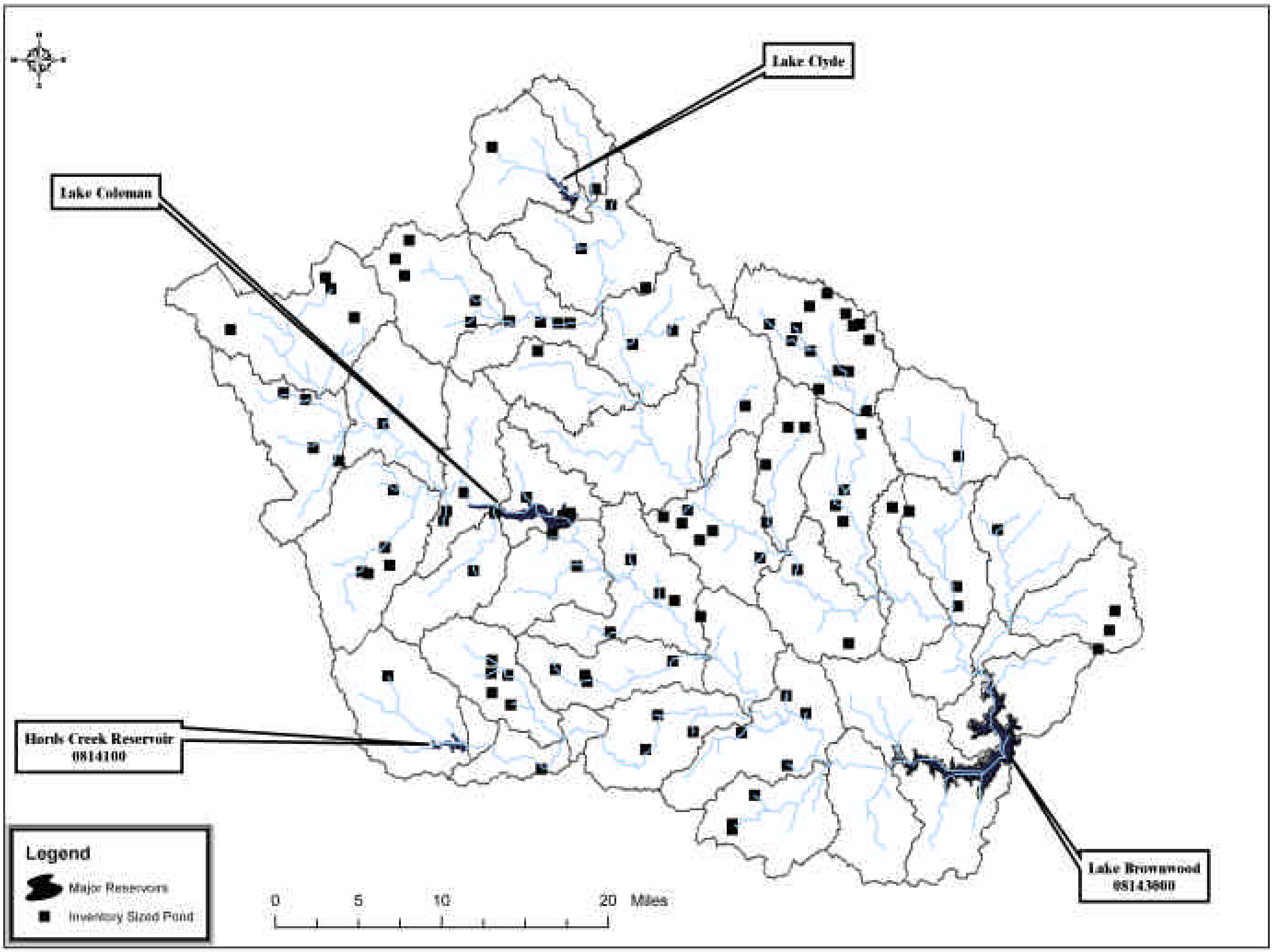
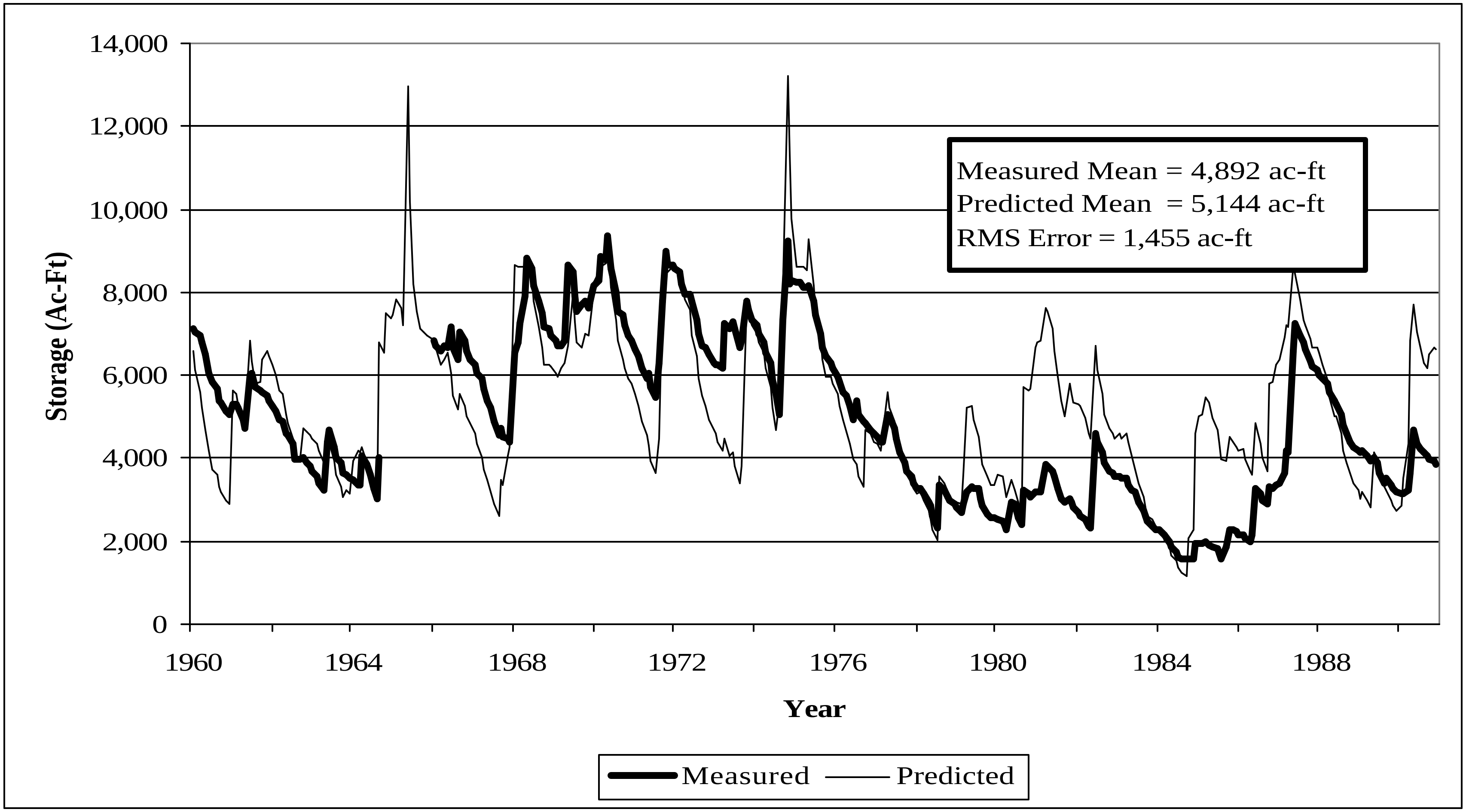


Figure 3-3. Inventory sized lakes and reservoirs in the Lake Brownwood watershed.



14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Storage (Ac-Ft)
1960
1964
1968
1972
1976
1980
1984
1988
Year
Measured Mean = 4,892 ac-ft
Predicted Mean = 5,144 ac-ft
RMS Error = 1,455 ac-ft
Measured
Predicted

Figure 3-4. Measured and predicted monthly storage in Hords Creek Reservoir (USGS Gage 08140100), 1960 through 1990. Measured data not available 10/1964 – 12/1965. Monthly statistics for months with measured data are shown in box.

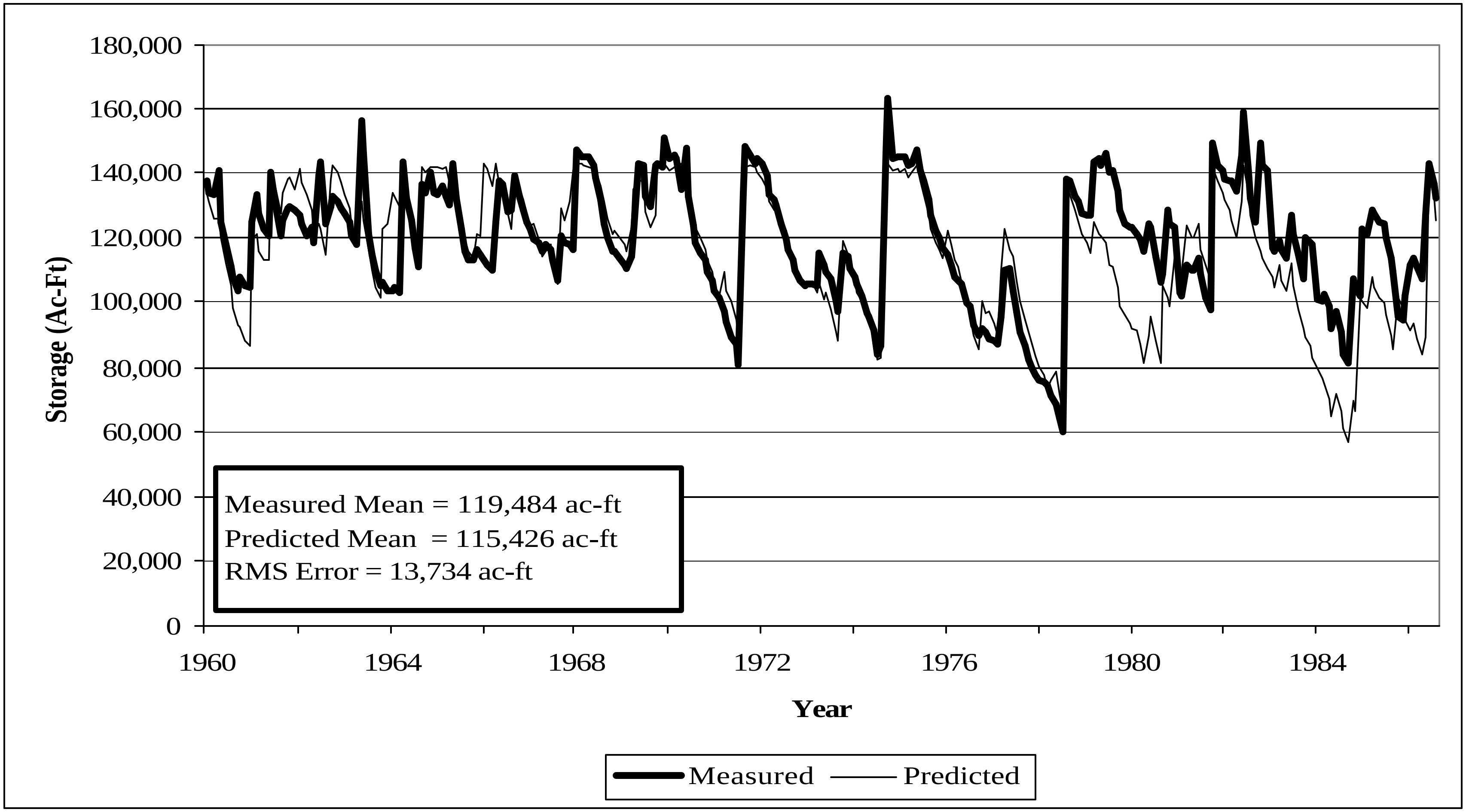


Figure 3-5. Measured and predicted monthly storage in Lake Brownwood (USGS Gage 08143000), 1960 through 1986. Monthly statistics are shown in box.

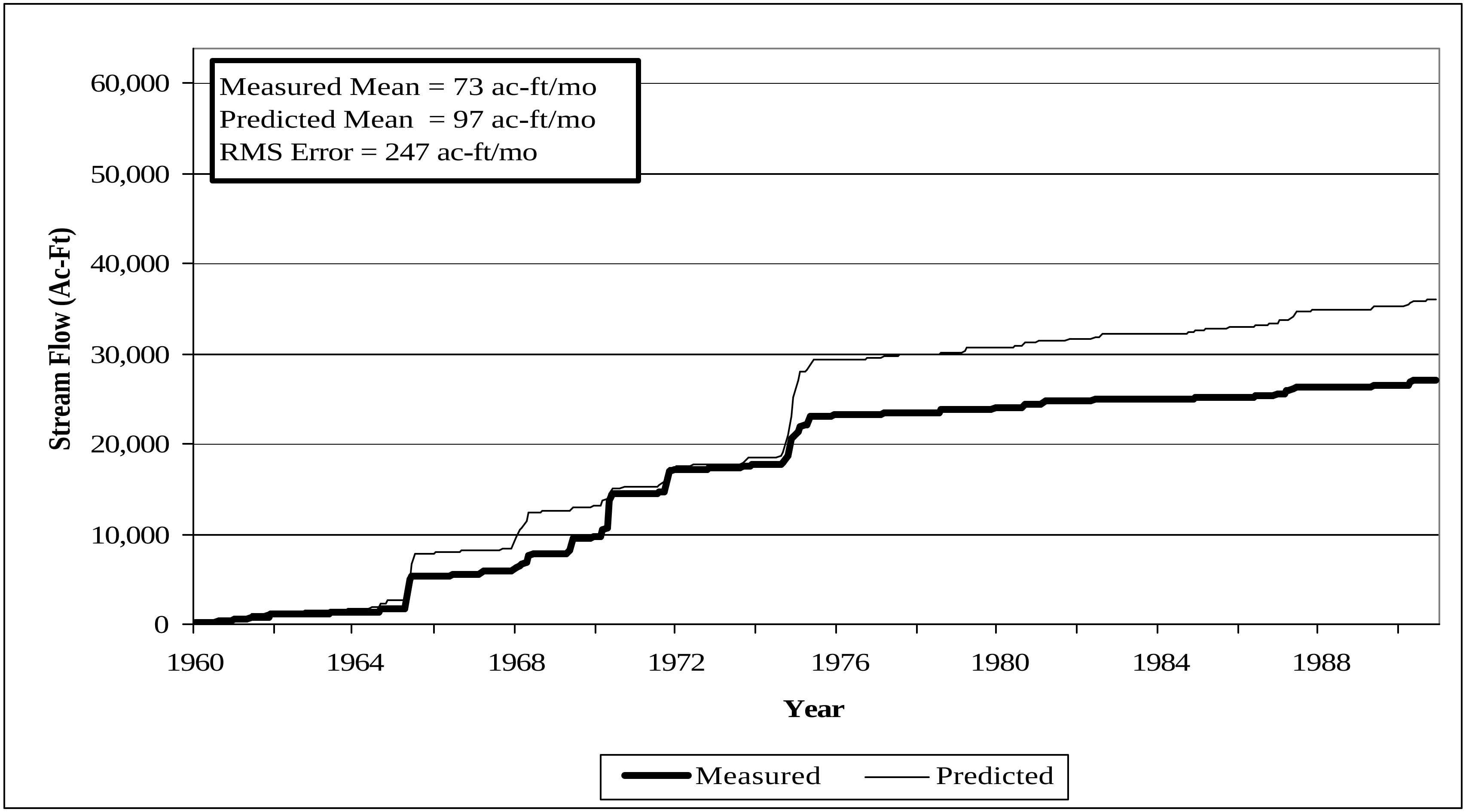


Figure 3-6. Cumulative monthly measured and predicted streamflow at gage 08141500 (Hords Creek near Valera), 1960 through 1990. Monthly statistics are shown in box.

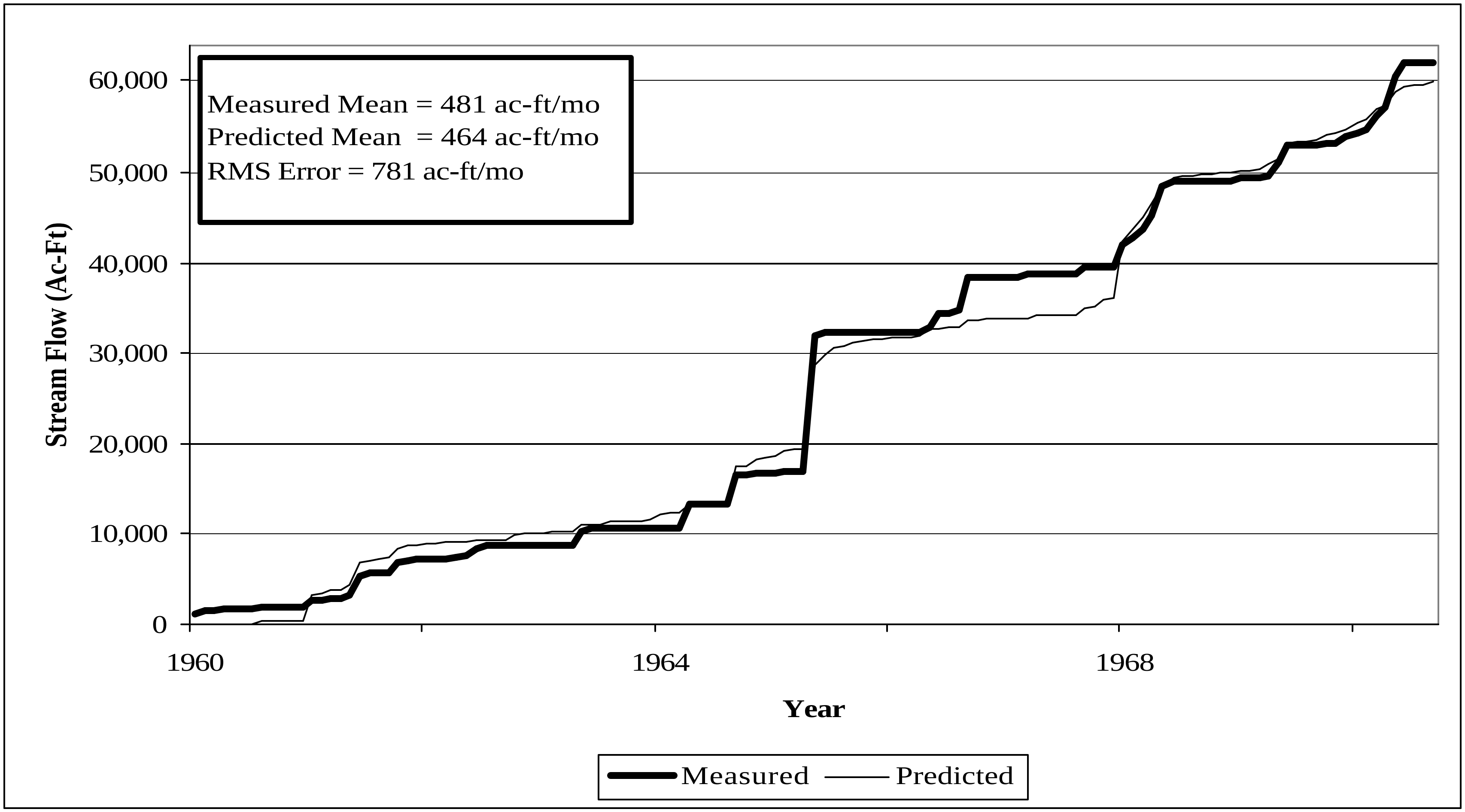


Figure 3-7. Cumulative monthly measured and predicted streamflow at gage 08142000 (Hords Creek near Coleman), 1960 through 1970. Monthly statistics are shown in box.

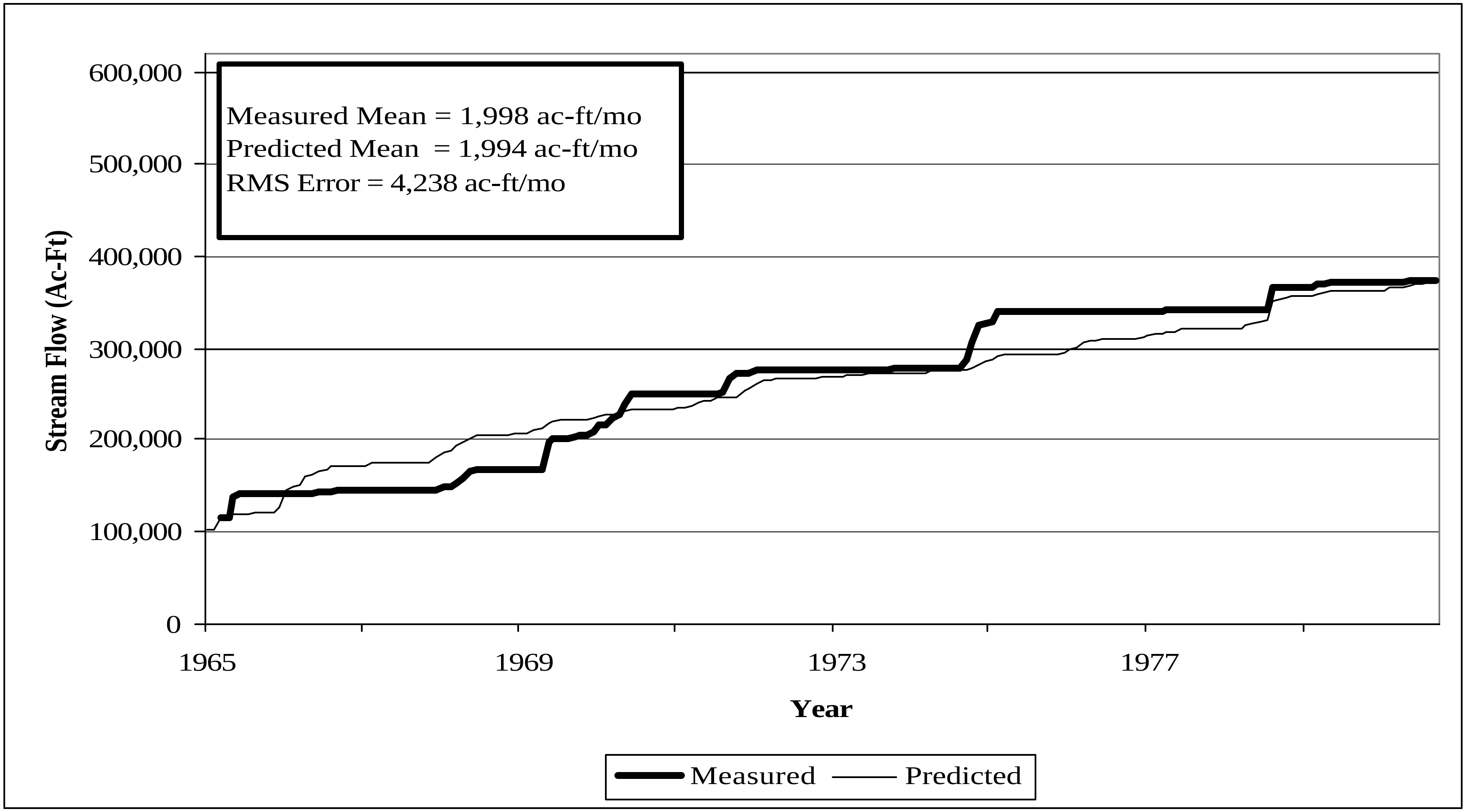


Figure 3-8. Cumulative monthly measured and predicted streamflow at gage 08140800 (Jim Ned Creek near Coleman), 1965 through 1980. Monthly statistics are shown in box.

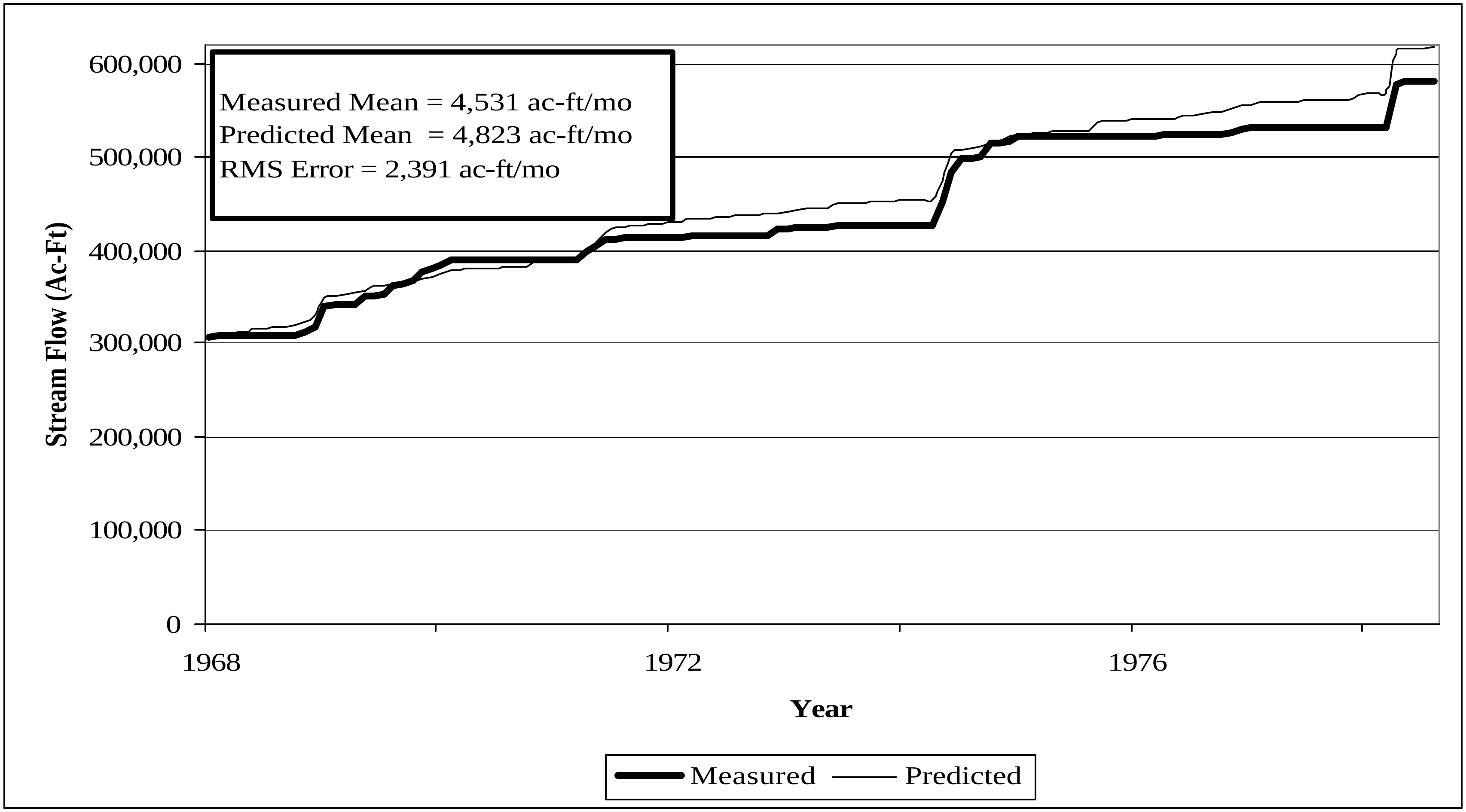


Figure 3-9. Cumulative monthly measured and predicted streamflow at gage 08140700 (Pecan Bayou near Cross Cut), 1968 through 1978. Monthly statistics are shown in box.

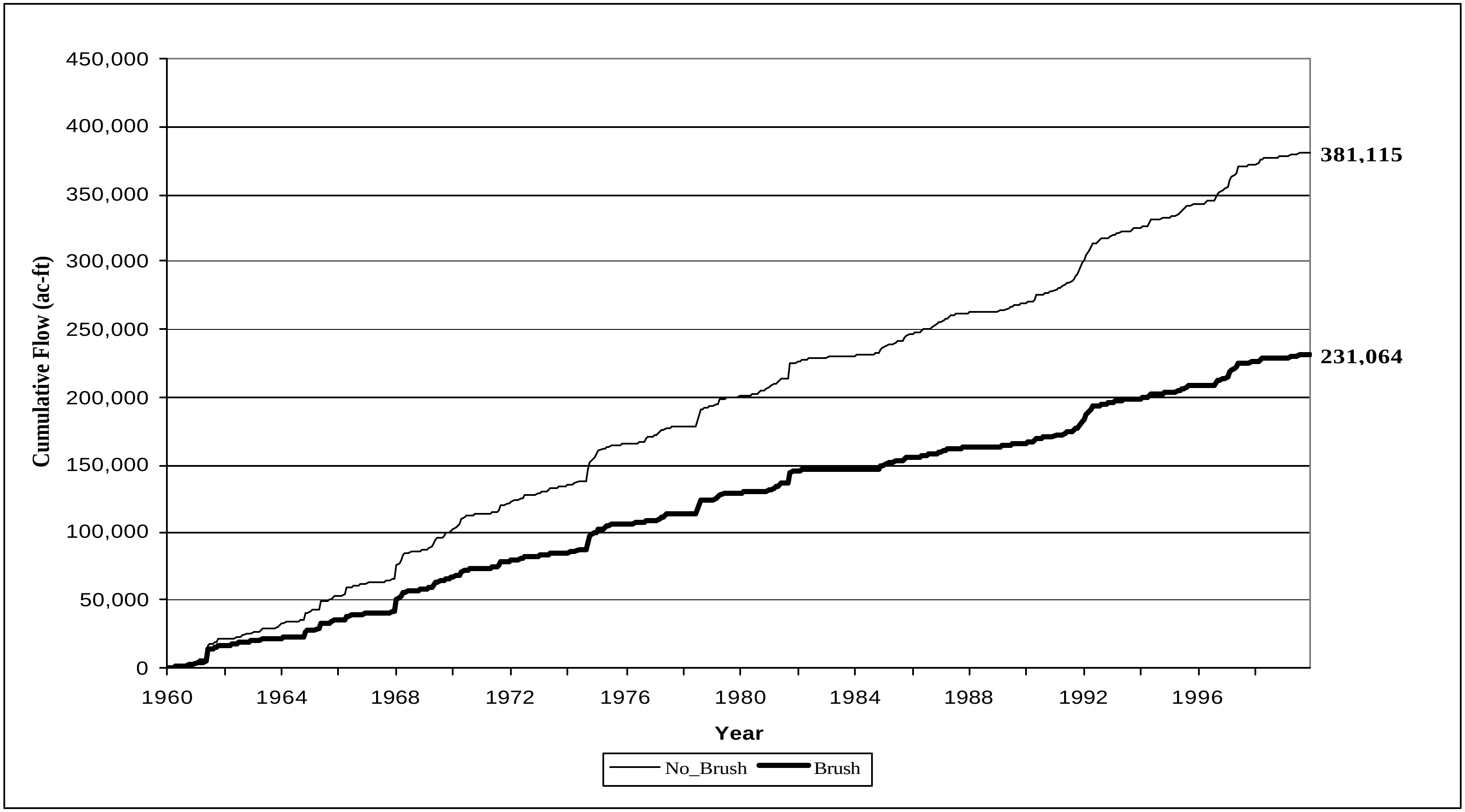


Figure 3-10. Predicted cumulative streamflow into Lake Clyde for brush and no-brush conditions.

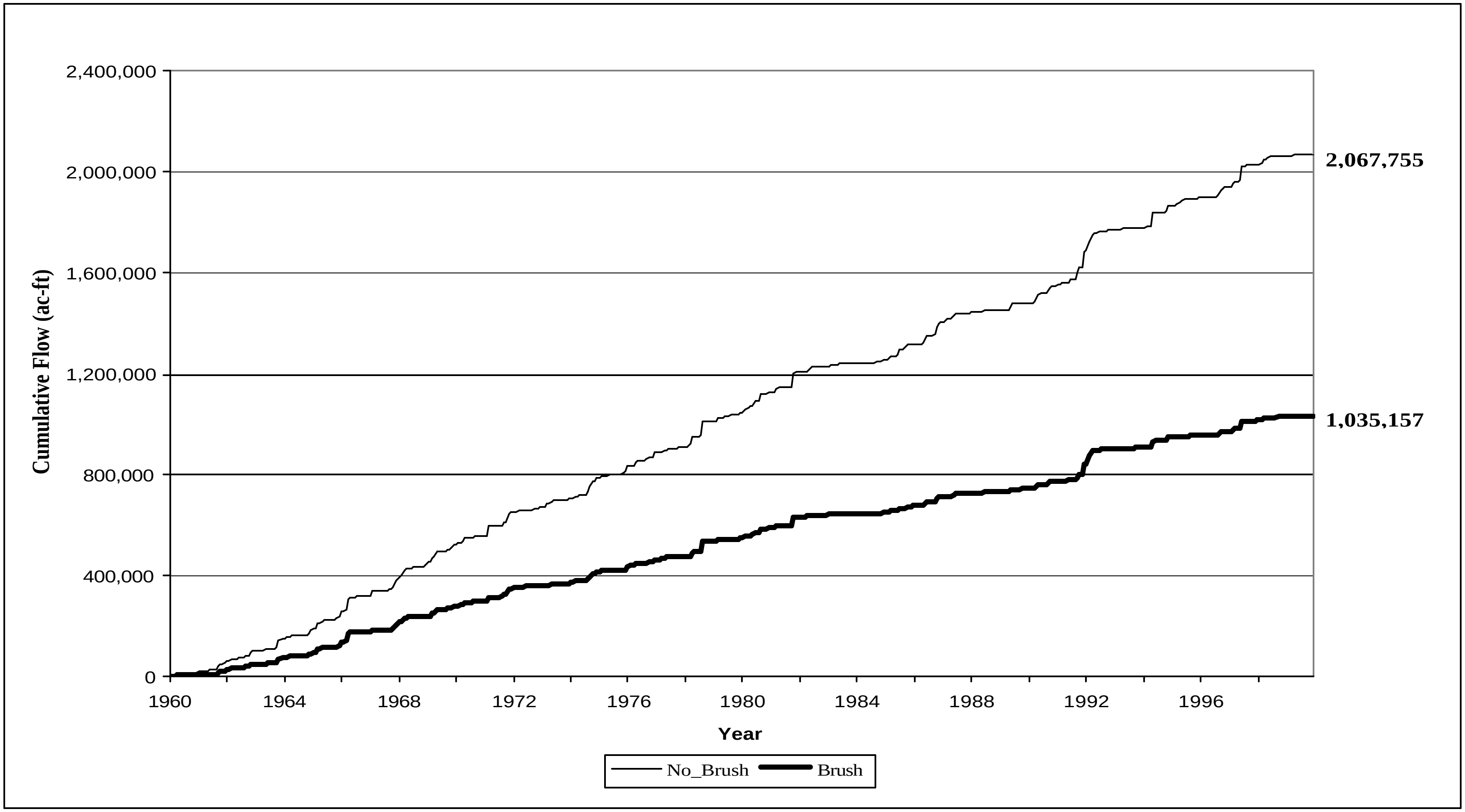


Figure 3-11. Predicted cumulative streamflow into Lake Coleman for brush and no-brush conditions.

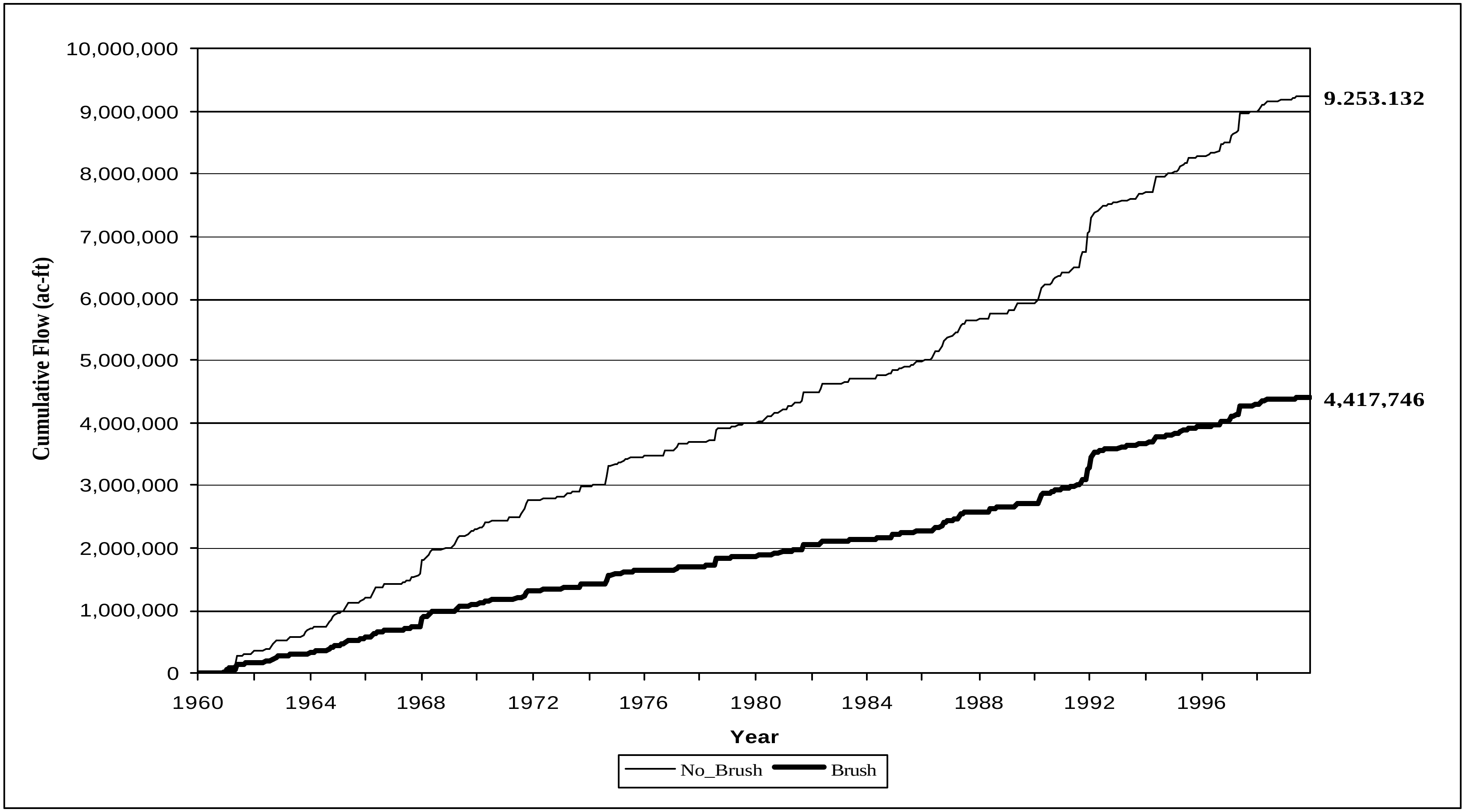


Figure 3-12. Predicted cumulative streamflow into Lake Brownwood for brush and no-brush conditions.

APPENDIX 4

LAKE BROWNWOOD WATERSHED – ECONOMIC ANALYSIS

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INTRODUCTION

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

BRUSH CONTROL COSTS

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

Obviously, the costs of control will vary among brush type-density categories. Present values (using a 6% discount rate) of control programs are used for comparison since some of the treatments will be required in the first and second years of the program while others will not be needed until year 6 or 7. Present values of total control costs in the project area (per acre) range from $35.57 for moderate mesquite that can be initially controlled with herbicide treatments to $203.17 for mechanical control of heavy mixed brush. Costs of treatments and year those treatments are needed for each brush type - density category are detailed in Table 4-1.

LANDOWNER AND STATE COST SHARES

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

Livestock production practices, revenues, and costs representative of the watershed were obtained from personal interviews with a focus group of local ranchers. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into livestock production investment analysis budgets. This information for the livestock enterprises (cattle) in the project areas is shown in Table 4-3. It is important to note once again (refer to Appendix 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 Appendix 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 Appendix 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 4- 4).

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state per acre cost share of brush control in the project area range from $14.20 for control of moderate mesquite with chemical treatments to $176.61 for control of heavy cedar by mechanical methods. Total treatment costs and landowner and state cost shares for all brush type-density categories are shown by both cost-share percentage and actual costs in Table 4-4.

COST OF ADDITIONAL WATER

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

The cost of added water was determined to average $37.95 per acre foot for the entire Lake Brownwood Watershed (Table 4-5). Subbasins range from costs per added acre foot of $19.42 to $100.49.

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

Heavy Mesquite - Chemical

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

Heavy Mesquite - Mechanical Choice

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

Heavy Cedar - Mechanical Choice

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

Heavy Cedar - Shears

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

Heavy Mixed Brush - Mechanical Choice

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

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

Heavy Mixed Brush - Shears

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

Heavy Post Oak/Shinnery Oak - Chemical

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

Moderate Mesquite - Chemical

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

Moderate Mesquite - Shears

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

Moderate Mesquite - Mechanical/Grub

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

Moderate Cedar - Mechanical/Grub

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

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

Moderate Cedar - Mechanical/Shears

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

Moderate Mixed Brush - Mechanical/Grub

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

Moderate Mixed Brush - Mechanical/Shears

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

Moderate Post Oak/Shinnery Oak - Chemical

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

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

Brush Type/ Category	Brush Control	Program Year									
		0	1	2	3	4	5	6	7	8	9
Heavy Mesquite	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	40.00	36.25	32.50	28.75	25.00	25.00	25.00	25.00	25.00	25.00
	No Control	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
Heavy Mixed-Brush	Control	35.0	31.3	27.5	23.8	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
Heavy Post/Shinnery Oak	Control	30.0	27.5	25.0	22.5	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Moderate Mesquite	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 Cedar	Control	35.0	32.5	30.0	27.5	25.0	25.0	25.0	25.0	25.0	25.0
	No Control	35.0	35.4	35.8	36.2	36.6	36.9	37.3	37.7	38.1	38.5
Moderate Mixed-Brush	Control	28.0	26.0	24.0	22.0	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	28.0	28.3	28.6	28.9	29.2	29.6	29.9	30.2	30.5	30.8
Moderate Post/Shinnery Oak	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 4-3. Investment Analysis Budget, Cow-Calf Production

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

Partial Variable Costs:

Variable Cost Item Description		Quantity	Unit	$ Per Unit	Cost
Supplemental Feed		1	1	48.00	48.00
Cattle Marketing - All Cattle		----------	Head	----------	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 4-4. Landowner/State Cost-Shares of Brush Control

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

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

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
1	867644.86	1219276893.56	3741.82	29192.55	29.72
2	1639769.61	1894866041.60	5815.13	45367.86	36.14
3	1279527.32	1201473087.05	3687.19	28766.29	44.48
4	1928553.23	1719308990.57	5276.37	41164.58	46.85
5	1622685.20	1666429695.57	5114.08	39898.52	40.67
6	957820.35	1649738485.26	5062.86	39498.89	24.25
7	1126172.85	1112575178.23	3414.37	26637.85	42.28
8	1475468.55	1816571291.29	5574.85	43493.28	33.92
9	786822.82	1231364246.73	3778.92	29481.96	26.69
10	753975.06	971016485.71	2979.94	23248.58	32.43
11	1071573.85	1335892970.60	4099.70	31984.64	33.50
12	1769525.67	2251154587.97	6908.54	53898.30	32.83
13	1178845.07	1479657612.51	4540.90	35426.72	33.28
14	1477138.14	2227513874.24	6835.99	53332.28	27.70
15	1512227.48	1730857363.57	5311.81	41441.08	36.49
16	952256.24	1378511436.79	4230.50	33005.03	28.85
17	174477.05	156976238.78	481.74	3758.41	46.42
18	1192299.49	1436890202.11	4409.65	34402.76	34.66
19	935076.23	1602703171.53	4918.52	38372.74	24.37
20	949856.02	1738506551.43	5335.28	41624.22	22.82
21	1779853.11	3006142541.89	9225.51	71974.61	24.73
22	1144308.58	2147640587.38	6590.87	51419.92	22.25
23	616490.51	1305694922.27	4007.03	31261.62	19.72
24	1212048.45	1310585406.81	4022.04	31378.71	38.63
25	764921.77	829481189.25	2545.58	19859.87	38.52
26	1033056.41	1214741177.56	3727.90	29083.96	35.52
27	1204344.21	1292688590.03	3967.12	30950.22	38.91
28	1142038.16	1103341675.25	3386.03	26416.77	43.23
29	1582599.75	1249553800.43	3834.74	29917.46	52.90
30	696222.91	1164290131.35	3573.08	27876.03	24.98
31	1843781.91	1982946055.50	6085.44	47476.71	38.84
32	1431138.27	1466499942.05	4500.52	35111.70	40.76
33	1699630.85	1272096859.32	3903.92	30457.20	55.80
34	1549705.93	1215353908.80	3729.78	29098.63	53.26
35	917642.02	1092745897.77	3353.51	26163.08	35.07
36	267133.90	304609070.01	934.81	7293.11	36.63
37	572942.68	504808369.04	1549.20	12086.38	47.40

38	910322.94	612035792.59	1878.27	14653.68	62.12
39	459247.45	389309229.50	1194.75	9321.04	49.27

Table 4-5. Cost of Added Water From Brush Control by Sub-Basin (Acre-Foot), Continued

Sub-basin	Total State Cost ($)	Added Gallons per Year	Added Ac. Ft./Yr.	Total Ac. Ft. 10Yrs. Dsctd.	State Cost/ Ac. Ft. ($)
40	1286160.60	913416272.75	2803.17	21869.48	58.81
41	449694.81	550353625.35	1688.97	13176.85	34.13
42	622906.45	258892220.84	794.51	6198.53	100.49
43	53014.00	53528367.66	164.27	1281.60	41.37
44	770528.68	1085681070.85	3331.83	25993.93	29.64
45	495281.15	626777246.50	1923.51	15006.62	33.00
46	52695.67	71484840.60	219.38	1711.53	30.79
47	1643952.90	1857770512.67	5701.29	44479.70	36.96
48	95005.60	204320909.36	627.04	4891.96	19.42
Total	49948384.77			1410407.43	
Average					37.95