PEDERNALES RIVER WATERSHED

BRUSH CONTROL ASSESSMENT AND FEASIBILITY STUDY

L O W E R   C O L O R A D O   R I V E R   A U T H O R I T Y

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Brush Control Assessment and Feasibility Study

Lower Colorado River Authority

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ACKNOWLEDGEMENTS

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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 Board 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 1999, the Texas Legislature provided appropriations through the TSSWCB for feasibility studies for eight additional watersheds on the effects of brush management on water yields. The studies focus on the changing water yields associated with brush management and the related economic aspects. The Pedernales River Watershed is one of the eight watersheds involved in this feasibility study.

The overall goal of this project is to increase the stream flow and water availability of the Pedernales River into Lake Travis 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 the study are to:

- Develop a historical profile of the vegetation in the Pedernales Watershed upstream of Lake Travis;
- Develop a hydrological profile of the Pedernales Watershed;
- Evaluate climatic data throughout the past century and its relative effects on the current hydrological conditions in the Pedernales Watershed.

This study is a cooperative ecosystem-level approach that involved the Lower Colorado River Authority (LCRA), the TSSWCB, the Pedernales and Gillespie Soil and Water Conservation Districts, and the Natural Resources Conservation Service.

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 Pedernales River watershed with regard to the feasibility of implementing brush control programs in the watershed.

Based on first-hand accounts of the vegetation in the Texas Hill Country and the Pedernales River watershed during the 18th and 19th centuries, differing viewpoints can be derived. Much of the area likely contained extensive woodland stands of juniper and oak. These communities existed, much as they do today, on (1) gentle to steep slopes, (2) shallow soils, and (3) sites where naturally occurring fires could not reach. In some areas, especially north of the Pedernales River on sandy, granitic soils, oak forests may have actually dominated. Prairies and grassy areas were common throughout the region. These were limited to (1) the flat areas of drainage divides and valley floors, (2) deeper soils, and (3) sites where fire could travel unchecked by topography.

Meteorological and river flow data began to be collected in the Pedernales watershed in 1939, and the data show there have been no major changes in climate or stream flow characteristics since that time, allowing for periodic droughts and floods. In fact, annual rainfall has increased slightly from 1939 to present, and this appears to have caused the average annual discharge of the river to increase gradually. As a result, this pattern of increasing rainfall may be obscuring the impact of brush infestation on water yields in the watershed.

Similarly, there is no evidence that groundwater levels have declined systematically in the aquifers beneath the watershed, with the probable exception of the Hickory aquifer. 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 may be the result of variations in natural rainfall or groundwater withdrawals.

While it does not appear that water yields in the Pedernales River watershed have been dramatically affected by brush infestation, geologic and hydrologic conditions in the watershed are very conducive to enhancement of water yields through brush management. Current and projected water demands in the watershed are expected to result in water shortages in the future, especially in the rural areas of Gillespie 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 the Pedernales River. Brush management may be an effective means of increasing groundwater supplies in the watershed and offsetting anticipated supply shortages.

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 Pedernales River watershed is in the region that TSSWCB (1999) has defined as generally suitable for brush control projects, based on rainfall and brush infestation (Figure 3-1). In addition, Johnson City Lake on the Pedernales River was identified by TSSWCB and the Texas Water Development Board (TWDB) in 1985 as a reservoir where brush control could possibly enhance water supplies. The following hydrologic evaluation describes the climate, vegetation, soil, topography, geology and hydrology of the watershed. This baseline information can be used to assess the feasibility of brush management in the watershed and to develop strategies for implementing brush management.

3.1 DESCRIPTION OF THE WATERSHED

The boundary of U. S. Geological Survey (USGS) hydrologic unit 12090206 was used to define the Pedernales River watershed for this study. The area encompasses approximately 815,000 acres (1,273 square miles) of Central Texas, mostly within Blanco and Gillespie counties, but including small portions of Burnet, Hays, Kendall, Kerr, Kimble, and Travis counties (Figure 3-2). The Pedernales River flows eastward through the watershed and empties into Lake Travis near the river's confluence with the Colorado River in western Travis County. The river's course is 957 miles long, of which 391 miles have perennial flow. USGS maintains two flow-monitoring stations on the Pedernales River: one near Fredericksburg (08152900), and one near Johnson City (08153500) (Figure 3-2).

Physiography and Topography

The Edwards Plateau is a physiographic region occupying about 35,900 square miles of central and west-central Texas (Figure 3-3). It and the High Plains to the northwest make up the southernmost extent of the Great Plains physiographic province of the United States (Thornberry, 1965). The central and western portions of the Edwards Plateau exhibit little relief, except along major stream valleys, and the plateau merges almost imperceptibly into the High Plains region to the northwest. The prominent Balcones Escarpment, which rises several hundred feet above the West Gulf Coastal Plain, forms the arc-shaped southeastern margin of the Edwards Plateau.

Headward erosion of the streams that flow across the Edwards Plateau toward the Balcones Escarpment has dissected the southeastern part of the plateau and formed the subregion known as the Balcones Canyonlands (LBJ School of Public Affairs, 1978) (Figure 3-3). The resulting terrain is generally known as the Texas Hill Country and is characterized by steep canyons, narrow divides, and high gradient streams (Riskind and Diamond, 1988). The Pedernales River valley is the northernmost watershed of the Balcones Canyonlands and is bounded on the north by the Llano Uplift region. Plateau elevations in the study area increase from about 900 feet msl (above mean sea level) at the southeast end of the Pedernales River valley to about 2,200 feet msl at the west end. Valley bottom elevations increase from about 700 feet msl at the Pedernales River's confluence with the Colorado River to about 2,100 feet msl at the river's headwaters.

Geology

The major geologic structure in the study area is the Llano Uplift, a large dome-shaped structure centered about 40 miles north of Fredericksburg. The basal Precambrian granites and metamorphic rocks of the dome are overlain by Paleozoic rocks (marine carbonates and nonmarine clastics) that are tilted and dip radially from the center of the uplift. Marine sedimentary rocks (limestone, dolomite, sandstone, and shale) were unconformably deposited on the eroded surface of the tilted Paleozoic rocks. The Cretaceous strata are generally undeformed, but dip gently to the south or southeast. Erosion that carved the Pedernales

River valley partially removed the Cretaceous strata, leaving progressively older Cretaceous rock units exposed on the watershed perimeter, valley slopes, and valley floor. In the northeast-central part of the river valley, erosion has completely removed the Cretaceous strata and exposed the underlying Paleozoic rocks. Most of the Cretaceous rock units and several Paleozoic rock units are aquifers in the study area. Dissolution has caused caves to be formed in some limestone rock units.

Climate

The Pedernales River watershed has a subtropical climate, with typically dry winters and hot humid summers. The rainfall distribution in the watershed 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.

Table 3-1 presents a summary of the mean monthly and mean annual temperatures, precipitation, and gross evaporation for the watershed. Temperature and precipitation data were obtained from the National Climatic Data Center for stations at Fredericksburg (41-3329) and Johnson City (41-4605). Between 1939 and 1999, annual precipitation measured at Fredericksburg in Gillespie County varied from approximately 11.3 to 45.5 inches and averaged 29.5 inches. At Johnson City in Blanco County, annual precipitation varied from approximately 16.9 to 54.1 inches and averaged approximately 34.0 inches between 1965 and 1999. Monthly gross evaporation for roughly the east and west halves of the watershed were obtained from the TWDB. From 1940 to 1997, monthly gross evaporation in the watershed varied from about 2.1 to 8.4 inches. The average annual gross evaporation was about 57.3 inches in the eastern part of the watershed and about 60.7 inches in the western part.

Land Use

The watershed is predominantly rangeland, and arable land suitable for crop production occurs only along streams. Rangeland is used mainly for livestock (i.e., cattle, sheep and goats). However, exotic game production is becoming increasingly important, and axis, sika, fallow deer and blackbuck antelope are increasing in number (Traweek, 1985). The area also supports one of the largest native deer populations in the United States. Crop production is largely oriented to livestock feed (e.g., hay, oats, sorghum), but a notable amount of land is used for cultivating food crops, including peaches and wine grapes. Urban land use is limited to the towns of Fredericksburg

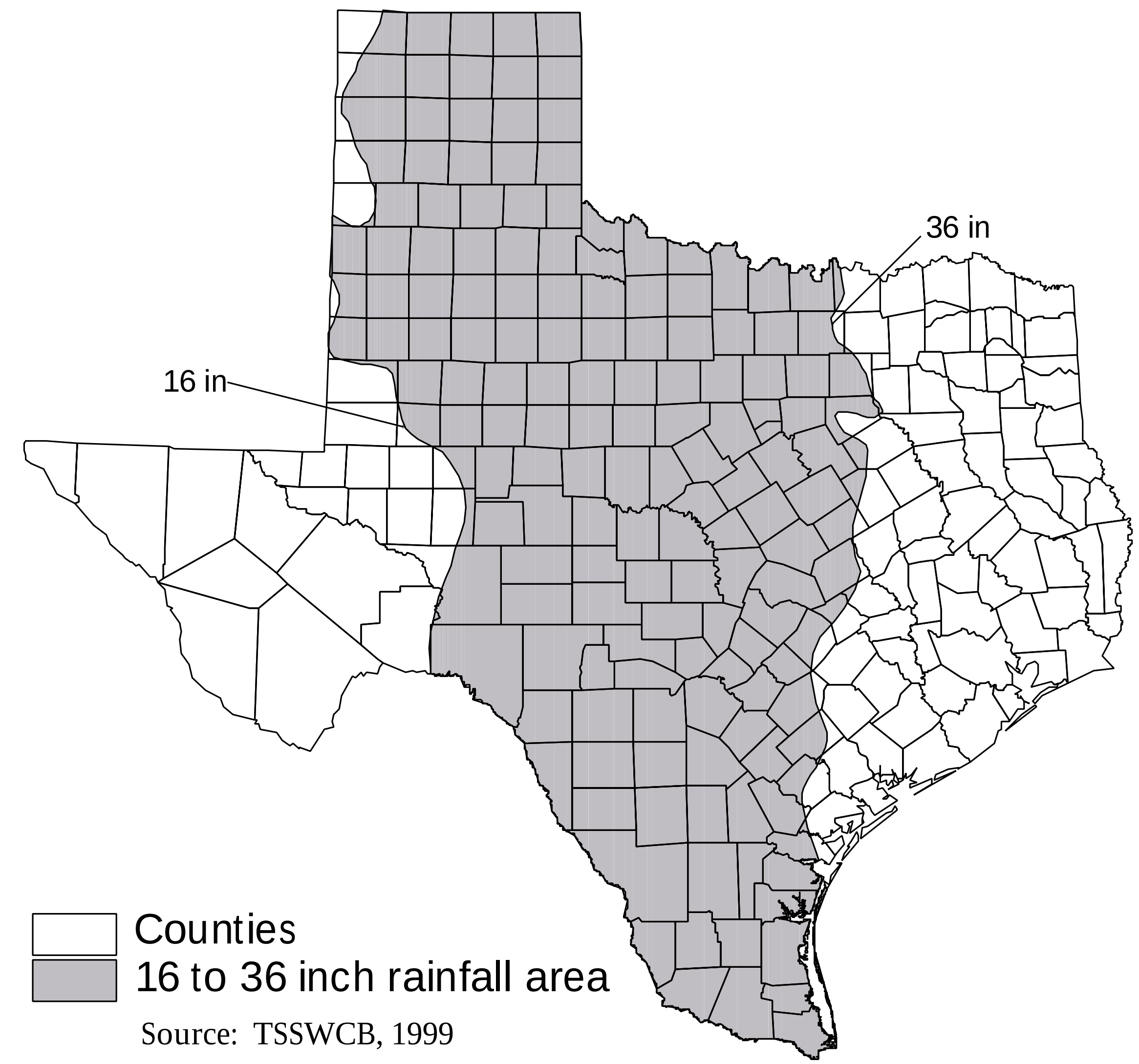


Figure 3-1

GENERAL BRUSH CONTROL ZONE

and Johnson City. Most of the surface water in the basin occurs in streams and stock ponds, and there are no major lakes or reservoirs in the watershed, except Lake Travis into which the Pedernales River empties.

Population

Table 3-2 presents population data for Gillespie and Blanco counties, Fredericksburg and Johnson City from 1940 to 1990, and population projections for Gillespie and Blanco counties from 2000 to 2050. Between 1940 and 1970, the populations of Blanco and Gillespie counties remained stable, at about 14,000 inhabitants combined. From 1970 to 2000, the population of both counties increased about 30 percent each decade. Fredericksburg and Johnson City have experienced similar growth, but their growth rates since 1970 are slightly less than the countywide rates. Since 1970, and especially since 1980, the population of the lower reaches of the watershed has increased significantly, which is attributable to rapid expansion of the Austin metropolitan area.

Wildlife

The watershed supports a diversity of vegetation types and associated wildlife species. The Balcones Canyonlands region supports 375 species of birds, approximately 55 species of mammals, more than 70 species of reptiles, 80 species of fish, and some of the highest cave fauna diversity in the southwestern United States (U. S. Fish and Wildlife Service, 1992). The area supports two rare bird species (golden-cheeked warbler and black-capped vireo), several rare karst invertebrates, and rare aquatic species (salamanders, darters, and plant species). Farming and ranching incomes are often supplemented throughout the region through consumptive and nonconsumptive wildlife uses, especially from the white-tailed deer population.

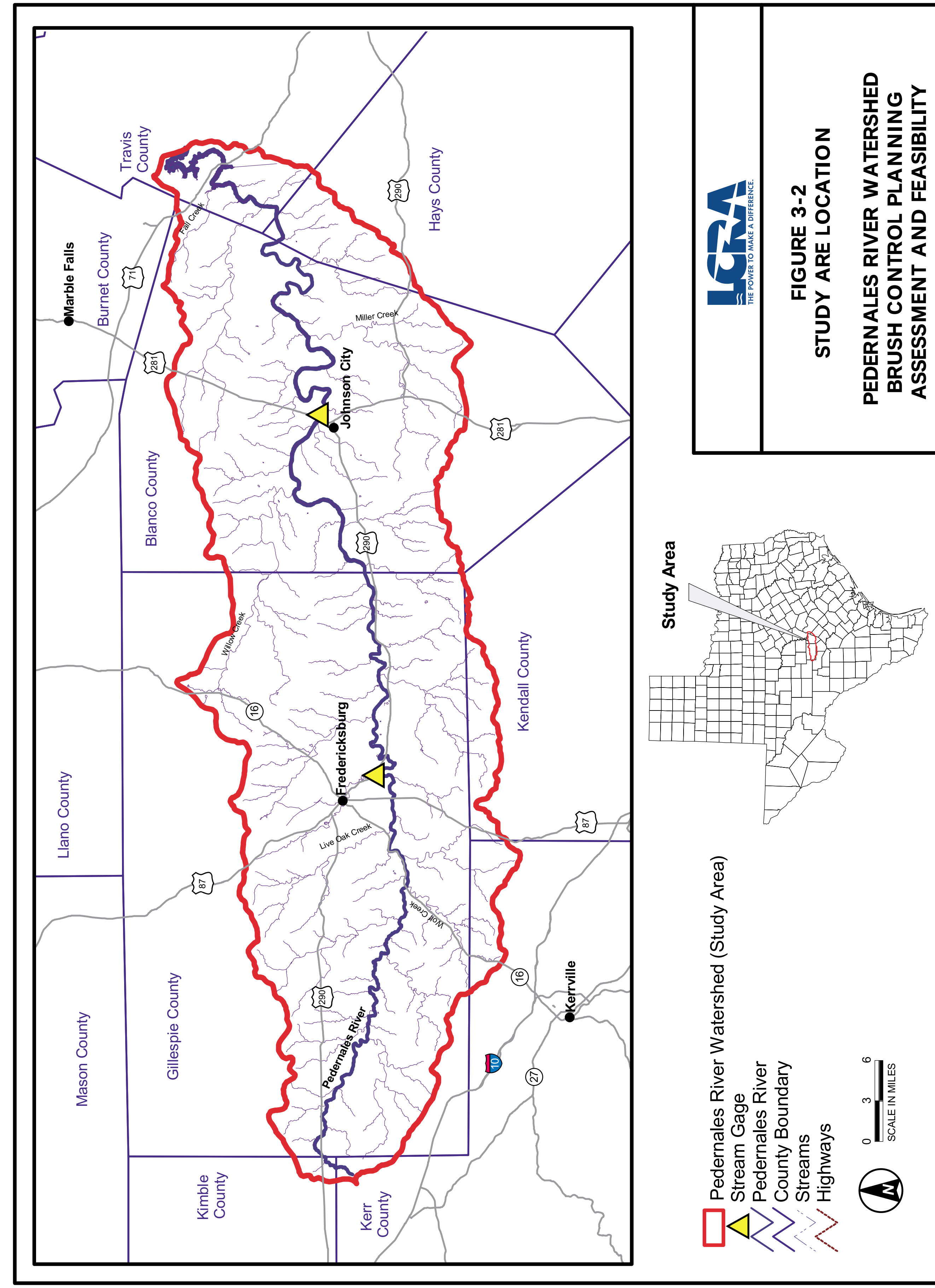
3.2 HISTORICAL CONSIDERATIONS

In many areas of the state, historical records show that higher levels of spring flow and stream base flow occurred in the past and that brush encroachment in watersheds has been an important factor in the declining flows. This phenomenon is not so apparent in the Pedernales River watershed. In contrast to the central and western parts of the Edwards Plateau, the Pedernales River valley has historically sustained extensive brush and tree cover. And, while springs occur throughout the watershed, there is little quantitative information, historical or current, about them.

3.2.1 VEGETATION HISTORY

First-hand accounts provide a generalized picture of the vegetation of the Texas Hill Country and the Pedernales River during the 18th and 19th centuries. Most likely, the area was predominantly woodland stands of juniper and oak. These communities existed, much as they do today, on (1) gentle to steep slopes (2) shallow soils, and (3) sites where naturally occurring fires could not reach. In some areas, especially north of the Pedernales River on sandy, granitic soils, oak forests dominated. Prairies and grassy areas were common throughout the region. However, these were limited in their extent to (1) the flat areas of drainage divides and valley floors, (2) deeper soils, and (3) sites where fire could travel unchecked by topography.

The apparent vegetational history of the Balcones Canyonlands differs from that of the northwestern Edwards Plateau. In the brush management feasibility study of the North Concho River watershed (Upper Colorado River Authority, et al., 1998), it was concluded that the vegetation surrounding and within the watershed has changed significantly since the first recorded observations were made. Before 1849, there were no noticeable growths of mesquite, juniper, or other noxious brush. Between 1849 and 1885, the area was predominantly grassland, with some growths of mesquite. From 1885 to the start of the 20th century, mesquite spread from the banks of streams and rivers and began to infest the grassland plains, growing most rapidly during the late 1940s and early 1950s.



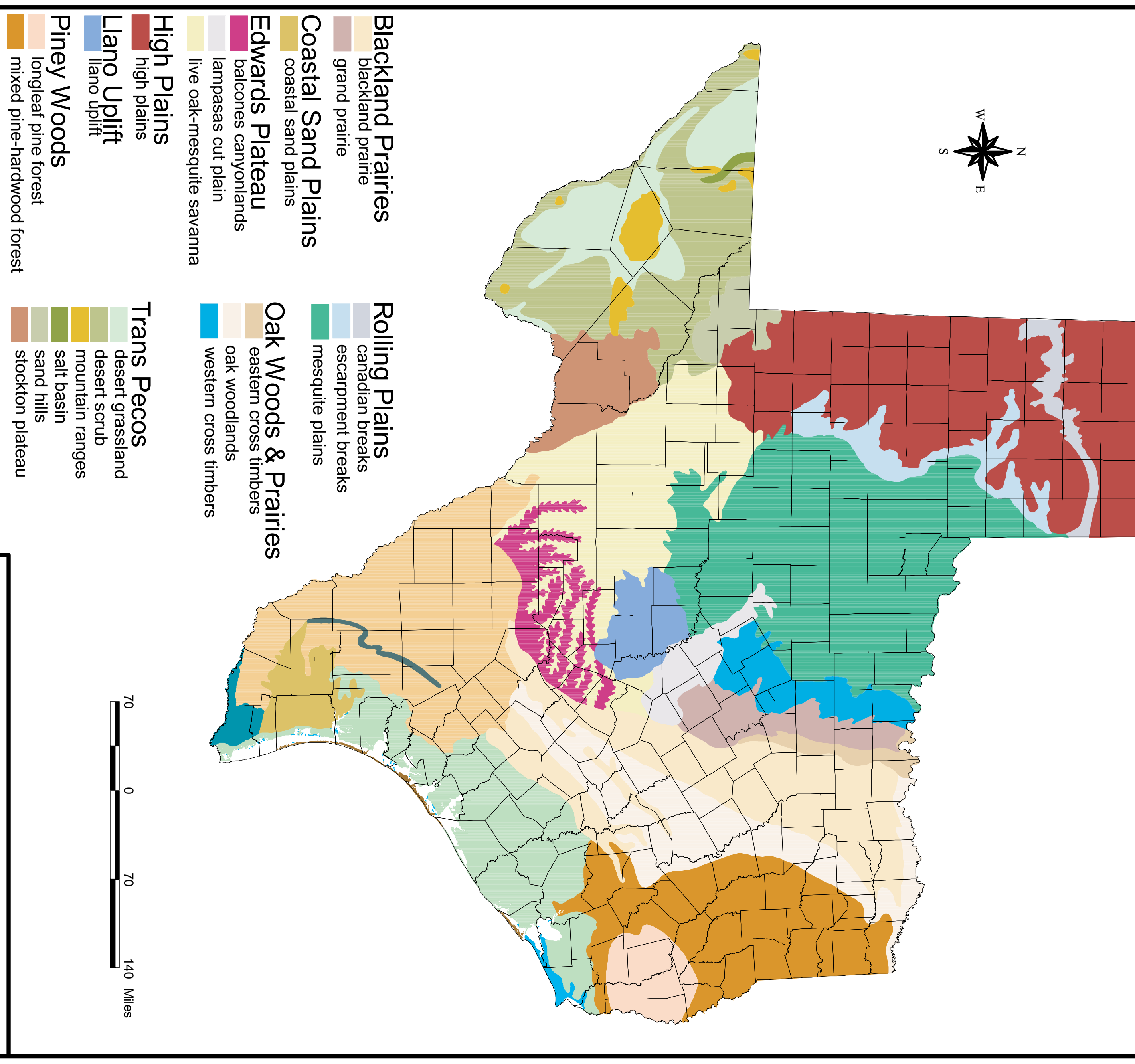


FIGURE 3-3
NATURAL REGIONS AND SUBREGIONS OF TEXAS

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING ASSESSMENT AND FEASIBILITY

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

TABLE 3-1

MONTHLY TEMPERATURE, PRECIPITATION, AND GROSS EVAPORATION, PEDERNALES RIVER WATERSHED

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Fredericksburg, Texas (1939-1999)													
Mean Minimum Temperature (F°)	35.9	39.6	46.0	54.1	61.7	67.5	69.4	68.7	64.1	55.1	44.6	38.0	---
Mean Maximum Temperature (F°)	60.4	64.5	71.7	78.9	84.3	90.2	93.8	94.1	88.1	79.9	69.1	62.6	---
Mean Temperature (F°)	48.2	52.1	58.9	66.5	73.0	78.9	81.6	81.4	76.1	67.5	56.8	50.3	66.0
Maximum Total Precipitation (inches)	7.00	6.88	5.20	8.03	11.77	11.65	9.45	13.15	16.48	10.49	5.12	15.05	45.49
Minimum Total Precipitation (inches)	0.03	0.01	0.01	0.00	0.33	0.00	0.00	0.00	0.01	0.00	0.00	0.00	11.29
Mean Total Precipitation (inches)	1.37	1.88	1.75	2.66	3.76	3.48	1.77	2.71	3.33	3.37	1.84	1.79	29.54
Johnson City, Texas (1965-1975, 1981-1999)													
Mean Minimum Temperature (F°)	34.4	38.0	45.7	53.7	61.8	68.3	70.7	69.7	64.3	54.3	44.8	36.4	---
Mean Maximum Temperature (F°)	60.6	63.8	71.1	79.2	84.8	90.7	94.8	94.8	88.8	80.5	70.4	62.4	---
Mean Temperature (F°)	47.5	50.9	58.4	66.4	73.3	79.5	82.8	82.3	76.6	67.4	57.7	49.4	66.1
Maximum Total Precipitation (inches)	9.53	6.98	5.29	9.65	9.06	13.80	7.70	8.65	7.48	10.23	7.20	11.53	54.09
Minimum Total Precipitation (inches)	0.00	0.00	0.20	0.05	1.08	0.02	0.00	0.00	0.04	0.02	0.00	0.04	16.91
Mean Total Precipitation (inches)	1.92	2.31	2.25	2.45	4.94	3.90	1.93	2.47	3.33	3.96	2.32	2.19	33.96
Gross Evaporation Data (1940-1997)													
West Gillespie County	2.30	2.66	4.19	5.10	5.36	7.16	8.42	8.26	6.27	4.97	3.47	2.52	60.69
East Gillespie and Blanco Counties	2.18	2.46	3.82	4.50	4.89	6.55	8.14	7.98	6.02	4.89	3.43	2.46	57.31

Sources: Temperature and Precipitation -- National Climatic Data Center, Asheville, North Carolina
Evaporation -- Texas Water Development Board

18th Century Accounts of the Pedernales River Watershed

The earliest written descriptions of the natural vegetation of Texas are contained in the accounts of the Spanish explorations of the 18th century (Weniger, 1984). These accounts make up the bulk of the information we have on 18th century Texas' natural history. However, the written history of the Texas Hill Country started more gradually than that of the rest of the state. These Spanish explorers apparently had reasons for avoiding the Hill Country and their descriptions of the region are limited.

In 1716, Fray Isidro Felis de Espinosa wrote that his exploring within the Texas Hill Country was halted because of "the density of its groves" and "the brushwood" along the headwaters of the San Antonio River (as cited in Weniger, 1984). Likewise, in 1718, Fray Francisco Celiz stopped at the edge of the hills in what is now Comal County and was forced to turn back when his scouts reported that upstream, the Guadalupe River "could not be traveled because it is more wooded and contains more rocks" (as cited in Weniger, 1984). [These early explorers were heavily encumbered with carts, carriages, etc., which would have made travel through brush and over rocks very difficult (Weniger, 1984)].

Even more threatening to the Spanish explorers were the Apache and Comanche Indians occupying the Hill Country during the 18th century. Juan Antonio de la Pena wrote in 1722 as he traveled through what are now Hays, Guadalupe, and Travis counties: "The Apaches live in ... very broken country about a league to the north...and travel in this country [is] dangerous...for it [is] inhabited by the warlike Apaches (Pena, 1935). The Spaniards dreaded and avoided the Texas Hill Country (Weniger, 1984).

The only 18th century explorer to give us a general account of the hills of Central Texas was Bernardo de Miranda (Weniger, 1984). In 1756, he wrote of what is now western Comal County: "Going past the Balcones, we arrived at the river they call Alarcon [the Guadalupe River]. This was an effort because of the many hills and rocks, the many arroyos formed by the hills, and some thickets that contain valuable cedar and oak timber." Also, about northern Comal and southern Blanco Counties, he wrote: "After many hardships because of the many hills, arroyos and brush, we arrived at a creek generally known as Arroyo Blanco [Little Blanco] which joins the Rio de San Marcos ...and is a distance from this creek to the [Guadalupe] of about eight leagues. In all of this region there are no commodities nor anything except good cedar and oak timber, and on the [Guadalupe]...there are cypress groves, very valuable in so far as it can be determined."

Further into Blanco County, Miranda continues: "Crossing many swollen creeks and thickets of cedar and oak timber, at a distance of eight leagues we arrived at the Arroyo de los Pedernales." Still in Blanco County, he wrote: "The stream called San Miguel that I cite in the auto of the twenty-fifth is considered useless for a farming settlement, for along as much of it as I examined I failed to find withdrawable water. Even if there was any, there are no level areas that could be irrigated, because of the many arroyos, thickets and hills along its course." (Miranda, 1970).

These early explorers seemed to have been impressed by the quantity and quality of the timber awaiting them as they attempted to search for the headwaters of these arroyos, streams and rivers draining the area we today call the Balcones Canyonlands. They also seemed to be deterred by the density of what they called "brushwood."

Little mention is made in these earliest accounts of either the presence or absence of grassland and grazing land. This seems a curious omission, as the Spanish missionaries in the eastern half of Texas were establishing large cattle herds. In Texas, the Spaniards were primarily in the business of cattle, horses and missions. By 1710, large herds of cattle were well established near the early East Texas mission of San Francisco de los Tejas. By 1721, these herds were observed to be roaming as far west as the Guadalupe River (Ricklis, 1996).

Espinosa, Celiz, Pena, and Miranda give testimony that many thickets of timber were found in the 18th century in Blanco and Comal counties. This timber was most likely cedar and oak with cypress along some streams. These explorers were entering the Hill Country from the southeast and traveling northward and westward into drainages with steep canyon slopes, narrow drainage divides, and small valley floors. As mentioned above, these sloping sites would have most likely supported woody species while sites supporting grasses would have been limited. Most likely grasses were not noted by these early explorers simply because grasslands were not extensive along the water courses they traveled.

TABLE 3-2

POPULATION TRENDS FOR GILLESPIE AND BLANCO COUNTIES, 1940-2050

	Gillespie County		Blanco County		Total	
Year	Population	% Change	Population	% Change	Population	% Change
1940	---	---	---	---	---	---
1950	10,520	---	3,780	---	14,300	---
1960	10,048	-4.5	3,657	-3.3	13,705	-4.2
1970	10,553	5.0	3,567	-2.5	14,120	3.0
1980	13,532	28.2	4,681	31.2	18,213	29.0
1990	17,204	27.1	5,972	27.6	23,176	27.2
2000	21,710	26.2	8,253	38.2	29,963	29.3
2010	23,820	9.7	9,874	19.6	33,694	12.5
2020	26,644	11.9	11,644	17.9	38,288	13.6
2030	28,435	6.7	12,964	11.3	41,399	8.1
2040	32,841	15.5	13,688	5.6	46,529	12.4
2050	36,006	9.6	13,799	0.8	49,805	7.0

	Fredericksburg		Johnson City		Total	
Year	Population	% Change	Population	% Change	Population	% Change
1940	3,544	---	---	---	---	---
1950	3,854	8.7	648	---	4,502	---
1960	4,629	20.1	611	-5.7	5,240	16.4
1970	5,295	14.4	< 1,000	---	< 6,295	---
1980	6,412	21.1	872	---	7,284	---
1990	6,934	8.1	932	6.9	7,866	8.0

Sources: 1940 - 1990 U.S. Department of Commerce, Bureau of the Census
2000 - 2050 Lower Colorado Regional Water Planning Group

19th Century Accounts of Vegetation in the Pedernales River Watershed

The beginning of the 19th century saw a new type of explorer entering Texas: those searching for sites to establish towns, to produce farms, and to raise families, and for means to otherwise buy their way into a promising geographic area. Some of these were willing to brave the natural obstacles of the Hill Country in hopes of claiming its richness. Fortunately, many of these people left us with detailed pictorials of the area.

Beginning in 1844, German emigrants arrived in North America aboard ships headed for Texas Gulf ports (Jordan, 1966). New Braunfels was among the many successful towns established in the mid-1800s. From this settlement on the eastern edge of the Edwards Plateau, a group of German settlers went on to explore the Pedernales River basin and eventually founded the town of Fredericksburg. It is this migration north and west of New Braunfels that gives us the most detailed descriptions available on natural conditions of Pedernales River watershed before its intense use by European settlers.

Shortly before the establishment of New Braunfels, J. W. Benedict gives us the first mention by Europeans of grass in the region. In his 1839 "Diary of a Campaign Against the Comanches," he speaks of the tall grass in southwestern Blanco County near Johnson City. "Today," he says, "first saw wild grass 3 to 4 feet high" (as cited in Weniger, 1984). F. L. Olmsted (1857) wrote of Kendall County: "A thin, coarse grass covered all the soils." In addition, Olmsted describes an area about 35 miles west of San Antonio as having "prairies [that] rise in gentle slopes into hills [and] [that] become steeper and nearer one another as you travel further." And "wherever [soil] exists, grass grows, even over the summits of the mountains if they be not bare rock."

Benedict also reports frequent signs of buffalo along the Pedernales River and, on October 31, 1839, claims to have killed a buffalo near his Blanco County encampment (as cited in Weniger, 1984). This would lead one to assume that the area supported sufficient grasslands to provide forage for roaming buffalo herds. On the other hand, Benedict's companions claim to have easily found and killed three black bear. Although black bear occur in a wide range of habitats, they are largely creatures of forests and woodlands (Davis and Schmidly, 1994). A picture begins to form of an area with a mosaic of vegetation types. Indeed, in 1848 George W. Bonnell wrote of a nearby area in the Hill Country: "Some areas of the hills are very well forested...others are prairie" (as cited in Weniger, 1984).

Perhaps the most vivid descriptions of the Texas Hill Country were left to us from Dr. Ferdinand Roemer (1935). He left us many accounts of travel along the road from New Braunfels to Fredericksburg. In 1849, he wrote: "We camped in a little valley, about twenty-two miles distant from New Braunfels. We covered the remaining thirty miles to Fredericksburg the following day...On leaving our camping place, we entered a beautiful, grass covered valley extending several miles upward." In contrast, upon approaching Fredericksburg from the north, Dr. Roemer later wrote: "A narrow Indian path wound along the dense undergrowth to the top of the hill along which the squaws could hardly pass with their pack mules. The summit was covered with a continuous oak forest [that] extended beyond Fredericksburg."

In other accounts, Roemer speaks of passing through a beautiful mesquite prairie of great fertility before descending into the broad wooded valley of the Pedernales River. Along the river he described pecan trees bordering the banks and an oak forest with a prevalence of post oak beginning on the north bank where the soil becomes light and sandy. In another reference to the region north of the Pedernales and south of the Llano River, he adds: "The more level plains between these granite elevations contained a light, red soil and in many places a bare, coarse, disintegrated granite gravel. Although light, it was by no means unfruitful, as was proven by the mesquite trees growing particularly along the course of the creeks."

The term "forest" as it applied to the Hill Country is laid out for us by Roemer: "Nothing is farther removed from the European idea of a virgin forest than a Texas oak forest, even when in a state of primitiveness or untouched by human hands. In it there are no trees of great height or huge thickness, and their height is seldom more than thirty to forty feet, and the diameter one and one-half feet...no impenetrable thickets cover the ground and one can walk unhindered among the trees, since all underbrush is lacking." And further describing the Fredericksburg area: "Fredericksburg is situated on a gently rising plain about six miles north of the Pedernales Creek...a dense, uniform oak forest covered the area on which the houses were now being erected. This forest extended over almost the entire surrounding country with the exception of a small strip of open prairie, which ran parallel with the creek."

In 1854, F. L. Olmsted, the landscape architect, used his keen eye to describe the Texas Hill Country. Of the area around the two Sisters Creeks, he wrote: "The valleys appear densely wooded, with here and there a green and fertile prairie...A thin, coarse grass covered all of the soil" (Olmsted, 1857).

In summary, German settlers to the Texas Hill Country leave us with the impression of a landscape predominated by woodland that was mostly brush land with some limited areas supporting forest. By their accounts, small prairies were numerous throughout the area. Therefore, we can assume that the Pedernales River watershed must have been a mosaic of brushland, forest and prairie (Weniger, 1984).

Historical Accounts of Fire in the Texas Hill Country

No description of vegetation ecology within the Texas Hill Country would be complete without addressing the issue of naturally occurring fires. Again, we turn to Dr. Roemer's accounts. While exploring the countryside around Fredericksburg he makes note that certain species of wildlife can "find a welcome shelter in the cavities at the foot of trees, caused by frequent forest fires" (Roemer, 1935). On several occasions, he speaks of observing the composition of the soil more easily in winter, "when all of the grass was burned off everywhere." Camped between New Braunfels and Fredericksburg, Roemer writes: "During the night, a prairie fire caused us considerable worry...We resorted to the usual method of protection by burning the grass around us." Such accounts support the widely held belief that fire played an important role in the ecology of the Edwards Plateau (Scifres, 1980).

Vegetation After the Mid-1800s

As pointed out by Riskind and Diamond (1988), the Texas Hill Country is very sensitive to intervention and disturbance by man. For that reason, it is difficult to interpret accounts of Hill Country vegetation after about the late 1800s. By the turn of the 19th century, rangeland practices had begun to include (1) suppression of prairie fires, (2) fencing of livestock allotments, and (3) intense overgrazing (Scifres, 1980). By then, it became increasingly difficult to distinguish natural conditions from those created by man (Riskind and Diamond, 1988). However, it is known that these practices tend to favor woody vegetation over grassland.

20th Century Vegetation of the Balcones Canyonlands Including the Pedernales River Watershed

Vegetation of the Balcones Canyonlands (i.e., Texas Hill Country) is dominated by woodland and forest with grasslands generally restricted to the broad drainage divides and valleys. Mesic slopes are dominated by Plateau live oak (*Quercus fusiformis*), Texas oak (*Q. texana*), Ashe juniper (*Juniperus asheii*), honey mesquite (*Prosopis glandulosa*), black cherry (*Prunus serotina*), and Texas ash (*Fraxinus texensis*). Cedar elm (*Ulmus crassifolia*), sugarberry (*Celtis laevigata*), and netleaf hackberry (*Celtis laevigata*) also may be present. A distinct understory may be present and, if so, it is likely to be dominated by yaupon (*Ilex vomitoria*), American beautyberry (*Callicorpa Americana*), hoptree (*Ptelea trifolia*), and Mexican buckeye (*Ungnadia speciosa*).

Slope communities on dry southern and western exposures are dominated by Ashe juniper. Often these are found in nearly pure stands called cedar breaks. Among the other species that may be present are Plateau live oak, Texas persimmon (*Diospyros texana*), evergreen sumac (*Rhus virens*), Texas oak, and Texas mountain laurel (*Sophora secundflora*) (Riskind and Diamond, 1988).

Most grasslands of the Balcones Canyonlands region have been disturbed by heavy grazing and brush control techniques. However, grassland variability that is due to soil and aspect differences is difficult to differentiate from that caused by past disturbance (Dunlap, 1983; Fowler and Dunlap, 1986). The eastern portion of the Texas Hill Country borders the Blackland Prairie which is an extension of the True or Tallgrass Prairie (Diamond and Smeins, 1985). However, most of the Edwards Plateau is considered by some to be a southern extension of the Mixedgrass Prairie (Allred, 1956). Thus, moist, moderately grazed uplands of the Hill Country tend to resemble tallgrass communities, while drier conditions and overgrazing tend to create midgrass and shortgrass communities (Smeins et al., 1976).

Little bluestem (*Schizachryium scoparium*), Texas wintergrass (*Stipa leucotricha*), tall dropseed (*Sporobolus asper*), sideoats grama (*Bouteloua curtipendula*), and curlymesquite (*Hilaria belangeri*) are among the dominant grasses of the tallgrass prairie sites. Drier and more disturbed sites are composed of short grasses such as curlymesquite, three-awns (*Arisitada spp.*), Texas grama (*Bouteloua rigidiseta*), red grama (*B. trifida*), hairy grama (*B. hirsuta*), and hairy tridens (*Erioneuron pilosum*) (Smeins et al., 1976).

Texas Hill Country floodplains along perennial springs and rivers can support bald cypress (*Taxodium distichum*) gallery forests that also may contain sycamore (*Platanus occidentalus*) and black willow (*Salix nigra*). Smaller floodplains and higher terraces are dominated by elms (*Ulmus crassifolia and U. americana*), pecan (*Carya illinoensis*), sugarberry, netleaf hackberry, and Texas ash (Beuchner, 1944).

Vegetation data for the entire state of Texas has been classified by the Texas Parks and Wildlife Department (TPWD) using Landsat satellite imagery primarily from the 1970s (Frye et al., 1984). Of more than 50 community types mapped by Frye et al. (1984) statewide, four major plant community types were shown in the Pedernales River watershed (Figure 3-4). These community types, with a brief description of common plant species associated with each type, are presented below:

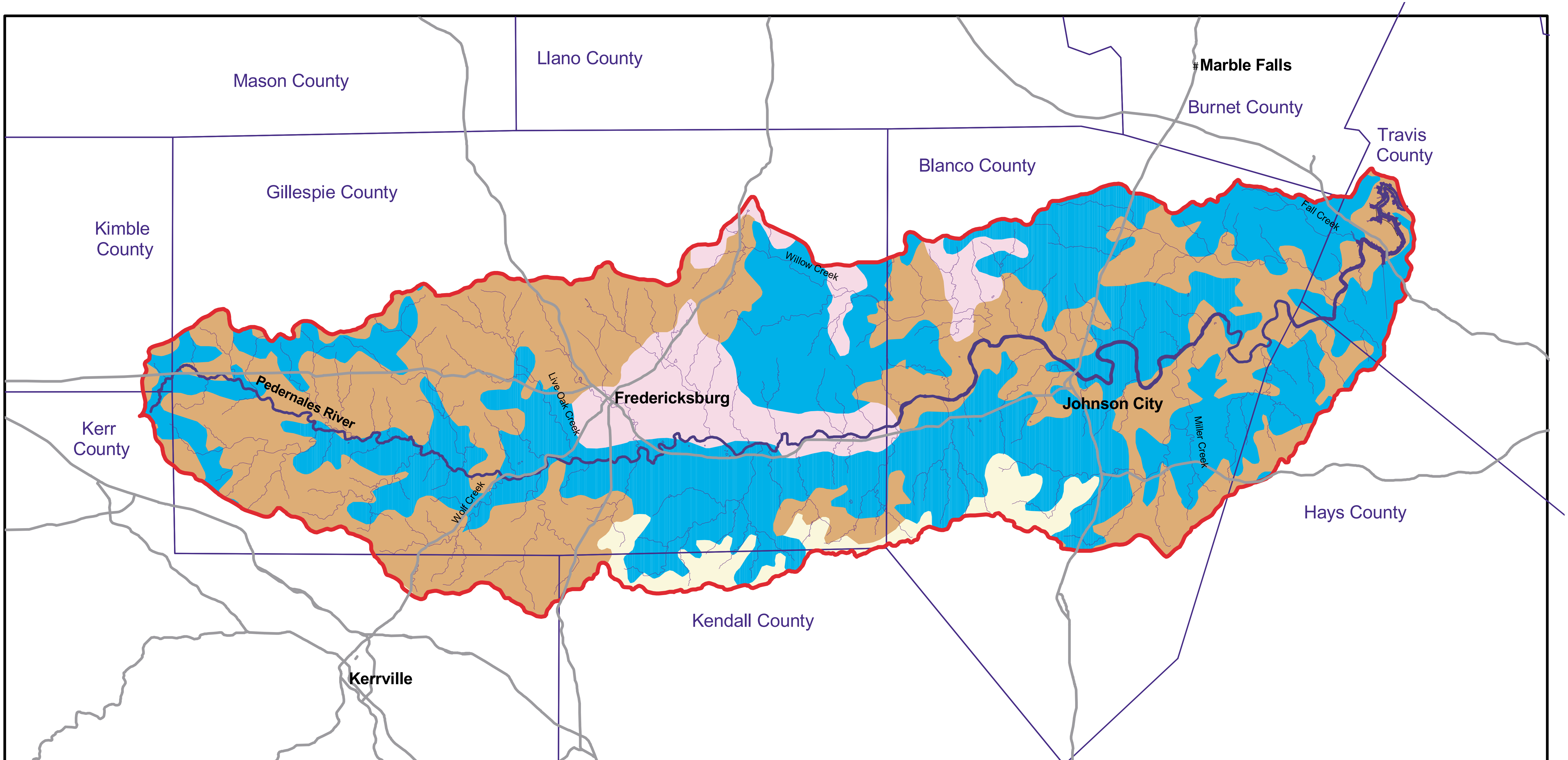
- **Live Oak-Mesquite Parks** — Along with live oak and honey mesquite, some commonly associated plants are post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*), cedar elm, Mexican persimmon, buffalograss (*Buchloe dactloides*), curlymesquite, Texas grama, sideoats grama, and little bluestem. Parks are described as communities supporting woody plants more than 9 feet tall which grow as clusters or scattered individuals throughout a grassland (less than 70 percent canopy coverage) (Frye et al., 1984).

- **Live Oak-Ashe Juniper Parks and Live Oak-Mesquite-Ashe Juniper Parks** — Along with live oak, Ashe juniper, and honey mesquite, some commonly associated plants are Texas oak, shin oak (*Quercus durandii*), cedar elm, netleaf hackberry, flameleaf sumac (*Rhus copallina*), agarito (*Berberis trifoliolata*), Mexican persimmon, Texas pricklypear (*Opuntia engelmannii*), Texas wintergrass, little bluestem, curlymesquite, Texas grama, and purple three-awn (Aristida purpurea).

- **Live Oak-Ashe Juniper Woods** — Along with live oak and Ashe juniper some commonly associated plants are Texas oak, shin oak, cedar elm, evergreen sumac, Texas mountain laurel, twistleaf yucca (*Yucca rupicola*), little bluestem, Texas grama, meadow dropseed (*Sporobolus asper var. drummondii*), Texas wintergrass, and curlymesquite. Woods include communities with trees up to 30 feet tall with a relatively close canopy (71 to 100 percent) (Frye et al., 1984).

TAMU's Blackland Research Center provides technical support to TSSWCB by conducting hydrologic modeling of brush management study areas. Vegetation data used by the Blackland Research Center to model the Pedernales River watershed were provided as a digital file of vegetation communities interpreted from satellite imagery. Figure 3-5 is a map of the 14 vegetation communities identified in the study area. An abrupt change in the vegetation mapping in the eastern part of the watershed indicates that the data were interpreted using two images most likely taken on different dates. This discontinuity also suggests that the images may have been interpreted using different techniques. Acreage values for the mapped communities are tabulated below.

Vegetation Community	Acreage	Percent
Agriculture	12,136	1.5
Moderate Oak and Moderate Cedar	16,520	2.0
Heavy Oak and Heavy Cedar	89,863	11.0
Heavy Oak and Moderate Cedar	148,925	18.3
Heavy Cedar	59,875	7.3
Heavy Mesquite	2,693	0.3
Heavy Oak	134,487	16.5
Medium Cedar	41,137	5.1
Medium Oak	141,369	17.3
Orchard	4,303	0.5
Pastureland	113,024	13.9
Brushy Rangeland	27,650	3.4
Open Rangeland	20,177	2.5
Water	2,937	0.4
Total	815,096	100.0



Pedernales River Vegetation
- Live Oak-Ashe Juniper Parks
- Live Oak-Ashe Juniper Woods
- Live Oak-Mesquite Parks
- Live Oak-Mesquite-Ashe Juniper Parks

- County Boundary
- Watershed
- Streams
- Highways

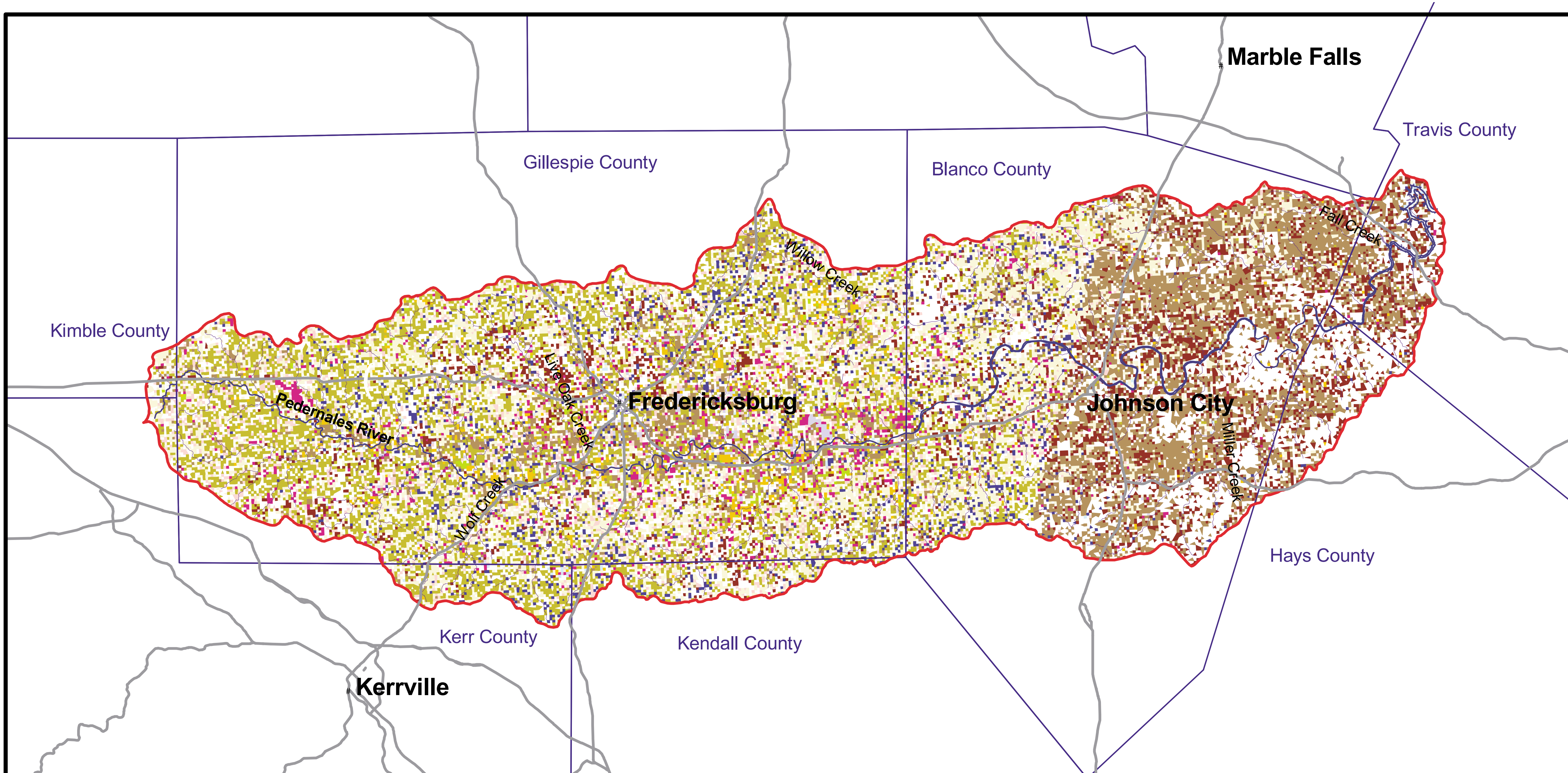
0 5 10 15 20
SCALE IN MILES

LCRA
THE POWER TO MAKE A DIFFERENCE.

FIGURE 3-4
1970 WATERSHED VEGETATION MAP

PEDERNALES RIVER WATERSHED
BRUSH CONTROL PLANNING
ASSESSMENT AND FEASIBILITY

Source of Vegetation: Texas Parks and Wildlife Dept., Vegetation Types of Texas, Sept. 1984.



Agriculture
Moderate Oak & Moderate Cedar
Heavy Oak & Heavy Cedar
Heavy Oak & Moderate Cedar
Heavy Cedar
Heavy Mesquite
Heavy Oak
Medium Cedar
Medium Oak
Orchard
Pastureland
Brushy Rangeland
Open Rangeland
Water
Study Area
Pedernales River
Streams
County Boundary
Highways

N

0 6 12
SCALE IN MILES

Source: Texas A&M University, Blacklands Research Center. 1999

LCRA
THE POWER TO MAKE A DIFFERENCE.

FIGURE 3-5
1999 WATERSHED VEGETATION MAP

PEDERNALES RIVER WATERSHED
BRUSH CONTROL PLANNING
ASSESSMENT AND FEASIBILITY

3.2.2 HYDROLOGICAL HISTORY

USGS maintains two flow-monitoring stations within the Pedernales River Basin (Figure 3-2): one near Fredericksburg (08152900) and one near Johnson City (08153500). The station near Johnson City has continuous records from May 1939 to September 1999, and the station near Fredericksburg has records from 1964 to 1999, with significant gaps in the data. Consequently, this study relied heavily on the data recorded at the station near Johnson City. Precipitation data was obtained from the National Climatic Data Center for stations at both Fredericksburg (41-3329) and Johnson City (41-4605).

The rainfall station near Fredericksburg has records from 1939 to present, while the station near Johnson City has records from 1964 to the present. Since the flow and the precipitation records are not measured at the same locations within the basin, a statistical analysis was performed to determine the correlation between the precipitation at these stations. Because the data are not normally distributed, the nonparametric Spearman R method of correlation was used, which produced a Spearman R value of 0.82 (Figure 3-6). This shows a fairly strong correlation between the two stations. Consequently, either station could be used in analyzing the flow data. The precipitation gauge at Fredericksburg, besides having more complete records, is in the central part of the watershed. Therefore, its data were used in this study.

Stream Flow

Figure 3-7 is a plot of total annual precipitation at Fredericksburg and total annual discharge of the Pedernales River near Johnson City from 1940 to 1993. It shows the expected relationship between discharge and precipitation (i.e., increased discharge with increased precipitation), but what is also apparent is a subtle trend of increasing precipitation and discharge during the period of record, except during the record drought from 1948 to 1957. The precipitation and discharge data are tabulated in Table 3-3, with mean discharge and precipitation for the predrought, postdrought, and full periods of record. Mean annual precipitation was 31.2 inches for the postdrought period 1957-1993, compared with 30.9 inches for the predrought period 1940-1947. Mean annual discharge was 154,810 acre-feet for the postdrought period, compared with 137,834 acre-feet for the predrought period.

A flow-duration curve is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. The discharge records from the Johnson City stream gauge were used to prepare flow-duration curves for progressively shorter times between 1960 and 1999 (Figure 3-8). The curves show that the discharge of the Pedernales River varies widely. There is flow in the river approximately 95 percent of the time, but at approximately 10 cubic feet per second (cfs), the flow drops to 0 cfs rapidly. Flows greater than about 500 cfs occur about 6 percent of the time, and the median flow (i.e., flow the 50th percentile) of the river is about 80 cfs. Interestingly, the graph shows that the median flow from 1990 to 1999 was about 20 cfs higher than from 1960 to 1999. The increase in flow may be attributable to increased precipitation in the watershed, or it may reflect a gradual increase in the amount municipal wastewater discharged to the river at Fredericksburg.

Low flow data were also examined to gain some insight into base flow, which should be at least partially attributable to groundwater discharge to the river. Figures 3-9 through 3-14 show the number of days each year that the mean daily flow was within selected flow ranges since 1939. The data also are tabulated in Table 3-4. Figure 3-9 shows that days when the flow was 0 cfs occurred more frequently after 1957 than before the record drought (1948-1957), even during years of generally “normal” rainfall. This is more evident in Figure 3-10, which shows that days with flow less than or equal to 5 cfs occurred much more frequently after 1957 than before the record drought. This reduction in apparent base flow could be related to reduced groundwater discharge to the river or to increased withdrawal of river water for irrigation upstream of Johnson City. Figures 3-11 through 3-13 suggest there was no significant difference in the frequency or number of days when flows were less than 10, 25, and 50 cfs before or after the record drought. In contrast, Figure 3-14, shows that flows greater than 50 cfs occurred more days each year after the drought than before the drought. This analysis does not provide strong indication that brush infestation has significantly reduced basin yields since stream flow measurements were begun in 1939.

Groundwater Levels

Since groundwater discharge presumably contributes to Pedernales River flow, water level data from wells in Blanco and Gillespie counties were examined for indications that the amount of groundwater discharged to the river has changed over time. TWDB maintains a database of water level records for hundreds of water wells in Blanco and Gillespie counties. A total of 76 wells in the watershed had water level data available for 20 or more years. Of these, 44 wells were completed in the Trinity Group aquifers (i.e., Upper, Middle, and Lower Trinity aquifers), 20 in the Ellenburger-San Saba aquifer, and 12 in the Hickory aquifer. Table 3-5 presents a summary of the approximate net water level changes for these wells.

Twenty-two of the 44 wells completed in the Trinity Group aquifers showed net water level declines, with an average loss per well of 8.0 feet. Net water level gains were recorded in the remaining Trinity Group wells, with an average gain per well of 15.9 feet. Thirteen of the 20 wells screened in the Ellenburger-San Saba aquifer showed net water level declines, averaging 13.1 feet per well. The remaining seven Ellenburger-San Saba wells showed net water level increases, with an average gain of 7.8 feet per well. Seven of the 12 wells completed in the Hickory aquifer showed net water level declines averaging 33.7 feet. Net water level gains were recorded in the remaining five Hickory wells, averaging 1.5 feet per well.

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.

Figures 3-15 and 3-16 present hydrographs for water levels in selected water wells in Gillespie and Blanco counties. These hydrographs show that water levels fluctuate in individual wells over time. Overall, the water level fluctuations observed for the wells in Gillespie and Blanco counties 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

Early explorers of the Pedernales River watershed mentioned springs, but only in passing, and no quantitative historical information on spring flows was found for this study. However, in what is arguably the most detailed inventory of springs in the state, Brune (1981) described 12 spring sites in the Pedernales River watershed in Blanco County. He measured and reported on the flow at 10 of the spring sites and provided information about their history, where available. Unfortunately, his published work did not include springs in Gillespie County. Brune's descriptions of the springs in Blanco County are summarized below.

- **Lewis Springs** — 1.2 miles east of Sandy. Harrison Lewis settled near them in 1854. Flow from the Paleozoic Hickory Sand. Flow in August 1941 was 7 gallons per minute (gpm).

- **Buffalo Springs** — 4.3 miles northwest of Johnson City on the Owen Ahrens ranch. Springs flow from a bluff on Hickory Creek, from joints in the Paleozoic Cap Mountain limestone. Buffalo Cave is about 985 feet northeast of the springs and has been mapped for a distance of 1,250 feet. The springs produced 490 gallons per minute (gpm) in July 1941, but only 56 gpm in November 1978, after much dry weather.

- **Sharp Springs** — 1.2 miles west of Round Mountain on the D. D. Sharp place near an old stone house. Existed when the site was settled in 1854. Spring flow was intermittent in 1978.

- **Hobbs or Pecan Spring** — 1.2 miles southwest of Johnson City at Wayne Robertson's housing development. Water issues from Ellenburger dolomite and flows 165 feet to the Pedernales River. Flow was 444 gpm in May 1969 and 33 gpm in November 1978.

Figure 3-6
Nonparametric Correlation for Rainfall Stations - Spearman R
JCRAIN = Johnson City Rainfall
FBRAIN = Fredericksburg Rainfall

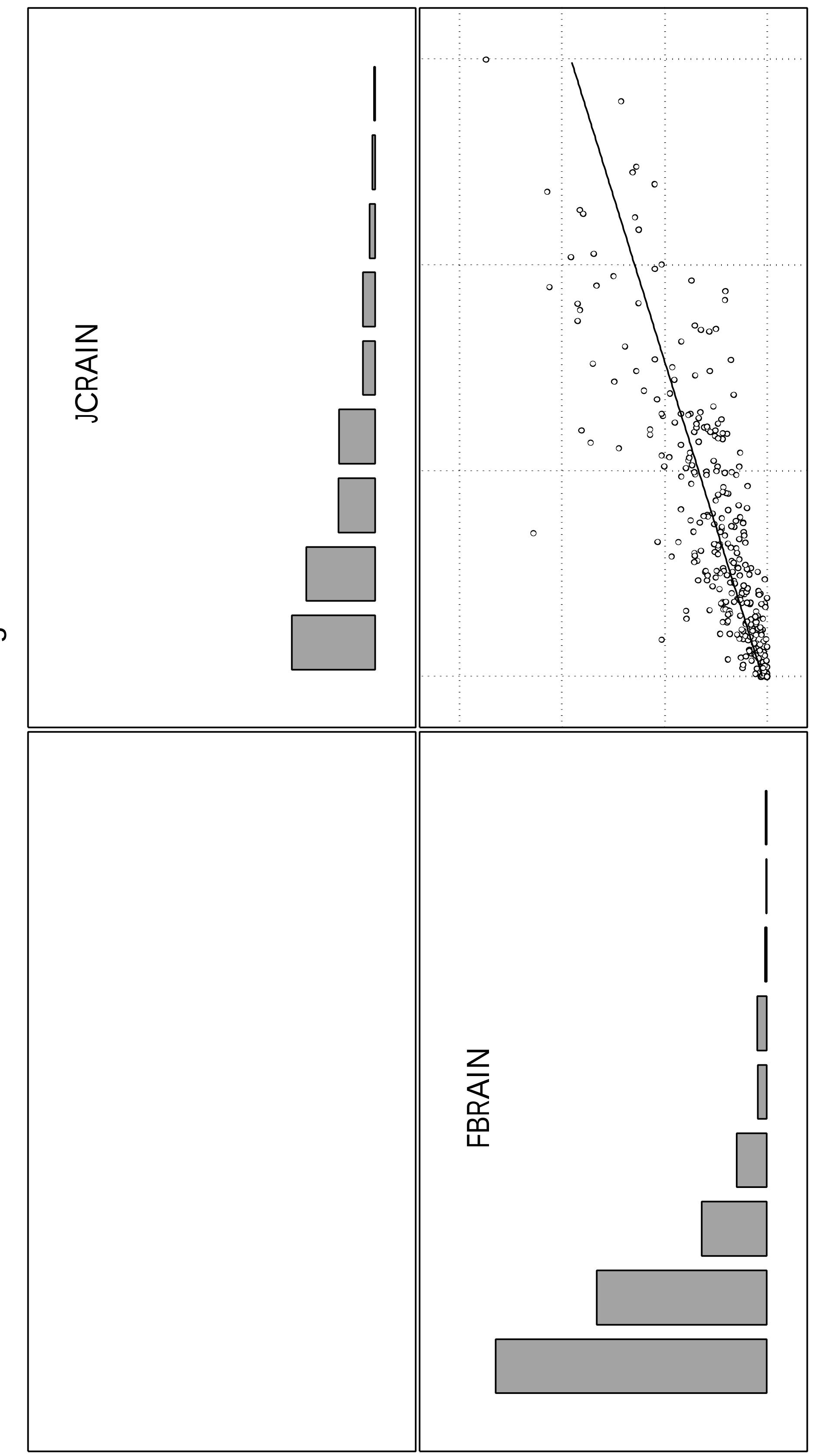


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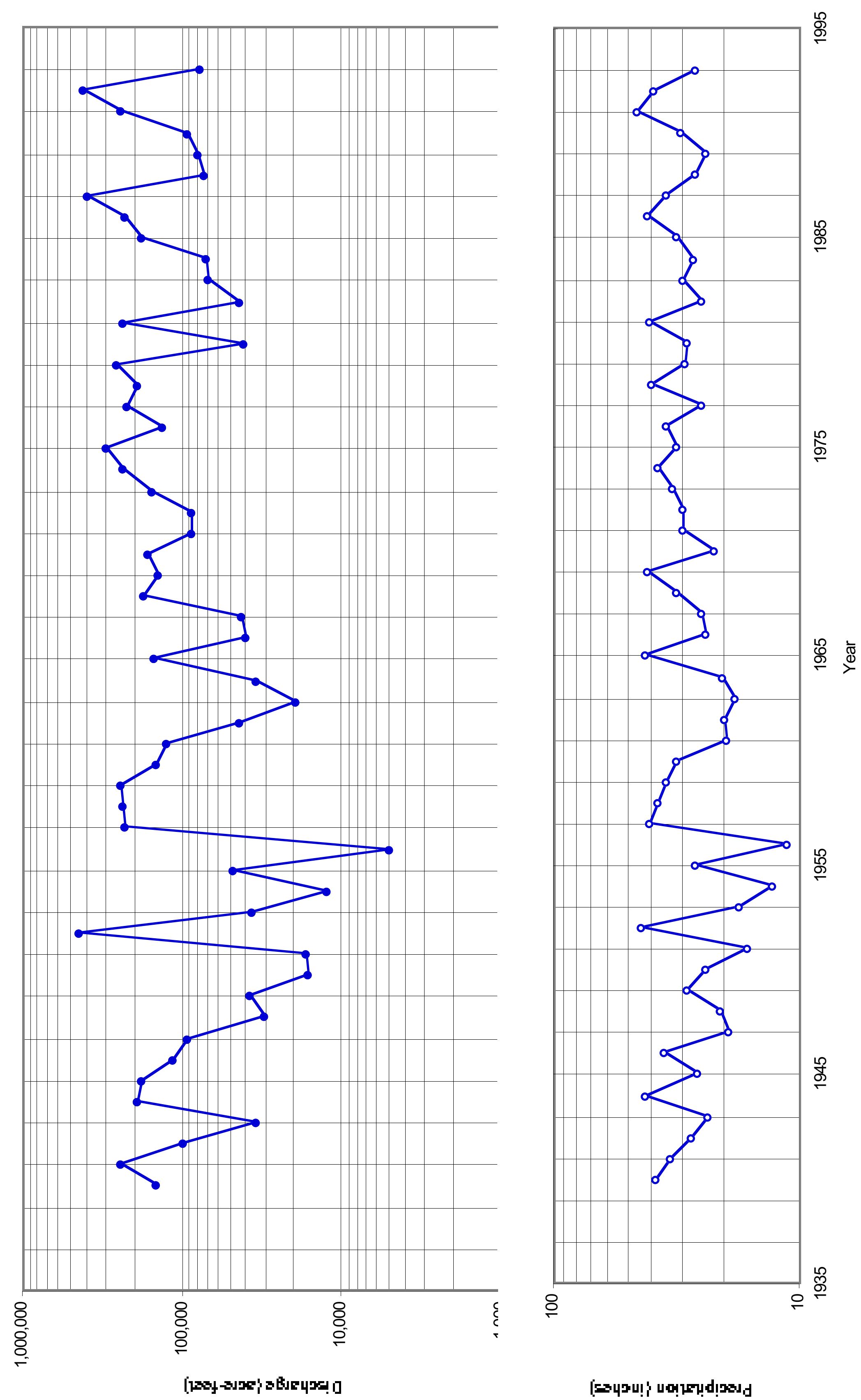
FIGURE 3-7
TOTAL ANNUAL DISCHARGE AND PRECIPITATION,
PEDERNALES RIVER WATERSHED



- **Salter Springs** — 4.3 miles northeast of Johnson City on Myron Weir's ranch. Water issues from Cambrian Wilberns dolomite and feeds Salter Springs Creek. Flow in November 1978 was 30 gpm.

- **Crofts or McCarty Spring** — 3.7 miles northeast of Johnson City on Martin Early ranch. Once a stage-coach stop. Moderately large, reliable spring that issues under artesian pressure from a fault in the Ellenburger limestone. Flow was 1,585 gpm in May 1968 and August 1975, and 206 gpm in May 1978.

- **Cypress Mill Springs** — On Cypress Creek northwest of Cypress Mill. Used as a water supply by a Mormon settlement in 1849. Water flows from limestone beds of the Ellenburger Formation below the creek's water surface. Flow was 490 gpm in August 1975. These are the most reliable springs on Cypress Creek.

- **Pedernales Spring** — At foot of falls in Pedernales Falls State Park, 11 miles east of Johnson City. Issues under artesian pressure from the Marble Falls limestone. Largest spring in Blanco County. Flow in April 1975 was 2,220 gpm.

- **Jones Spring** — In Pedernales Falls State Park about 3.1 miles south-southwest of Pedernales Spring. Flow is from Cretaceous sand in Travis Peak Formation. Small but reliable. Flowing in May 1978 after a year of very dry weather.

- **Three Springs** — 6.2 miles east-northeast of Johnson City on the R. W. Robinson ranch leased by Roy Weinheimer. Copious springs that issue from Ellenburger limestone that dips toward the Pedernales River.

- **Honeycut Springs** — In a cove 5 miles east-southeast of Johnson City on the C. O. Browning ranch. Mortar holes in limestone reveal this was a prehistoric living site. Issues from Cow Creek limestone and runs about 1,650 feet before disappearing. Flow in November 1978 was 16 gpm.

- **Uecker Springs** — 6.8 miles southwest of Johnson City on David Bramberger ranch. Trickle from Edwards limestone. Flow in November 1978 was 0.8 gpm. Many other small springs are in same area, including Walnut Springs (0.6 miles to north) and Duncan Springs (4.3 miles to southeast).

TABLE 3-3

TOTAL ANNUAL DISCHARGE AND PRECIPITATION, PEDERNALES RIVER WATERSHED

Year	Precipitation (inches)	Annual Discharge (acre-feet)	Year	Precipitation (inches)	Annual Discharge (acre-feet)
1940	38.5	148,401	1970	22.4	163,492
1941	33.7	243,396	1971	30.1	88,834
1942	27.7	97,999	1972	29.9	88,445
1943	23.8	34,497	1973	33.0	154,268
1944	42.3	193,303	1974	37.9	235,601
1945	26.0	179,252	1975	31.7	297,870
1946	35.4	113,600	1976	35.0	131,925
1947	19.4	92,220	1977	25.2	219,644
1948	20.9	30,248	1978	40.0	190,977
1949	28.6	38,149	1979	29.3	257,270
1950	24.2	16,144	1980	28.7	41,764
1951	16.3	17,038	1981	40.5	238,979
1952	44.0	441,570	1982	25.0	44,156
1953	17.6	36,864	1983	29.9	69,883
1954	12.8	12,307	1984	27.2	71,963
1955	26.7	48,305	1985	31.5	182,096
1956	11.3	5,079	1986	41.9	232,312
1957	41.1	231,841	1987	34.6	389,647
1958	37.7	233,260	1988	26.7	73,950
1959	34.7	245,107	1989	24.2	81,169
1960	31.9	147,687	1990	30.6	92,369
1961	19.9	126,456	1991	45.5	245,796
1962	20.3	43,616	1992	39.4	424,455
1963	18.1	19,711	1993	26.5	78,423
1964	20.7	34,387			
1965	42.1	150,947	Period	Mean	Mean
1966	24.2	39,841		(inches)	(acre-feet)
1967	24.9	42,762	1940-1947	30.9	137,834
1968	31.5	173,340	1957-1993	31.2	154,810
1969	41.2	143,736	1940-1993	29.7	138,451

Pedernales River discharge measured at USGS guage station 08153500 near Johnson City.
Watershed precipitation measured at National Weather Service station 41-3329 at Fredericksburg.

Figure 3-8
PEDERNALES RIVER FLOW-DURATION CURVE
(USGS Station 08153500 near Johnson City, Texas)

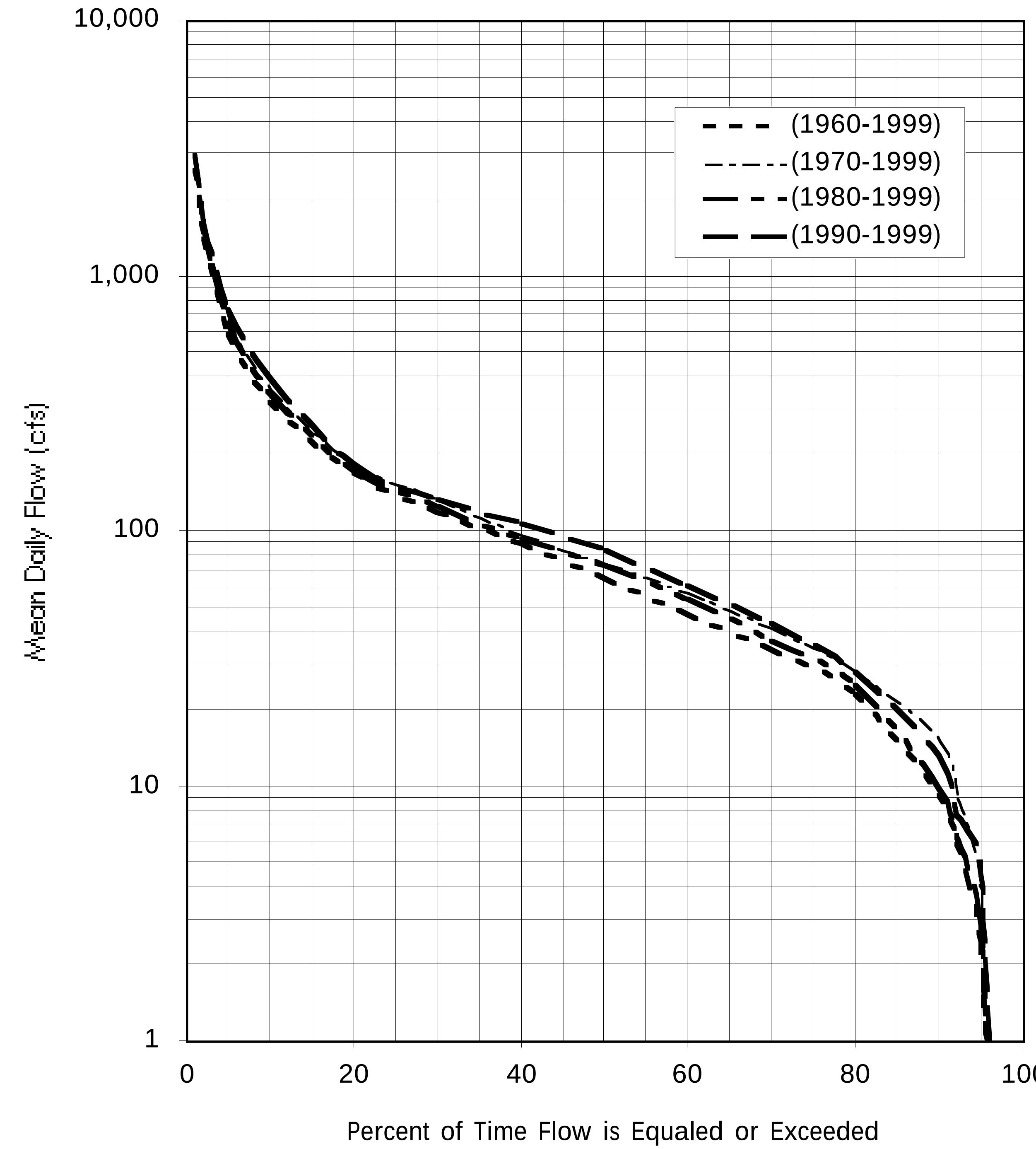


Figure 3-9
FLOWS OF 0 CFS (1939-1999)
(Station 08153500 near Johnson City, Texas)

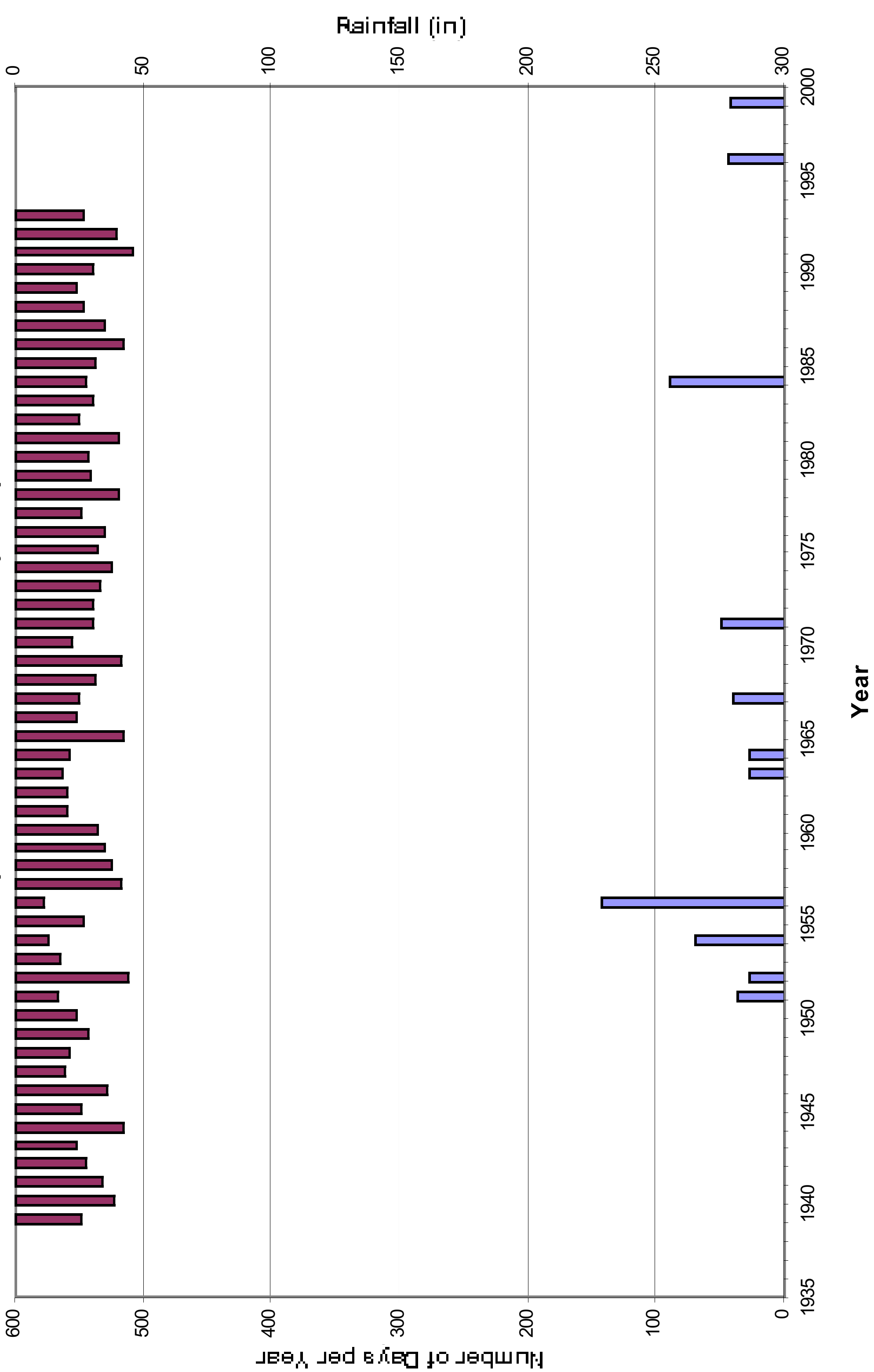
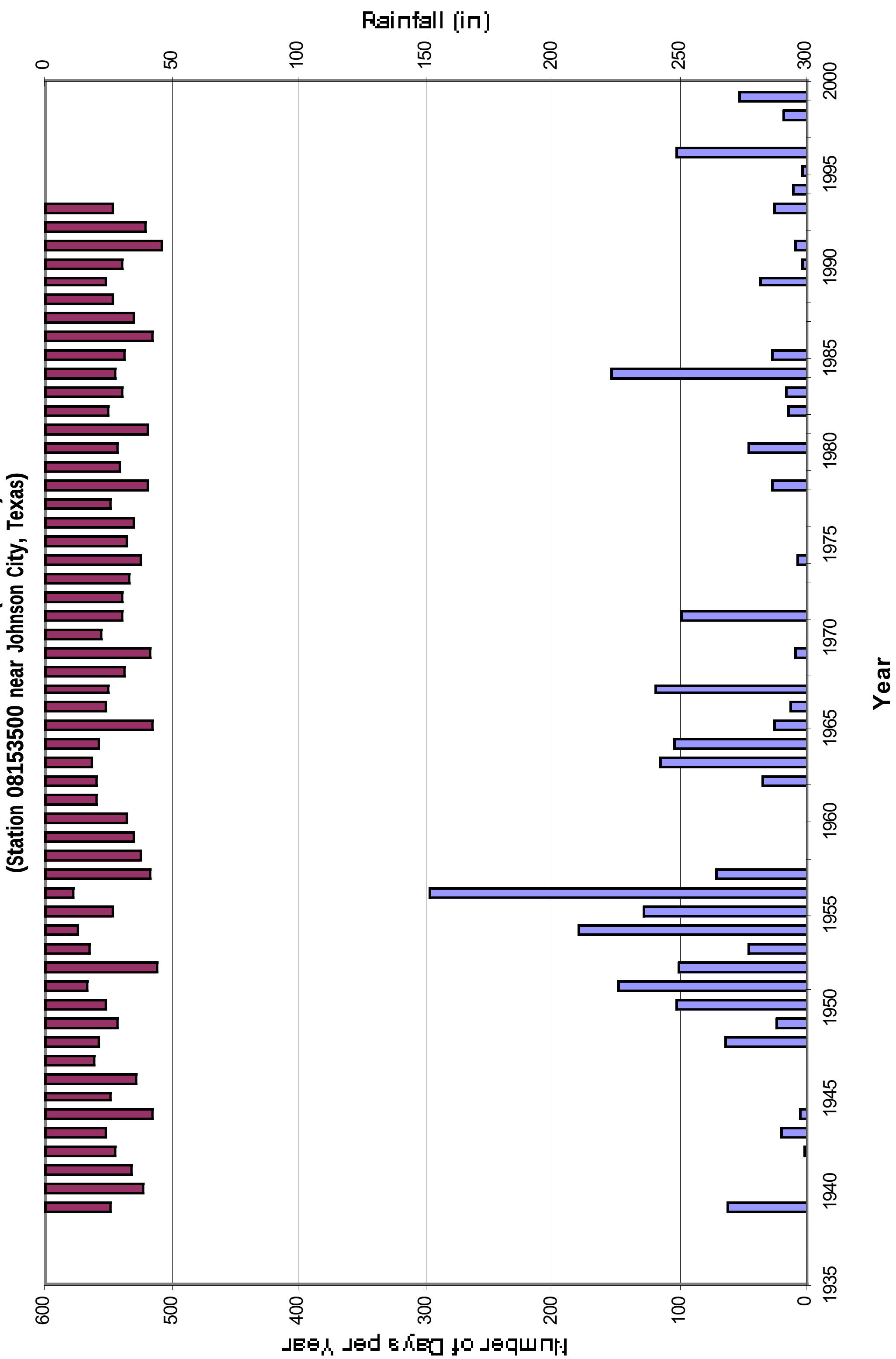


Figure 3-10
FLOWS OF 5 CFS OR LESS (1939-1999)
(Station 08153500 near Johnson City, Texas)



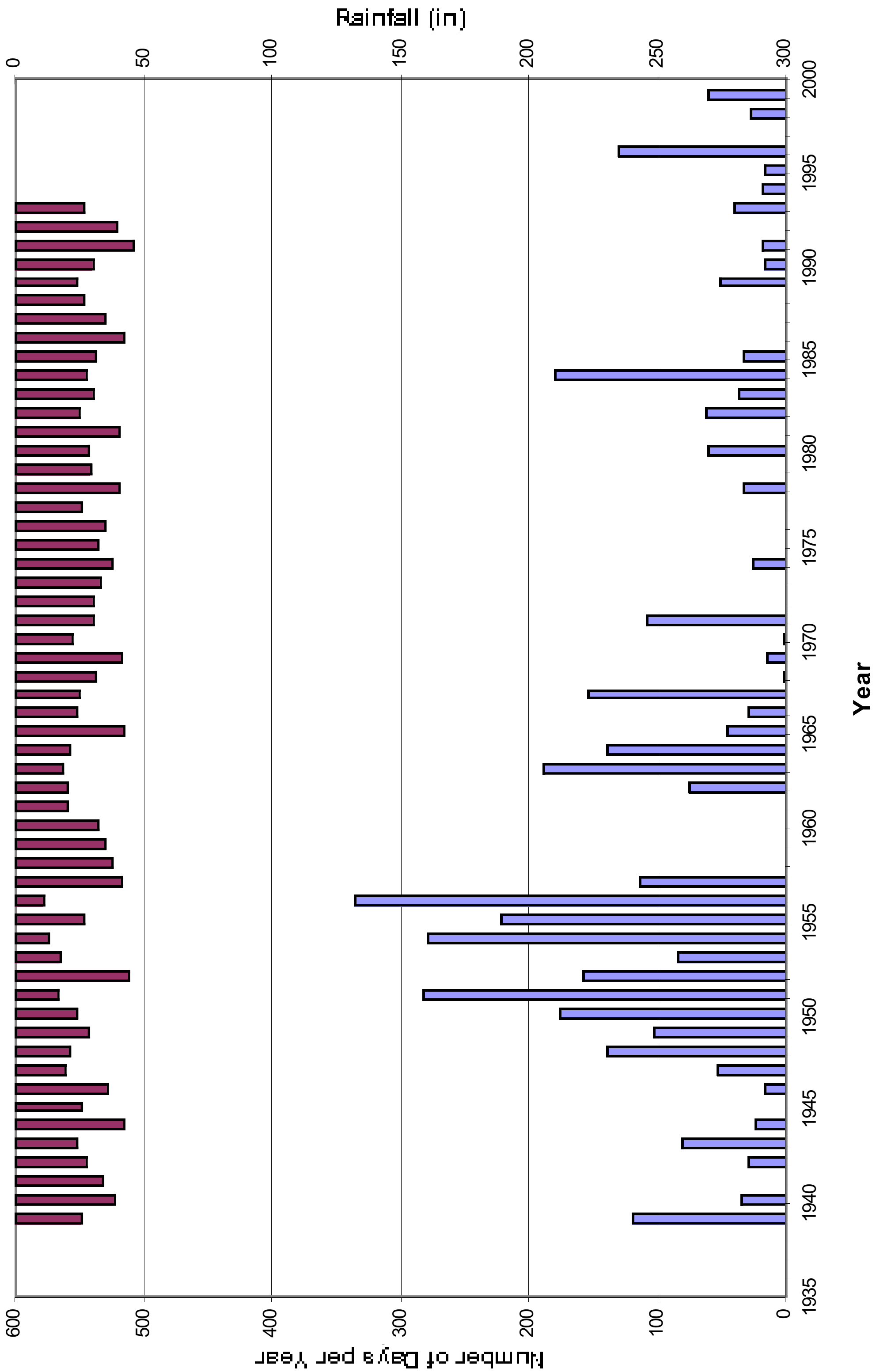


Figure 3-11
FLOWS OF 10 CFS OR LESS (1939-1999)
(Station 08153500 near Johnson City, Texas)

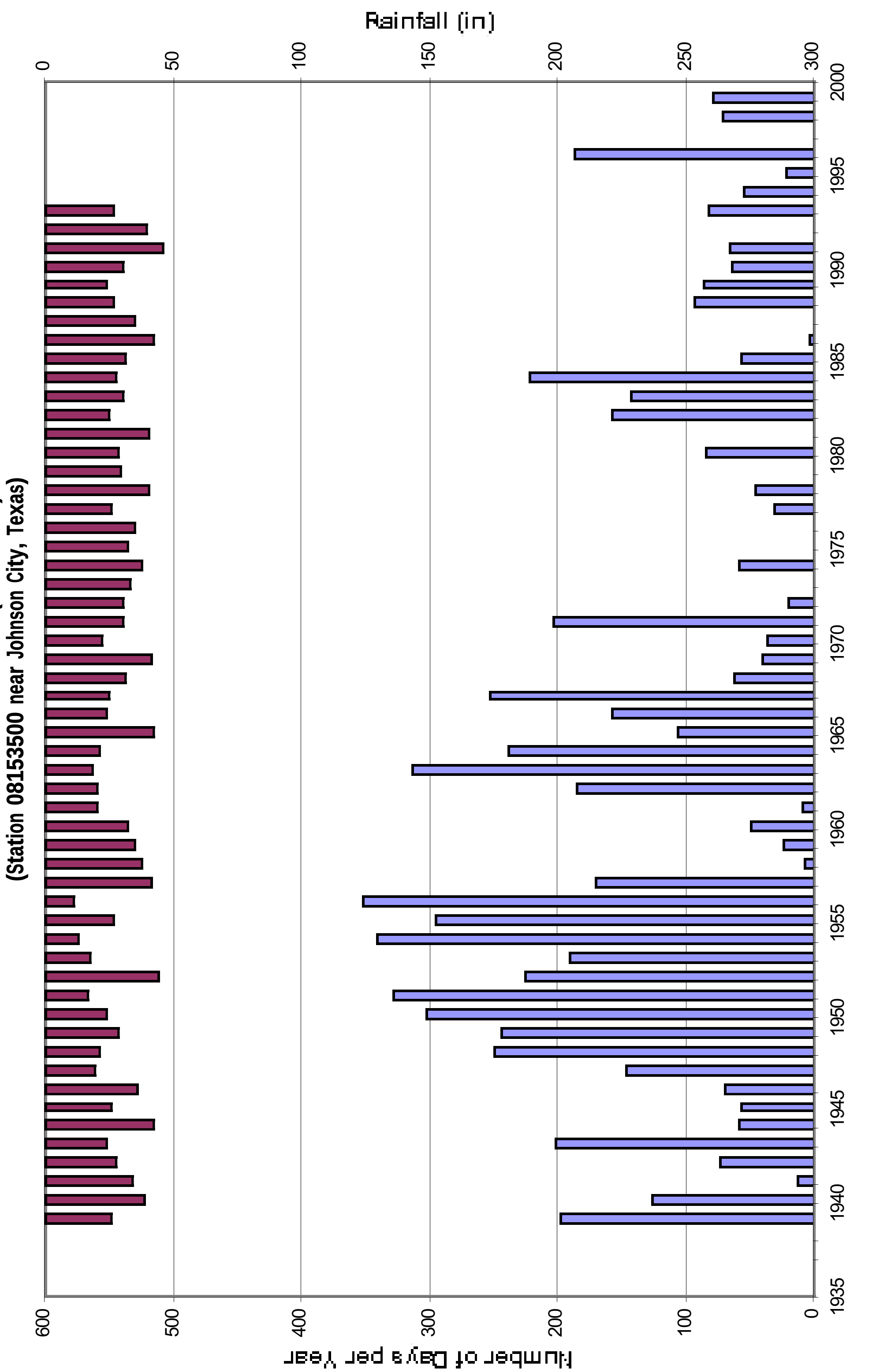


Figure 3-12
FLOWS OF 25 CFS OR LESS (1939-1999)
(Station 08153500 near Johnson City, Texas)

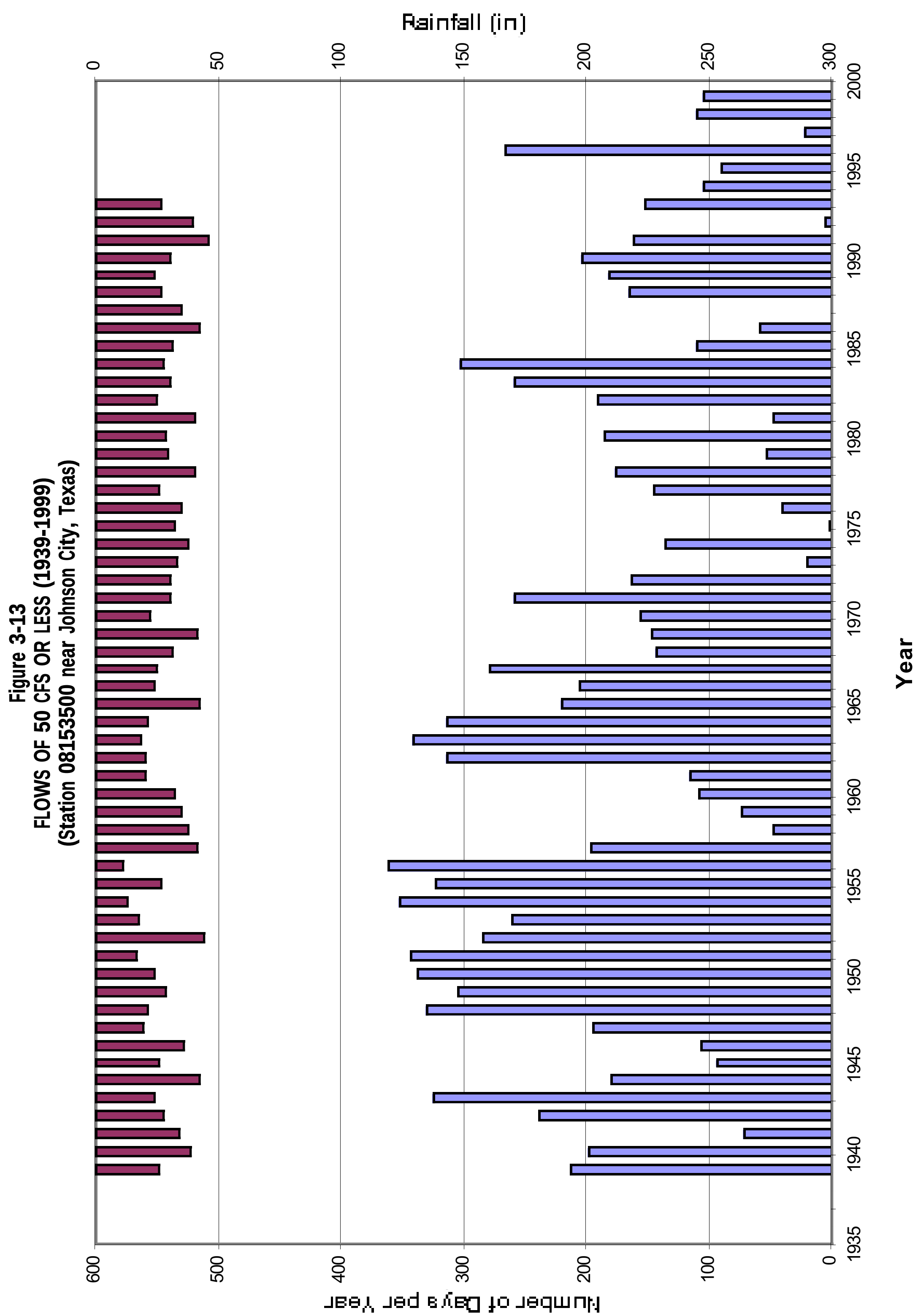


Figure 3-13
FLOWS OF 50 CFS OR LESS (1939-1999)
(Station 08153500 near Johnson City, Texas)

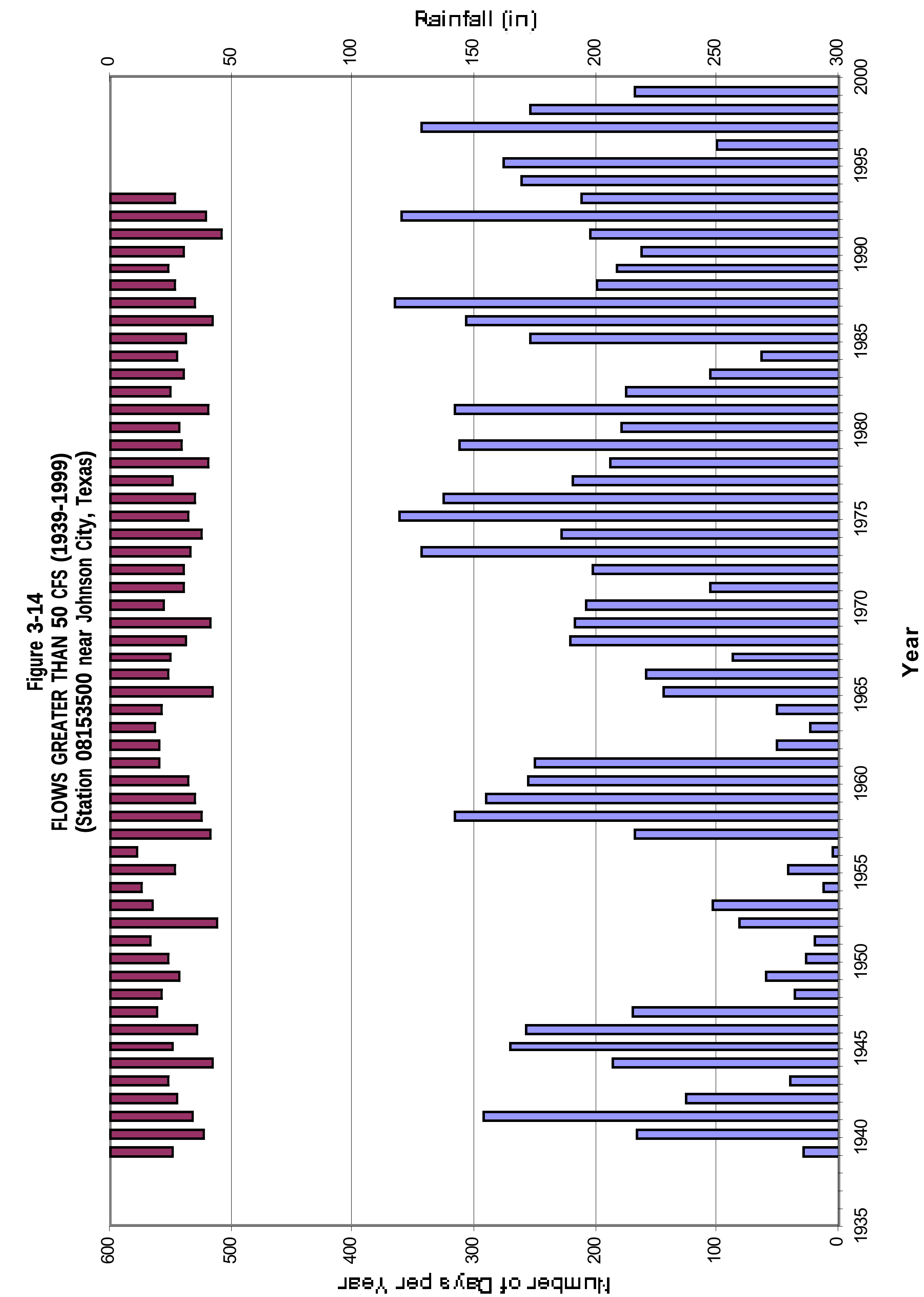


Figure 3-14
FLOWS GREATER THAN 50 CFS (1939-1999)
(Station 08153500 near Johnson City, Texas)

TABLE 3-4

FREQUENCY OF SELECTED RANGES OF STREAM FLOW,
PEDERNALES RIVER NEAR JOHNSON CITY

	Number of Days At Specified Flow					
Year	0 cfs	£ 5 cfs	£ 10 cfs	£ 25 cfs	£ 50 cfs	>50 cfs
1939	0	62	120	198	213	29
1940	0	0	35	127	199	167
1941	0	0	0	13	72	293
1942	0	2	30	73	238	127
1943	0	20	81	201	325	40
1944	0	6	23	59	180	186
1945	0	0	0	56	94	271
1946	0	0	17	69	107	258
1947	0	0	53	147	194	171
1948	0	64	140	249	330	36
1949	0	23	103	244	304	61
1950	0	103	177	303	337	28
1951	37	148	283	328	344	21
1952	27	101	157	225	284	82
1953	0	45	84	191	261	104
1954	69	179	278	342	352	13
1955	0	129	222	296	323	42
1956	143	298	335	353	361	5
1957	0	71	114	170	196	169
1958	0	0	0	8	48	317
1959	0	0	0	24	74	291
1960	0	0	0	50	109	257
1961	0	0	0	10	115	250
1962	0	34	76	185	314	51
1963	28	116	189	314	341	24
1964	27	105	139	239	314	51
1965	0	26	46	106	221	144
1966	0	12	29	158	205	160
1967	41	119	155	254	278	87
1968	0	0	2	63	144	222
1969	0	10	15	40	147	218
1970	0	0	2	37	156	209
1971	50	99	109	204	258	107
1972	0	0	0	20	163	203
1973	0	0	0	0	21	344
1974	0	8	26	58	136	229
1975	0	0	0	0	2	363
1976	0	0	0	0	40	326
1977	0	0	0	32	145	220
1978	0	28	33	45	177	188
1979	0	0	0	0	53	312
1980	0	46	61	85	186	180
1981	0	0	0	0	48	317
1982	0	14	63	157	190	175

TABLE 3-4 (Concluded)

	Number of Days At Specified Flow					
Year	0 cfs	£ 5 cfs	£ 10 cfs	£ 25 cfs	£ 50 cfs	>50 cfs
1983	0	16	36	144	258	107
1984	89	155	179	222	302	64
1985	0	28	33	57	110	255
1986	0	0	0	3	58	307
1987	0	0	0	0	0	365
1988	0	0	0	93	165	200
1989	0	37	51	86	182	183
1990	0	3	16	65	203	162
1991	0	10	19	66	161	204
1992	0	0	0	0	5	361
1993	0	26	41	82	152	213
1994	0	11	18	55	104	261
1995	0	4	16	22	89	276
1996	44	102	131	188	266	100
1997	0	0	0	0	22	343
1998	0	19	28	72	111	254
1999	42	54	61	78	104	169
Total*	597	2,333	3,826	6,966	10,891	11,172
Average*	10	38	63	114	179	183
Total**	321	1,243	2,047	4,435	7,995	10,780
Average**	6	24	39	85	154	207

* Includes drought period 1948-1956
** Excludes drought period 1948-1956

TABLE 3-5

NET WATER LEVEL CHANGE IN WATER WELLS, BLANCO AND GILLESPIE COUNTIES

State Well Number	Aquifer	Period	Decline (-) or Rise (+) (feet)	Rate of Change (feet/year)
5647604	Trinity Group	1973-1993	+ 4.48	+ 0.22
5737702	Trinity Group	1941-1997	- 6.36	- 0.11
5737802	Trinity Group	1941-1968	+ 2.78	+ 0.10
5737805	Trinity Group	1941-1968	+ 117.30	+ 4.34
5738506	Trinity Group	1938-1968	+ 1.90	+ 0.06
5738701	Trinity Group	1938-1968	+ 6.41	+ 0.21
5739703	Trinity Group	1938-2000	+ 11.88	+ 0.19
5739801	Trinity Group	1938-1961	+ 0.22	+ 0.01
5741402	Trinity Group	1936-1962	+ 2.22	+ 0.09
5741601	Trinity Group	1936-1961	+ 3.39	+ 0.14
5741903	Trinity Group	1959-1999	+ 29.53	+ 0.74
5742204	Trinity Group	1979-1999	- 1.66	- 0.08
5742402	Trinity Group	1936-1961	+ 1.01	+ 0.04
5742503	Trinity Group	1960-1987	+ 12.10	+ 0.45
5742719	Trinity Group	1977-1999	- 21.09	- 0.96
5742720	Trinity Group	1977-1998	- 1.91	- 0.09
5744503	Trinity Group	1941-1968	+ 28.65	+ 1.06
5744601	Trinity Group	1941-1961	- 8.46	- 0.42
5744602	Trinity Group	1941-1999	- 14.82	- 0.26
5745804	Trinity Group	1941-1968	+ 14.25	+ 0.53
5745910	Trinity Group	1968-1997	- 2.26	- 0.08
5746310	Trinity Group	1938-1968	+ 6.37	+ 0.21
5746601	Trinity Group	1938-1968	- 0.20	- 0.01
5746704	Trinity Group	1938-1968	- 1.68	- 0.06
5751802	Trinity Group	1971-1999	- 30.45	- 1.09
5752301	Trinity Group	1941-1968	- 8.91	- 0.33
5752304	Trinity Group	1941-1968	- 2.53	- 0.09
5752308	Trinity Group	1941-1968	- 0.54	- 0.02
5752314	Trinity Group	1941-1968	- 1.23	- 0.05
5752404	Trinity Group	1971-1993	+ 34.00	+ 1.55
5752606	Trinity Group	1941-1968	- 3.77	- 0.14
5752804	Trinity Group	1941-1990	- 55.36	- 1.13
5753205	Trinity Group	1941-1968	- 5.18	- 0.19
5753206	Trinity Group	1941-1968	- 0.71	- 0.03
5753211	Trinity Group	1941-1968	+ 11.02	+ 0.41
5753212	Trinity Group	1941-1968	- 0.96	- 0.04
5753301	Trinity Group	1941-1968	+ 24.38	+ 0.90
5753305	Trinity Group	1968-2000	- 2.18	- 0.07
5753506	Trinity Group	1941-1968	- 3.10	- 0.11
5753510	Trinity Group	1941-1961	+ 5.90	+ 0.30
5753603	Trinity Group	1938-1968	+ 21.71	+ 0.72
5754409	Trinity Group	1938-1968	- 3.01	- 0.10
5754602	Trinity Group	1938-1968	+ 1.67	+ 0.06

TABLE 3-5 (Cont'd)

State Well Number	Aquifer	Period	Decline (-) or Rise (+) (feet)	Rate of Change (feet/year)
5755101	Trinity Group	1968-1992	+ 10.40	+ 0.43
5738802	Ellenburger-San Saba	1938-1968	+ 16.84	+ 0.56
5738908	Ellenburger-San Saba	1938-1968	+ 3.01	+ 0.10
5744801	Ellenburger-San Saba	1941-1961	+ 0.48	+ 0.02
5744905	Ellenburger-San Saba	1941-1968	- 7.10	- 0.26
5745604	Ellenburger-San Saba	1941-1968	+ 0.12	+ 0.00
5745711	Ellenburger-San Saba	1941-1968	+ 3.27	+ 0.12
5745806	Ellenburger-San Saba	1941-1968	- 9.04	- 0.33
5745903	Ellenburger-San Saba	1938-1989	- 2.84	- 0.06
5746306	Ellenburger-San Saba	1938-1968	+ 16.03	+ 0.53
5746403	Ellenburger-San Saba	1938-1968	- 12.05	- 0.40
5746701	Ellenburger-San Saba	1938-2000	- 7.70	- 0.12
5750101	Ellenburger-San Saba	1939-1999	+ 14.54	+ 0.24
5750103	Ellenburger-San Saba	1935-1963	- 0.41	- 0.01
5750106	Ellenburger-San Saba	1979-1999	- 35.24	- 1.76
5750107	Ellenburger-San Saba	1977-1999	- 23.80	- 1.08
5750205	Ellenburger-San Saba	1974-1999	- 28.07	- 1.12
5750227	Ellenburger-San Saba	1978-1999	- 12.13	- 0.58
5750303	Ellenburger-San Saba	1956-1987	- 17.40	- 0.56
5751404	Ellenburger-San Saba	1979-1999	- 7.68	- 0.38
5753302	Ellenburger-San Saba	1968-2000	- 6.90	- 0.22
5656601	Hickory	1974-1999	+ 2.25	+ 0.09
5736803	Hickory	1941-1968	- 3.00	- 0.11
5741301	Hickory	1962-1989	- 66.46	- 2.46
5742101	Hickory	1953-1989	- 104.86	- 2.91
5742303	Hickory	1969-1999	+ 1.85	+ 0.06
5742304	Hickory	1969-1999	+ 0.60	+ 0.02
5742305	Hickory	1969-1999	- 22.40	- 0.75
5742306	Hickory	1974-1999	- 5.77	- 0.23
5742502	Hickory	1962-1999	- 31.74	- 0.86
5745101	Hickory	1968-1999	- 1.73	- 0.06
5745110	Hickory	1941-1968	+ 0.47	+ 0.02
5745113	Hickory	1941-1968	+ 1.51	+ 0.06

Total number of wells: 76
- 44 Trinity Group
- 20 Ellenburger-San Saba
- 12 Hickory

Number of wells declining: 42
- 22 Trinity Group; average decline per well = 8.0 feet
- 13 Ellenburger-San Saba; average decline per well = 13.1 feet
- 7 Hickory; average decline per well = 33.7 feet

Number of wells unchanged or increasing: 34
- 22 Trinity Group; average gain per well = 15.9 feet
- 7 Ellenburger-San Saba; average gain per well = 7.8 feet
- 5 Hickory; average gain per well = 1.5 feet

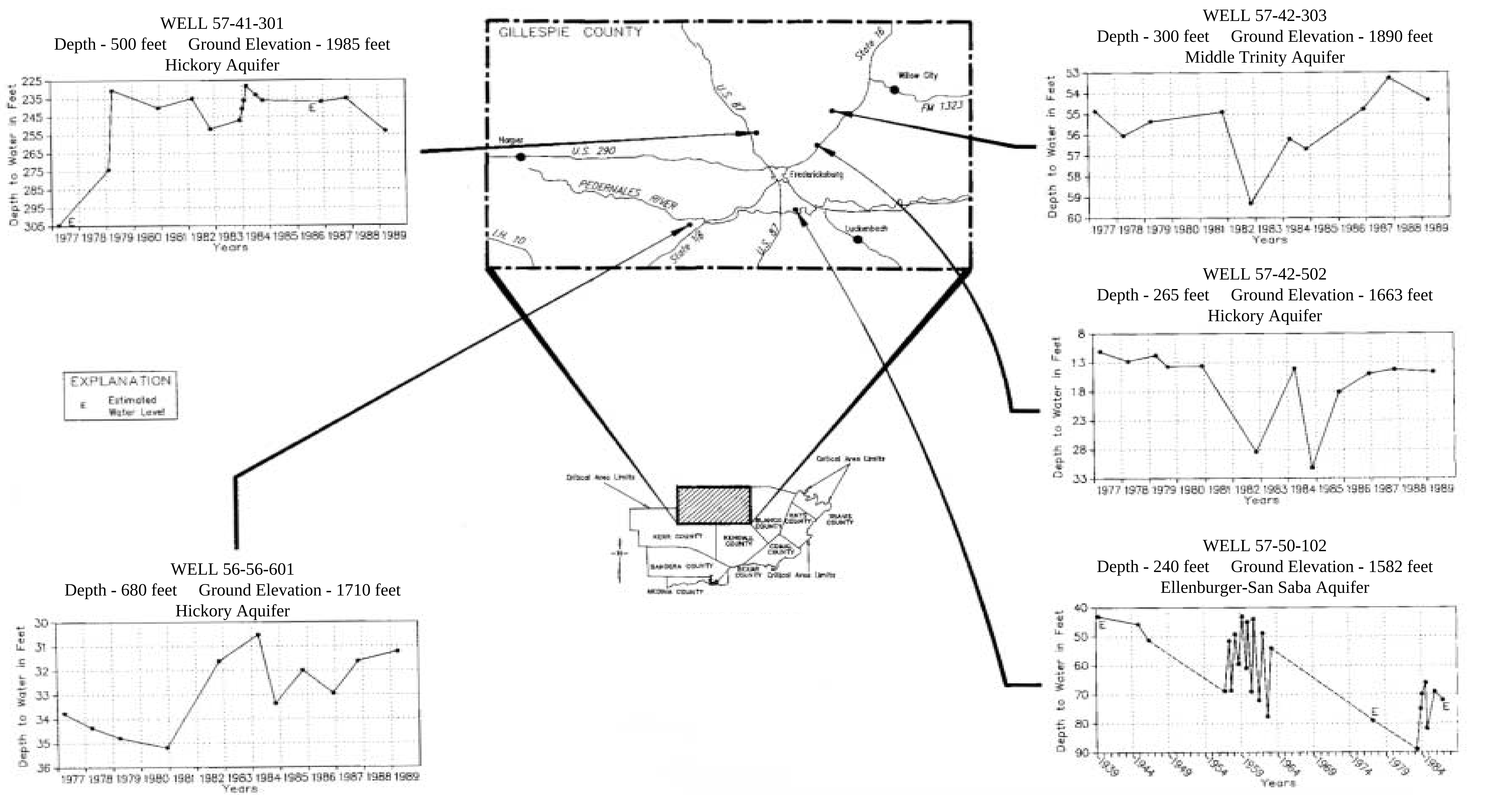


Figure 3-15

HYDROGRAPHS OF WATER LEVELS IN SELECTED WELLS, GILLESPIE COUNTY

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY

Source : Bluntzer, 1992

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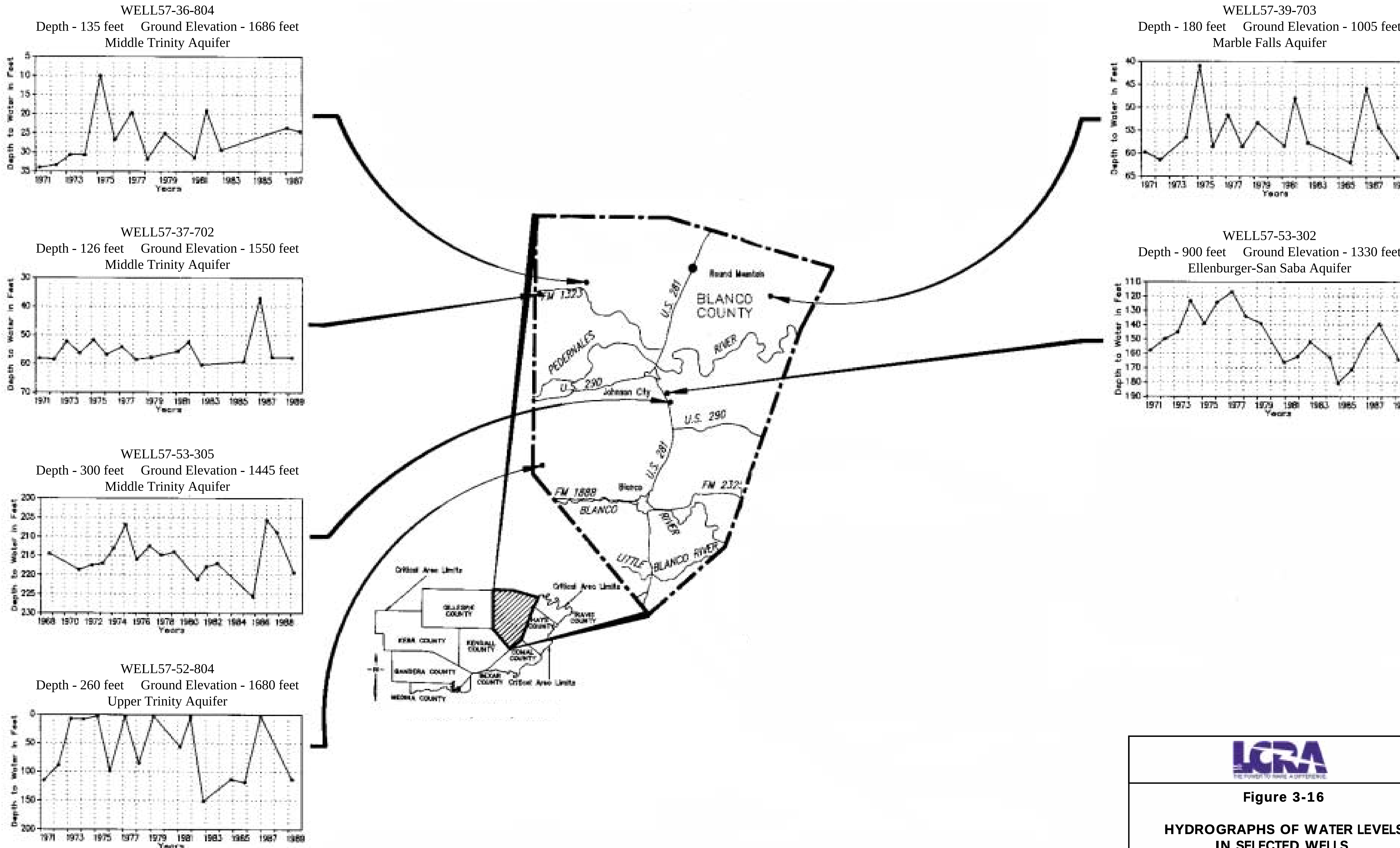

Source : Bluntzer, 1992

Figure 3-16

HYDROGRAPHS OF WATER LEVELS IN SELECTED WELLS, BLANCO COUNTY

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY

m:/hq1/projects/440700/cad/figure3-16.ai

3.3 GEOLOGICAL CONSIDERATIONS

Geologic units at the surface within the study area are delineated on the geologic map in Figure 3-17. The tributaries that form the Pedernales River are on the Cretaceous-age Edwards Formation, Glen Rose Formation, and the Hensell Sand Member of the Travis Peak Formation. Several Paleozoic rock units that normally underlie the Cretaceous formations are exposed at the surface north of the Pedernales River in the east-central part of the watershed. Quaternary alluvium, derived from locally eroded limestones and other surface rocks, occurs along or near the Pedernales River and many of its tributaries. The thin alluvium consists of gravel, sand, silt and clay and is present as narrow belts and discontinuous patches that form floodplain and terraces along the present streams.

The Pedernales River flows over the Hensell Sand Member from about 15 miles west of Fredericksburg to about the Gillespie - Blanco county line, where it encounters Paleozoic strata. In this area, the Pedernales is on the Ordovician age Honeycut, Gorman, and Tanyard formations and the Cambrian age San Saba, Point Peak, Morgan Creek Limestone, and Welge Sandstone members of the Wilberns Formation and the Lion Mountain Sandstone and Cap Mountain Limestone members of the Riley Formation. Along the southeastern edge of the Llano Uplift, the river flows over the Pennsylvanian age Marble Falls Formation. Farther east, and to its confluence with the Colorado River, the Pedernales River again flows over Cretaceous units including the Hensell Sand, Cow Creek Limestone, and Hammett Shale members of the Travis Peak Formation

Table 3-6 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. From oldest to youngest, rocks of Cambrian, Ordovician, Pennsylvanian, and Cretaceous age are present within the study area. Stratigraphic units underlying the study area are composed largely of limestone, dolomite, chalk, shale, sand and clay. Precambrian granites are north of the study area within northern Gillespie and Blanco counties. Geological cross sections that illustrate the subsurface geology within the watershed are presented in figures 3-18, 3-19, and 3-20.

Cretaceous rocks within the western portion of the study area generally dip gently to the south at approximately 10 to 15 feet per mile, with localized increases in dip associated with beds lapping onto the structurally high pre-Cretaceous rocks associated with the Llano Uplift (Ashworth, 1983). The pre-Cretaceous rocks that unconformably underlie the lower Cretaceous rocks and flank the southern portion of the Llano Uplift have much greater dips, ranging from 400 to 900 feet per mile to the south and southeast (Bluntzer, 1992).

3.4 EXISTING SURFACE WATER HYDROLOGY

The hydrologic characteristics of the Pedernales River are closely linked to precipitation patterns in the river basin, 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. Stream flow measurements began in the river basin in 1939, and the data show there has been a significant or major drought in almost every decade since then. Average monthly flows range from about 400 cfs in May and June to about 125 cfs in July and August. The Pedernales River and its tributaries have generally steep narrow channels with rocky soils and sparse vegetative cover. During intense rain events, this allows for rapid runoff, resulting in sharp-crested floods with high peak discharges and velocities. Annual discharge and low-flow information has been presented in Section 3.2.2 (Hydrological History) of this report. The average annual runoff from 1940 to 1993 was 138,451 acre-feet at Johnson City, and the median flow at that location was about 80 cfs.

From a point immediately upstream of the confluence of Fall Creek in Travis County to FM 385 in Kimble County, the Pedernales River is classified by the Texas Natural Resource Conservation Commission (TNRCC) as suitable for contact recreation, aquatic life, and public water supply. Overall, the quality of the water in the river is high and supports a diversity of aquatic life. Surrounding vegetation is [COMMENT10]characteristic of the Live Oak-Ashe Juniper parks and Live Oak-Mesquite-Ashe Juniper parks vegetation communities (Section 3.2.1). The river is spring-fed and free flowing, with many limestone outcrops. The National Park Service identified the segment for inclusion in the National Rivers Inventory based on the degree to which the river is free flowing, the degree to which the river and corridor are undeveloped, and the outstanding natural and cultural characteristics of the river and its immediate environment. Bald cypress, red columbine, and native orchids are found beside the river. Among the fish species in the stream is the Guadalupe bass (Micropterus treculi). Other aquatic species typical of Hill Country spring-fed streams also inhabit the Pedernales River. Along the river are several parks including Pedernales Falls State Park, LBJ State Park, LBJ National Park, and Stonewall Park. The Lower Colorado River Water Planning Group (LCRWPG) has recommended that most of the Pedernales River warrants study and possible designation as ecologically unique based on its biologic function and exceptional aesthetic value (LCRWPG, 2000).

The primary water quality issue for the river is the increasing potential for water contamination from nonpoint-source pollution. Nonpoint 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 nonpoint 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 nonpoint pollution, as are the habitats of threatened and endangered species that live in and near springs and certain stream segments (TNRCC, 1996).

3.5 EXISTING GROUNDWATER HYDROLOGY

The important Cretaceous aquifers within the study area include, from oldest to youngest, the Lower Trinity, Middle Trinity, Upper Trinity, and Edwards aquifers. The recharge areas for these aquifers occur within their outcrops in Gillespie, Blanco, Hays, and Travis counties. Stratigraphic units that make up the Lower Trinity aquifer include, in ascending order, the Hosston and Sligo members of the Travis Peak Formation (Table 3-6). The Lower Trinity does not outcrop within the study area and is likely not present within the watershed in most of Gillespie and Blanco counties. When present, the Lower Trinity aquifer consists of only the Hosston Member and is composed of pebbly, sandy conglomerate grading upwards into fine to coarse-grained sand and sandstone. Clays and shales are interbedded and gradational both laterally and vertically.

The Middle Trinity aquifer consists of, from oldest to youngest, the Crow Creek Limestone and Hensell Sand members of the Travis Peak Formation, and the lower member of the Glen Rose Formation. The Middle Trinity aquifer outcrops extensively within the study area, with the Hensell Sand present at the surface throughout much of the watershed. The Hensell is composed of conglomerate, sandstone, silt, clay and shale. Within its outcrop area along the Pedernales River in Gillespie and Blanco counties, the Hensell rests unconformably on faulted pre-Cretaceous rocks (Ashworth, 1983). The lower member of the Glen Rose Formation is found within the eastern portion of the Pedernales River watershed and consists of massive, fossiliferous limestone at its base grading to dolomite, marl, and shale. Within the study area, approximately 30 percent of the water wells in Gillespie County and 35 percent of the wells in Blanco County draw water from the Middle Trinity aquifer.

Within the study area, the Upper Trinity aquifer consists of the upper member of the Glen Rose Formation. The Upper Trinity is exposed at the surface throughout the watershed at higher elevations within the river valley. The upper member of the Glen Rose Formation consists of shale and marl alternating with thin beds of limestone and dolomite. In Gillespie County, where the lower member has pinched out, the upper member thins rapidly by grading laterally into the underlying Hensell Sand and eventually pinches out north of the Pedernales River (Ashworth, 1983). Approximately 14 percent of the water wells in the Pedernales River watershed in Blanco County are completed in the Upper Trinity aquifer.

The Edwards aquifer within the study area consists of the Segovia and Fort Terrett members of the Edwards Formation. The aquifer is present in the watershed only within Gillespie County and is exposed north and south of the watershed as outliers capping ridges and hills in Blanco County. The Segovia and Fort Terrett members consist of brecciated limestone, cherty limestone, dolomite, and fossiliferous clay. Approximately 19 percent of the water

wells within the Pedernales River watershed in Gillespie County are completed in the Edwards Aquifer.

Paleozoic aquifers within the study area include, from oldest to youngest, the Hickory, Mid-Cambrian, Ellenburger-San Saba, and Marble Falls aquifers. These aquifers are important water bearing units mainly in the part of the watershed nearest the Llano Uplift. The recharge areas for these aquifers occur within their outcrop areas associated with the Llano Uplift in Gillespie and Blanco counties.

The Hickory Aquifer consists of conglomerate and sandstone of the Hickory Member of the Cambrian age Riley Formation. The Mid-Cambrian aquifer consists of the sandstones of the Lion Mountain Member of the Riley Formation and the overlying Weldge Member of the Wilbern Formation. Limestones and dolomites of the San Saba Member of the Cambrian age Wilberns Formation and Ordovician age Ellenburger Group (Tanyard, Gorman, and Honeycut formations) make up the Ellenburger-San Saba Aquifer. The Marble Falls Aquifer consists of limestones of the upper and lower units of the Pennsylvanian-age Marble Falls Formation. Within the Pedernales River watershed in Gillespie and Blanco counties, approximately 9 percent of the water wells draw water from the Hickory Aquifer, 4 percent of the wells from the Mid-Cambrian Aquifer, and 34 percent of the wells from the Ellenburger-San Saba Aquifer.

The primary source of the recharge to the Cretaceous and Paleozoic aquifers is precipitation in outcrop areas and seepage from surface water bodies. The Upper and Middle Trinity aquifers crop out over most of the watershed, and these aquifers receive the greatest amount of direct recharge. The Paleozoic aquifers receive a comparatively small amount of direct recharge due to the limited extent of their outcrops in the watershed. The Cretaceous and Paleozoic aquifers are commonly connected hydraulically, and downward movement of groundwater from water-bearing units exposed at the surface accounts for recharge to underlying aquifers that do not crop out widely in the study area (Bluntzer, 1992).

Groundwater in the Cretaceous and Paleozoic 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, structural dip of the rock units comprising the aquifer, and faults and fractures. Groundwater withdrawals also can influence the rate and direction of the natural groundwater movement by affecting the local hydraulic gradient. Regional groundwater movement in the Paleozoic aquifers is likely southward and southeastward along the dip of the aquifers (Bluntzer, 1992). Within the Pedernales watershed in Gillespie and Blanco counties, a significant portion of groundwater probably moves from the Paleozoic aquifers into the Middle Trinity aquifer and discharges at approximately right angles into the Pedernales River and its tributaries (Bluntzer, 1992). Regional groundwater movement within the Cretaceous aquifers is generally to the south, southeast, and east (Ashworth, 1983). However, within the watershed, local groundwater movement in these aquifers also is toward the Pedernales River.

Groundwater in the Cretaceous and Paleozoic aquifers is discharged naturally through springs, by channel seeps associated with base flow of effluent streams, by subsurface underflow, and by evapotranspiration. Some prominent springs within the Pedernales watershed are described in Section 3.2.2. Although some recharge of underlying aquifers comes from streams, most streams within the watershed show increases in base flow in the downstream direction, indicating that groundwater is moving from the aquifer to the streams. The Pedernales River receives its base flow from groundwater that is naturally discharged from aquifers near the surface (Bluntzer, 1992). Much of the initial flow in the Pedernales River comes from springs and seeps derived from the dissected Edward and Trinity aquifers. The Pedernales River generally gains in flow from headwater springs issuing from the base of the Edwards aquifer on its main stem and along some tributaries, contributions from the Middle Trinity aquifer through its tributaries and seepage into alluvium, to springs and seeps originating from Cretaceous and Paleozoic aquifers along its lower reaches (Preston, et al., 1996). Losses in base flow are principally due to evaporation and withdrawals for irrigation.

Annual groundwater discharge can vary considerably depending on the amount, frequency, and distribution of rainfall (i.e., recharge). Groundwater elevations, storage, and natural discharge increase during periods of high recharge. Conversely, during periods of low recharge, groundwater elevations decline, groundwater storage is reduced, and natural discharge decreases. When groundwater levels intercept the land surface, groundwater can discharge at seeps and

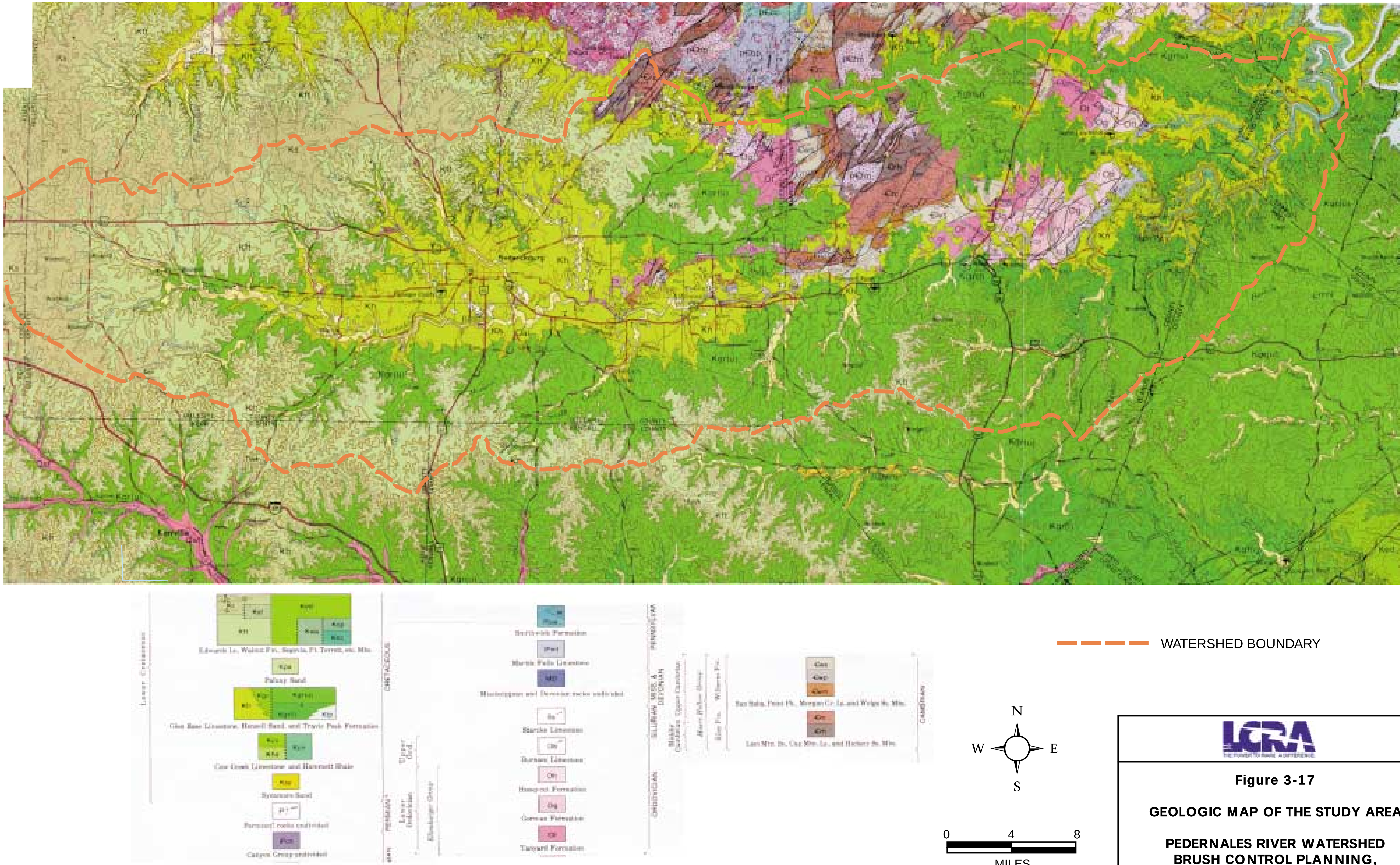

Figure 3-17

GEOLOGIC MAP OF THE STUDY AREA

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY

Source : Bureau of Economic Geology, 1981

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TABLE 3-6

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES, PEDERNALES RIVER WATERSHED

System	Group	Formation	Member	Hydrologic Unit	Lithology	Water-Bearing Properties
Cretaceous	Fredericksburg Group	Edwards Formation	Segovia Member	Edwards Aquifer	Cherty limestone, dolomite, marl, and clay	Yields small to moderate quantities of fresh water. Confining bed of clay at base is not known to yield water.
			Fort Terrett Member			
	Trinity Group	Glen Rose Formation	Upper Member	Upper Trinity Aquifer	Alternating beds of limestone, dolomite, shale, and marl.	Yields very small to small quantities of fresh to moderately saline water.
			Lower Member	Middle Trinity Aquifer	Massive limestone and dolomite in basal part grading upwards into beds of limestone, shale, and marl.	Yields very small to large quantities of fresh to moderately saline water.
		Travis Peak Formation	Hensell Sand Member		Sand, gravel, conglomerate, sandstone, siltstone and shale .	
			CowCreek Limestone Member		Massive, sandy, dolomitic limestone.	
			Hammett Member	Confining Bed	Shale and clay with some sand and dolomitic limestone.	Not known to yield significant amounts of water.
			Sligo Member	Lower Trinity Aquifer	Limestone, dolomite, and shale	Yields small to moderate quantities of fresh to moderately saline water.
			Hosston Member		Basal conglomerate grading upward into a mixture of sand, siltstone, and shale with some limestone beds.	

TABLE 3-6 (Cont'd)

System	Group	Formation	Member	Hydrologic Unit	Lithology	Water-Bearing Properties
Pennsylvanian	Canyon Group	Not Differentiated	Not Differentiated	Confining Beds	Limestone, shale, and fine grained sandstone.	Not known to yield significant amounts of water.
	Bend Group	Smithwick Formation	Not Differentiated		Claystone, siltsone, and sandstone.	
		Marble Falls Formation	Upper Unit	Marble Falls Aquifer	Cherty limestone.	Yields very small to moderate quantities of fresh to slightly saline water.
			Lower Unit		Massive limestone grading to shale at base.	
Ordovician	Ellenburger Group	Honeycut Formation	Not Differentiated	Ellenburger - San Saba Aquifer	Cherty limestone and dolomite.	Yields very small to large quantities of fresh to slightly saline water.
		Gorman Formation	Not Differentiated		Upper part predominantly limestone grading to dolomite in lower part.	
		Tanyard Formation	Staendebach Member		Cherty limestone and dolomite.	
			Threadgill Member		Dolomite and massive limestone.	
Cambrian	Moore Hollow Group	Wilberns Formation	San Saba Member		Cherty dolomite.	
			Point Peak Member	Confining Beds	Siltstone with some limestone and shale	Not known to yield significant amounts of water.
			Morgan Creek Member		Fossiliferous limestone.	
			Welge Member	Mid - Cambrian Aquifer	Thickly bedded sandstone.	Yields very small to moderate quantities of mainly fresh water.
		Riley Formation	Lion Mountain Member		Sandstone and limestone with some shale and siltstone.	
			Cap Mountain Member	Confining Bed	Limestone and siltstone grading to sandstone at base.	Not known to yield significant amounts of water.
			Hickory Member	Hickory Aquifer	Sandstone with pebble conglomerate at base.	Yields small to large quantities of fresh to slightly saline water.

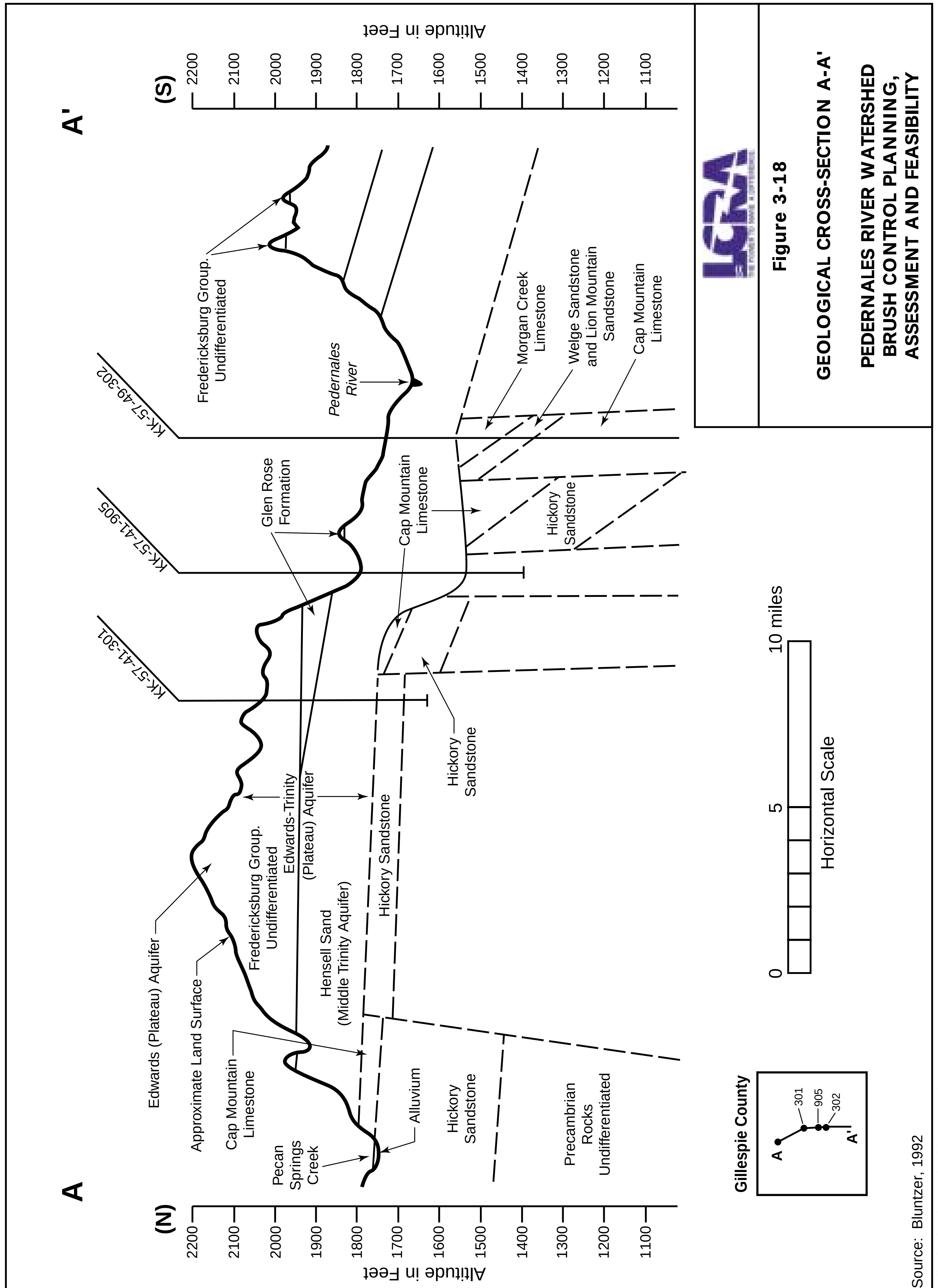


Figure 3-18

GEOLOGICAL CROSS-SECTION A-A'

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY

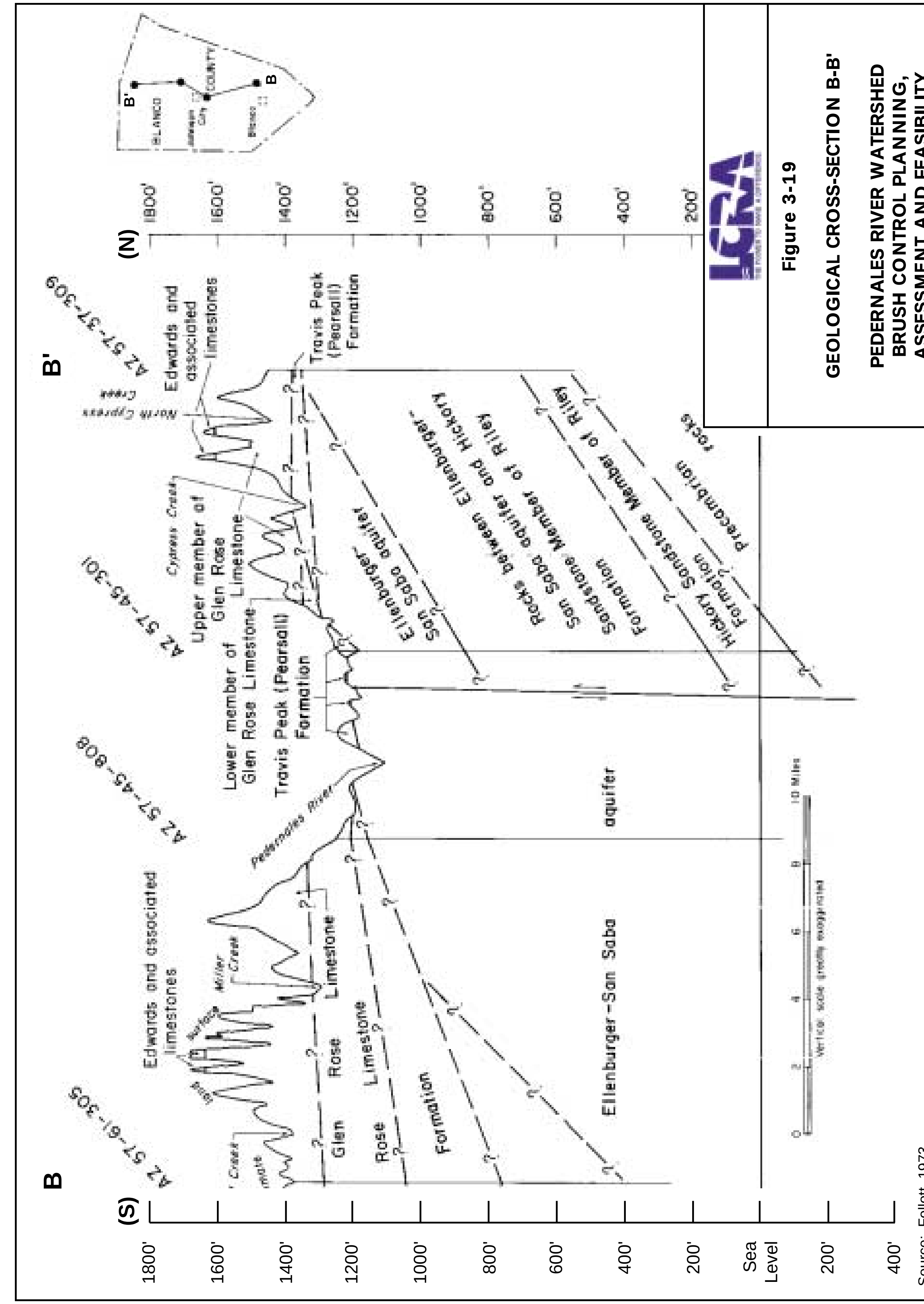
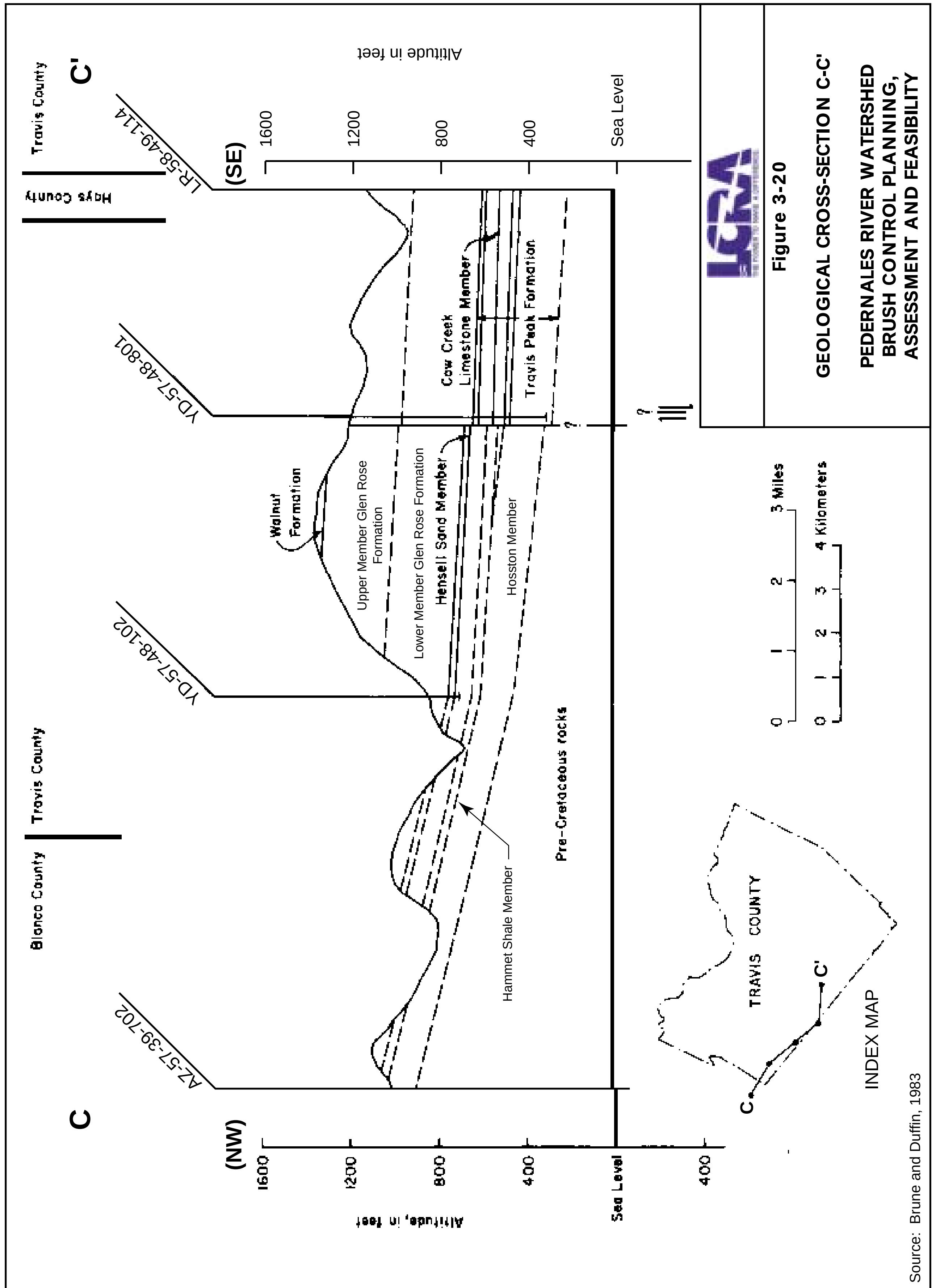


Figure 3-19

GEOLOGICAL CROSS-SECTION B-B'

PEDERNALES RIVER WATERSHED BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY



springs and become surface runoff. Downgradient of the springs and seeps, runoff can recharge alluvium deposits. Groundwater discharge to the Pedernales River also occurs from point springs and diffuse seepage.

Artificial discharge of groundwater is by water wells in the region. Figure 3-21 presents a location map of water wells within the Pedernales River watershed. The largest groundwater withdrawals from the Cretaceous and Paleozoic aquifers within the watershed are by the cities of Fredericksburg and Johnson City. Fredericksburg withdraws groundwater from the Hickory, Ellenburger-San Saba, and Middle Trinity aquifers. Johnson City uses groundwater mainly from the Ellenburger-San Saba aquifer. Significant amounts of groundwater are withdrawn from the Cretaceous and Paleozoic aquifers throughout the watershed for use by rural residential subdivisions, unincorporated communities, and individuals for domestic, irrigation and livestock use.

3.6 DESCRIPTION OF THE WATERSHED HYDROLOGIC SYSTEM

The hydrologic system of the Pedernales River 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 the Pedernales River drainage system 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. The Pedernales River receives its base flow from groundwater that is naturally discharged from the near surface aquifers (Bluntzer, 1992). Much of the initial flow in the Pedernales River comes from springs and seeps derived from the dissected Edward and Trinity aquifers. The Pedernales River generally gains in flow from headwater springs issuing from the base of the Edwards aquifer on its main stem and along some tributaries, contributions from the Middle Trinity aquifer through its tributaries and seepage into alluvium, to springs and seeps originating from Cretaceous and Paleozoic aquifers along its lower reaches (Preston, et al., 1996). Losses in base flow are principally due to evaporation and irrigation withdrawals. Discharge from the system occurs as stream flow crossing the downstream boundary of the watershed, as artificial surface water and groundwater withdrawals, as groundwater flow crossing the downgradient boundary of the watershed, and as returns to the atmosphere through evapotranspiration.

Gillespie and Blanco counties are part of the Lower Colorado Regional Water Planning Area (LCRWPG, 2000) that all or part of 14 counties, mostly within the river basin, between the Hill Country and the Gulf of Mexico. The planning region's population now consumes about 1.1 million acre-feet of water each year, with 72 percent used for agricultural and livestock, 14 percent put to municipal use, 6 percent devoted to mining and manufacturing, and the remaining 8 percent to electric power (LCRWPG, 2000). Water demand in the region is expected to increase approximately 300,000 acre-feet per year by 2030. Currently developed groundwater, surface water, reclaimed water and other water supplies now provided through contractual agreements or operation of the existing system of reservoirs on the Colorado River will not be adequate to meet the projected needs in all parts of the region. Most of the water demand is downstream of the Perdernales River's confluence with the Colorado River in western Travis County. About 75 percent of the region's population of approximately 1 million is currently concentrated in the rapidly growing Austin metropolitan area, which includes parts of Williamson and Hays counties. By 2050, the population of the region as a whole is projected to double.

Approximate current and future water demands in the study area were estimated using demand projections made by TWDB for Blanco and Gillespie counties, exclusive of the city of Blanco. The estimated demands of different water user groups are presented in Table 3-7. Municipal (i.e., residential and commercial) water demands in Gillespie County are dependent on groundwater supplies, and areas outside the city of Fredericksburg are expected to experience a water shortage under current use conditions during a severe drought (LCRWPG, 2000). The projected municipal water deficit for the rural area of Gillespie County is as follows:

Year	Deficit (acre-feet)
2000	507
2010	547
2020	617
2030	677
2040	887
2050	1,013

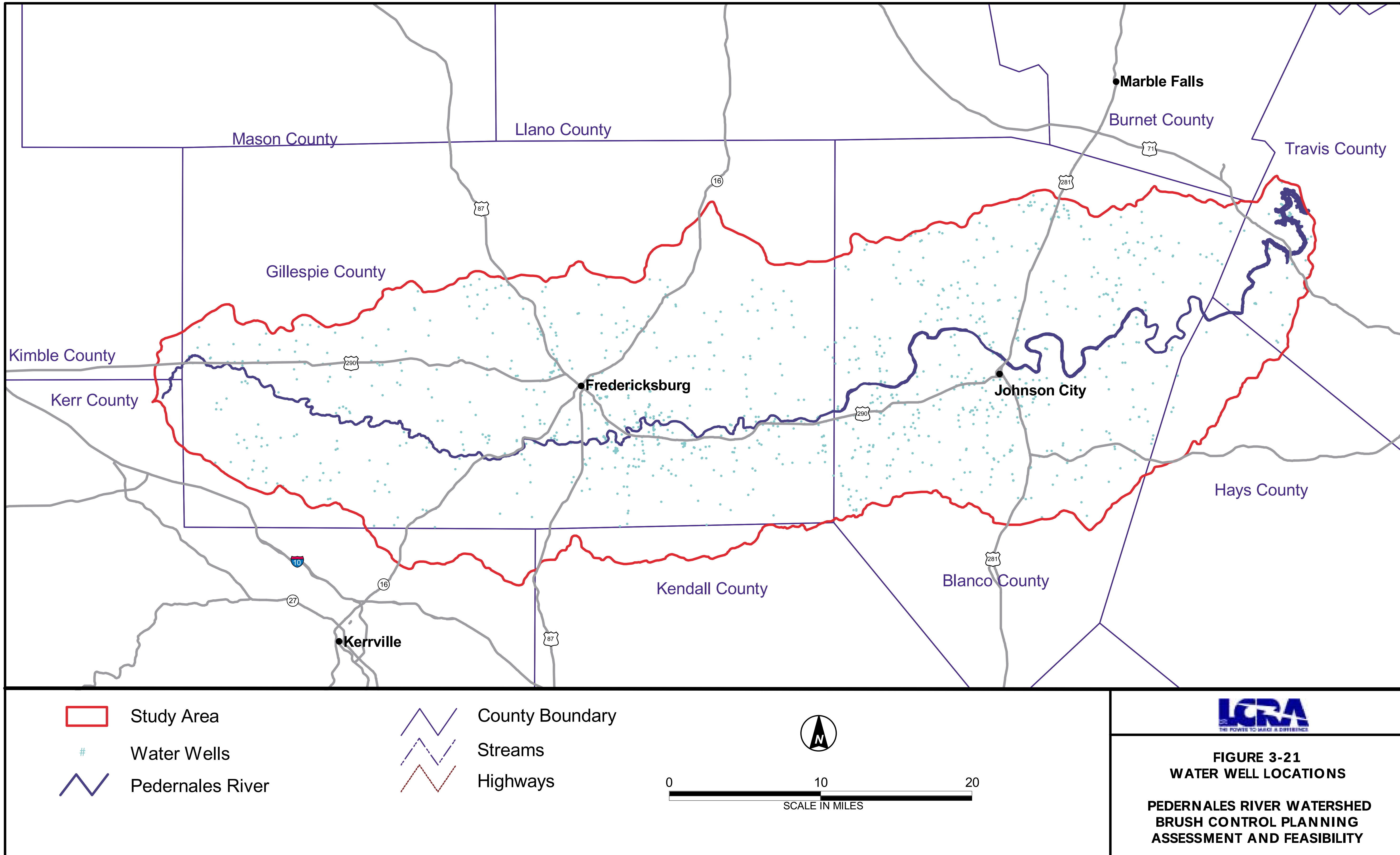


FIGURE 3-21
WATER WELL LOCATIONS

PEDERNALES RIVER WATERSHED
BRUSH CONTROL PLANNING
ASSESSMENT AND FEASIBILITY

TABLE 3-7

CURRENT AND FUTURE WATER DEMAND IN GILLESPIE AND BLANCO COUNTIES

Water Demand Category	Annual Water Demand (acre-feet)						
	1990	2000	2010	2020	2030	2040	2050
Blanco County							
Municipal (Excluding City of Blanco)	677	985	1,130	1,285	1,424	1,482	1,493
Irrigation	483	458	435	413	392	362	353
Livestock	553	670	670	670	670	670	670
Mining	-	13	9	5	1	-	-
Manufacturing	-	-	-	-	-	-	-
Total	1,713	2,126	2,244	2,373	2,487	2,514	2,516
Gillespie County							
Municipal	3,154	4,130	4,259	4,487	4,675	5,268	5,768
Irrigation	2,000	1,184	1,169	1,154	1,139	1,124	1,110
Livestock	1,056	1,294	1,294	1,294	1,294	1,294	1,294
Mining	14	5	3	1	-	-	-
Manufacturing	451	502	556	608	657	727	795
Total	6,675	7,115	7,281	7,544	7,765	8,413	8,967
Total							
Municipal	3,831	5,115	5,389	5,772	6,099	6,750	7,261
Irrigation	2,483	1,642	1,604	1,567	1,531	1,486	1,463
Livestock	1,609	1,964	1,964	1,964	1,964	1,964	1,964
Mining	14	18	12	6	1	-	-
Manufacturing	451	502	556	608	657	727	795
Grand Total	8,388	9,241	9,525	9,917	10,252	10,927	11,483

Municipal category includes residential and commercial use
Source: Texas Water Development Board

As the demand for water increases in the area, the city of Fredericksburg may experience water supply problems due to competition for water. The Hill Country Undergroud Water Conservation District understands the importance of water conservation efforts and intends to pursue these efforts. The regional water plan for addressing this shortage is based on the approved Water Management Plan for the Hill Country Underground Water Conservation District and includes the following alternatives.

- **Aquifer Storage and Recovery (ASR)** — This alternative would entail constructing a raw water intake structure and pump station on the Pedernales River (the use of shallow alluvial wells near the river is also being evaluated), a surface water treatment plant, transmission pipelines, and an ASR well. The LCRA completed a Phase 1 study for a small system with a capacity of 1,120 acre-feet per year. The anticipated capital expenditure necessary to implement a system this size is $8 million. The expected annual expenditures would be $900,000 including $350,000 for operations and maintenance. The anticipated unit cost of water for this alternative is $839 per acre-foot. The Hill Country Underground Water Conservation District intends to conduct more studies of this alternative, including the ability to increase the capacity of the system.

- **Development of Additional Groundwater Resources** — As additional subdivisions are developed in the county, these subdivisions would drill additional wells to meet their demands. Depending upon where the subdivisions are developed, the aquifer may be depleted in certain areas of the county. When this occurs, it is anticipated that development will move to areas of the county with remaining groundwater, or groundwater from other areas of the county will be piped to the location of new subdivisions. Since the location of new subdivisions and their relative density cannot be predicted, it is not feasible to develop an opinion of probable costs for the development of additional groundwater resources.

3.7 SUMMARY AND CONCLUSIONS

This evaluation of the hydrology of the Pedernales River 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:

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

2. Changes in the historical vegetation of the watershed have not been dramatic. Based on first-hand accounts of the vegetation during the 18th and 19th centuries, the area most likely was predominantly woodland stands of juniper and oak, with prairies and grassy areas common throughout the region. There is no clear indication that brush or tree cover in the watershed is significantly more extensive today than it was historically.

3. Good quality data on stream flow have been collected from the USGS gauging station on the Pedernales River at Johnson City continuously since 1939 (i.e., 61 years). Continuous flow data is available for the USGS stream gauge at Fredericksburg from 1979 to present (i.e., 21 years).

4. The available stream flow data show that no major changes have occurred in stream characteristics during the period of record.

5. 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 is indicated, except for the Hickory aquifer.

6. The Pedernales River is naturally a "gaining" stream (i.e., flow increases downstream). The river generally gains flow by the discharge of groundwater to the river. Groundwater contributions come from headwater springs issuing from the base of the Edwards aquifer on its main stem and along some tributaries, the Middle Trinity aquifer through its tributaries and seepage into alluvium, and from springs and seeps originating from Cretaceous and Paleozoic aquifers.

7. Soils formed on Cretaceous and Paleozoic rock units exposed on the upper and lower slopes of the river valley are typically thin, rocky, and generally conducive to groundwater recharge. Soils across the valley bottom are generally thicker and less conducive to groundwater recharge.

8. Water supply shortages are projected to occur in the basin because of increased water demand. groundwater availability in rural areas of Gillespie County is a particular concern. Brush management could help offset supply deficits. 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 the year 2000 to 1.4 million acre-feet in the year 2050.

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ABOUT THE LCRA

The Lower Colorado River Authority is a nonprofit government entity created by the Texas Legislature in 1934 and dedicated to providing public services to the people of Texas. The LCRA cannot levy taxes, but gets its income to fund its operations from the sale of electricity, water and other services.

The LCRA sells wholesale electricity to city-owned utilities and cooperatives that serve more than 1 million people in Texas. The LCRA also sells stored water; develops and operates water and wastewater utilities; manages the lower Colorado River; protects water quality; owns and operates parks; promotes conservation of soil, water and energy; and offers economic and community development assistance to rural communities.

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APPENDIX 1

BRUSH / WATER YIELD FEASIBILITY STUDIES

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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 8 watersheds in Texas for 1960 through 1998. Landsat7 satellite imagery was used to classify land use, and the 1:24,000 scale digital elevation model (DEM) was used to delineate the watershed boundaries and subbasins. After calibration of SWAT to existing stream gauges, brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Treatment or removal of light brush was not simulated. Results of brush treatment in all watersheds are presented. Water yield (surface runoff and base flow) varied by subbasin, but all subbasins showed an increase in water yield as a result of removing brush. Economic and wildlife habitat considerations will impact actual amounts of brush removed.

BACKGROUND

Recent droughts in Texas have brought attention to the critical need for increasing water supplies in some water-short locations, especially the western portion of the state. Increases in brush area and density may contribute to a decrease in stream flow, possibly due to increased evapotranspiration (ET) (Thurow, 1998; Dugas et al., 1998). A modeling study of the North Concho River watershed (Upper Colorado River Authority, 1998) indicates that removing brush may result in a significant increase in water yield.

During the 1998-99 legislative session, the Texas Legislature appropriated funds to study the effects of brush removal on water yield in eight watersheds in Texas. These watersheds are: Canadian River above Lake Meredith, Wichita River above Lake Kemp, Upper Colorado River above Lake Ivie, Concho River, Pedernales River, watersheds above the Edwards Aquifer, Frio River above Choke Canyon Reservoir, and Nueces River above Choke Canyon. The feasibility studies were conducted by a team from the Texas Agricultural Experiment Station (TAES), Texas Agricultural Extension Service (TAEX), U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), and the Texas State Soil and Water Conservation Board (TSSWCB). The goals of the study were:

1. Predict the effects of brush removal or treatment on water yield in each watershed.
2. Prioritize areas within each watershed relative to their potential for increasing water yield.
3. Determine the benefit/cost of applying brush management practices in each watershed.
4. Determine effects of brush management on livestock production and wildlife habitat.

This report will only address the first two.

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-Agricultural Research Service (ARS), including development of CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985; Arnold et al., 1990), and ROTO (Arnold et al., 1995).

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. To satisfy the objective, the model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. SWAT allows a basin to be divided into hundreds or thousands of grid cells or sub-watersheds.

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 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, 1993) 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.

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.

Topography. The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of a watershed as a topographical database. The DEM available for the project area is the 1:24,000 scale map (U.S. Geological Survey, 1999). The resolution of the DEM is 30 meters, allowing detailed delineation of subbasins within each watershed. Some of the 8 watersheds designated for study were further sub-divided for ease of simulation. The location and boundaries of the watersheds are shown in Figure 1.

The number of subbasins delineated in each watershed varied because of size and methods used for delineation, and ranged from 5 to 312 (Table 1).

Table 1. Subbasin Delineation

WATERSHED	NUMBER OF SUBBASINS
Canadian River	312
Edwards-Frio	23
Edwards-Medina	25
Edwards-Hondo	5
Edwards-Sabinal	11
Edwards-Seco	13
Frio (Below Edwards)	70
Main Concho	37
Nueces (Above Edwards)	18
Nueces (Below Edwards)	95
Pedernales	35
Twin Buttes/Nasworthy	82
Upper Colorado	71
Wichita	48

Climate. Daily precipitation totals were obtained for National Weather Service (NWS) stations within and adjacent to the watersheds. 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. The average annual precipitation for each watershed for the 1960 through 1998 period is shown in Figure 2.

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, dispersion, albedo, etc.).

The soils database used for this project was developed from three major sources from the NRCS (USDA-Natural Resources Conservation Service):

1. The majority of the information was a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. This database was known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display

System (MIADS) (Nichols, 1975) soils data. 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. This method of cell attribute labeling had the advantage of a more accurate measurement of the various soils in an area. The disadvantage was for any given cell the attribute of that cell may not reflect the soil that actually makes up the largest percentage of that cell.

2. The Soil Survey Geographic (SSURGO) was the most detailed soil database available. This 1:24,000-scale soils database was available as printed county soil surveys for over 90% of Texas counties. It was only currently available as a vector or high resolution cell data base at the inception of this project for a few counties in the project area. In the SSURGO database, each soil delineation (mapping unit) was described as a single soil series.

3. The soils data base currently available for all of the counties of Texas is the State Soil Geographic (STATSGO) 1:250,000-scale soils data base. The STATSGO database covers the entire United States and all STATSGO soils were defined in the same way. In the STATSGO database, each soil delineation of a STATSGO soil was a mapping unit made up of more than one soil series. Some STATSGO soils were made up of 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 the project area was a compilation of CBMS, SSURGO, and STATSGO information. The most detailed information was selected for each individual county and patched together to create the final soils layer. In the project area, approximately 2/3 of the soil data was derived from CBMS and the remainder was largely STATSGO data. Only a very small percentage was represented by SSURGO.

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

<u>Land Use/Land Cover</u>. Land use and cover affect surface erosion, water runoff, and ET in a watershed. The NRCS 1:24,000 scale CBMS land use/land cover database was the most detailed data presently available. However, for this project much more detail was needed in the rangeland category of land uses. The CBMS data did not identify varying densities of brush or species of brush – only the categories of open range versus brushy range.

Development of more 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 satellite carries an ETM+ instrument, which is an eight-band multi-spectral scanning radiometer capable of providing high-resolution image information of the Earth's surface. It detects spectrally-filtered radiation at visible, near-infrared, short-wave, and thermal infrared frequency bands (Table 2).

Table 2. Characteristics of Landsat-7

Band Number	**Spectral Range**(microns)	**Ground Resolution**(meters)
1	.45 to .515	30
2	.525 to .605	30
3	.63 to .690	30
4	.75 to .90	30
5	1.55 to 1.75	30
6	10.40 to 12.5	60
7	2.09 to 2.35	30
Pan	.52 to .90	15

Swath width:	185 kilometers
Repeat coverage interval:	16 days (233 orbits)
Altitude:	705 kilometers

Portions of eighteen Landsat-7 scenes were classified using ground truth points collected by NRCS field personnel. The Landsat-7 satellite images used a spectral resolution of six channels (the thermal band (6) and panchromatic band (Pan) were not used in the classification). The imagery was taken from July 5, 1999 through December 14, 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 with Gordon Wells, TNRIS).

Over 1,100 ground control points (GCP) were located and described by NRCS field personnel in November and December 1999. Rockwell precision lightweight 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, estimated canopy coverage, areal extent, and other pertinent information about each point. This database was converted into an ArcInfo™ point coverage.

ERDAS's Imagine™ was used for imagery classification. The Landsat-7 images were imported into Imagine (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.). These adjoining scenes were then mosaiced and trimmed into one image that covered an individual watershed.

The ArcInfo coverage of ground points was then employed to instruct the software to recognize differing land uses based on their spectral properties. Individual ground control points were "grown" into areas approximating the areal extent as reported by the data collector. 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 then performed with the spectral signatures for various land use classes. The ground data was used to perform an accuracy assessment of the resulting image. A sampling of the initial classification was further verified by NRCS field personnel.

The use of remote sensed data and the process of classifying it with ground truthing resulted in a current land use/land cover GIS map that includes more detailed divisions of land use/land cover. Although the vegetation classes varied slightly among all watersheds, the land use and cover was generally classified as follows:

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

The accuracy of the classified image was 70% - 80%. Table 3 summarizes land use/land cover categories for each watershed in the project area.

A small area of the USGS land use/land cover GIS layer was patched to the detailed land use/land cover map developed using remotely sensed data for the western-most (New Mexico) portion of the Upper Colorado River and Canadian River watersheds, which were not included in the satellite scenes for this study.

Table 3. Land Use and Percent Cover

Watershed	Percent Cover					
	Heavy & Mod. Brush (no oak)	Oak	Light Brush (no oak)	Open Range & Pastureland	Cropland	Other (Water Urban,Barren,etc)
Canadian *	69	0	4	5	18	4
Edwards-Frio	60	22	17	1	< 1	< 1
Edwards-Medina	56	24	18	1	1	< 1
Edwards-Hondo	59	24	15	1	1	< 1
Edwards-Sabinal	60	22	16	1	1	< 1
Edwards-Seco	65	24	10	1	< 1	< 1
Frio (Below Edwards)	58	17	18	1	5	1
Main Concho	40	5	19	10	26	< 1
Nueces (Above Edwards)	60	23	17	< 1	< 1	< 1
Nueces (Below Edwards)	62	17	19	< 1	1	< 1
Pedernales	25	50	7	16	1	1
Twin Buttes/Nasworthy *	57	2	31	5	3	2
Upper Colorado *	41	3	21	14	20	1
Wichita	63	4	15	9	7	2

* Percentage of watershed where brush removal was planned

Model Inputs

Required inputs for each subbasin (e.g. soils, land use/land cover, topography, and climate) were extracted and formatted using the SWAT/GRASS input interface. The input interface divided each subbasin into a maximum of 30 virtual subbasins or hydrologic response units (HRU). 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 5 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 was dependent on the number of subbasins and the variability of the land use and soils within the watershed. The soil properties for each of the selected soils were automatically extracted from the model-supported soils database.

Surface runoff was predicted using the SCS curve number equation (USDA-SCS, 1972). Higher curve numbers represent greater runoff potential. Curve numbers were selected assuming existing brush sites were fair hydrologic condition and existing open range and pasture sites with no brush were good hydrologic condition. The precipitation intercepted by canopy was based on field experimental work (Thurow and Taylor, 1995) and calibration of SWAT to measured stream flows. 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 were used in dry climates to account for moisture loss from deeper soil layers.

Shallow aquifer storage is water stored below the root zone. Ground water flow is not allowed until the depth of water in the shallow aquifer is equal to or greater than the input value. Shallow aquifer re-evaporation coefficient controls the amount of water which 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. The amount of re-evaporation is also controlled by setting the minimum depth of water in the shallow aquifer before re-evaporation is allowed. Shallow aquifer storage and re-evaporation inputs affect base flow.

Potential heat units (PHU) is the number of growing degree days needed to bring a plant to maturity and varies by latitude. PHU decreases as latitude increases. PHU was obtained from published data (NOAA, 1980).

Channel transmission loss is the effective hydraulic conductivity of channel alluvium, or water loss in the stream channel. The fraction of transmission loss that returns to the stream channel as base flow can also be adjusted.

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

Model Calibration
The calibration period was based on the available period of record for stream gauges within each watershed. Measured stream flow was obtained from USGS. A base flow filter (Arnold et al., 1999) was used to determine the fraction of base flow and surface runoff at selected gauging stations.

Appropriate plant growth parameters for brush and native grass 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.

Brush Removal Simulations
T.L. Thurow (Thurow, 1998) suggested that brush control is most likely to increase water yields in areas that receive at least 18 inches of average annual rainfall. Therefore, brush treatment was not planned in areas generally west of the 18 inch rainfall isohyet (Figure 3). One exception is the Canadian River watershed. Most of this watershed is west of the 18 inch isohyet, and also extends into New Mexico. Brush treatment was simulated in the portion of the Canadian River watershed that lies within Texas.

Some areas in the Upper Colorado and Twin Buttes/Nasworthy watersheds do not contribute to stream flow at downstream gauging stations (USGS, 1999). These areas have little or no defined stream channel, and considerable natural surface storage (e.g. playa lakes) that capture surface runoff. We used available GIS and stream gauge data to estimate the location of these areas, most of which are west of the 18 inch isohyet. Brush treatment was not planned in these areas (Figure 3).

In order to simulate the “treated” or “no-brush” condition, the input files for all areas of heavy and moderate brush (except oak) were converted to native grass rangeland. Appropriate adjustments were made in growth parameters to simulate the replacement of brush with grass. 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 opportunity for re-evaporation from the shallow aquifer is higher. All other calibration parameters and inputs were held constant.

It was assumed all categories of oak would not be treated. In the Pedernales and Edwards watersheds, oak and juniper were mixed together in one classification. We assumed the category was 50 % oak and 50 % juniper and modeled only the removal of juniper.

After calibration of flow, each watershed was simulated for the brush and no-brush conditions for the years 1960 through 1998.

RESULTS

The results of flow calibration and brush treatment simulations for individual watersheds are presented in the subchapters of this report.

Watershed Calibration

The comparisons of measured and predicted flow were, in most cases, reasonable. Deviations of predicted flow from measured were generally attributed to precipitation variability which was not reflected in measured climate data.

Brush Treatment Simulations

Total area of each watershed is shown in Figure 4. For watersheds that lie across the 18 inch isohyet, the area shown represents only the portion of those watersheds where brush treatment was planned.

The fraction of heavy and moderate brush planned for treatment or removal in each watershed is shown in Figure 5. For watersheds that lie across the 18 inch isohyet, this is the fraction of the portion of the watershed where brush treatment was planned.

Average annual water yield increase per treated acre varied by watershed and ranged from 13,000 gallons per treated acre in the Canadian to about 172,000 gallons per treated acre in the Medina watershed (Figure 6).

The average annual stream flow (acre-feet) for the brush and no-brush conditions is shown for each watershed outlet in Figure 7. Average annual stream flow increase varied by watershed and ranged from 6,650 gallons per treated acre in the Upper Colorado to about 172,000 gallons per treated acre in the Medina watershed (Figure 8). In some cases, the increase in stream flow was less than the increase in water yield because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occurred between each subbasin and the watershed outlet.

There was a high correlation between stream flow increase and precipitation (Figure 9). The amount of stream flow increase was greater in watersheds with higher average annual precipitation.

Variations in the amount of increased water yield and stream flow were expected and were influenced by brush type, brush density, soil type, and average annual rainfall, with watersheds receiving higher average annual rainfall generally producing higher increases. The larger water yields and stream flows were most likely due to greater rainfall volumes as well as increased density and canopy of brush.

SUMMARY

The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in 8 watersheds in Texas for 1960 through 1998. Landsat7 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 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 13,000 gallons per treated acre in the Canadian watershed to about 172,000 gallons per treated acre in the Medina watershed.

For this study, we assumed removal of 100 % of heavy and moderate categories of brush (except oak). Removal of all brush in a specific category is an efficient modeling scenario. However, other factors must be considered in planning brush treatment. Economics and wildlife habitat considerations will impact the specific amounts and locations of actual brush removal.

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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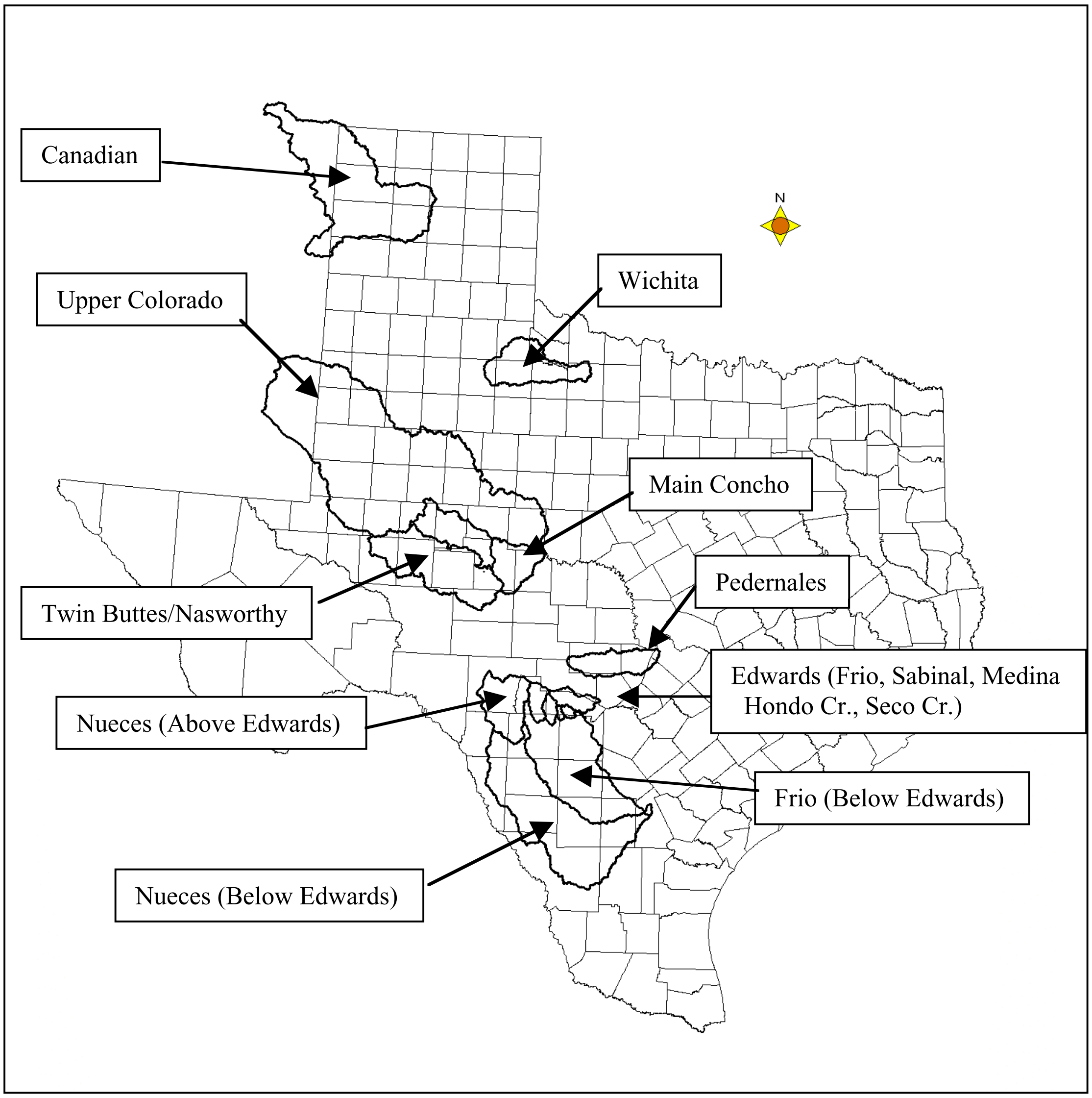

Figure 1. Watersheds included in the study area.

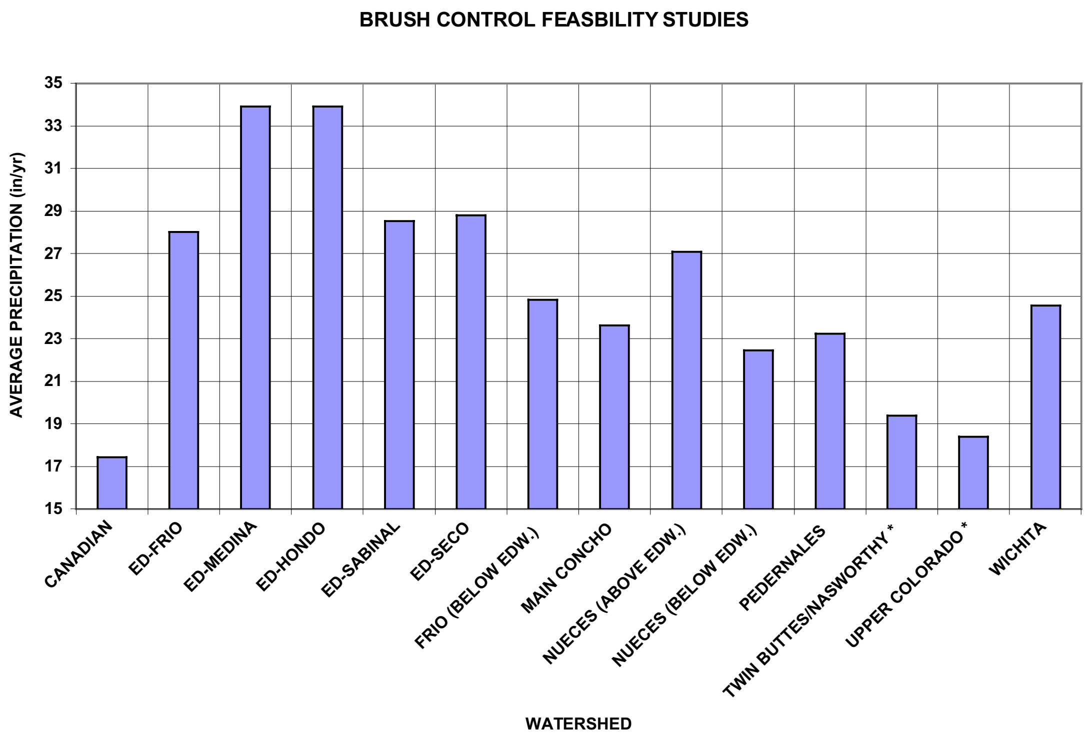

Figure 2. Average annual precipitation. Averages are for all climate stations in each watershed.

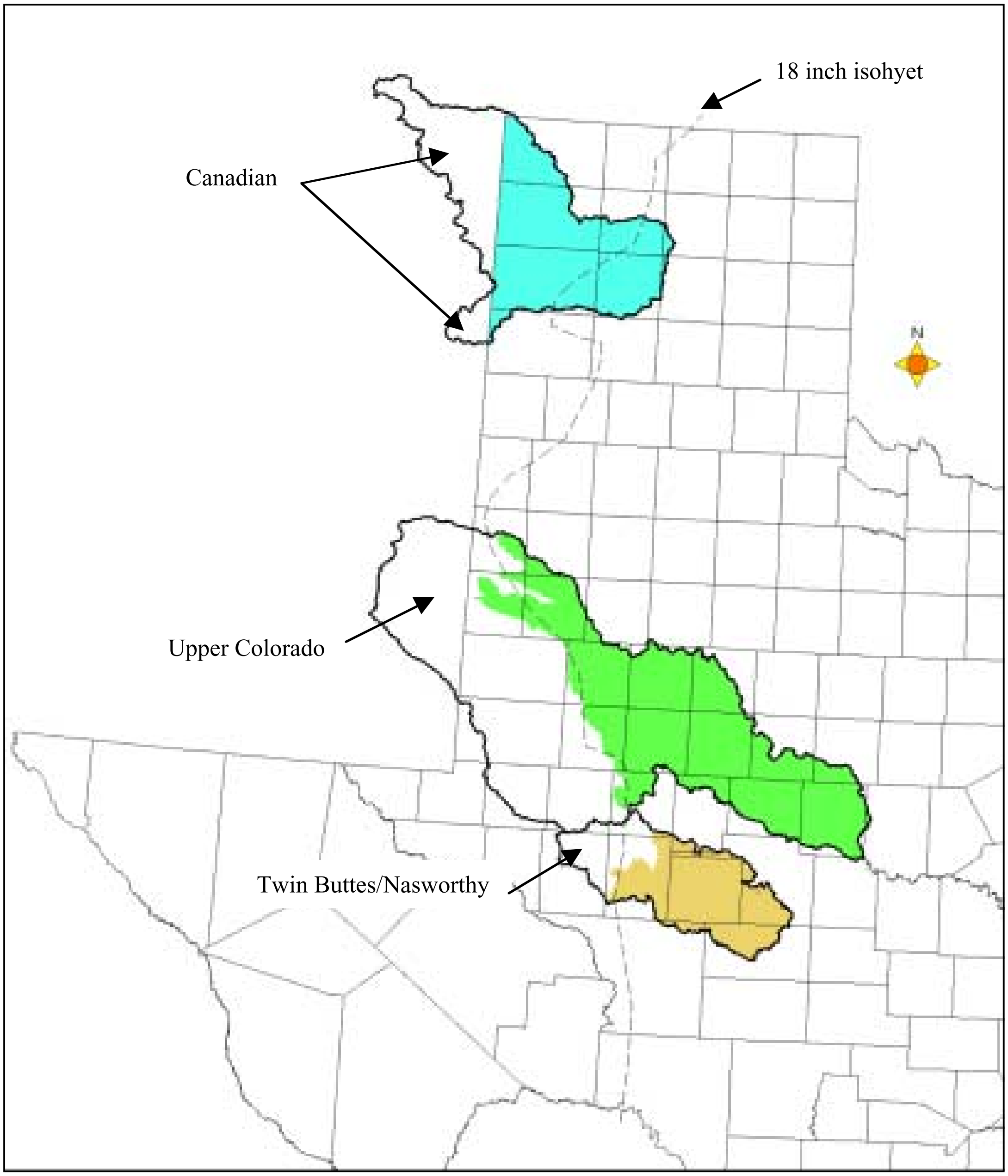

Figure 3. Areas where brush treatment was not planned (non-shaded portions of each watershed).

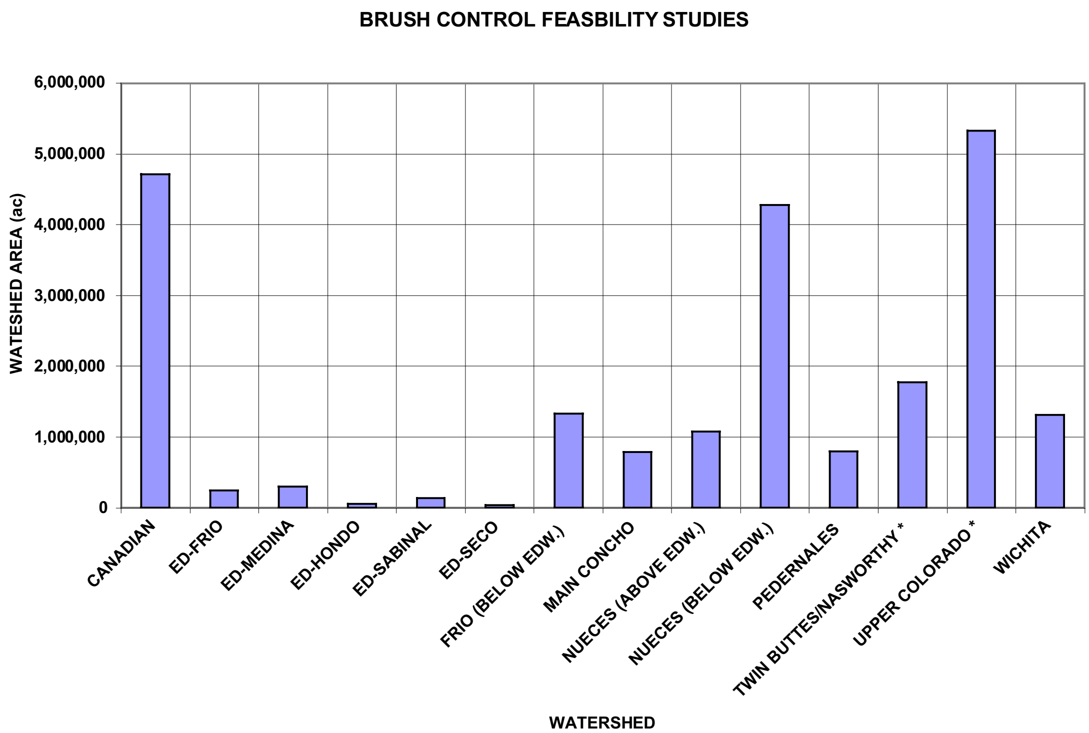

Figure 4. Watershed area. For watersheds that lie across the 18 inch isohyet, the area shown represents only the portion of those watersheds where brush treatment was planned and simulated.

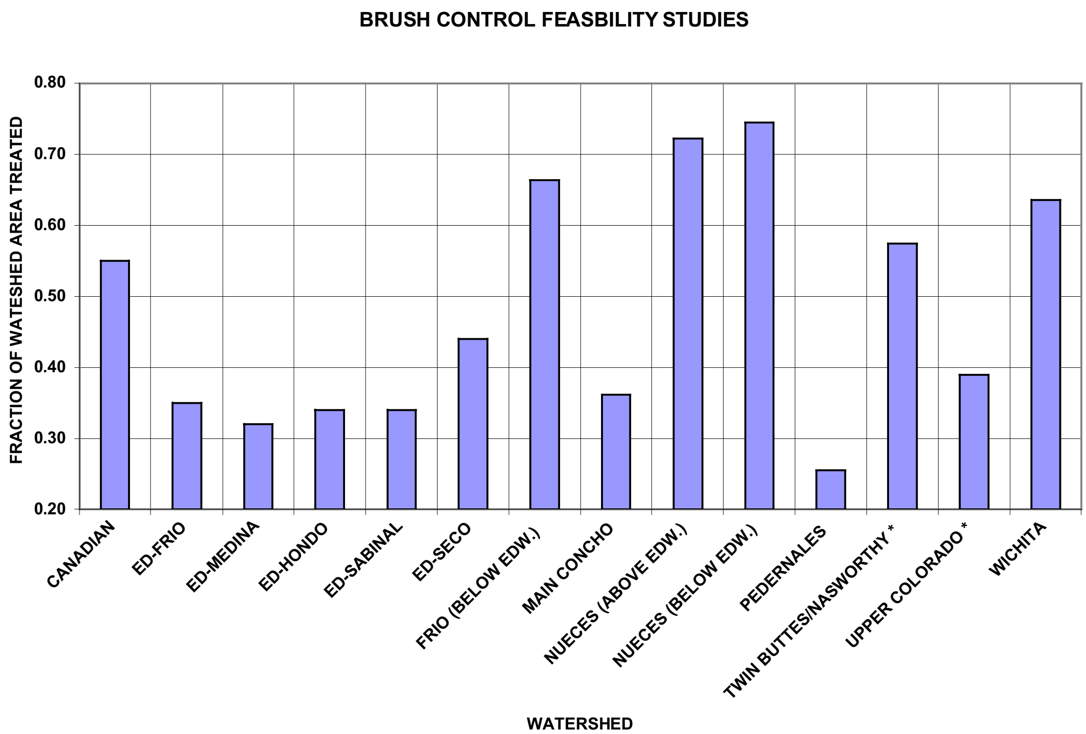

Figure 5. Fraction of watershed containing heavy and moderate brush that was treated. For watersheds that lie across the 18 inch isohyet, this is the fraction of the portion of the watershed where brush treatment was planned and simulated.

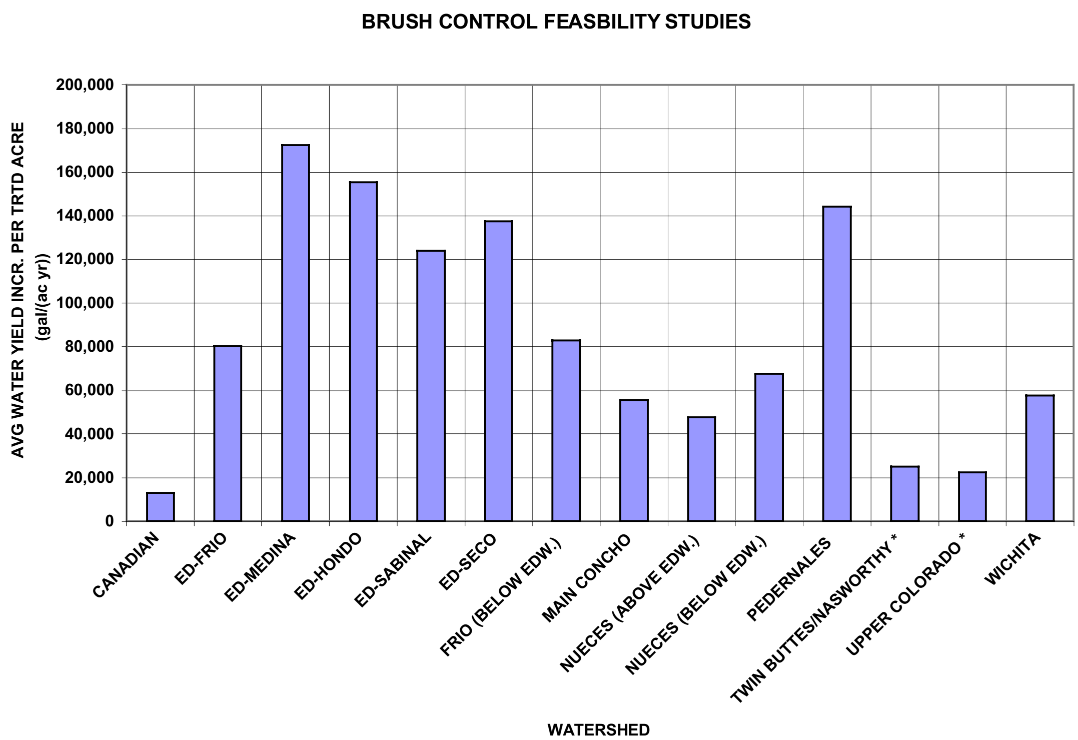

Figure 6. Average annual water yield increase, 1960 through 1998.

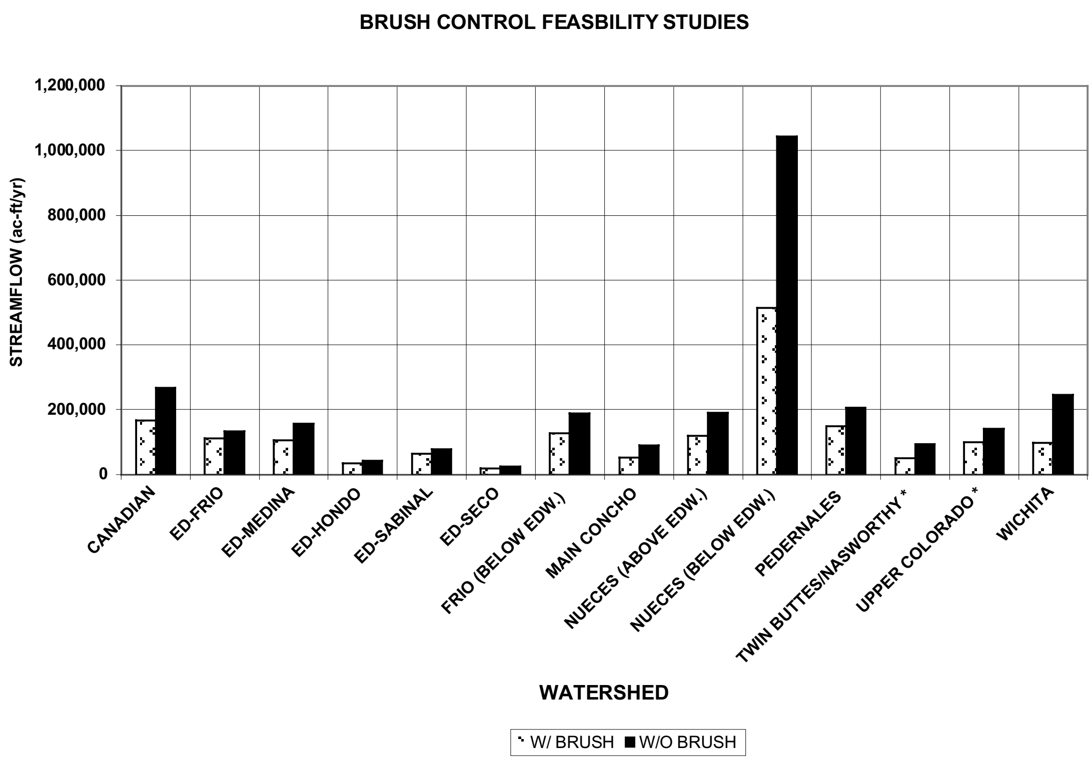

Figure 7. Average annual stream flow at watershed outlet, 1960 through 1998.

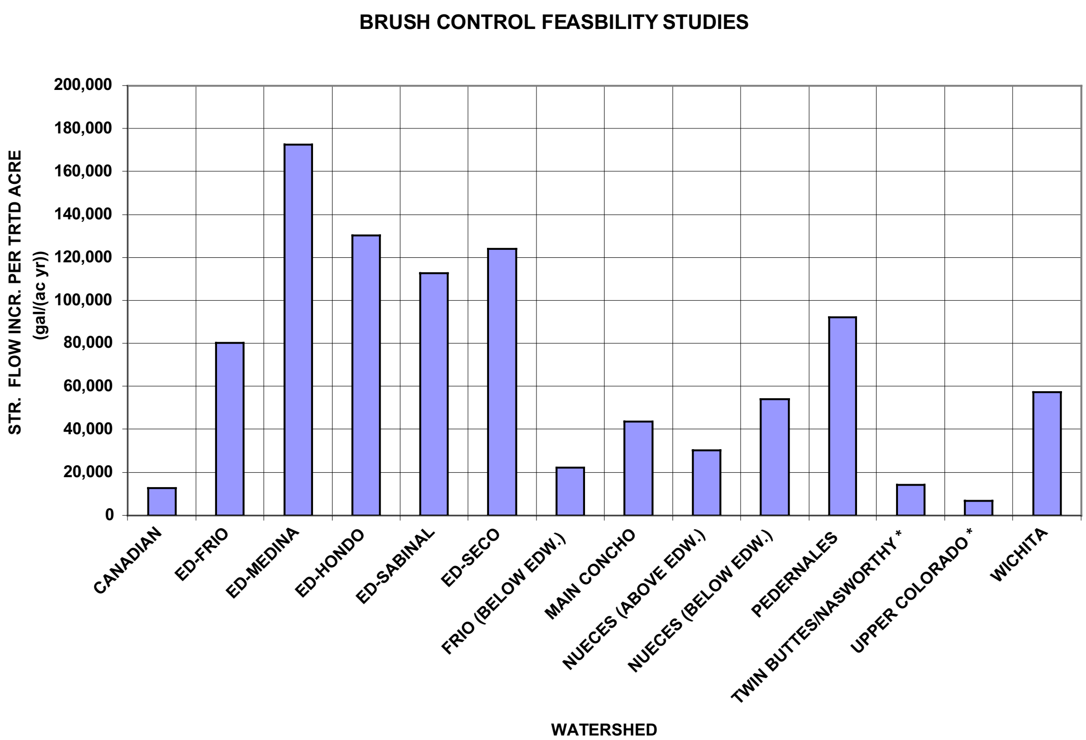

Figure 8. Average annual stream flow increase at watershed outlet, 1960 through 1998.

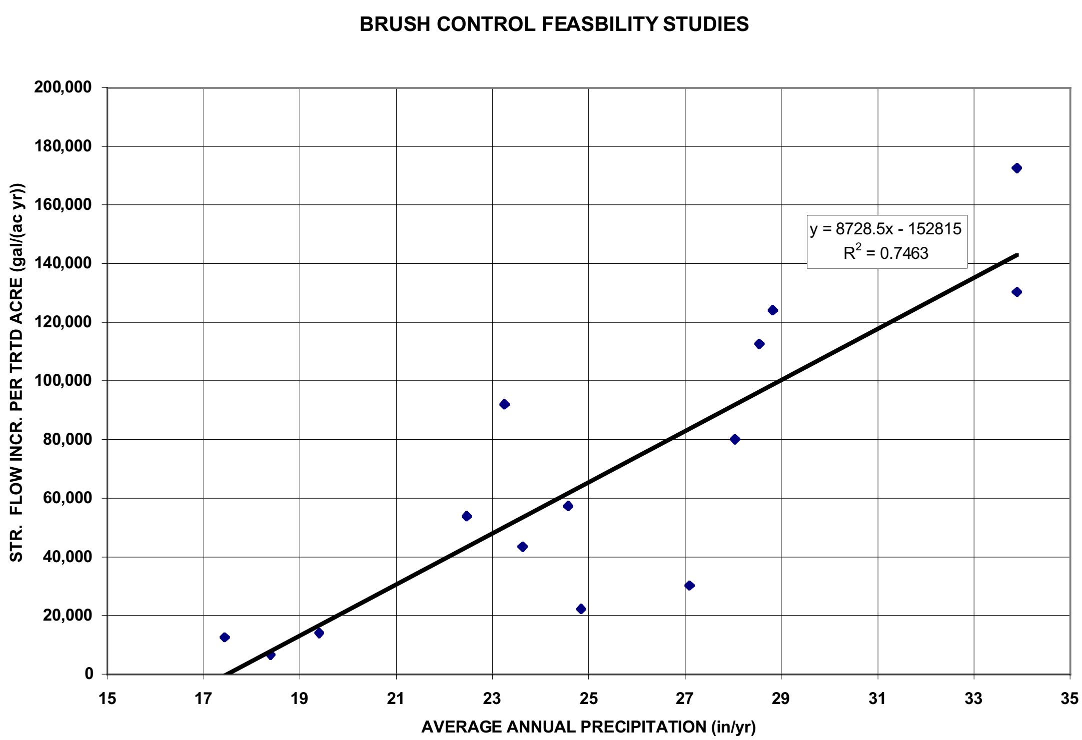

Figure 9. Average annual stream flow increase versus average annual precipitation, 1960 through 1998. Each point represents one watershed.

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. Subsequently, studies were conducted on eight additional Texas watersheds. Economic analysis was based on estimated control costs of the different options compared to the estimated rancher benefits of 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 rancher 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 $33.75 to $159.45. Rancher benefits, based on the present value of the improved net returns to typical cattle, sheep, goat and wildlife enterprises, ranged from $52.12 per acre to $8.95. Present values of the state cost share per acre ranged from $138.85 to $21.70. The cost of added water estimated for the eight watersheds ranged from $16.41 to $204.05 per acre-foot averaged over each watershed.

INTRODUCTION

As was reported in Chapter 1 of this report, a feasibility study of brush control for water yield on the North Concho River near San Angelo, Texas was conducted in 1998 Results indicated estimated cost of added water at $49.75 per acre-foot averaged over the entire North Concho basin (Bach and Conner).

In response to this study, the Texas Legislature, in 1999, appropriated approximately $6 million to begin implementing the brush control program on the North Concho Watershed. A companion Bill authorized feasibility studies on eight additional watersheds across Texas.

The Eight watersheds ranged from the Canadian, located in the northwestern Texas Panhandle to the Nueces which encompasses a large portion of the South Texas Plains (Chapter 1, Figure 1). In addition to including a wide variety of soils, topography and plant communities, the 8 watersheds included average annual precipitation zones from 15 to 26 inches and growing seasons from 178 to 291days. The studies were conducted primarily between February and September of 2000.

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

Brush control practices include initial and follow-up treatments required to reduce the current canopies of all categories of brush types and densities to 3-8 percent and maintain it at the reduced level for at least 10 years. These practices, or brush control treatments, differed among watersheds due to differences in terrain, soils, amount and distribution of cropland in close proximity to the rangeland, etc. An example of the alternative control practices, the time (year) of application and costs for the Wichita 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 an 8% 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 $33.75 for moderate mesquite that can be initially controlled with herbicide treatments to $159.45 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 from $0.50 to $1.50 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.

Table 1 Wichita Water Yield Brush Control Program Methods and Costs by Type-Density Category

Heavy Mesquite Aerial Chemical			
Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	25.00	25.00
4	Aerial Spray Herbicide	25.00	18.38
7	Choice Type IPT or Burn	15.00	8.75
			$ 52.13

Heavy Mesquite Mechanical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Tree Doze or Root Plow, Rake and Burn	150.00	150.00
6	Choice Type IPT or Burn	15.00	9.45
			$159.45

Heavy Cedar Mechanical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Tree Doze, Stack and Burn	107.50	107.50
3	Choice Type IPT or Burn	15.00	11.91
6	Choice Type IPT or Burn	15.00	9.45
			$ 128.86

Heavy Cedar Mechanical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Two-way Chain and Burn	25.00	25.00
3	Choice Type IPT or Burn	15.00	11.91
6	Choice Type IPT or Burn	15.00	9.45
			$ 46.36

Heavy Mixed Brush Mechanical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Tree Doze, Stack and Burn	107.50	107.50
3	Choice Type IPT or Burn	15.00	11.91
6	Choice Type IPT or Burn	15.00	9.45
			$ 128.86

Table 1 (Continued) Wichita Water Yield Brush Control Program Methods and Costs by Type-Density Category

Heavy Mixed Brush Mechanical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Two-way Chain and Burn	25.00	25.00
3	Choice Type IPT or Burn	15.00	11.91
6	Choice Type IPT or Burn	15.00	9.45
			$ 46.36

Moderate Mesquite Mechanical or Chemical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	25.00	25.00
7	Choice Type IPT or Burn	15.00	8.75
			$ 33.75

Moderate Cedar Mechanical or Chemical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Chemical or Mechanical – Burn Choice	45.00	45.00
7	Choice Type IPT or Burn	15.00	8.75
			$ 53.75

Moderate Mixed Brush Mechanical or Chemical Choice			
Year	Treatment Description	Cost/Unit	Present Value
0	Chemical or Mechanical – Burn Choice	45.00	45.00
7	Choice Type IPT or Burn	15.00	8.75
			$ 53.75

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 70 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.

Table 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	
Watershed	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Canadian	-	-	30	20	37	23	-	-	25	20	30	23
Edwards Aquifer	60	30	35	20	45	25	45	30	25	20	35	25
Frio – North	50	30	36	24	36	24	40	30	32	24	32	24
Frio – South	-	-	38	23	35	23	-	-	30	23	30	23
Mid Concho	70	35	38	25	50	30	52	35	32	25	40	30
Nueces – North	50	30	39	27	39	27	40	30	35	27	35	27
Nueces – South	-	-	41	26	38	26	-	-	33	26	33	26
Pedernalis	45	28	28	15	40	22	38	28	24	15	34	22
Upper Colorado – East	56	24	32	18	48	21	44	24	28	18	36	21
Upper Colorado – West	70	35	38	25	50	30	52	30	32	25	40	30
Wichita	50	25	32.5	20	38.5	20	40	25	25	20	32.5	20

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 moderate cedar in the Upper Colorado – West watershed.

Table 3 Net Present Value Report - Upper Colorado – West Watershed, Moderate Cedar Control

Year	Animal Units	Total Increase In Sales	Total Added Investment	Increased Variable Costs	Additional Revenues	Cash Flow	Annual NPV	Accumulated NPV
0	0.0	0	0	0	0	0	0	-
1	4.2	1423	2800	520	0	-1897	-1757	-1757
2	9.8	3557	3500	1171	0	-1113	-955	-2711
3	10.1	3557	0	1171	0	2387	1895	-817
4	10.3	3557	0	1171	0	2387	1754	937
5	10.6	3557	0	1171	0	2387	1624	2562
6	10.8	3913	0	1171	0	2742	1728	4290
7	11.1	3913	0	1171	0	2742	1600	5890
8	11.4	3913	0	1171	0	2742	1482	7371
9	11.6	3913	0	1171	0	2742	1372	8743
				Salvage Value:		6300	3152	11895

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 $11,895 shown in Table 3 must be divided by 1,000, which results in $11.90 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 $8.95 per acre for control of moderate mesquite in the Canadian Watershed to $52.12 per acre for control of heavy mesquite in the Edwards Aquifer Watershed.

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

	Brush Type-density Category											
	Heavy Cedar		Heavy Mesquite		Heavy Mixed Brush		Moderate Cedar		Moderate Mesquite		Moderate Mixed Brush	
Watershed	Rancher Benefits	State Costs	Rancher Benefits	State Costs	Rancher Benefits	State Costs	Rancher Benefits	State Costs	Rancher Benefits	State Costs	Rancher Benefits	State Costs
Canadian	-	-	10.37	40.33	10.44	54.93	-	-	8.95	26.10	10.48	23.43
Edwards Aquifer	43.52	138.5	52.12	98.49	45.61	105.00	23.27	93.75	20.81	43.71	23.88	40.64
Frio – North	30.69	79.81	39.76	90.18	39.76	84.57	10.44	92.29	23.43	60.56	23.43	60.56
Frio – South	-	-	38.71	75.95	41.6	72.32	-	-	21.07	55.57	21.07	62.92
Mid Concho	16.59	78.30	15.66	57.46	16.35	78.54	11.79	53.10	10.49	41.76	9.91	54.98
Nueces – North	30.69	79.81	34.49	95.45	34.49	89.84	10.44	92.29	19.73	64.26	19.73	64.26
Nueces – South	-	-	35.69	79.02	36.53	77.40	-	-	17.14	59.50	17.14	66.85
Pedernalis	31.86	108.56	40.61	88.77	33.31	96.07	25.74	54.68	21.22	49.20	21.22	49.20
Upper Colorado – East	14.90	69.99	17.22	60.62	16.35	83.54	11.32	58.57	12.07	42.68	10.92	58.97
Upper Colorado – West	16.76	42.14	15.89	57.23	15.07	64.82	11.90	32.99	10.55	29.84	10.25	34.64
Wichita	18.79	68.82	18.70	87.09	21.80	65.81	15.13	38.62	12.05	21.70	19.09	34.65

Note: Rancher Benefits and State Costs are in $ / Acre.

State Cost Share

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 $21.70 for control of moderate mesquite in the Wichita Watershed to $138.85 for control of heavy cedar in the Edwards Aquifer 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 Chapter 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 Wichita Watershed. The cost of added water from brush control for the Wichita is estimated to average $36.59 per acre-foot for the entire watershed. Sub-basin cost per added acre-foot within the Wichita range from $17.56 to $91.76.

As might be expected, there is a great deal of variation in the cost of added water between sub-basins in the watersheds. Likewise, there is a great deal of variation from watershed to watershed in the average cost of added water for the entire watershed. For an example that contrasts dramatically with the results shown for the Wichita in Table 5, the Middle Concho analysis resulted in an estimated average cost across all its sub-basins of $204.05 per acre-foot. Most of the watershed analyses, however, resulted in estimates of costs in the $40 to $100 per acre-foot range. Although the cost of added water from alternative sources are not currently known for the watersheds in the study, a high degree of

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

Sub-Basin #	Total State Cost ($)	Added Gallons/Acre	Added Acre/Feet/Year	Total Acre/Feet/ 10-Years	Cost Per Acre/Foot ($)
1	457182.65	216078212.22	663.12	5173.66	88.37
2	1772111.33	806617084.67	2475.42	19313.20	91.76
3	344487.78	351071562.48	1077.40	8405.87	40.98
4	270611.17	307249619.41	942.91	7356.62	36.78
5	405303.9	244374185.73	749.96	5851.16	69.27
6	551815.58	321549997.08	986.80	7699.02	71.67
7	1829171.16	1767009344.68	5422.75	42308.32	43.23
8	1620183.78	1949004323.95	5981.27	46665.90	34.72
9	1338434.24	1365709430.82	4191.21	32699.81	40.93
10	590024.3	439341539.12	1348.29	10519.36	56.09
11	343140.75	175512983.29	538.63	4202.39	81.65
12	440716.1	337140645.01	1034.65	8072.31	54.60
13	262233	175936587.60	539.93	4212.53	62.25
14	299909.61	323150451.65	991.71	7737.34	38.76
15	354443.07	369339368.84	1133.46	8843.26	40.08
16	187848	230953440.19	708.77	5529.82	33.97
17	84634.43	88598612.82	271.90	2121.36	39.90
18	522247.77	662499062.28	2033.13	15862.52	32.92
19	124871.5	139554413.54	428.28	3341.42	37.37
20	246020.32	290468000.94	891.41	6954.81	35.37
21	2730475.37	1642473500.85	5040.57	39326.50	69.43
22	110738.33	67570294.84	207.37	1617.87	68.45
23	1369643.8	926200497.94	2842.40	22176.44	61.76
24	1563106.99	1414807304.26	4341.88	33875.38	46.14
25	971017.42	992524276.72	3045.95	23764.46	40.86
26	771619.1	1834810250.24	5630.83	43931.70	17.56
27	1478568.35	2291114837.65	7031.17	54857.21	26.95
28	1801533.32	1678434945.84	5150.93	40187.54	44.83
29	1948506.76	1790375041.38	5494.46	42867.77	45.45
30	3769655.99	3613101057.14	11088.20	86510.14	43.57
31	439757.96	589436154.61	1808.91	14113.14	31.16
32	613063.06	867628625.83	2662.65	20774.03	29.51
33	260808.4	318809382.14	978.39	7633.40	34.17
34	722243.11	1057274449.79	3244.66	25314.81	28.53
35	801913.88	1601922140.98	4916.12	38355.56	20.91
36	472961.33	534304493.17	1639.72	12793.10	36.97
37	522081.31	783102254.46	2403.25	18750.18	27.84
38	293231.45	413705742.62	1269.62	9905.55	29.60
39	3111539.76	4332844817.46	13297.01	103743.29	29.99
40	2006939.15	3063451744.60	9401.39	73349.63	27.36
41	307258.55	350869992.59	1076.78	8401.04	36.57
42	424456.46	732734077.37	2248.68	17544.19	24.19
43	493711.42	637433871.96	1956.21	15262.37	32.35
44	452996.05	793219617.91	2434.30	18992.42	23.85
45	272492.79	501654318.26	1539.52	12011.34	22.69
46	243926.57	353972454.43	1086.30	8475.32	28.78
47	24499.3	39919320.98	122.51	955.81	25.63
48	3371088.17	5745904234.60	17633.53	137576.82	24.50
Total	43,395,224.5		152004.32	1185937.68	
				Average	36.59

Note: Total Acre/Feet are adjusted for time-supply availability of water.

variation is likely, based mostly on population and demand. Since few alternatives exist for increasing the supply of water, these values are likely to compare well.

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. (2001) that indicated that only about 66% of ranchers surveyed were willing to enroll their land in a similarly characterized program. Also, some landowners will not be financially able to incur the costs expected of them in the beginning of the program due to current debt load.

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

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APPENDIX 3

PEDERNALES RIVER WATERSHED – HYDROLOGIC SIMULATION

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METHODS

Climate

For the simulations actual weather data from 1960-1998 were used. The model used daily maximum and minimum air temperatures, precipitation and solar radiation. Solar radiation was generated using the WGEN model based on parameters for the specific climate station. Climate stations are shown in Figure P-1. For each subbasin, precipitation and temperature data are retrieved by the SWAT input interface for the climate station nearest the centroid of the subbasin.

Topography

The outlet or "catchment" for the portion of the Pedernales River simulated in this study is Lake Travis, which is located in subbasin number 1. The subbasin delineation and numbers are shown in Figure P-2. Roads (obtained from the Census Bureau) are overlaid in Figure P-3.

Soils

The dominant soil series in the Pedernales River watershed are Tarrant, Brackett, Doss, Hensley, and Purves. These six soil series represent about 56 percent of the watershed area. A short description of each follows:

Tarrant. The Tarrant series consists of a very shallow and shallow, well drained, moderately slow permeable soils formed in residum from limestone, and includes interbedded marls, shalks, and marly materials. These upland soils have slopes ranging from 1 to 50 percent.

Brackett. The Brackett series consists of deep, well drained moderately permeable soils that formed in marly loamy earth interbedded with chalky limestone. These soils are on uplands with slopes ranging from 1 to 30 percent.

Doss. The Doss series consists of shallow, well drained moderately slow permeable soils that formed in marls and limestone. The soils are on gently sloping to slopint uplands. Slopes range from 1 to 8 percent.

Hensley. The Hensley series consists of shallow, well draijned, slowly permeable soils fromed in residuum of weathered limestone. These upland soils hav slopes ranging from 0 to 5 percent.

Purves. The Purves series consists of shallow, well drained moderately slowly permeable soils that formed in interbedded limestone and marl. These upland soils have slopes mainly of 1 to 5 percent, but the range is 1 to 40 percent.

Land Use/Land Cover
Figure P-4 shows the areas of heavy and moderate brush (oak not included) in the Pedernales River Watershed. This is the area of brush removed or treated in the no-brush simulation. Oak that was included in any mixed brush was split out so any cedar or mesquite was removed. This corresponds to 25% of the total watershed area

Model Input Variables
Significant input variables for the SWAT model for the Pedernales River Watershed are shown in Table P-1. Input variables for all subbasins in the watershed were the same, with three exceptions:

It was necessary to increase the curve number by 5 in order to calibrate flow at stream gauge feeding into Lake Travis.

0. The base flow factor was calculated to be 0.013. Also the amount of heat units for the crops to mature were for cedar 4769 degree days, oak 4149 degree days and brushy range 3195 degree days.
0. We assumed the re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and opportunity for re-evaporation from the shallow aquifer is higher. The re-evaporation coefficient for all brush hydrologic response units is 0.4, and for non-brush units is 0.1. Also, for the non-brush condition curve number increased by 5 units to account for the change from fair to good hydrologic conditions and from brush to range conditions.

PEDERNALES RIVER WATERSHED RESULTS

Calibration
SWAT was calibrated for the flow at stream gauges near Johnson City. The results of calibration are shown on Figures P-5. Measured and predicted average monthly flows compare reasonably well with a 4% difference between measured and simulated cumulative flow. At Johnson City the measured monthly mean is 12,830 acre-feet, and predicted monthly mean is 12,284 acre-feet. The coefficient of determination (r^2) was 0.99 between measured and simulated. Average base flow for the entire watershed is 16% of total flow.

Brush Removal Simulation
The average annual rainfall for the Pedernales River Watershed is 23.24 inches. Average annual evapo-transpiration (ET) is 19.61 inches for the brush condition (calibration) and 18.14 inches for the no-brush condition. This represents 84% and 78% of precipitation for the brush and no-brush conditions, respectively.

The increases in water yield by subbasin for the Pedernales River Watershed are shown in Figures P-6, 7 and 8 and Table P-2. The amount of annual increase varies among the subbasins and ranges from 739 gallons per acre of brush removed per year in subbasin number 26, to 611,720 gallons per acre in subbasin number 32. Variations in the amount of increased water yield are expected and are influenced by brush type, brush density, soil type, and average annual rainfall, with subbasins receiving higher average annual rainfall generally producing higher water yield increases. The larger water yields are most likely due to greater rainfall volumes as well as increased density and canopy of brush. Table P-2 gives 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.

For the entire simulated watershed, the average annual water yield increases by 36 % or approximately 89,348 acre-feet. The average annual flow to Lake Travis increases by 57,050 acre-feet. The increase in volume of flow to Lake Travis is slightly less than the water yield because of stream channel transmission losses that occur after water leaves each subbasin and the shallow soils that allow for percolation.

TABLE P-1

SWAT INPUT VARIABLES FOR PEDERNALES RIVER WATERSHED		
VARIABLE	BRUSH CONDITION (CALIBRATION)	NO BRUSH CONDITION
Runoff Curve Number Adjustment	+5	+10
Soil Available Water Capacity Adjustment (%)	0	0
Soil Evaporation Compensation Factor ($in^3\ in^{-3}$)	0.99	0.99
Min. Shallow Aqu. Storage for GW flow (inches)	0	0
Shallow Aqu.Re-Evaporation (Revap) Coefficient	0.4	0.1
Min. Shallow Aqu. Storage for Revap (inches)	0.3	0.3
Potential Heat Units (degree-days)		
Heavy Cedar	4769	N/A
Heavy Mesquite	N/A	N/A
Heavy Mixed Brush	N/A	N/A
Moderate Cedar	4149	N/A
Moderate Mesquite	N/A	N/A
Moderate Mixed Brush	N/A	N/A
Heavy Oak	4149	4149
Moderate Oak	3911	3911
Light Brush & Open Range/Pasture	3195	3195
Precipitation Interception (inches)		
Heavy Cedar	0.79	N/A
Heavy Mesquite	0	N/A
Heavy Mixed Brush	0.59	N/A
Moderate Cedar	0.59	N/A
Moderate Mesquite	0	N/A
Moderate Mixed Brush	0.39	N/A
Heavy Oak	0	0
Moderate Oak	0	0
Light Brush & Open Range/Pasture	0	0
Plant Rooting Depth (feet)		
Heavy and Moderate Brush	6.5	N/A
Light Brush & Open Range/Pasture	3.3	3.3
Maximum Leaf Area Index		
Heavy Cedar	6	N/A
Heavy Mesquite	4	N/A
Heavy Mixed Brush	4	N/A
Moderate Cedar	5	N/A
Moderate Mesquite	2	N/A
Moderate Mixed Brush	3	N/A
Heavy Oak	4	4
Moderate Oak	3	3
Light Brush	2	2
Open Range & Pasture	1	1
Channel Transmission Loss (inches/hour)	0.02	0.02
Subbasin Transmission Loss (inches/hour)	0.015	0.015
Fraction Trans. Loss Returned as Base Flow	0.16	0.16

Table P-2. Pedernales areas and water yield

Subbasin	Subbasin Total Area (acres)	Brush Removal Area (acres)	Fraction of Subbasin Containing Brush	Avg. Annual Water Yield (gallons)	Water Yield Per acre (gal/ac)
1	26,951	11,294	0.42	3509934604	310766
2	48,747	12,456	0.26	3830330157	307505
3	23,362	11,487	0.49	1173085471	102122
4	18,206	7,322	0.40	1203434375	164352
5	37,687	12,304	0.33	2613606806	212420
6	21,437	3,836	0.18	2078427110	541837
7	72,037	16,982	0.24	2142472557	126164
8	12,075	2,620	0.22	143029849	54591
9	9,397	1,983	0.21	969947825	489030
10	43,245	6,735	0.16	3499761808	519659
11	8,532	1,021	0.12	82369342	80663
12	32,645	10,810	0.33	3339561545	308919
13	12,319	2,284	0.19	45832580	20066
14	20,595	6,368	0.31	1120243861	175919
15	19,478	6,074	0.31	482484548	79440
16	29,202	6,743	0.23	224459965	33290
17	7,359	0	0.00	0	
18	5,272	1,432	0.27	552188395	385687
19	3,665	412	0.11	54225936	131751
20	24,943	3,774	0.15	2606809374	690679
21	4,661	0	0.00	0	
22	27,850	6,144	0.22	3290299232	535568
23	27,156	7,292	0.27	686889242	94197
24	26,025	5,497	0.21	1530495204	278402
25	17,631	4,026	0.23	803690121	199616
26	24,708	2,861	0.12	2113161	739
27	23,364	3,142	0.13	1352300667	430366
28	3,780	507	0.13	1858684	3669
29	23,396	5,569	0.24	1073272439	192729
30	12,893	3,171	0.25	476201733	150173
31	19,389	2,808	0.14	324609923	115592
32	18,093	2,478	0.14	1515842097	611720
33	13,794	1,866	0.14	300394705	160941
34	56,624	21,884	0.39	2445623566	111752
35	23,757	10,570	0.44	24635822	2331

APPENDIX 4

PEDERNALES RIVER 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 Pedernales River 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 Extension Service, 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 an 8% 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 $70.42 for moderate mesquite that can be initially controlled with herbicide treatments to $160.42 for mechanical control of heavy cedar, mesquite and mixed brush. The costs of treatments, year those treatments are needed and treatment life for each brush type density category are detailed in Table 1.

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

Heavy Cedar - Mechanical[1]

Year	Treatment	Acre Cost	Present Value
0	Tree Doze or Shear	100.00	100.00
5	IPT or Burn	30.00	20.42
		Total:	120.42

[1] Doze or tree shear, stack, and burn.

Extra Heavy Cedar – Mechanica1[1]

Year	Treatment	Acre Cost	Present Value
0	Pre-doze & Tree Doze	140.00	140.00
5	IPT or Burn	30.00	20.42
	Note: Canopy Cover for this practice is 40% or greater	Total:	160.42

[1] Heavy pre-doze, rake, stack and burn.

Heavy Mesquite - Herbicide[1]

Year	Treatment	Acre Cost	Present Value
0	Chemical Herbicide	60.00	60.00
4	Chemical Herbicide	35.00	25.73
7	Choice IPT or Burn	25.00	14.59
		Total:	100.32

[1] Either aerial or individual chemical application may may be used.

Heavy Mesquite – Rootplow[1]

Year	Treatment	Acre Cost	Present Value
0	Rootplow	110.00	110.00
6	IPT or Burn	30.00	18.91
		Total:	128.91

[1] Rootplow, rake, stack, and burn.

Extra Heavy Mesquite – Rootplow with Pre-Doze[1]

Year	Treatment	Acre Cost	Present Value
0	Pre-doze and Rootplow	140.00	140.00
6	IPT or Burn	30.00	18.91
	Note: Canopy Cover for this practice is 40% or greater	Total:	158.91

[1] Heavy tree-doze, rootplow, rake, stack, and burn.

Heavy Mixed Brush - Chemical Herbicide[1]

Year	Treatment	Acre Cost	Present Value
0	Chemical Herbicide	60.00	60.00
4	Chemical Herbicide	35.00	25.73
7	Choice IPT or Burn	25.00	14.59
		Total:	100.32

[1] Individual chemical application may also be used.

Heavy Mixed Brush – Rootplow[1]

Year	Treatment	Acre Cost	Present Value
0	Rootplow	110.00	110.00
6	IPT or Burn	30.00	18.91
		Total:	128.91

[1] Rootplow, rake, stack, and burn.

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

Extra Heavy Mixed Brush – Rootplow with Pre-Doze[1]

Year	Treatment	Acre Cost	Present Value
0	Pre-doze and Rootplow	140.00	140.00
6	IPT or Burn	30.00	18.91
	Note: Canopy Cover for this practice is 40% or greater	Total:	158.91

[1] Heavy tree-doze, rootplow, rake, stack, and burn.

Moderate Cedar – Mechanical[1]

Year	Treatment	Acre Cost	Present Value
0	Tree Doze or Shear	60.00	60.00
5	IPT or Burn	30.00	20.42
		Total:	80.42

[1] Doze or shear, stack, and burn.

Moderate Mesquite – Chemical Herbicide[1]

Year	Treatment	Acre Cost	Present Value
0	Aerial or IPT Herbicide	50.00	50.00
5	IPT or Burn	30.00	20.42
		Total:	70.42

[1] Either aerial or individual chemical application may be used.

Moderate Mixed Brush – Chemical Herbicide[1]

Year	Treatment	Acre Cost	Present Value
0	Aerial or IPT Herbicide	50.00	50.00
5	IPT or Burn	30.00	20.42
		Total:	70.42

[1] Either aerial or individual chemical application may be used.
* Pedernales River Watershed

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 watershed are shown in Table 2. Data relating to grazing capacity was entered into the investment analysis model (see Chapter 2).

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

Brush Type-Density Classification	Brush Control (Or) No Control	Program Year									
		0	1	2	3	4	5	6	7	8	9
Heavy Cedar	Brush Control	45.0	39.3	33.7	28.0	28.0	28.0	28.0	28.0	28.0	28.0
	No Control	45.0	45.1	45.1	45.2	45.2	45.3	45.3	45.4	45.4	45.5
Heavy Mesquite	Brush Control	28.0	23.7	19.3	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	No Control	28.0	28.0	28.1	28.1	28.1	28.2	28.2	28.2	28.2	28.3
Heavy Mixed Brush	Brush Control	40.0	34.0	28.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
	No Control	40.0	40.0	40.1	40.1	40.2	40.2	40.3	40.3	40.4	40.4
Moderate Cedar	Brush Control	38.0	34.7	31.3	28.0	28.0	28.0	28.0	28.0	28.0	28.0
	No Control	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	39.9
Moderate Mesquite	Brush Control	24.0	21.0	18.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
	No Control	24.0	24.1	24.3	24.4	24.5	24.7	24.8	24.9	25.1	25.2
Moderate Mixed brush	Brush Control	34.0	30.0	26.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
	No Control	34.0	34.2	34.4	34.6	34.8	34.9	35.1	35.3	35.5	35.7

* Pedernales River Watershed

As with the brush control practices, the grazing capacity estimates represent a consensus of expert opinion obtained through discussions with landowners, Texas Agricultural Experiment Station and Extension Service Scientists and USDA-NRCS Range Specialists with brush control experience in the area. Livestock grazing capacities range from about 15 acres per AUY for land on which mesquite is controlled to 45 acres per animal unit year (AUY) for land infested with heavy cedar.

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, sheep, and goats) in the project areas is shown in Tables 3a, 3b, and 3c. It is important to note once again (refer to Chapter 2) that the investment analysis budgets are for analytical purposes only, as they do not include all revenues nor all costs associated with a production enterprise. The data are reported per animal unit for each of the livestock enterprises. From these budgets, data was entered into the investment analysis model, which was also described in Chapter 2.

Rancher benefits were also calculated for the financial changes in existing wildlife operations. Most of these operations in this region were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. Therefore, wildlife costs and revenues were entered into the model as simple entries in the project period. For control of heavy brush categories, wildlife revenues are expected to increase by about $0.50 per acre (from $8.00 per acre to $8.50 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.

Table 3a. Investment Analysis Budget, Cow-Calf Production*

Partial Revenues

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Calves	403.75	Pound	.91	367.41
Cows	111.1	Pound	.40	0.00
Bulls	250.0	Pound	.50	0.00
			Total	367.41

Partial Variable Costs

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	740.00	Pound	0.10	74.00
Salt & Minerals	100.0	Pound	0.20	20.00
Marketing	1.0	Head	6.32	6.32
Veterinary Medicine	1.0	Head	14.00	14.00
Miscellaneous	1.0	Head	12.00	12.00
Net Replacement Cows	1.0	Head	35.28	35.28
Net Replacement Bulls	1.0	Head	3.09	6.09
			Total	167.69

* Pedernales River Watershed

This budget is for presentation of the information used in the investment analysis only.
Net returns cannot be calculated from this budget, for not all revenues and variable costs have been included.

Table 3b. Investment Analysis Budget, Sheep Production*

Partial Revenues

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Lambs	290.0	Pound	0.85	246.50
Cull Ewes	0.83	Head	20.00	0.00
Cull Rams	0.038	Head	40.00	0.00
Wool	40.00	Pounds	0.60	24.00
			Total	270.50

Partial Variable Costs

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	400.0	Pound	0.10	40.00
Salt & Minerals	72.00	Pound	0.25	18.00
Marketing	1.0	Head	2.00	10.00
Veterinary Medicine	1.0	Head	3.20	16.00
Miscellaneous	1.0	Head	1.20	6.00
Shearing	1.0	Head	1.80	9.00
Net Replacement Ewes	1.0	Head	6.96	34.80
Net Replacement Rams	1.0	Head	0.05	7.80
			Total	141.60

* Pedernales Concho River Watershed
This budget is for presentation of the information used in the investment analysis only.
Net returns cannot be calculated from this budget, for not all revenues and variable costs have been included.

Table 3c. Investment Analysis Budget, Meat Goat Production*

Partial Revenues

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Kid Goats	252.00	Pound	0.90	226.80
Cull Nannies	1.0	Head	20.00	0.00
Cull Bucks	0.045	Head	40.00	0.00
			Total	226.80

Partial Variable Costs

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	200.0	Pound	0.10	20.00
Salt & Minerals	75.0	Pound	0.20	15.00
Marketing	1.0	Head	2.55	12.00
Veterinary Medicine	1.0	Head	2.29	16.00
Miscellaneous	1.0	Head	1.03	7.20
Net Replacement Nannies	1.0	Head	5.21	36.48
Net Replacement Bucks	1.0	Head	0.02	4.74
			Total	111.42

*Pedernales River Watershed

This budget is for presentation of the information used in the investment analysis only.
Net returns cannot be calculated from this budget, for not all revenues and

With the above information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $21.22 per acre for control of moderate mesquite and mixed brush to $40.61 per acre for the control of heavy mesquite (Table 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 $49.20 for control of moderate mesquite and mixed brush with chemical treatments to $128.56 for control of heavy cedar. 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.

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

Brush Category Type & Density	Control Practice	PV Total Cost ($/Acre)	Landowner Share ($/Acre)	Landowner Percent	State Share ($/Acre)	State Percent
Heavy Cedar	Doze or Shear	120.42	31.86	0.26	88.56	0.74
	Doze - Heavy	160.42		0.20	128.56	0.80
Heavy Mesquite	Chemical	100.32	40.61	0.40	59.71	0.60
	Rootplow	128.91		0.32	88.30	0.68
	Doze & Plow[1]	158.91		0.26	118.30	0.74
Heavy Mixed Brush	Chemical	100.32	33.31	0.33	67.01	0.67
	Rootplow	128.91		0.26	95.60	0.74
	Doze & Plow[1]	158.91		0.21	125.60	0.79
Moderate Cedar	Doze or Shear	80.42	25.74	0.32	54.68	0.68
Moderate Mesquite	Chemical	70.42	21.22	0.30	49.20	0.70
Moderate Mixed Brush	Chemical	70.42	21.22	0.30	49.20	0.70
	Averages:	16.22	32.15	0.29	84.07	0.71

* Pedernales River Watershed

[1]Average is calculated as simple average, not relative average. The averages are based on the Heavy Mesquite Chemical comprising 50% of the cost for Heavy Mesquite control and Heavy Mesquite Mechanical comprising the other 50% of the cost for Heavy Mesquite. Also, it is assumed that Mechanical and Chemical comprise 50% each of cost for Moderate Mesquite control. Actual averages may change depending on relative amounts of each Type- Density Category of brush in each control category.

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 $16.41 per acre foot for the entire basin and ranges from $5.92 per acre foot for Subbasin 18 to over $6,139.23 per acre foot for Subbasin 26. Details of the costs of added water for each Subbasin of the Pedernales are shown in Table 5.

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	938,379.39	10,771.59	84,039.97	11.17
2	1,076,826.70	11,754.85	91,711.35	11.74
3	862,557.20	3,600.07	28,087.72	30.71
4	579,534.36	3,693.20	28,814.38	20.11
5	1,063,687.50	8,020.86	62,578.79	17.00
6	416,425.30	6,378.46	49,764.73	8.37
7	1,503,135.60	6,575.01	51,298.20	29.30
8	231,102.24	438.94	3,424.63	67.48
9	172,041.49	2,976.66	23,223.91	7.41
10	731,119.03	10,740.37	83,796.40	8.72
11	55,839.22	252.78	1,972.21	28.31
12	923,234.38	10,248.74	79,960.65	11.55
13	124,894.59	140.66	1,097.39	113.81
14	495,537.10	3,437.90	26,822.51	18.47
15	450,494.89	1,480.69	11,552.35	39.00
16	595,143.09	688.84	5,374.35	110.74
17	0.00	0.00	0.00	0.00
18	78,285.36	1,694.60	13,221.30	5.92
19	22,506.29	166.41	1,298.36	17.33
20	409,738.01	8,000.00	62,416.03	6.56
21	0.00	0.00	0.00	0.00
22	534,242.78	10,097.56	78,781.14	6.78
23	398,726.56	2,107.99	16,446.50	24.24
24	451,531.88	4,696.92	36,645.35	12.32
25	353,602.60	2,466.43	19,243.12	18.38
26	310,622.73	6.49	50.60	6,139.23
27	341,117.23	4,150.06	32,378.76	10.54
28	27,700.89	5.70	44.50	622.45
29	488,733.87	3,293.75	25,697.85	19.02
30	274,075.84	1,461.41	11,401.92	24.04
31	304,869.05	996.19	7,772.28	39.23
32	269,065.96	4,651.95	36,294.50	7.41
33	102,060.22	921.88	7,192.49	14.19
34	1,689,484.70	7,505.34	58,556.69	28.85
35	820,034.68	75.60	589.87	1,390.20
Totals:	$17,096,351.00	----------	$1,041,550.82	Average: $16.41

* Pedernales River Watershed