# *Nueces River Watershed*

## *Brush Control Planning, Assessment, and Feasibility Study*

***Prepared for:***

**Texas State Soil and Water Conservation Board**

***Prepared by:***

**HDR Engineering, Inc.**

***In association with:***

**Texas A&M University**

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# *Section 1*
# *Introduction*

This report is one of eight prepared under funding from the 1998–1999 Texas Legislature to study the effects of brush removal on water yield in eight watersheds. The watersheds studied are the Canadian River above Lake Meredith, Wichita River above Lake Kemp, Upper Colorado River above Lake Ivie, Concho River, Pedernales River, the watersheds above the Edwards Aquifer, the Frio River above Choke Canyon Reservoir, and the Nueces River above Lake Corpus Christi (not including the Frio and Atascosa Rivers), which is this report. The impetus for this series of studies was a modeling study of the North Concho River watershed (Upper Colorado River Authority, 1998).

The recognition of decreased streamflows coupled with increased brush coverage in the North Concho River in recent decades suggested the possibility of a correlation. During the last 35 years, streamflow on the North Concho River has decreased to less than 22 percent of that of the previous 35 years, even though average annual rainfall has increased slightly in the same period. The North Concho River and its tributaries have ceased to have perennial continuous flow. The North Concho River report concluded that brush infestation had directly influenced reductions in streamflow. The report estimated the costs of controlling brush and concluded that, through brush control, streamflow could increase, groundwater supplies can be enhanced, and relatively inexpensive water supplies were possible.

The method used for determining whether a relationship between brush proliferation and decreasing streamflow exists involves statistical analysis for identification of any trends in rainfall and runoff (on a per unit of rainfall basis) for selected watersheds. Runoff per unit rainfall or percent runoff measures the response of a watershed to rainfall and effectively normalizes highly variable runoff records for many years and many watersheds thereby allowing for equitable comparisons.

A significant change in the relationship between the runoff and rainfall over time may be indicative of a change that has occurred in a watershed. An increase in runoff per unit rainfall concomitant with observed brush proliferation over time generally does not support the hypothesis that brush proliferation has reduced yield (runoff) at the watershed level. An observed decrease in runoff per unit rainfall concomitant with brush proliferation tends to support the hypothesis that brush proliferation has reduced yield. However, further investigation is warranted because there are other factors, such as groundwater level decline, stock pond development, and land management practices that could have a similar effect. Identification of increasing trends in runoff per unit rainfall may eliminate some watersheds from further investigation. On the other hand, identification of decreasing trends in runoff per unit rainfall in some watersheds may provide support for further investigation of the causes of decreasing runoff. Such investigations may include more detailed brush control studies.

Simulations of streamflow resulting from brush control using the SWAT model were made for all sub-watersheds in the Edwards Aquifer Watershed using the assumptions and data described in Section 6 of this report. However, the only water supply quantities and costs reported on the Executive Summary (Section 2) are those for sub-watersheds in which there is either a clear decrease in runoff or some uncertainty about these results as depicted in Section 5. Appendix A provides background information on the hydrologic simulation model and Appendix B provides background information on the costs used in Section 7.

State and federal agencies have cooperated and assisted one another to undertake this comprehensive study. These include the Nueces River Authority, the Edwards Aquifer Authority, Texas A&M Research and Extension Center, the Texas State Soil and Water Conservation Board, the Blackland Research Center, and the USDA Natural Resources Conservation Service. This assessment will determine whether brush control has a role in enhancing potential water yields and, if so, it will provide the people of Texas with means, procedures, and recommendations of how to recapture and utilize water, now consumed by brush, for increased public benefit on an entire watershed.

# Section 2
# Executive Summary

This report presents the background information, technical analyses, and findings regarding the potential to increase water yield through brush control. The background information includes a general description of the watershed in Section 3 and a discussion of historical considerations in Section 4 along with the background hydrological data in Section 5. Section 6 describes the hydrological simulations which estimate runoff due to brush control. Section 7 uses the results of regional hydrologic models completed by Texas A&M University to estimate costs of additional water supplies that might be created through brush control programs. Appendix A and Appendix B contain the background information on hydrological simulations and costs of brush control, respectively.

The Nueces River originates in Edwards and Real Counties as a spring-fed stream and flows into Nueces Bay near Corpus Christi after a journey of more than 400 stream miles. In the portion of the river located above the Balcones Escarpment, it flows through canyons until it enters the Coastal Plain in Uvalde County. For the purposes of this study, the area represented by the Nueces River Watershed includes portions of the following counties: Edwards, Kinney, Real, Uvalde, Maverick, Zavala, Dimmit, Webb, La Salle, Duval, and McMullen. Although the Frio and Atascosa Rivers are major tributaries of the Nueces, they are not included in the Nueces River Watershed for this report. The watershed covers approximately 8,100 square miles above Tilden, mostly through the natural region known as the South Texas Brush Country, and is more than 99 percent rural with the rural area consisting of approximately 14 percent crops, 9 percent rangeland, and 77 percent heavy brush and forest.

Vegetation in the watershed is characterized by the two major regions of Texas that the river crosses—the Edwards Plateau and the South Texas Plains. The Edwards Plateau soils are typically thin and calcareous. The Balcones Escarpment distinctly divides the Edwards Plateau from the South Texas Plains, which is the origin and north part of the Nueces River Watershed. Live oak, shinnery oak, cedar, and mesquite are the dominant woody plants. Woody plants predominate over forage plants in this region. Grasses include tall grasses along rock outcrops and midgrasses and shortgrasses on the shallow, drier meadows. Tall grasses include bluestem and switchgrass, and shorter grasses include sideoats grama, buffalograss, and Texas grama. The

South Texas Plains includes the Brush Country, which covers several counties in the watershed. This area is level to rolling. Upland soils include clayey, loamy, and sandy soils that typically overlay firm clayey soils. Bottom soils are calcareous silt loams and clayey alluvial soils. Mesquite, small live and post oak, prickly pear cactus, and other brush are commonly dense in this region.

Going back to some of the earliest written accounts of the Nueces River Watershed, mesquite, oak, cedar, prickly pear, and other brushland plants were observed throughout the region. Some accounts even described rather dense concentrations of trees and brush. Unlike some watersheds in the state where there are more dramatic changes from accounts detailing no growths of brush to widespread growths, in the Nueces River Watershed the changes have been subtler. The difference between earlier descriptions (1860–1939) and those of the mid-1900s addresses the relative coverage of grasslands, and these coverages are difficult, if not impossible, to quantify. As stated early in this section, if the observer has no means of confirming the general description of a region by using aerial, GIS, or other tools we typically have today, there is always a question about the validity of the observation. However, two general conclusions were made for the purpose of this study.

The first conclusion is the change in descriptions regarding the relative importance of grasslands as a major feature in the landscape. It does seem clear that earlier accounts characterize grasses and their coverage more than woody plants in many areas of the watershed. The second conclusion is the increasing number of accounts regarding a concern about the loss of grasslands to brush country. These conclusions support the belief that the vegetation has changed over time, but perhaps not as dramatically as some other watersheds in the state.

The hydrology of the watershed is influenced by topography which in the upper portion of the basin is steep. This region of the Hill Country encompasses the Balcones Escarpment or uplift to the Edwards Plateau and is characterized by steep, arid terrain. The hills, cliffs, crevasses, exposed rock, and clay soils in this area cause rapid runoff. During large storm events, rainfall rapidly flows to streams and washes, sometimes resulting in flashfloods. Due to the terrain of the Hill Country and its impact on runoff, vegetation has relatively little influence over flash flooding. However, vegetation in the Hill Country can have a significant influence on runoff due to interception of rainfall by cedar canopy. Downstream of the Balcones fault zone, the land is not as steep or hilly and tends to flatten out as the river flows southward and eastward.

It is these areas with less dramatic topography in which vegetation may have a greater influence on runoff.

The Nueces River watershed crosses four major aquifer recharge zones including the Edwards, Carrizo-Wilcox, Queen City-Bigford, and Sparta-Laredo. The most significant aquifer outcrop or recharge zone spanning the Nueces River watershed is the Edwards Aquifer recharge zone. Streams crossing this recharge zone lose a significant portion of their flow through faults and solution cavities in the limestone formations. At the Edwards Aquifer recharge zone, about 90,500 acft/yr enters the aquifer from the Nueces River and its tributaries.

Two streamflow gages in the Nueces River Basin within the study area started recording in 1923 on the Nueces River at Laguna and Cotulla. Since that time, numerous stream and precipitation gages have been established throughout the basin. The periods of record and location descriptions for each of the five long-term streamflow gages considered herein are listed in Table 2-1.

Precipitation or rainfall gages provide information for specific locations in the basin. To better compare the rainfall data to streamflow data, the basin was divided into sub-basins according to the streamflow gage locations and average rainfall over a particular sub-basin, or areal precipitation, has been calculated. Areal precipitation for each of the five watersheds considered herein was calculated in the course of earlier studies sponsored by the Nueces River Authority and the City of Corpus Christi.

***Table 2-1. Summary of Streamflow Gages Used in this Study***

| ***USGS Gage #*** | ***Location*** | ***Drainage Area (sq. mi.)*** | ***Period of Record*** |
|---|---|---|---|
| 08190000 | Nueces River at Laguna | 737 | 10/1923 – 12/1996 |
| 08192000 | Nueces River at Uvalde | 1,861 | 10/1927 – 12/1996 |
| 08193000 | Nueces River at Asherton | 4,082 | 10/1939 – 12/1996 |
| 08194000 | Nueces River at Cotulla | 5,171 | 11/1923 – 12/1996 |
| 08194500 | Nueces River at Tilden | 8,093 | 12/1942 – 12/1996 |

The statistical tests applied to historical annual rainfall and runoff per unit rainfall include the non-parametric Kendall Tau test, and linear regression and sample partitioning, which may be classified as parametric tests. Sample partitioning, in this case, simply involves subdivision of the available historical record into halves so that the means and variances from the earlier and later sub-periods can be compared to one another. Assessment of the statistical significance of differences in sub-period means and variances was accomplished using standard t-tests and F-tests, respectively. Similarly the statistical significance of the slope of a trendline obtained by linear regression of annual rainfall or runoff per unit rainfall versus time was evaluated using the t-test. Statistical significance is assumed at the 90 percent confidence level in this study.

Significant increases in annual rainfall are indicated for the watersheds in the headwaters of the Nueces River Basin. More specifically, the Nueces River at Laguna (USGS #08190000) indicates an increasing trend in rainfall that cannot be rejected at the 90 percent confidence level. This headwater area is in the Hill Country upstream of the outcrop of the Edwards Aquifer.

Additional long-term (1916–1996) statistical analysis of areal precipitation for Hill Country sub-basins, however, does not support the short-term indications of increasing rainfall. Nevertheless, further research into the characteristics of Hill Country rainfall in terms of intensity, duration, and frequency as they vary with time may be warranted.

The watersheds above the Nueces River at Laguna (USGS #08190000) and Nueces River at Uvalde (USGS #08192000) demonstrate increasing trends in the ratio of runoff per unit rainfall that cannot be rejected at the 90 percent confidence level. Further investigation based on modified Soil Conservation Service curve number procedures indicates that increased runoff per unit rainfall may be explained by increased rainfall during the latter time periods. Most importantly, however, none of the Hill Country watersheds considered in this study exhibits any indications of decreasing annual runoff per unit rainfall with time.

Three watersheds within the Nueces River Basin exhibit apparent decreases in runoff per unit rainfall over time. These watersheds include the lower portion of the Nueces River Basin between the Nueces River at Uvalde (USGS #08192000) and Asherton (USGS #08193000), between the Nueces River at Asherton (USGS #08193000) and Cotulla (USGS #08194000), and between the Nueces River at Cotulla (USGS #08194000) and Tilden (USGS #08194500). These watersheds encompass approximately 6,232 square miles, or about 77 percent of the Nueces River Basin in this study area. In addition to brush proliferation, pumpage from the Carrizo Aquifer may be affecting observed runoff per unit rainfall in these subwatersheds.

Potential sites for brush control are those sites where observations and statistical analyses indicate decreasing runoff relative to rainfall. The sites identified in this section are sub-basins that should be considered in future studies. Physical systems are very complex and subject to the influences of many factors. These factors may affect each other in ways that are not historically or currently measured. The nature of explaining trends in physical systems is to continue to identify and quantify sources and sinks in the system. In this study, rainfall is the primary source, streamflow (runoff per unit rainfall) is the main variable of concern, and brush is the main sink considered. However, the question still remains, "Is brush proliferation (alone) causing observed changes in runoff per unit rainfall?"

Of the five sub-basins considered in the Nueces River Basin, the sub-basins between the streamflow gages at Uvalde (USGS #08192000) and Asherton (USGS #08193000), Asherton (USGS #08193000) and Cotulla (USGS #08194000), and Cotulla (USGS #08194000) and Tilden (USGS #08194500) are the most promising for brush control. Analyses of runoff as a percentage of rainfall indicate that there are significant decreasing trends in these sub-basins. Possible sinks in these three sub-basins include not only brush proliferation, but also pumpage from and recharge to the Carrizo Aquifer, small reservoir (stock tank) development, and changes in land management practices with time. Further investigation of these sub-basins may more precisely determine the causes of apparent changes in runoff.

The SWAT model simulated streamflow for the watersheds that might warrant further consideration for brush control. Using sub-basins 103-9,12,14-17 and 104-1 to represent the watershed between the USGS gaging stations at Uvalde (USGS #08192000) and Asherton (USGS #08193000), the SWAT model estimated an average increase of about 32,160 acre-feet per year of streamflow that might be obtained through brush control. Using sub-basins 103-2-5,10,11,22 and 105-22 to represent the watershed between the USGS gaging stations at Asherton (USGS #08193000) and Cotulla (USGS #08194000), the SWAT model estimated an average increase of about 38,051 acre-feet per year of streamflow that might be obtained through brush control. Using sub-basins 105-3,6,7,9,10,12,13,18,19,20,22,23, and 24 to represent the watershed between the USGS gaging stations at Cotulla (USGS #08194000) and Tilden (USGS #08194500), the SWAT model estimated an average increase of about 123,830 acre-feet per year of streamflow that might be obtained through brush control.

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 10-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. 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 percent discount rate).

The cost of added water thus determined averages about $73 per acre-foot for the sub-watersheds evaluated between USGS stations at Uvalde (USGS #08192000) and Asherton (USGS #08193000). The cost of added water thus determined averages about $58 per acre-foot (acft) for the sub-watersheds evaluated between USGS stations at Asherton (USGS #08193000) and Cotulla (USGS #08194000). The cost of added water thus determined averages about $42 per acre-foot (acft) for the sub-watersheds evaluated between USGS stations at Cotulla (USGS #08194000) and Tilden (USGS #08194500).

Although the costs per acft of water supply (unit cost) might seem particularly attractive as compared to other water supply alternatives in the region, it is understood that the water supply "yields" described above do not represent firm yield or dependable water supply continuously available in a drought of record. Therefore, the comparison of these unit cost figures to those for other alternatives (e.g., unit cost information for numerous water supply options presented in the South Central Regional Water Plan[1] is based on firm, dependable water supply available during a report of the drought of record.) cannot be made directly. A direct comparison would involve numerous considerations:

- Validation that there has been a decrease in streamflow over the period of hydrologic record.

[1] HDR Engineering, Inc., et. al., "South Central Texas Regional Water Plan," South Central Texas Regional Water Planning Group, San Antonio River Authority, Texas Water Development Board, January 2001.

- Confirmation that the decrease in streamflow was not due to factors other than increasing brush coverage such as groundwater level decline, stock pond development, and land management practices.
- Confirmation that the SWAT computer simulation accurately reflects the increased runoff under the conditions present in the specific watersheds.
- Determination of which landowners would commit to participate in brush control, including long-term maintenance in the manner prescribed by the inputs into the model.
- Validation that the unit costs used represent actual costs for the specific land on which brush control would be practiced.
- Modification of the project life of brush control programs (10 years) to better approximate competing water supply alternatives, which is typically 50 years.
- Quantification of changes in firm yield with due consideration of drought hydrology, water rights, and existing natural or man-made features. For example, if brush control resulted in a long-term average increase of 100,000 acft/yr in streamflow entering Lake Corpus Christi, but an average increase of only 10,000 acft/yr during the most severe drought on record, the actual increase in firm yield could be only 10,000 acft/yr (neglecting evaporation). The unit cost for increased dependable water supply comparable to other alternatives, therefore, would be approximately ten times greater than a unit cost simply based on the long-term average increase in streamflow entering Lake Corpus Christi.
- Consideration of the fact that increased streamflow during drought as a result of brush control above Asherton, Cotulla, and/or Tilden would be subject to substantial channel losses prior to arriving at downstream locations such as Lake Corpus Christi. These channel losses limit the effectiveness of brush control in positively affecting the reliability of downstream water rights and firm yield of downstream reservoirs.

# Section 3
# Description of the Watershed

## 3.1 Area Comprising the Nueces River Watershed

The Nueces River originates in Edwards County as a spring-fed stream and flows into Nueces Bay near Corpus Christi after a journey of 315 stream miles. In the portion of the river located in the Balcones Escarpment, it flows through canyons until it enters the Coastal Plain in northern Uvalde County. It was named by the Spanish explorer Alonso de Leon in 1689, although earlier Cabeza de Vaca had documented a "Rio de las Nueces (roughly, River of Nuts)," which was probably the same river. The Nueces River has a place in history as the boundary between the Mexican states of Texas and Nuevo Santander prior to Texas' independence. After Texas gained independence from Mexico in 1836, both countries claimed ownership of the land between the Nueces and Rio Grande Rivers. This dispute was not settled until the Treaty of Guadalupe Hidalgo in 1848, which established the Rio Grande as the boundary between Mexico and the United States.

For the purposes of this study, the area represented by the Nueces River Watershed includes portions of the following counties: Edwards, Kinney, Real, Uvalde, Maverick, Zavala, Dimmit, Webb, La Salle, Duval, and McMullen (Figure 3-1). Although the Frio and Atascosa Rivers are major tributaries of the Nueces, they are not included in the Nueces River Watershed for this report. The watershed covers approximately 10,300 square miles, mostly through the natural region known as the South Texas Brush Country (Figure 3-2) and is more than 99 percent rural with the rural area consisting of approximately 14 percent crops, 9 percent rangeland, and 77 percent heavy brush and forest.

## 3.2 Climate

The climate is warm and dry and is similar among the various counties of the watershed. Table 3-1 shows that annual rainfall, average minimum January air temperature, average maximum July air temperature, and number of days of the growing season are very consistent across the watershed. The standard deviation for each climate parameter shown is less than 10 percent of the mean. Extreme cold weather including snow, ice, sleet, and prolonged sub-freezing air temperatures is very rare. The watershed can, however, be influenced by the


*Figure 3-1. Location Map*

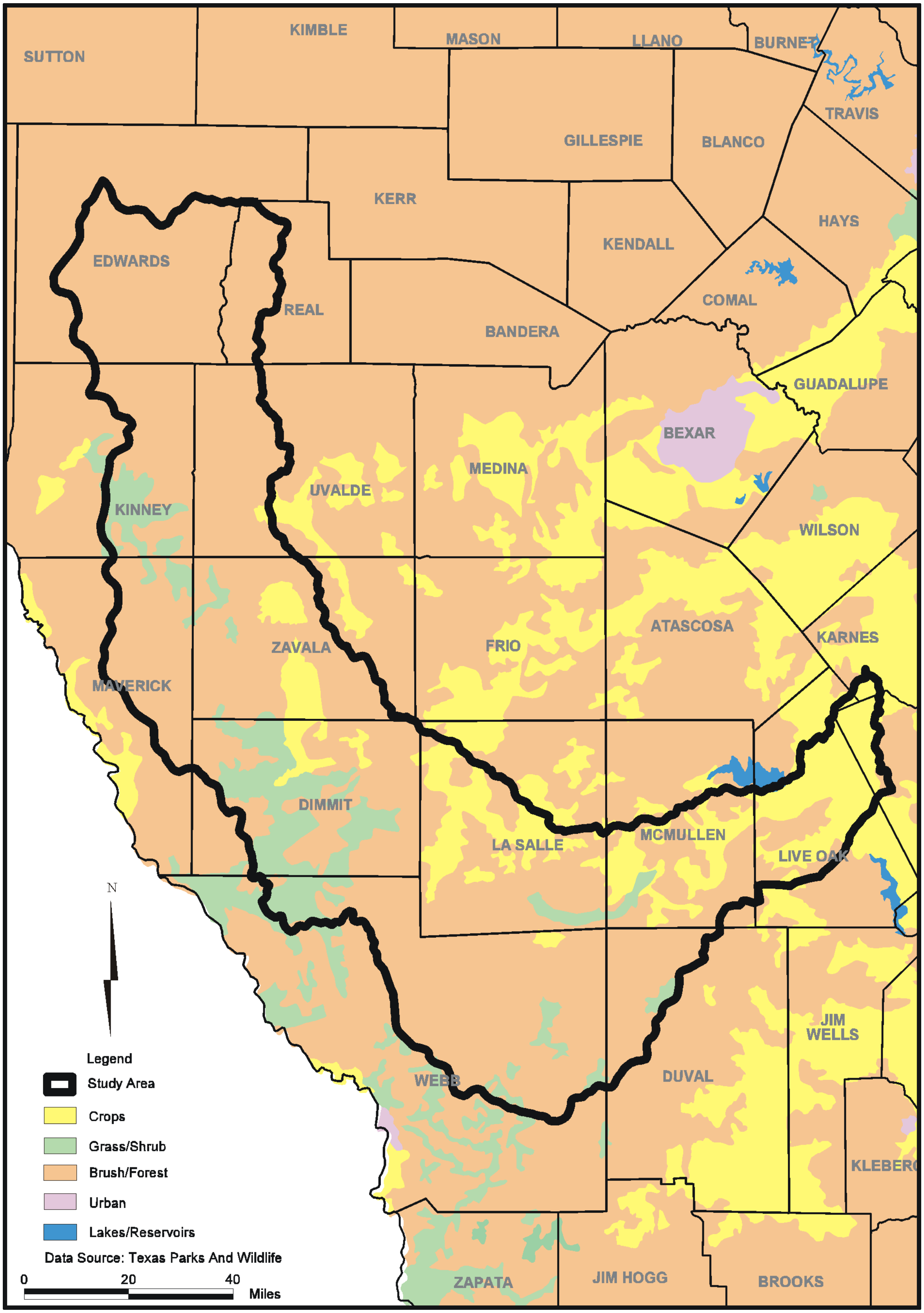


*Figure 3-2. Vegetation*

precipitation from tropical storms and hurricanes. The extreme rainfall events of record are nearly all attributed to such storms.

**Table 3-1. Climate of Nueces River Watershed Counties**

| County | Annual Rainfall (in.) | Jan. Avg. Min. Temp. (F) | July Avg. Max. Temp (F) | Growing Season (days) |
|---|---|---|---|---|
| Dimmit | 21.5 | 41 | 100 | 290 |
| Duval | 24.4 | 41 | 97 | 298 |
| Edwards | 23.6 | 35 | 95 | 250 |
| Kinney | 21.1 | 36 | 96 | 270 |
| La Salle | 21.6 | 42 | 99 | 288 |
| Maverick | 21 | 38 | 99 | 285 |
| McMullen | 24.4 | 39 | 97 | 291 |
| Real | 25.7 | 31 | 92 | 236 |
| Uvalde | 24.1 | 37 | 97 | 255 |
| Webb | 20.1 | 45 | 99 | 322 |
| Zavala | 21.3 | 41 | 98 | 280 |
| Mean | 22.6 | 38.7 | 97.2 | 278.6 |
| Standard Deviation | 1.9 | 3.9 | 2.3 | 24.4 |
| Source: *Texas Almanac*, 1992-3. | | | | |

### 3.3 Physiography

The watershed, for the purposes of this report, extends from the Edwards Plateau region to near the Gulf Coast at elevation 2,410 feet above mean sea level (msl) to Lake Corpus Christi whose spillway elevation is 88 feet above msl. The terrain varies from that found in the Hill Country of Texas to that of the vast South Texas Brush Country. The Edwards Plateau portion (Edwards and Real Counties) is characterized by hilly, rocky terrain, and thin soils. Further downstream and including the remainder of the counties comprising the watershed, the terrain is typical of the South Texas Brush Country, which is characterized by flat to gently rolling terrain. Slopes in the watershed range from 0 to 10 percent, as a broad range.

Surface water features are principally the Nueces River and its tributaries. Lake Corpus Christi and Choke Canyon Reservoir are the only large reservoirs in the Nueces River system, although there are several small, local reservoirs located throughout the watershed on Nueces

River tributaries. For the purposes of this report, Choke Canyon Reservoir is not included in the study area. Although spring-fed creeks are prevalent in the Edwards Aquifer, most streams in the watershed are wet-weather streams, often measuring zero discharge during dry periods.

### *3.4 Geology and Soils*

The watershed extends across three major geologic zones from north to south—Cretaceous (Comanche and Gulf series), Eocene, and Cenozoic. The upper segment of the watershed is underlain by Cretaceous limestone forming the Edwards Plateau. South of the Edwards Escarpment are Cretaceous chalk, clay, and limestone beds which are younger than Edwards formations. The entire region, including the Nueces watershed dips to the southeast. Upland soils are dark, calcareous to slightly acid clays, loams, and sands. Bottomlands are brown to gray, calcareous, alluvial soils. An important part of the geologic history of the Balcones Escarpment and the downstream portions of the Nueces River Watershed occurred between 10 and 20 million years ago.

The Edwards Plateau region is largely composed of Cretaceous rocks that were marine sandstones, limestones, dolomites, and shales which were deposited in an ancient ocean below sea level about 100 million years ago. One geological theory is that the Edwards Plateau was uplifted along the Balcones Fault Zone as part of a regional uplift across the western United States during the Miocene time, about 10 to 20 million years ago. The Cretaceous rocks were uplifted 2,000 feet with little deformity, as evidenced by the relative levelness of the rock strata. The Balcones Escarpment is the flat terrain above the Balcones fault line through which softer rock (to the southeast) eroded at a faster rate than rock above the fault line. Water erosion has continually worked to flatten the Plateau and is now estimated to be about 50 percent complete with the process. This is demonstrated by the deep erosion of the Hill Country versus the relative uneroded western half of the plateau, which remains higher and flatter. Interaction of water has also shaped the region in ways other than surface erosion.

The geographical proximity of the Balcones Fault Zone and the Cretaceous limestones of the Edwards Plateau resulted in the formation of the Edwards Aquifer. Since the downstream rocks were not uplifted, the same Calcareous formations that characterize the western part of the Edwards Plateau are found in the Nueces River Watershed below the Escarpment. Dissolving of limestone and dolomite along the faulting has created the karst aquifer, which contains waterbearing formations ranging in size from a few millimeters to large honeycombed structures. The same dissolution of stone has also created openings (solution holes, fractures, and joints) from the surface into the aquifer. These openings form the Edwards Aquifer recharge zone in outcrops that cross-streams. Thus, in the Nueces and its tributaries there are places where streamflow disappears for a distance because it has entered the aquifer through the surface openings. It is estimated that about 75 percent of the Edwards Aquifer recharge is from surface streams.

Another feature of the upper watershed of the Nueces River in the escarpment is that the dissolution of limestone in the Plateau rocks allows for springflow in the downstream (lower) watershed. This is another key feature of the geology of the region due to the elevated Cretaceous limestone beds channeling water from rainfall and streamflow into natural surface outlets, which form the headwaters of the tributary creeks of the Nueces River.

## 3.5 Water Resources

The Nueces River system, excluding the Frio and Atascosa Rivers and the Nueces downstream from Wesley Seale dam, defines the surface water resources of the watershed. The Edwards and Carrizo aquifers define the groundwater resources. As presented earlier, annual rainfall in the semi-arid basin averages 23 inches. Rainfall in the basin is highly variable in magnitude and frequency, as most significant rainfall originates from localized convective thunderstorms or from tropical storms and hurricanes covering wider areas. The sporadic nature of rainfall in the basin results in short periods of high flows in the streams and rivers, preceded and followed by long periods of low or zero flows. This intermittent, variable nature of streamflow in the Nueces River Basin significantly affects water availability.

The watershed is part of a highly complex hydrologic environment with active surface and groundwater interaction. Streams throughout the basin cross several major aquifer outcrops or recharge zones. The most significant of these is the Edwards Aquifer recharge zone, where an average of 334,000 acre-feet per year (acft/yr) entered the aquifer from the Nueces and other rivers which cross the recharge zone in the period 1934 to 1996. Other major aquifer outcrops include the Carrizo-Wilcox, Queen City-Bigford, Sparta-Laredo, and Gulf Coast-Goliad Sand.

### 3.5.1 Surface Water

Land use in the Nueces River Basin is predominately related to agriculture, with 10 percent classified as cropland, 6 percent pastureland, and 84 percent rangeland. The largest municipality located within the basin is the City of Uvalde, with a population of about 16,650. The City of Corpus Christi, located in the Nueces-Rio Grande Coastal Basin, is the single largest user of water from the Nueces River Basin. The City of Corpus Christi operates two large reservoirs: Choke Canyon Reservoir (on the Frio River upstream of Three Rivers) with a permitted capacity of 700,000 acft and Lake Corpus Christi (on the Nueces River near Mathis) with a permitted capacity of 300,000 acft. The City of Corpus Christi operates Choke Canyon Reservoir and Lake Corpus Christi as a system in order to supply water to retail and wholesale customers within its regional service area. A population of approximately 400,000 is provided water supply from these reservoirs. The majority of the water supplied by these reservoirs is released and diverted downstream of Lake Corpus Christi at the Calallen Diversion Dam near Calallen. The next largest permitted capacity of any reservoir operated for water supply in the basin is the Upper Nueces Reservoir, owned by the Zavala-Dimmit Counties Water Improvement District No. 1, with a permitted capacity of 4,010 acft.

Groundwater/surface water interactions play a significant role in the Nueces River Basin. The Nueces River Basin is traversed by the outcrops of seven major aquifers. The most significant of these is the Edwards Aquifer, a highly porous, fractured limestone formation outcropping in Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties. The formation is so efficient in recharging the aquifer that only the Nueces River sustains a minimal base flow across the outcrop. Other streams in the Nueces River Basin such as the Frio and Sabinal Rivers are very often dry at the downstream edge of the outcrop. Recharge of the Edwards Aquifer in the Nueces River Basin averaged an estimated 334,400 acft/yr during the 1934 to 1996 period.

With the exception of a few springs, interactions between groundwater and surface water in the Nueces River Basin occur primarily in form of recharge in outcrop areas where surface waters may percolate directly into the aquifer. When this recharge occurs in a defined stream, it becomes one component of a more generalized depletion of surface water flows referenced herein as “channel losses.” Channel losses may include aquifer recharge, bank storage, over-bank flooding, evaporation, and transpiration by riparian vegetation. Channel losses can be quite significant and become most evident between streamflow gaging stations when intervening runoff is minimal. For example, less than 15 percent of the measured streamflow in the Nueces River at Uvalde (USGS #08192000) resulting from a major storm above Uvalde in October 1996 arrived downstream at Three Rivers (USGS #08210000). Hence, consideration of channel losses and aquifer recharge are essential components of accurate natural streamflow development and water availability modeling in the Nueces River Watershed.

In 1996, the Regional Assessment of Water Quality in the Nueces River Basin found that the water quality is generally good. However, there are some areas of concern. A few stream segments in the Nueces River Basin had elevated levels of dissolved solids, nutrients, and fecal coliforms (Table 3-2). Water quality in public water supply systems has been described as good.

### 3.5.2 Groundwater

There are two major aquifers that lie beneath the region, the Carrizo-Wilcox Aquifer and the Edwards Aquifer (Figure 3-3). The Carrizo-Wilcox Aquifer contains moderate to large amounts of either fresh or slightly saline water. Slightly saline water is defined as water that contains 1,000 to 3,000 milligrams per liter of dissolved solids. Although this aquifer reaches from the Rio Grande River north into Arkansas, it only underlies parts of McMullen and Live Oak counties within the Coastal Bend Region. In this downdip portion of the Carrizo-Wilcox Aquifer, the water is softer, hotter (140 degrees Fahrenheit), and contains more dissolved solids.

**Table 3-2. Water Quality Concerns by Stream Segment**

| ***Surface Water Resource (Stream Segment Number)*** | ***Water Quality Concerns (1996 Assessment for Clean Rivers Program)*** |
|---|---|
| Choke Canyon Reservoir *(2116)* | Nutrients, Dissolved Solids, Fecal Coliforms |
| Nueces/Lower Frio River *(2106)* | Fecal Coliforms |
| Lake Corpus Christi *(2103)* | Nutrients |
| Nueces River Below Lake Corpus Christi *(2102)* | Nutrients, Fecal Coliforms |
| Nueces River Tidal *(2101)* | None |

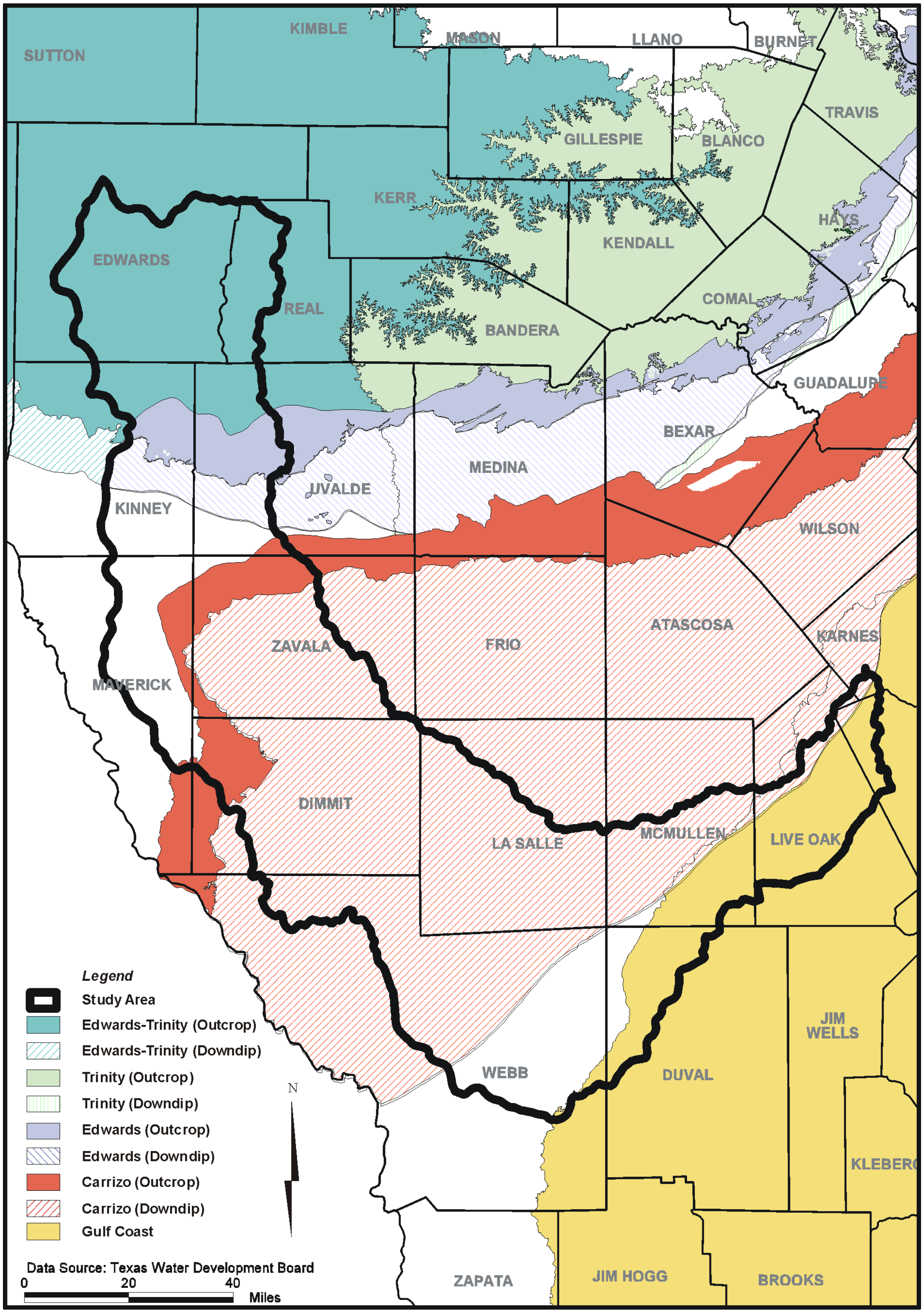


***Figure 3-3. Aquifers***

The Edwards Aquifer has been called "…a long, narrow conduit through which water moves underground across parts of South-Central Texas."[1] The aquifer is approximately 175 miles long and varies in width from about 5 to 30 miles. The aquifer exists due to its limestone composition and its proximity to the Balcones Fault Zone, which is a series of close, parallel faults arching across South-Central Texas. Because the general drainage pattern is towards the Gulf Coast to the southeast, surface water crossing the fault zone has dissolved extensive areas of the aquifer as it enters the limestone formations through the faults. The resultant karst aquifer is replenished through the natural recharge of surface water from the Nueces River and other streams and rivers that cross the fault zone. This characteristic loss of streamflow in the Nueces River Watershed is accounted for in the naturalized flows used in the hydrology section of this report.

The Edwards Aquifer ranges in thickness from about 400 feet to about 900 feet. Yields of large-capacity wells average about 900 gallons per minute (gpm). The Carrizo is 3,000 feet thick in places and produces 700 gpm from large-capacity wells.

### 3.6 Resource Aspects

While the watershed is well known for its valuable mineral resources, especially oil and gas, the area is also rich and diverse in living natural resources. Ecosystems range from the South Texas Brush Country characterizing the inland portion of the Coastal Bend Region to the Edwards Plateau along the northern extent of the watershed. Because the watershed is located along many migratory flyways, birds comprise a major portion of the wildlife population of the area.

### 3.7 Vegetation

Vegetation in the watershed is characterized by the two major regions of Texas that the river crosses—the Edwards Plateau and the South Texas Plains. The Edwards Plateau soils are typically thin and calcareous. The Balcones Escarpment distinctly divides the Edwards Plateau from the South Texas Plains, which is the origin and north part of the Nueces River Watershed. Live oak, shinnery oak, cedar, and mesquite are the dominant woody plants. Woody plants

[1] Harden, Rollin W, "The Edwards Connection," The Edwards Aquifer—Underground River of Texas, Guadalupe-Blanco River Authority, 1988.

predominate over forage plants in this region. Grasses include tall grasses along rock outcrops and midgrasses and shortgrasses on the shallow, drier meadows. Tall grasses include bluestem and switchgrass and shorter grasses include sideoats grama, buffalograss, and Texas grama.

The South Texas Plains includes the Brush Country, which covers several counties in the watershed. This area is level to rolling. Upland soils include clayey, loamy, and sandy soils that typically overlay firm clayey soils. Bottom soils are calcareous silt loams and clayey alluvial soils. Mesquite, small live and post oak, prickly pear cactus, and other brush are commonly dense in this region.

# Section 4
# Historical Considerations

Mankind can learn about the past only through collecting information on natural phenomenon and human observations and applying our reasoning to reach valid conclusions about the past. This is the practice in the studies of geology, archaeology, anthropology, and history. The prehistoric humans left traces of their occupation, but no written records. The earliest Europeans who explored Texas provided written accounts of their experiences and observations. It is from fossils, sediments, and these and subsequent written accounts of the land, streams, flora, and fauna of Texas that researchers have suggested that the landscape changed over the course of time. In recent history, the pre-European landscape in this region of Texas is thought to be one of typical savannah, consisting of short and tall grasses, with intermittent brush and woody plant infestations limited to upper ravines and along watercourses. It has been suggested that this vegetation promoted the enhancement of rainfall runoff and deep drainage, which would contribute to streamflow and springflow, respectively.

Archeological findings and historical anecdotes presented in this section from earliest to most recent provide an insight into climate, vegetation, and land use. However, this information is not *prima facie* support for linking water yield to changes in land use for two reasons: (1) written accounts are limited geographically and in other ways such that it always remains questionable whether generalized patterns and characterizations can be discerned from such accounts; and (2) enhancing water yield through brush control is required to be a quantifiable and predictable science because, presumably, economic investments will be needed to effect the desired outcome. The information presented in the following section should be evaluated in terms of indirect evidence that, if climate is the same, there is more water available from grasslands than brushlands. Direct evidence, or correlation, of such would necessarily require quantification and predictability, neither of which can be ascertained from this information.

## 4.1 Paleo-Indian

Evidence of human habitation in the Edwards Plateau and surrounding areas of Texas dates to at least 11,000 years ago.[1] These humans were from the northeast Asian populations

[1] Hester, T. R, "Early Human Occupation along the Balcones Escarpment," The Balcones Escarpment, pp. 55-62, Geological Society of America, San Antonio, Texas, 1986.

that crossed to North America over a temporary land bridge in the Bering Strait during periods of glacial activity. They were hunter-gatherers, not agriculturists. Evidence of their activities as well as bones of large, extinct mammals have been found in caves and along streams in the southwest part of the Edwards Plateau dating to a period 11,000 to 9,000 years ago. Due to the glacial activity in North America at the time, it is very likely the climate in this part of Texas was cooler and wetter. As glaciers receded, the climate began a gradual change toward the warmer and drier weather we experience now. Pollen fossils dating from 7,000 to 4,000 years ago for this region demonstrate a decrease in tree pollen, and corresponding increase in grass pollen.[2] The drier climate favored expansion of the grasslands at the expense of forests.

Archeological investigations provide evidence that human habitation occurred in areas that were likely to have had a more permanent streamflow than present flow. For example, it is known that acorns were plentiful in the region and a principal source of fat in the human diet. However, it is believed that water was needed to process the acorns into a useable food supply (to remove tannic acids from the acorns),[3] and, thus, permanent water would have to have been reasonably convenient to those early humans. Archeologists use burned rock that has accumulated in large amounts to investigate sites where food processing like this would have occurred. Texas A&M University Research Station researchers found several in the region located far from permanent water supplies,[4] indicating that these streams are wet-weather streams only now. If convenient water sources were needed to process acorns, and the current sites of burned rock accumulations are far from such sources, it is reasonable to suggest that surface water circumstances may have been very different in past times. This could be the result of having more streamflow because of the greater presence of grasslands, or because of simply having a lot more precipitation that we currently experience.

Determining whether the Nueces River Watershed was mostly a grassland in prehistoric periods requires speculating on what is known about early humans and then comparing or contrasting that knowledge with other evidence, such as sediments, fossils, and other physical records. The more recent the time period, the more difficult it is to find this latter "hard"

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2 Bryant, V. M., "Pollen – Nature's Tiny Capsules of Information," Ancient Texans Rock Art and Lifeways along the Lower Pecos, pp. 50-55, Gulf Publishing Co., Houston, 1986.

3 Taylor, Charles, A., Jr., and Fred E. Smiens, "A History of Land Use of the Edwards Plateau and Its Effect on the Native Vegetation," 1994 Juniper Symposium, Texas A & M University Research Station at Sonora, Texas, April 14, 1994.

4 *Ibid*., page 2.

evidence to support or refute characterizations such as this. The period of the last 8,000 years is one of gradual drying and warming of the climate, but not much, if any, change in land use until the arrival of the Europeans. What is known is that the Indians, unlike the Europeans, did not develop intensive agriculture practices or domesticate wild animals such as the bison, but, rather, maintained their hunter-gatherer roots. As a result, the human population was limited by the food supply, which was the indigenous wildlife, and fruit and grain harvest. While there were herds of bison and other ruminants, they were not domesticated, and, therefore, suffered natural selection. Another fact is that wildfires were logically more frequent because Indians had no sophisticated means of fire control caused by lightning and careless use by humans. Also, they likely used fires at times for their own purposes (e.g., to hunt). Such frequent wildfires across an abundant, fuel-rich grassland would prevent the growth of large vegetation, thus keeping grasses as the predominant vegetation.

### *4.2 Spanish Influence*

The Spanish were the first Europeans known to explore and attempt to settle Texas. Their goal was to establish an empire for the advantage of Spain and the Catholic Church. Their goal necessarily implied that they would have a different perspective of what the land and other resources would be used for than their predecessors, the Indians. The earliest exploration was in 1519 when Alonso Alvarez de Pineda mapped the Gulf Coast. A later expedition lead by Francisco Vazquez de Coronado journeyed across the American Southwest in search of precious metals. His report to Spanish King Charles V recommended Spain not explore or settle what they called New Spain because his journey across the High Plains, Oklahoma, and Kansas was not promising in terms of the kind of natural resources Spain had hoped to exploit. The Spanish presence, though, made permanent and significant changes to how Texas developed, beginning with the introduction of the horse.

The first permanent change brought to Texas by the Spanish was the use of the horse. Historians suggest that the use of horses by the Spanish and the adoption of horses by the American Indians ultimately increased grazing, mobility, and opportunity for further agricultural changes, such as livestock ranching.[5] The horse allowed the Spanish to first explore the region.

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[5] *Ibid., page* 5.

The early written accounts of these explorations are useful in understanding what those observers saw in Texas.

Perhaps the earliest such account, although not in the Nueces River Watershed, was by the Spanish explorer Cabeza de Vaca (1490–1555) in the early 1530s. His account of the San Antonio River suggests there was plenty of water, but the landscape was not limited to grassland savanna. "Here there was plenty of drinking water from the clear streams and springs. And there were great meadows filled with ripe prickly-pear..."[6] As part of the Edwards Plateau region, the upper Nueces River Watershed may not have been strictly a grassland prairie, but rather contained large numbers of brush-like vegetation, such as the prickly pear. Another account in 1691 near San Antonio (Teran de los Rios Expedition) supports this idea. "Traveling across prairie country, the men saw huge herds of buffalo, an animal unknown to them in Mexico. Progress slowed when dense thickets of mesquite and cat claw were encountered."[7] Figure 4-1 shows the approximate route of the Teran Expedition across the region. As cautioned previously, the perspective of the observers in these early expeditions is a limited one, as can be surmised from Figure 4-1 when one considers just how much of the watershed the observer was able to see.

Spanish accounts of the Nueces River suggest water and larger vegetation were plentiful. An account of the Nueces River by the Basque-Larios Expedition on April 22, 1675: "The water is good. The country is well supplied with nuts and other food products, such as wild turkeys, sweet potatoes, buffalo,…fish… On both sides (of the river) are great bottoms; there is a luxuriance of plants, nuts,…wild grapes, good pasturage, a variety of birds and wild hens."[8] Later, during the Teran Expedition of 1691, "We crossed two ravines and stretches of timber and entered a region covered with mesquite. This lasted until we reached the banks of the (Nueces) river."(June 6, 1691)[9] On June 7, 1691, the Teran Expedition noted, "…we worked our way toward the east about two leagues through timber and big pecan tress, cutting a passage for the troops…The country was level and covered with mesquite and cat's claw."[10]

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[6] Warren, Betsy, "E*xplorers in Early Texas, p. 18, Hendrick-Long Publishing Co., Dallas, Texas, 1992.*

*7 Ibid., page 81.*

[8] Bolton, Herbert *Eugence*, "Spanish Exploration in the Southwest, 1542-1706, Barnes and Noble, New York, 1908.

[9] Hatcher, Mattie Austin, "The Expedition of Don Domingo Teran de los Rios into Texas," Preliminary Studies of the Texas Catholic Historical Society, Volume 1, No. 1.

[10] *Ibid.*, page 13.

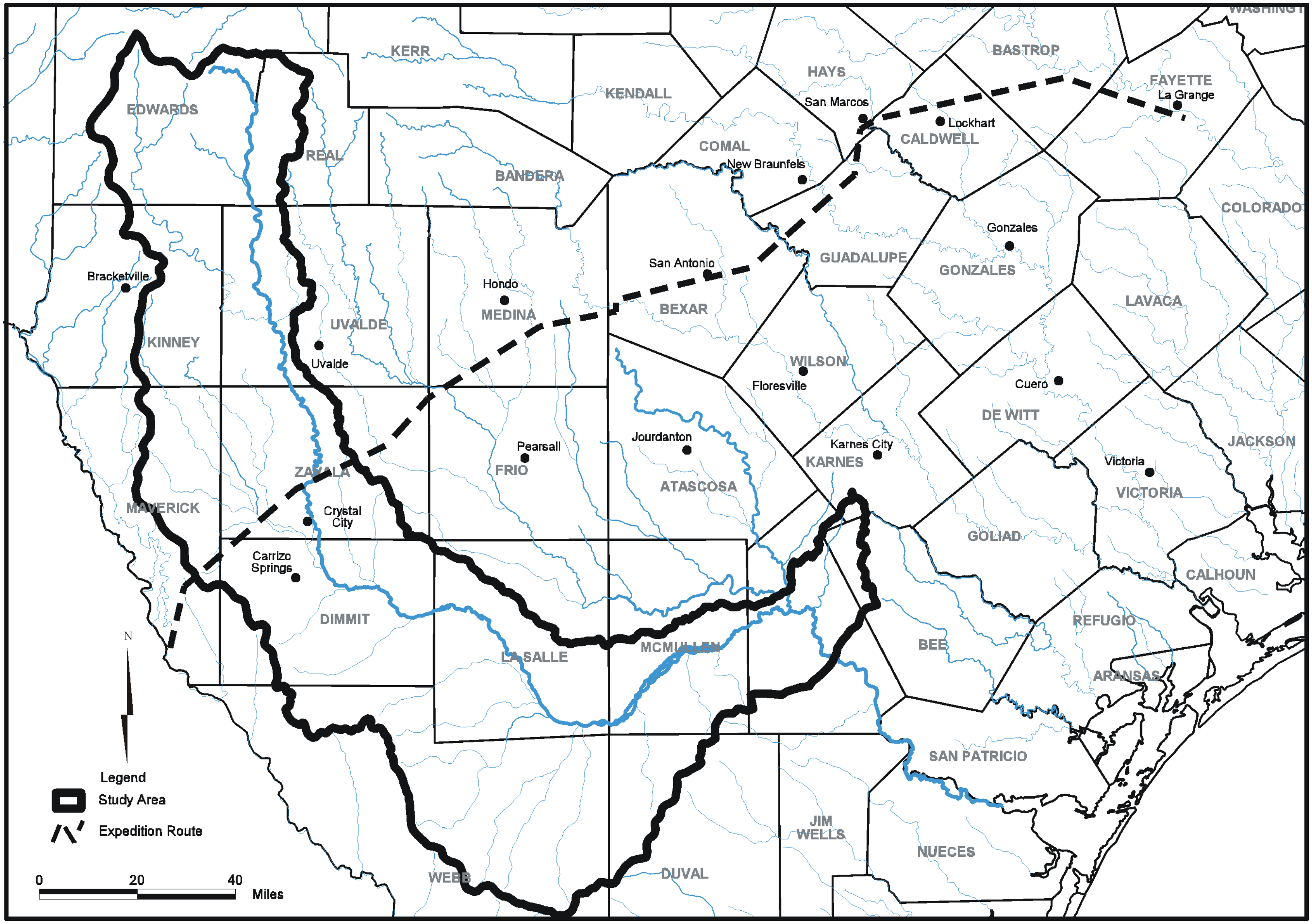


Figure 4-1. Governor Domingo Terán de los Ríos's 1691 - 1692 Expedition

The Aguayo Expedition in the early 1700s suggests more support for the existence of grassland savannas in its accounts. March 28, 1721 at Turkey Creek near the Nueces River, "…abundant water and pastureland; turkey, quail, rabbit and hares found the Aguayo Expedition (Figure 4-2) had to cross the river by a branch and dirt bridge…"[11] On March 29, 1721 at Tortuga Creek (between Nueces and Leona River east of what are now Crystal City and Carrizo Springs), "…abundant fish, water year round, pool surrounded by a large plain and pasture…found turkey, quail, and peacock…"[12] Tortuga Creek is not a flow-monitored stream, so comparison of recent flows to flows described above is not possible. However, there are several explanations of why Tortuga Creek would be seasonal now, but have "…water year round…" in 1721. The creek could have been spring-fed from the Carrizo Aquifer, which was not pumped in those times. It is also not known how the author determined that flow was permanent. It has been documented that some explorers embellished their observations deliberately for the purpose of funding a subsequent exploration, among other reasons.[13] The author may have only been there in the spring during very wet weather. If anything is clear from these few explorer observations of the Nueces River Watershed, it is that the landscape then had elements in common with the current landscape. The degree of prior brush coverage versus grassland is likely to be debated well into the future, but to say the region was mostly grassland appears to depend upon site-specific information. Obviously, at least some areas were mostly heavy brush and trees.

From the early 1500s until the late 1600s, Spanish interest in Texas was limited except for Catholic missionary involvement in the El Paso area. In 1685 the French, under the famous explorer La Salle, arrived in Matagorda Bay and built a fort near there. Even though Indians quickly destroyed it, the arrival of the French was a warning to the Spanish that another nation might try to colonize "their" land. In response two missions were established in 1690. The Camino Real (King's Highway) was built between these missions and San Antonio, which had become the Spanish capital of the territory. Throughout the 1700s there were additional French excursions, small increases in Spanish missionary activity and military presence, and continued widespread agitation from Indians.

[11] Santos, Richard G, "Aguayo Expedition into Texas, 1721," p. 28, Jenkins Publishing Co., Austin, Texas, 1981.
[12] *Ibid*., P. 28.
[13] Fehrenbach, T.R, "Lone Star: A History of Texas and the Texan," Wings Books, New York, 1968.

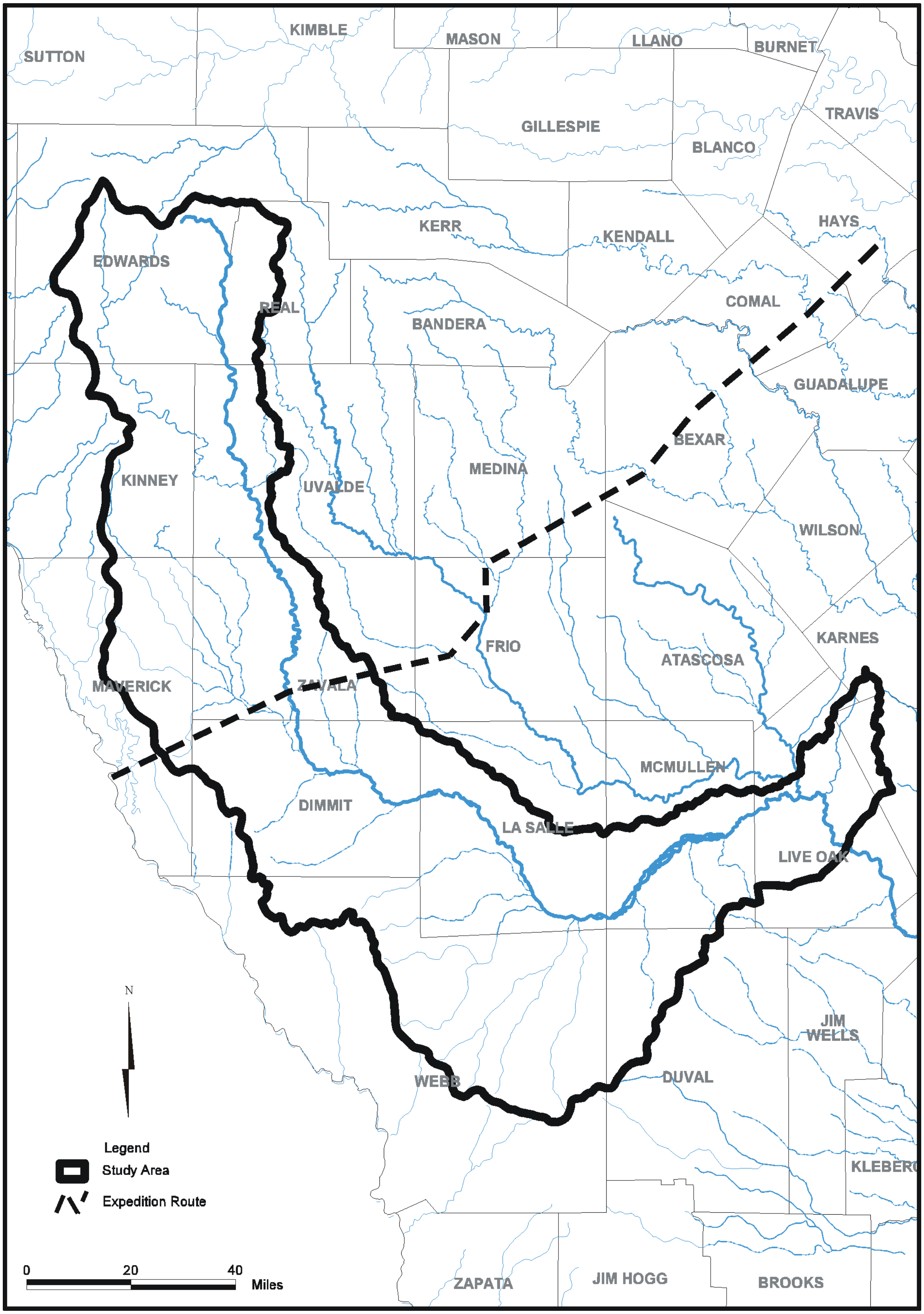


***Figure 4-2. Aguayo's Expedition 1721***

Major immigration into Texas, however, did not begin until Spain's control over Mexico began to weaken in the 1820s. Seeking to protect itself from Mexican dominance, the Spanish legislature opened all Spanish territories to foreigners. This action opened the way for additional European immigration, but this time from the United States. Mexico won independence from Spain in 1821, but allowed open immigration until 1830, by which time many thousands of new settlers from the United States had arrived, been granted estates, and had begun the movement toward Texas independence from Mexico, which happened in 1836. This brief history of the three centuries of Spanish presence in Texas connects the first European expeditions to the early 1800's when intensive agriculture arrived in Texas from the United States.

## 4.3 Rangeland History of the Watershed

Domesticated livestock ranching, as we know it, has been practiced in the Nueces River Watershed for over 150 years. Initially, there were open ranges where livestock roamed freely and followed existing water supplies before groundwater was made available. This section seeks to describe the observations of ranchers and others over three periods—about 1860 to 1900, 1901 to 1939, and 1940 to 1953.

### 4.3.1 1860 to 1900

Edwards County was described in 1860 in terms of water availability and vegetation. In 1860, running streams in the upper watershed of the Nueces River in Edwards County were identified as the following:

- East and Middle Fork of the Nueces,
- West Fork of the Frio River,
- South Llano River,
- Cedar Creek,
- Bull Head Creek, and
- Hackberry Creek.

Apparently the most common grass was mesquite grass and fruits included wild grapes, cherries, and pecans.[14]

An old *Texas Almanac* from 1873 described grasses in Webb County near the Nueces River, "There are two kinds of grasses here—the mesquite grass, which is the better of the two, and is a coarse grass common to prairie counties, and the Bermuda grass, which does well, spreads rapidly and soon kills out weeds and other grasses."[15]

Later, the same *Almanac* described changes in prairie fires. "The prairie fires that formerly so often swept over the western plains, destroying every shrub and preventing the growth of timber, have become far less frequent and confined to comparatively narrow limits. Hence, there are now thousands of acres in nearly all the western counties growing up in mesquite and various kinds of timber, where a few years ago there was not a shrub to be seen."[16] Further description of the region is provided in the *Almanac* regarding the streams: "Western Texas (Edwards, Frio, and Nueces watersheds) is generally undulating prairie…There are numerous rivers or small streams, but most of the smaller ones are subject to become very low or even dry in the dry season, and again subject to overflow, and often impassible during the heavy rains. All of them are lined with timber…cypress, hackberry, cottonwood, pecan, oak of many kinds, and hickory. The wide prairie is covered with grass, what is called mesquite."[17]

The feature of streams crossing the Edwards Aquifer recharge zone and evidence of these streams being dry in places were observed by outside chroniclers of the 1880s. "The Nueces River, although dry in many places, is well-timbered from the heads of its fork to its mouth…Head of fork: chestnut, Texas red oak, scrapberry, wild mulberry, and black willow."[18] The same observer noted dry streams from Uvalde to Eagle Pass, "…drained by several creeks: Turkey, Chuparosa, Live Oak, Comanche, and Penitencia…They are mostly dry, but their courses are well-marked with hackberry, green ash, retama, and black willow."[19]

The noticeable observations during this period contrast accounts of streamflow and wildfires with prior accounts. At least in this sample of accounts, there are more references to "dry streams" than in the sample from earlier periods. Also, the observations reported in the 1873 *Almanac* are insightful because they track well with the maturity of the ranching industry in Texas. By the 1880s the buffalo herds were gone, Indian tribes were defeated, windmills could generate drinking water for livestock, fencing was in use. All these changes discouraged the previous tolerance for prairie fires. The effectiveness of prairie fires in causing the selection of

[14] Stovall, Allan A, "Nueces Headwater Country," p. 12, Naylor Company, San Antonio, Texas, 1959.
[15] "Texas Almanac and State Industrial Guide,". p. 109, Richardson, Belo and Co., Galveston, 1873.
[16] *Ibid*. Page 117.
[17] *Ibid*., Page 176.
[18] Harvard, Valery, "Report on the Flora of Western and Southern Texas," Vol. 8, No. 29, Washington, D.C., 1885.
[19] *Ibid*., p. *462*.

grasses over larger, woody vegetation underscores the potential for rapid growth of the latter in areas where grasslands previously dominated and fires are less frequent.

The most compelling explanation for less frequent prairie fires in the ranching technology of the late 1800s was the elimination of (1) predators, through the use of fencing; and (2) natural hazards like droughts through use of windmills offered ranchers the opportunity to over-graze their land. In the Edwards Plateau during this time, ranches were over-stocked with livestock above the carrying capacity of the rangeland. The carrying capacity of rangeland is related to the amount of forage a ruminant animal needs versus the capability of the land to regenerate the forage naturally. It is reasonable, therefore, to suggest that there was a large net loss of grass (fuel). This loss of grass made wildfires more difficult to start and sustain. As historian Fehrenbach explains, "Two inventions, the windmill and the barb-wire fence, destroyed the seas of grass…It was predictable that the ranchmen would overstock, and that the cattle, which cropped closer than bison, would eventually destroy the rich grass."[20] The lack of fires allowed woody plants that are undesirable forage like junipers and oaks to survive and eventually succeed at the expense of grasses.

#### *4.3.2 1901 to 1939*

In certain parts of the Nueces River Watershed accounts from the early 1900s are similar to much earlier times when brush was not as extensive in coverage. In other parts of the watershed, one can argue that dramatic changes in brush had already occurred. The *Texas Almanac* of 1904 contains many of these accounts. For example, in La Salle County, "The Nueces River, a bold, running stream, traverses the center of the county, while the Frio, which ceases to run during droughts, traverses the northern portion."[21] Contrast that account with this one from the same reference (page 267), "The Leona runs dry, but the Frio is never without its deep blue pools of water as clear as a crystal." In Dimmit County, "The general surface is an undulating prairie, with occasional broken and timbered lands along the water courses. Timber is scarce and consists mainly of pecan, hackberry, elm, and live oak in the bottomlands. Mesquite grasses grow on the uplands. Comanche, Pendencia, Rocky Pena, Carrizo, San Lorenzo, and San Ambrosia all are running creeks."[22]

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[20] *Op. Cit.*. Feherenbach. pp. 566,567.
[21] "Texas Almanac *and* State Industrial Guide," p. 311, Richardson, Belo and Co., Galveston, 1904.
[22] *Ibid*., p. *253*.

Descriptions of the vegetation offer the suggestion that some areas were changing. In Maverick County, "…with the exception of scattering elms and cottonwoods near the (Nueces) river and creek, there is no timber but mesquite of a rather scrubby character."[23] In McMullen County, "…trees near streams—live oak, ash, elm, cottonwood, and willow; trees in prairies—mesquite…"[24] Uvalde County, "…mesquite prominent native grass; water inexhaustible, timber throughout county…, northern county—post oak and blackjack; mountain (timber)—large cedar."[25]

By 1939, indications of stress are found in the same areas where there was no such concern previously. One description of watersheds of South Central Texas noted, "…more intensive grazing held the grasses under greater and greater restraint, the "brush" has spread into adjacent more level and fertile areas that formerly supported abundant grass. Prairie relicts are still sufficiently numerous and variant to indicate the stages of the progressive invasion by mesquite, acacia, Texas ebony, hackberry, purple sage, etc…."[26] In part of the Nueces River Watershed, "…grazing, especially by sheep and goat, has greatly depleted the wealth of wild flowers which formerly covered the whole region in profusion. At present time, one may drive over the whole region and hardly see any flower but bitterweed."[27] These characterizations contrast notably with those of the region less than two decades later.

Accounts in 1951 from the *Texas Almanac* clearly describe the Texas Brush Country in many counties of the Nueces River Watershed. Uvalde County was "…largely covered with cedar, mesquite, brush…; upland timber—cedar; canyon timber—pecan, cypress, oak, walnut, wild cherry; southern (county) timber—mesquite, small oak, and brush…"[28] In Zavala County, "Timber includes mesquite, catclaw, live oak, mulberry, hackberry, cottonwood, pecan. Part prairie, largely brushland…"[29] Dimmit County was noted to be "Largely covered with mesquite, oak, elm, and brush…a lot of brush covered ranchland…"[30]

23 *Ibid*., p. *321*.
24 *Ibid*., p. *325*.
25 *Ibid*., p. *381*.
26 Tharp, Benjamin Carroll, "The Vegetation of Texas," p. 10, The Anson Jones Press, Houston, Texas, 1939.
27 *Ibid*., p. 21.
28 "Texas Almanac and State Industrial Guide. Page 610. Richardson, Belo and Co. Galveston. 1951.
29 *Ibid*., p. 619.
30 *Ibid*., p. 538.

### 4.4 Summary

Going back to some of the earliest written accounts of the Nueces River Watershed, mesquite, oak, cedar, prickly pear, and other brushland plants were observed throughout the region. Some accounts even described rather dense concentrations of trees and brush. Unlike some watersheds in the state where there are more dramatic changes from accounts detailing no growths of brush to widespread growths, in the Nueces River Watershed the changes have been subtler. The difference between earlier descriptions (1860-1939) and those of the mid-1900s addresses the relative coverage of grasslands and these coverages are difficult, if not impossible, to quantify. As stated early in this section, if the observer has no means of confirming the general description of a region by using aerial, GIS, or other tools we typically have today, there is always a question about the validity of the observation. However, two general conclusions can be made for the purpose of this study.

The first conclusion is the change in descriptions regarding the relative importance of grasslands as a major feature in the landscape. It does seem clear that earlier accounts characterize grasses and their coverage more than woody plants in many areas of the watershed. The second conclusion is the increasing number of accounts regarding a concern about the loss of grasslands to brush country. These conclusions support the belief that the vegetation has changed over time, but, perhaps not as dramatically as some other watersheds in the state. Figure 4-3 shows the watershed as it exists today.

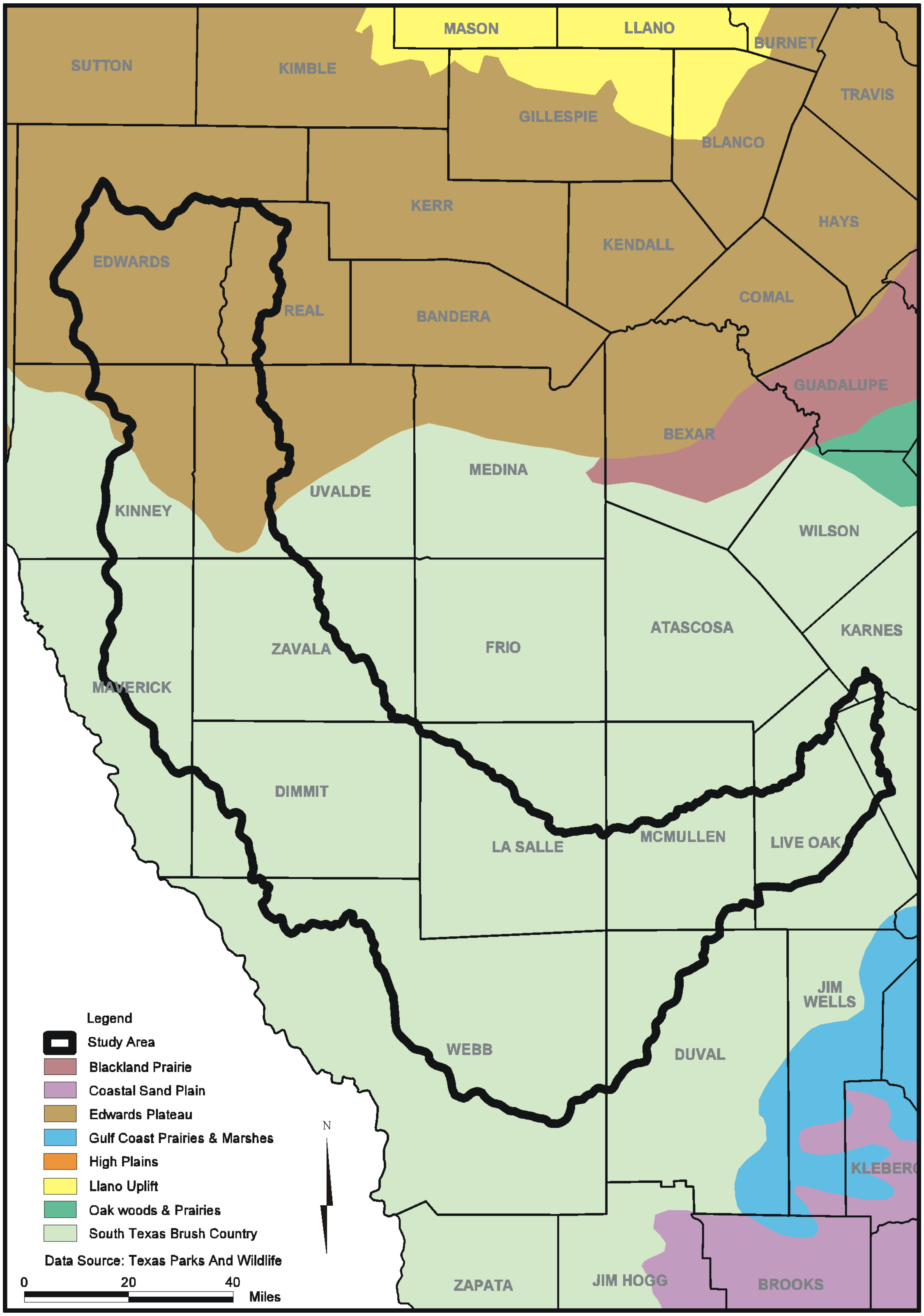


*Figure 4-3. Natural Regions*

# Section 5
# Hydrologic Evaluation

## 5.1 Hydrologic Description of Basin

Approximately 8,093 square miles of drainage area comprise the Nueces River Watershed upstream of Tilden. The headwaters are in the Hill Country in Edwards and Real Counties. The Nueces River Watershed extends from the headwaters to Calallen Dam located at the coast near the City of Corpus Christi. Major tributaries of the Nueces River include the Frio River, Atascosa River, West Nueces River, San Casimiro Creek, and Lagarto Creek. The Frio River, Atascosa River, and Lagarto Creek are not presented in this report. The Atascosa River watershed studied previously[1] and the Frio River results are presented in a separate report.[2]

The topography of the upper portion of the basin is steep. This region of the Hill Country encompasses the Balcones Escarpment or uplift to the Edwards Plateau and is characterized by steep, arid terrain. The hills, cliffs, crevasses, exposed rock, and soils in this area cause rapid runoff. During large storm events, rainfall rapidly flows to streams and washes, sometimes resulting in flashfloods. Due to the terrain of the Hill Country, vegetation has relatively little influence on runoff, with the exception of cedar where the canopy intercepts extremely large amounts of rainfall. Downstream of the Balcones fault zone the land is not as steep or hilly and tends to flatten out as the river flows southward and eastward. It is these areas with less dramatic topography in which vegetation may have a greater influence on runoff.

The Nueces River Watershed crosses four major aquifer recharge zones including the Edwards, Carrizo-Wilcox, Queen City-Bigford, and Sparta-Laredo. The most significant aquifer outcrop or recharge zone spanning the Nueces River Watershed is the Edwards Aquifer recharge zone. Streams crossing this recharge zone lose a significant portion of their flow through faults and solution cavities in the limestone formations. At the Edwards Aquifer recharge zone, about 90,500 acft/yr[3] enters the aquifer from the Nueces River and its tributaries.

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1 HDR, Inc., "Water Supply Update for City of Corpus Christi Service Area," Section 7, City of Corpus Christi, January 1999.
2 HDR, Inc., "Frio River Watershed: Brush Control Planning, Assessment, and Feasibility Study," Texas State Soil and Water Conservation Board, October 2000.
3 HDR, "Edwards Aquifer Recharge Analysis," Trans-Texas Water Program, West Central Study Area, Phase II, San Antonio River Authority, et. al., March 1998.

### 5.2 Hydrologic History and Conditions

The Nueces River Watershed much like the rest of South Texas has experienced extreme droughts and floods. Large storms of record in the Nueces River Watershed occurred in 1913, 1935, 1955, 1967, and 1996. Table 5-1 lists the largest floods known at several of the long-term gages in the watershed. The largest flow measured for the Nueces River at the Nueces River at Laguna (USGS #08190000) is 307,000 cfs on September 24, 1955. The next largest flow is 222,000 cfs on July 13, 1939, also at Laguna.

From the period of 1934 to 1996, droughts ranging in severity have occurred throughout the Nueces River Basin. The most severe drought prior to 1994 is the drought that started in 1947 and continued through 1956. This drought is referred to as the "drought of the 50s." Annual rainfall during the 1950s drought was 19 to 22 percent less than the long-term average annual rainfall. For instance, the average areal rainfall for Nueces River Watershed above Laguna is 25.3 inches, and the average rainfall during the 1950s drought was 20.1 inches. Other dry times include 1934, 1961–1963, 1980, 1984, 1988–1989, and 1996.

### 5.3 Precipitation and Naturalized Streamflow Development

Locations of the streamflow gages in the Nueces Basin and the period of record for each gage are shown in Figure 5-1. The dark circles indicate the gages considered in this Nueces River Watershed study. Two streamflow gages in the Nueces River Basin within the study area started recording in 1923 on the Nueces River at Laguna and Cotulla. Since that time, numerous stream and precipitation gages have been established throughout the basin.

The periods of record and location descriptions for each of the five long-term streamflow gages considered herein are listed in Table 5-2.

Precipitation or rainfall gages provide information for specific locations in the basin. To better compare the rainfall data to streamflow data, the basin has been divided into sub-basins according to the streamflow gage locations and average rainfall over a particular sub-basin, or areal precipitation, has been calculated. Areal precipitation for each of the five watersheds considered herein was calculated in the course of two earlier studies[4,5] sponsored by the Nueces

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4 HDR, "Nueces River Basin Regional Water Supply Planning Study, Phase I," Nueces River Authority, et al., May 1991.

5 HDR, "Water Supply Update for City of Corpus Christi Service Area," City of Corpus Christi, January 1999.

***Table 5-1. Nueces River Watershed — Flood History Summary***

| USGS Gage # | Gage Location | Drainage Area ($mi^2$) | Continuous Record Since | Largest Flood for Period of Record | | | Largest Flood Outside Period of Record | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Peak Flow (cfs) | Peak Stage (feet) | Date | Peak Flow (cfs) | Peak Stage (feet) | Date |
| 08190000 | Nueces River at Laguna | 737 | 1923 | 307,000<br>222,000 | 32.70<br>26.40 | 9/24/1955<br>7/13/1939 | —<br>160,000 | 29<br>26.5 | 6/1913<br>9/21/1923 |
| 08192000 | Nueces River at Uvalde | 1,861 | 1939 | 201,000<br>189,000 | 24.88<br>24.61 | 10/28/1996<br>9/24/1955 | 616,000<br>— | 40.4<br>— | 6/14/1935<br>— |
| 08193000 | Nueces River at Asherton | 4,082 | 1939 | 24,000<br>21,800 | 30.40<br>30.23 | 9/2/1944<br>6/20/1958 | —<br>— | 33.0<br>33.0 | 6/17/1935<br>6/30/1913 |
| 08194000 | Nueces River at Cotulla | 5,171 | 1923 | 82,600<br>46,000 | 32.40<br>27.75 | 6/18/1935<br>9/17/1964 | —<br>— | 29.7<br>— | 9/19/1899<br>— |
| 08194500 | Nueces River at Tilden | 8,093 | 1942 | 76,500<br>70,000 | 26.57<br>26.46 | 9/24/1967<br>10/11/1946 | —<br>— | 23.7<br>22.0 | 6/1935<br>7/1942 |

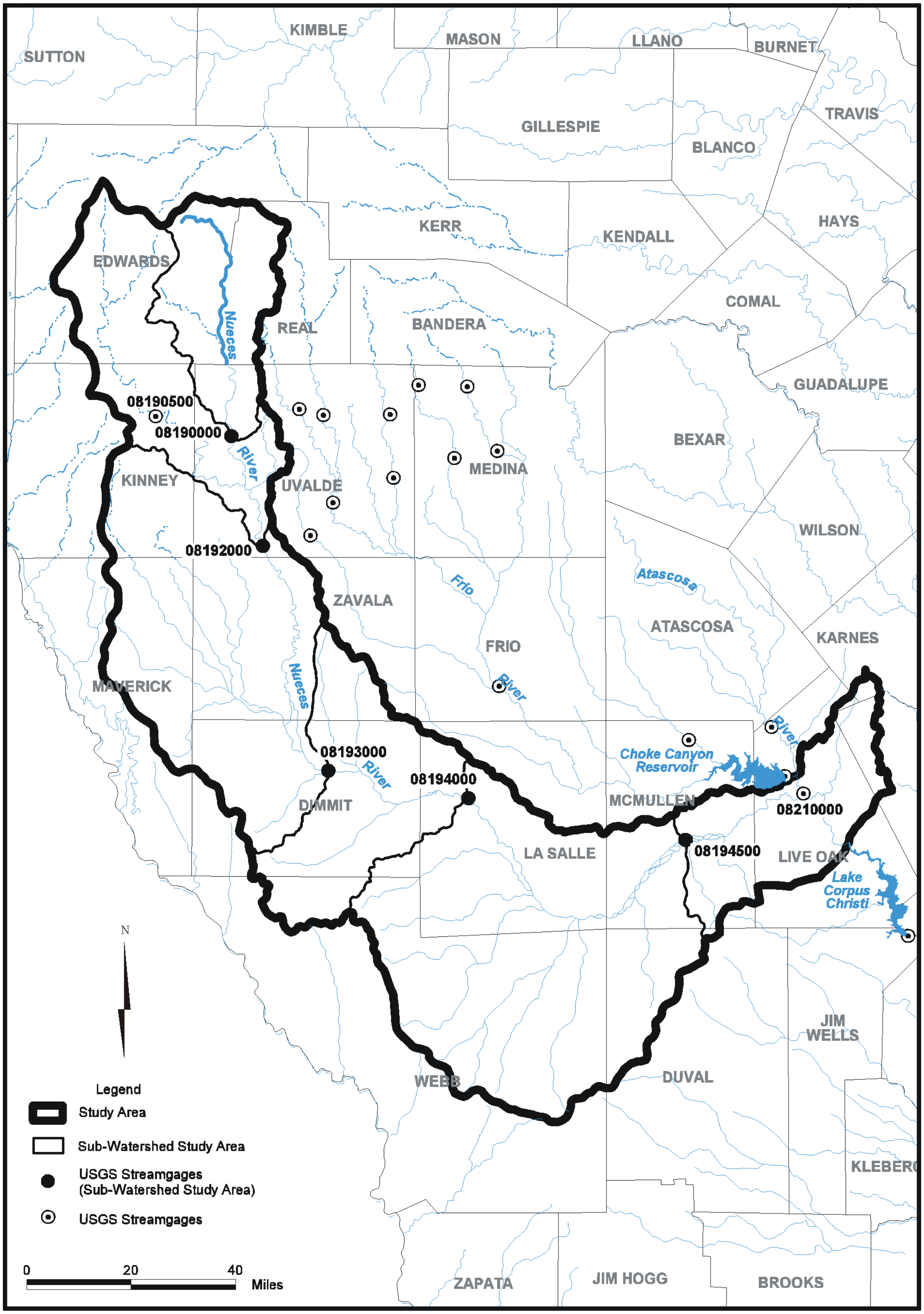


***Figure 5-1. USGS Streamgages***

River Authority and the City of Corpus Christi. Annual areal precipitation for each subwatershed corresponding with the selected streamflow gages is listed in Table 5-3.

***Table 5-2. Summary of Streamflow Gages Used in this Study***

| USGS Gage # | Location | Drainage Area (sq. mi.) | Period of Record |
|---|---|---|---|
| 08190000 | Nueces River at Laguna | 737 | 10/1923 – 12/1996 |
| 08192000 | Nueces River at Uvalde | 1,861 | 10/1927 – 12/1996 |
| 08193000 | Nueces River at Asherton | 4,082 | 10/1939 – 12/1996 |
| 08194000 | Nueces River at Cotulla | 5,171 | 11/1923 – 12/1996 |
| 08194500 | Nueces River at Tilden | 8,093 | 12/1942 – 12/1996 |

Streamflow gages measure the discharge in a river at the gage location. To accurately assess the possible presence of trends in the streamflow, the discharge must be "naturalized" to remove man-made influences. Water supply diversions, wastewater effluents, and reservoir influences are typically accounted for in the adjustment of measured flow to obtain naturalized flow. Monthly natural streamflows were developed for each of the gage locations identified in Table 5-2 in the course of previous studies.[6,7] Annual naturalized flow for five streamgages is listed in Table 5-4.

Two of the five watersheds considered in this study are evaluated as headwater watersheds or watersheds for which natural streamflows at the outlet are considered representative of the entire tributary area. The remaining three watersheds were evaluated as intervening watersheds between the streamflow gages located on the Nueces River at Uvalde and Asherton, between the Nueces River at Asherton and Cotulla, and between the Nueces River at Cotulla and Tilden. For these watersheds, local historical runoff at each downstream gage is estimated by subtracting historical gaged streamflow at the upstream gage (without adjustment) from gaged streamflow at the downstream gage with adjustment for reported intervening diversions. This provides the best representation of local historical runoff for the intervening watershed even though some years may have negative calculated differences due to channel losses or large storms in late December.

[6] Op. Cit., HDR, May 1991.
[7] Op. Cit., HDR, January 1999.

**Table 5-3. Annual Areal Precipitation for Watershed Above Gage**

| Year | Nueces River at Laguna USGC #08190000 (in) | Nueces River at Uvalde USGS #08192000 (in) | Nueces River at Asherton USGS #08193000 (in) | Nueces River at Cotulla USGS #08194000 (in) | Nueces River at Tilden USGS #08194500 (in) |
|---|---|---|---|---|---|
| 1934 | 13.94 | 14.52 | 18.01 | 23.05 | 22.16 |
| 1935 | 43.00 | 42.17 | 28.39 | 24.50 | 30.17 |
| 1936 | 35.82 | 34.34 | 25.41 | 22.20 | 25.56 |
| 1937 | 20.82 | 20.42 | 15.10 | 16.81 | 16.77 |
| 1938 | 17.29 | 17.06 | 14.96 | 12.81 | 14.34 |
| 1939 | 19.47 | 19.95 | 22.39 | 21.02 | 16.21 |
| 1940 | 21.89 | 22.46 | 25.05 | 28.88 | 26.25 |
| 1941 | 30.10 | 29.85 | 22.72 | 25.34 | 32.52 |
| 1942 | 28.45 | 27.19 | 23.60 | 23.48 | 25.79 |
| 1043 | 22.39 | 22.30 | 20.21 | 17.71 | 17.68 |
| 1944 | 24.03 | 24.36 | 25.53 | 24.22 | 23.66 |
| 1945 | 17.71 | 17.16 | 19.99 | 22.50 | 18.59 |
| 1946 | 24.45 | 24.65 | 25.48 | 28.82 | 26.18 |
| 1947 | 22.02 | 21.82 | 20.03 | 19.65 | 21.04 |
| 1948 | 20.29 | 20.77 | 20.16 | 18.68 | 16.33 |
| 1949 | 40.03 | 38.11 | 31.14 | 31.05 | 30.12 |
| 1950 | 18.19 | 17.74 | 18.70 | 18.91 | 17.07 |
| 1951 | 16.87 | 16.30 | 15.97 | 15.08 | 19.86 |
| 1952 | 18.56 | 17.63 | 12.04 | 12.51 | 11.53 |
| 1953 | 16.17 | 16.13 | 13.40 | 13.66 | 19.49 |
| 1954 | 18.89 | 18.69 | 16.53 | 14.43 | 17.23 |
| 1955 | 22.08 | 22.30 | 19.30 | 14.05 | 15.71 |
| 1956 | 8.23 | 8.15 | 8.17 | 8.62 | 12.49 |
| 1957 | 32.01 | 32.58 | 34.17 | 27.58 | 25.04 |
| 1958 | 40.07 | 40.18 | 34.51 | 32.44 | 34.87 |
| 1959 | 29.79 | 29.75 | 27.69 | 26.67 | 21.64 |
| 1960 | 25.87 | 24.67 | 24.88 | 26.70 | 28.79 |
| 1961 | 22.26 | 21.89 | 16.72 | 15.75 | 16.08 |
| 1962 | 15.98 | 15.52 | 12.12 | 14.06 | 15.05 |
| 1963 | 21.86 | 21.26 | 17.19 | 18.25 | 16.52 |
| 1964 | 26.00 | 25.22 | 23.29 | 22.20 | 19.55 |
| 1965 | 21.91 | 21.89 | 22.59 | 20.97 | 18.65 |
| 1966 | 24.46 | 24.04 | 20.15 | 17.81 | 27.68 |
| 1967 | 24.85 | 22.03 | 21.22 | 28.03 | 31.20 |

### *Table 5-3. Annual Areal Precipitation for Watershed Above Gage (Continued)*

| Year | Nueces River at Laguna USGC #08190000 (in) | Nueces River at Uvalde USGS #08192000 (in) | Nueces River at Asherton USGS #08193000 (in) | Nueces River at Cotulla USGS #08194000 (in) | Nueces River at Tilden USGS #08194500 (in) |
|---|---|---|---|---|---|
| 1968 | 29.58 | 26.74 | 23.25 | 24.16 | 24.84 |
| 1969 | 31.74 | 31.90 | 27.74 | 21.01 | 20.89 |
| 1970 | 22.16 | 19.16 | 19.20 | 18.13 | 20.49 |
| 1971 | 34.57 | 35.19 | 32.50 | 38.04 | 37.06 |
| 1972 | 25.71 | 22.89 | 17.10 | 19.80 | 25.53 |
| 1973 | 31.63 | 30.60 | 29.93 | 30.13 | 31.70 |
| 1974 | 25.89 | 24.22 | 21.65 | 24.85 | 26.87 |
| 1975 | 30.30 | 28.04 | 26.27 | 26.63 | 19.85 |
| 1976 | 38.23 | 38.74 | 35.41 | 29.03 | 35.73 |
| 1977 | 23.98 | 20.51 | 13.85 | 12.58 | 15.07 |
| 1978 | 20.90 | 23.15 | 22.69 | 19.65 | 22.79 |
| 1979 | 22.27 | 21.69 | 21.55 | 16.00 | 19.26 |
| 1980 | 24.33 | 20.16 | 18.50 | 20.92 | 18.80 |
| 1981 | 41.52 | 36.28 | 26.01 | 27.21 | 32.54 |
| 1982 | 22.91 | 20.54 | 19.61 | 19.12 | 20.68 |
| 1983 | 23.71 | 23.00 | 17.38 | 15.50 | 16.87 |
| 1984 | 21.82 | 19.11 | 15.48 | 15.30 | 15.36 |
| 1985 | 25.91 | 23.13 | 21.59 | 23.99 | 34.76 |
| 1986 | 34.49 | 33.58 | 28.42 | 31.75 | 25.46 |
| 1987 | 34.18 | 34.95 | 29.66 | 25.22 | 23.83 |
| 1988 | 17.43 | 16.03 | 10.75 | 11.35 | 14.99 |
| 1989 | 19.49 | 18.98 | 16.15 | 14.47 | 16.87 |
| 1990 | 34.07 | 33.00 | 30.98 | 27.70 | 24.57 |
| 1991 | 31.75 | 30.99 | 23.18 | 21.83 | 25.31 |
| 1992 | 27.95 | 27.88 | 29.92 | 26.47 | 27.32 |
| 1993 | 14.62 | 14.86 | 13.94 | 14.38 | 16.62 |
| 1994 | 31.10 | 31.51 | 24.58 | 21.35 | 23.79 |
| 1995 | 22.24 | 20.72 | 42.33 | 20.24 | 22.88 |
| 1996 | 24.47 | 23.34 | 16.65 | 15.68 | 15.79 |
| Maximum (in) | 43.00 | 42.17 | 42.33 | 38.04 | 37.06 |
| Minimum (in) | 8.23 | 8.15 | 8.17 | 8.62 | 11.53 |
| Average (in) | 25.31 | 24.51 | 22.11 | 21.28 | 22.35 |

**Table 5-4. Annual Naturalized Streamflow for Watershed Above Gage**

| Year | Nueces River at Laguna USGC #08190000 (acft) | Nueces River at Uvalde USGS #08192000 (acft) | Nueces River at Asherton USGS #08193000 (acft) | Nueces River at Cotulla USGS #08194000 (acft) | Nueces River at Tilden USGS #08194500 (acft) |
|---|---|---|---|---|---|
| 1934 | 18,007 | 4,824 | — | — | — |
| 1935 | 465,058 | 752,134 | — | — | — |
| 1936 | 233,426 | 195,694 | — | — | — |
| 1937 | 62,030 | 45,809 | — | — | — |
| 1938 | 72,578 | 42,088 | — | — | — |
| 1939 | 158,485 | 85,684 | — | — | — |
| 1940 | 52,903 | 12,721 | 90,980 | 85,835 | — |
| 1941 | 86,769 | 31,279 | 40,939 | 37,751 | — |
| 1942 | 96,175 | 41,629 | 77,169 | 57,120 | — |
| 1043 | 43,593 | 12,461 | 38,378 | 22,522 | 55,352 |
| 1944 | 63,885 | 13,974 | 303,164 | 183,134 | 122,735 |
| 1945 | 45,561 | 6,953 | 127,211 | 149,151 | 80,534 |
| 1946 | 66,856 | 22,878 | 78,492 | 110,558 | 421,090 |
| 1947 | 66,087 | 15,159 | 38,100 | 33,122 | 148,937 |
| 1948 | 39,664 | 38,174 | 36,855 | 19,148 | 1,578 |
| 1949 | 183,620 | 193,130 | 56,714 | 44,710 | 163,338 |
| 1950 | 47,520 | 11,331 | 42,703 | 11,128 | 125,490 |
| 1951 | 19,765 | 3,270 | 29,435 | 966 | 92,135 |
| 1952 | 22,685 | 5,326 | 57,155 | 12,078 | 47,647 |
| 1953 | 23,063 | 11,495 | 74,817 | 27,902 | 150,344 |
| 1954 | 60,161 | 55,786 | 51,919 | 4,027 | 109,585 |
| 1955 | 195,063 | 150,224 | –24,808 | –20,477 | –6,885 |
| 1956 | 16,352 | 1,686 | 13,490 | 19,361 | 7,564 |
| 1957 | 62,977 | 21,102 | 278,964 | 90,094 | 280,242 |
| 1958 | 273,602 | 385,150 | 68,838 | 24,341 | 381,296 |
| 1959 | 161,431 | 178,256 | 145,091 | 33,240 | 4,252 |
| 1960 | 117,876 | 77,082 | 40,181 | 15,654 | 41,173 |
| 1961 | 134,566 | 112,769 | 17,321 | 6,708 | –11,121 |
| 1962 | 54,500 | 22,055 | –15,832 | 4,524 | 8,246 |
| 1963 | 56,475 | 31,154 | –4,520 | 4,168 | 93,248 |
| 1964 | 141,029 | 204,917 | 123,786 | 184,986 | –6,554 |
| 1965 | 80,148 | 60,769 | 54,442 | 26,688 | 66,568 |
| 1966 | 145,866 | 77,911 | 62,982 | 6,427 | 164,851 |
| 1967 | 75,052 | 27,104 | 71,477 | 107,200 | 556,484 |

**Table 5-4. Annual Naturalized Streamflow for Watershed Above Gage (Continued)**

| Year | Nueces River at Laguna USGC #08190000 (in) | Nueces River at Uvalde USGS #08192000 (in) | Nueces River at Asherton USGS #08193000 (in) | Nueces River at Cotulla USGS #08194000 (in) | Nueces River at Tilden USGS #08194500 (in) |
|---|---|---|---|---|---|
| 1968 | 140,676 | 81,092 | 77,744 | –4,230 | –13,658 |
| 1969 | 117,925 | 90,795 | 76,136 | 39,517 | –1,444 |
| 1970 | 115,207 | 63,633 | –6,921 | 15,922 | 77,242 |
| 1971 | 278,146 | 338,588 | 314,224 | 317,004 | 1,047,881 |
| 1972 | 130,543 | 122,408 | –33,279 | –2,275 | 91,104 |
| 1973 | 233,006 | 273,866 | –64,891 | 56,998 | 215,847 |
| 1974 | 103,273 | 90,032 | 2,042 | 34,444 | 83,767 |
| 1975 | 103,885 | 100,262 | 104,081 | 27,450 | 70,621 |
| 1976 | 170,641 | 218,638 | 22,388 | 55,530 | 347,471 |
| 1977 | 157,812 | 172,116 | –10,844 | 17,001 | 22,800 |
| 1978 | 56,929 | 38,448 | 26,562 | 6,927 | 26,152 |
| 1979 | 66,191 | 53,513 | 127,063 | 21,057 | –2,708 |
| 1980 | 34,745 | 13,077 | 61,654 | 44,014 | 71,126 |
| 1981 | 266,614 | 363,953 | 23,646 | 128,860 | 218,214 |
| 1982 | 74,355 | 73,335 | 2,850 | 4,381 | 91,102 |
| 1983 | 59,015 | 20,389 | 39,828 | –10,101 | –5,903 |
| 1984 | 68,046 | 39,560 | 43,205 | 6,471 | –4,490 |
| 1985 | 136,979 | 117,139 | 67,602 | 21,366 | 301,465 |
| 1986 | 128,071 | 89,522 | 79,773 | 28,676 | –28,069 |
| 1987 | 291,315 | 373,316 | 109,005 | 62,743 | 7,488 |
| 1988 | 73,244 | 46,483 | 3,476 | 1,845 | 14,881 |
| 1989 | 39,543 | 13,449 | 6,780 | 2,796 | 2,692 |
| 1990 | 170,572 | 156,045 | 115,306 | 21,951 | 51,092 |
| 1991 | 193,509 | 151,449 | –56,637 | –17,001 | 13,566 |
| 1992 | 255,172 | 257,006 | 51,411 | –25,463 | 103,636 |
| 1993 | 47,161 | 46,914 | –12,051 | –1,337 | 13,479 |
| 1994 | 80,909 | 38,149 | –9,634 | –4,973 | 17,368 |
| 1995 | 66,971 | 22,059 | –3,322 | 8,894 | 31,554 |
| 1996 | 167,001 | 236,731 | –142,953 | –15,428 | 10,057 |
| Maximum (in) | 465,058 | 752,134 | 314,224 | 317,004 | 1,047,881 |
| Minimum (in) | 16,352 | 1,686 | –142,953 | –25,463 | –28,069 |
| Average (in) | 115,401 | 105,618 | 52,451 | 37,633 | 110,601 |

### *5.3.1 Analysis Methods*

Historical accounts in Section 4 suggest that brush in the Hill Country has increased over the centuries since the Europeans began inhabiting this region of Texas. Accounts of tall prairie grasses and few brush or trees contrast with the current proliferation of brush. These accounts, coupled with recent research[8,9] have led some researchers to suggest that controlling brush in certain watersheds could increase water yields. One purpose of this study is to determine if historical data supports a relationship between increasing brush coverage and decreasing streamflow. The method used for determining whether a relationship between brush control and streamflow exists involves statistical analysis for identification of any trends in rainfall and runoff (on a per unit of rainfall basis) for related watersheds. Runoff per unit rainfall or percent runoff measures the response of a watershed to rainfall and effectively normalizes highly variable runoff records for many years and many watersheds thereby allowing for equitable comparisons.

A significant change in the relationship between the runoff and rainfall over time may be indicative of a change that has occurred in a watershed. An increase in runoff per unit rainfall concomitant with observed brush proliferation over time does not support the hypothesis that brush proliferation has reduced yield (runoff) at the watershed level. While an observed decrease in runoff per unit rainfall concomitant with brush proliferation tends to support the hypothesis that brush proliferation has reduced yield, further investigation is warranted as there are other factors, such as groundwater level declines, stock pond development, and land management practices that could have a similar effect. Identification of increasing trends in runoff per unit rainfall may eliminate some watersheds from further investigation. On the other hand, identification of decreasing trends in runoff per unit rainfall in some watersheds, may provide support for further investigation of the causes of decreasing runoff. Such investigations may include more detailed brush control studies.

## *5.4 Trends in Streamflow Characteristics*

Historical areal precipitation or rainfall for each sub-basin defined by the selected streamflow gage locations is plotted as a time series in Figure 5-2. The mean or average annual

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8 "North Concho River Watershed, Brush Control Planning, Assessment & Feasibility Study," Upper Colorado River Authority, et al.

9 Dugas, W.A., et al., "Effect of Removal of *Juniper ashei* on Evapotranspiration and Runoff in the Seco Creek Watershed," Water Resources Research, Vol. 34, No. 6, pp. 1499-1506, June 1998.

rainfalls for the first and second halves of the available period of streamflow records are summarized in Table 5-5 and drawn as horizontal lines on each plot. All of the sub-basins show an increase in average rainfall from the earlier to the latter period. Statistical analyses are used to assess the significance of these differences.

Runoff as a percentage of rainfall for each of the selected sub-basins is plotted as a time series in Figure 5-3. These plots and Table 5-5 show the average values of runoff as a percentage of rainfall for the first and second halves of the available period of streamflow records. The averages for each watershed upstream of the Nueces River at Uvalde (USGS #08192000) show an increase from the first time period to the second, while the average for each watershed downstream shows a decrease. Similar to the consideration of rainfall, statistical tests are used to assess the significance of these differences.

***Table 5-5. Comparison of Average Annual Rainfall and Runoff per Unit Rainfall***

| Location | USGC Gage # | Drainage Area ($mi^2$) | Period | Average Rainfall (in) | Average RO/RF (%) |
|---|---|---|---|---|---|
| Nueces River at Laguna | 08190000 | 737 | 1934-65 | 23.6 | 9.7 |
| | | | 1966-96 | 27 | 11.8 |
| Nueces River at Uvalde | 08192000 | 1,861 | 1934-65 | 23.4 | 3 |
| | | | 1966-96 | 25.7 | 4.4 |
| Nueces River at Asherton[1] | 08193000 | 4,082 | 1940-68 | 21.2 | 2.6 |
| | | | 1969-96 | 23.3 | 0.96 |
| Nueces River at Cotulla[2] | 08194000 | 5,171 | 1940-68 | 21.1 | 3.3 |
| | | | 1969-96 | 21.7 | 1.8 |
| Nueces River at Tilden[3] | 08194500 | 8,093 | 1943-69 | 21 | 3 |
| | | | 1970-96 | 23.4 | 2.3 |

Notes:
1 Areal precipitation and naturalized streamflow for subwatershed above the Nueces River at Asherton (USGC #08193000) and below the Nueces River at Uvalde (USGC #08192000)
2 Areal precipitation and naturalized streamflow for subwatershed above the Nueces River at Cotulla (USGC #08194000) and below the Nueces River at Asherton (USGC #08193000)
3 Areal precipitation and naturalized streamflow for subwatershed above the Nueces River at Tilden (USGC #08194500) and below the Nueces River at Cotulla (USGC #08193000)

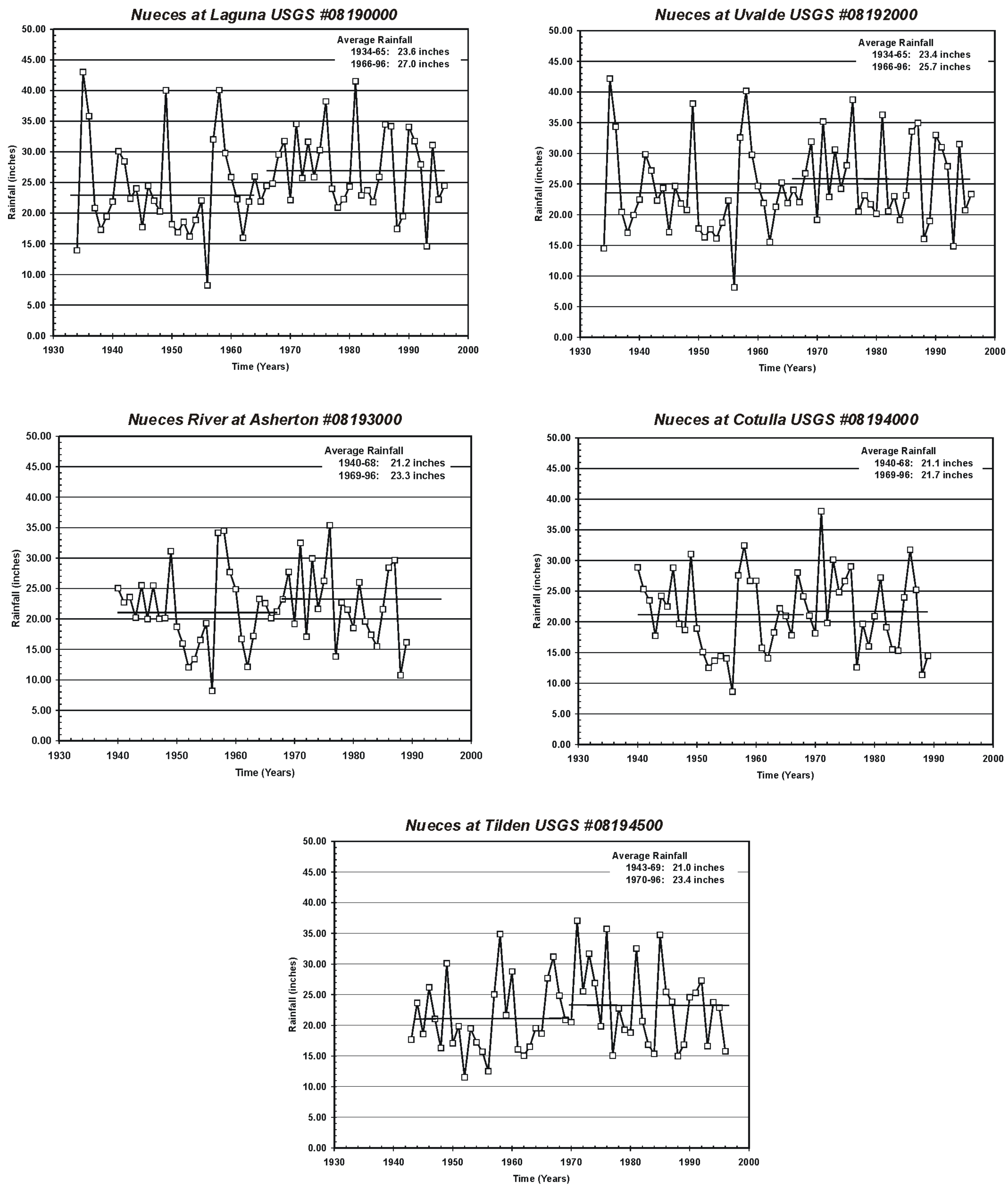


***Figure 5-2. Rainfall Time Series for Nueces River Watershed***

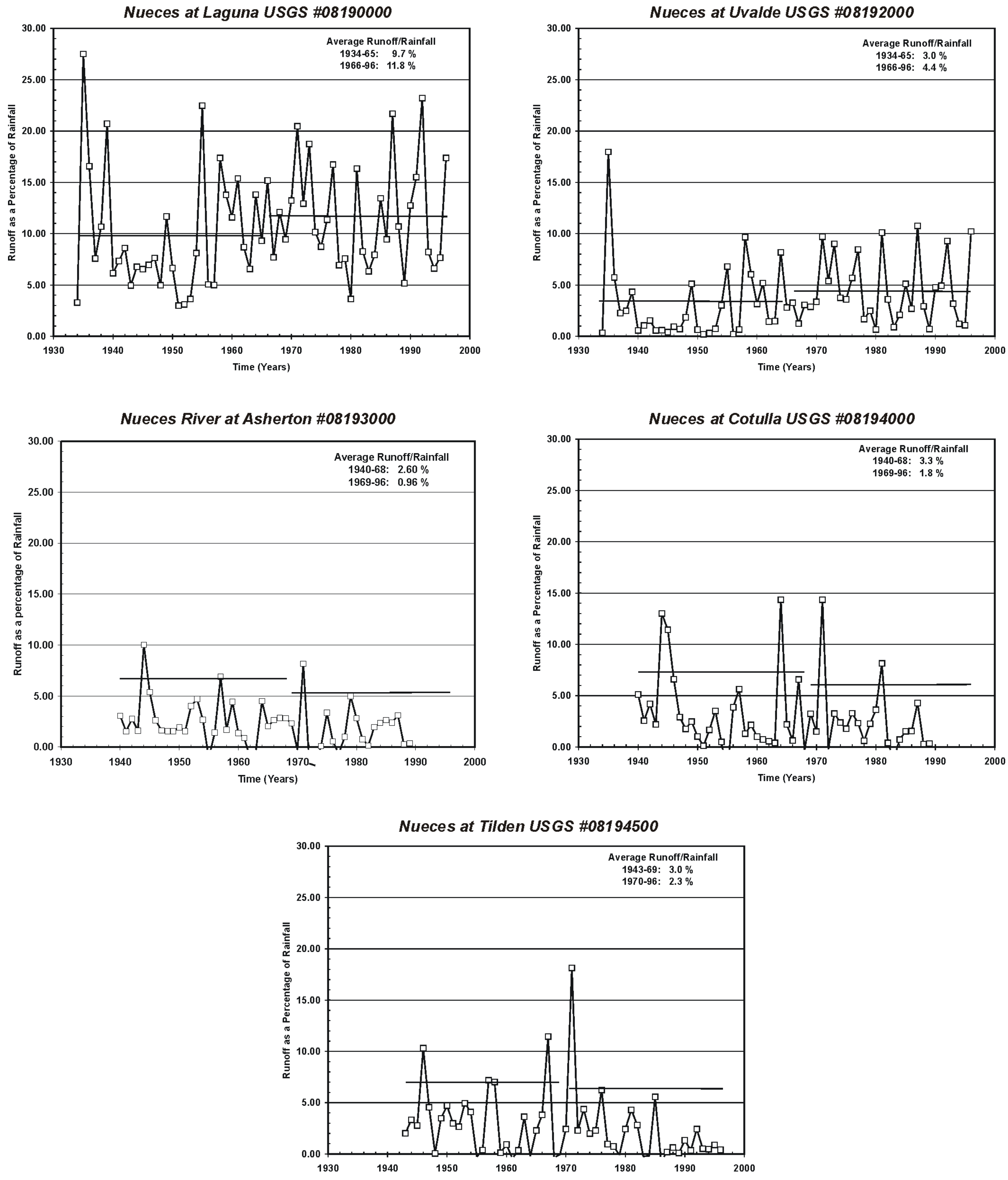


***Figure 5-3. Runoff as a Percentage of Rainfall Time Series for Nueces River Watershed***

The statistical tests applied to historical annual rainfall and runoff per unit rainfall include the non-parametric Kendall Tau test,[10] and linear regression and sample partitioning which may be classified as parametric tests. Sample partitioning, in this case, simply involves subdivision of the available historical record into halves so that the means and variances from the earlier and later sub-periods can be compared to one another. Assessment of the statistical significance of differences in sub-period means and variances was accomplished using standard t-tests and F-tests,[11] respectively. Similarly the statistical significance of the slope of a trendline obtained by linear regression of annual rainfall or runoff per unit rainfall versus time was evaluated using the t-test. Statistical significance is assumed at the 90 percent confidence level in this study.

The results of statistical tests seeking to identify trends in annual rainfall are shown in Table 5-6. Significant increases in annual rainfall are indicated for the watersheds in the headwaters of the Nueces River Basin. More specifically, the Nueces River at Laguna (USGS #08190000) indicates an increasing trend in rainfall that cannot be rejected at the 90 percent confidence level. This headwater area is in the Hill Country upstream of the outcrop of the Edwards Aquifer. Figure 5-4 shows the sub-basin that is indicating increased rainfall for the time periods considered.

***Table 5-6. Indication of Statistically Significant Trend in Rainfall in Nueces River Watershed — 90% Confidence Level***

| | | ***Nueces River Watershed*** | | | | |
|---|---|---|---|---|---|---|
| ***Statistical Test*** | ***Test Type*** | ***#08190000 Nueces River, Laguna*** | ***#08192000 Nueces River, Uvalde*** | ***#08193000 Nueces River, Asherton*** | ***#08194000 Nueces River, Cotulla*** | ***#08194500 Nueces River, Tilden*** |
| Kendall Tau | Non-parametric | Tau = 0.147 increasing, Yes | No | No | No | No |
| Simple Regression, t-distribution | Parametric | Increasing, Yes | No | No | No | No |
| Sample Partitioning, Mean Comparison, t-distribution | Parametric | Increasing, Yes | Increasing, Yes | No | No | Increasing, Yes |
| Sample Partitioning, Variance Comparison, F-distribution | Parametric | Yes | Yes | No | No | No |

[10] Maidment, D.R., "Handbook of Hydrology," McGraw-Hill, Inc., 1993.
[11] Haan, C.T., "Statistical Methods in Hydrology," Iowa State University Press, 1977.

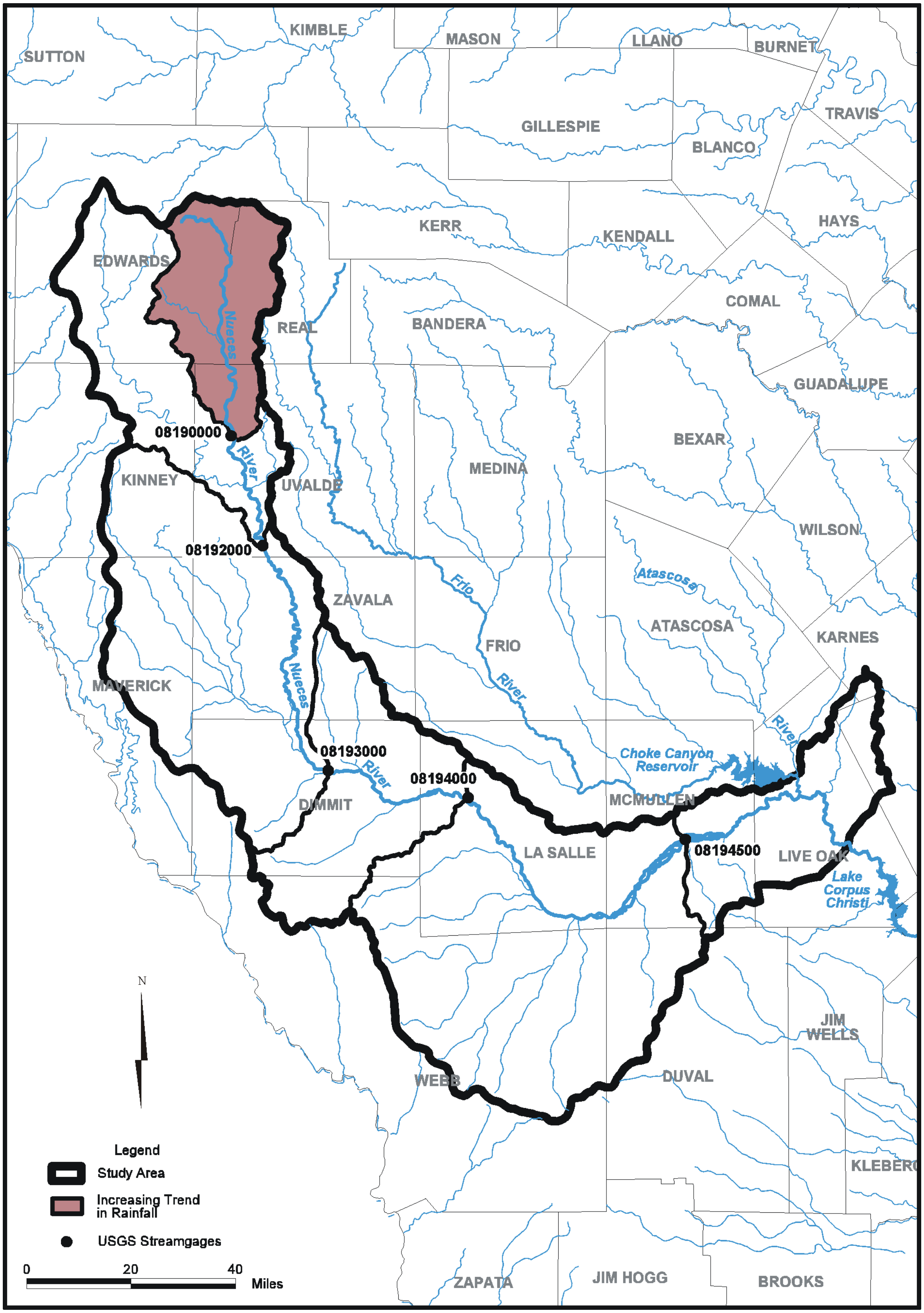


***Figure 5-4. Results of Statistical Analyses of Rainfall***

Additional long-term (1916–1996) statistical analysis of areal precipitation for Hill Country sub-basins, however, does not support the short-term indications of increasing rainfall. Nevertheless, further research into the characteristics of Hill Country rainfall in terms of intensity, duration, and frequency as they vary with time may be warranted.

The results of statistical tests seeking to identify trends in annual runoff as a percentage of rainfall are shown in Table 5-7. Figure 5-5 highlights the sub-basins of increasing and decreasing trends. The watersheds above the Nueces River at Laguna (USGS #08190000) and Nueces River at Uvalde (USGS #08192000) demonstrate increasing trends in this ratio that cannot be rejected at the 90 percent confidence level. Further investigation based on modified Soil Conservation Service curve number procedures[12] indicates that increased runoff per unit rainfall may be explained by increased rainfall during the latter time periods. Most importantly, however, none of the Hill Country watersheds considered in this study exhibits any indications of decreasing annual runoff per unit rainfall with time.

Three watersheds within the Nueces River Basin exhibit apparent decreases in runoff per unit rainfall over time. These watersheds include the lower portion of the Nueces River Basin between the Nueces River at Uvalde (USGS #08192000) and Asherton (USGS #08193000), between the Nueces River at Asherton (USGS #08193000) and Cotulla (USGS #08194000), and between the Nueces River at Cotulla (USGS #08194000) and Tilden (USGS #08194500). These watersheds encompass approximately 6,232 square miles, or about 77 percent of the Nueces River Basin in this study area. In addition to brush proliferation, pumpage from the Carrizo Aquifer may be affecting observed runoff per unit rainfall in these subwatersheds.

### 5.5 Potential Sites for Brush Control

Potential sites for brush control are those sites where observations and statistical analyses indicate decreasing runoff relative to rainfall. The sites identified in this section are sub-basins that should be considered in future studies. Physical systems are very complex and subject to the influences of many factors. These factors may affect each other in ways that are not historically or currently measured. The nature of explaining trends in physical systems is to continue to identify and quantify sources and sinks in the system. In this study, rainfall is the primary source, streamflow (runoff per unit rainfall) is the main variable of concern, and brush is the

[12] Op. Cit., HDR, May 1991.

***Table 5-7. Indication of Statistically Significant Trend in Runoff/Rainfall in the Nueces River Watershed — 90% Confidence Level***

| | | Nueces River Watershed | | | | |
|---|---|---|---|---|---|---|
| **Statistical Test** | **Test Type** | **#08190000 Nueces River, Laguna** | **#08192000 Nueces River, Uvalde** | **#08193000 Nueces River, Asherton** | **#08194000 Nueces River, Cotulla** | **#08194500 Nueces River, Tilden** |
| Kendall Tau | Non-parametric | Increasing, Yes | Increasing, Yes | Decreasing, Yes | Decreasing, Yes | Decreasing, Yes |
| Simple Regression, t-distribution | Parametric | Increasing, Yes | Increasing, Yes | Decreasing, Yes | Decreasing, Yes | Decreasing, Yes |
| Sample Partitioning, Mean Comparison, t-distribution | Parametric | Increasing, Yes | Increasing, Yes | Decreasing, Yes | Decreasing, Yes | No |
| Sample Partitioning, Variance Comparison, F-distribution | Parametric | Yes | Yes | No | No | No |

main sink considered. However, the question still remains, "Is brush proliferation (alone) causing observed changes in runoff per unit rainfall?"

Of the five sub-basins considered in the Nueces River Basin, the sub-basins between the streamflow gages at Uvalde (USGS #08192000) and Asherton (USGS #08193000), Asherton (USGS #08193000) and Cotulla (USGS #08194000), and Cotulla (USGS #08194000) and Tilden (USGS #08194500) are the most promising for brush control. Analyses of runoff as a percentage of rainfall indicate that there are significant decreasing trends in these sub-basins. Possible sinks in these three sub-basins include not only brush proliferation, but also pumpage from and recharge to the Carrizo Aquifer, small reservoir (stock tank) development, and changes in land management practices with time. Further investigation of these sub-basins may more precisely determine the causes of apparent changes in runoff.

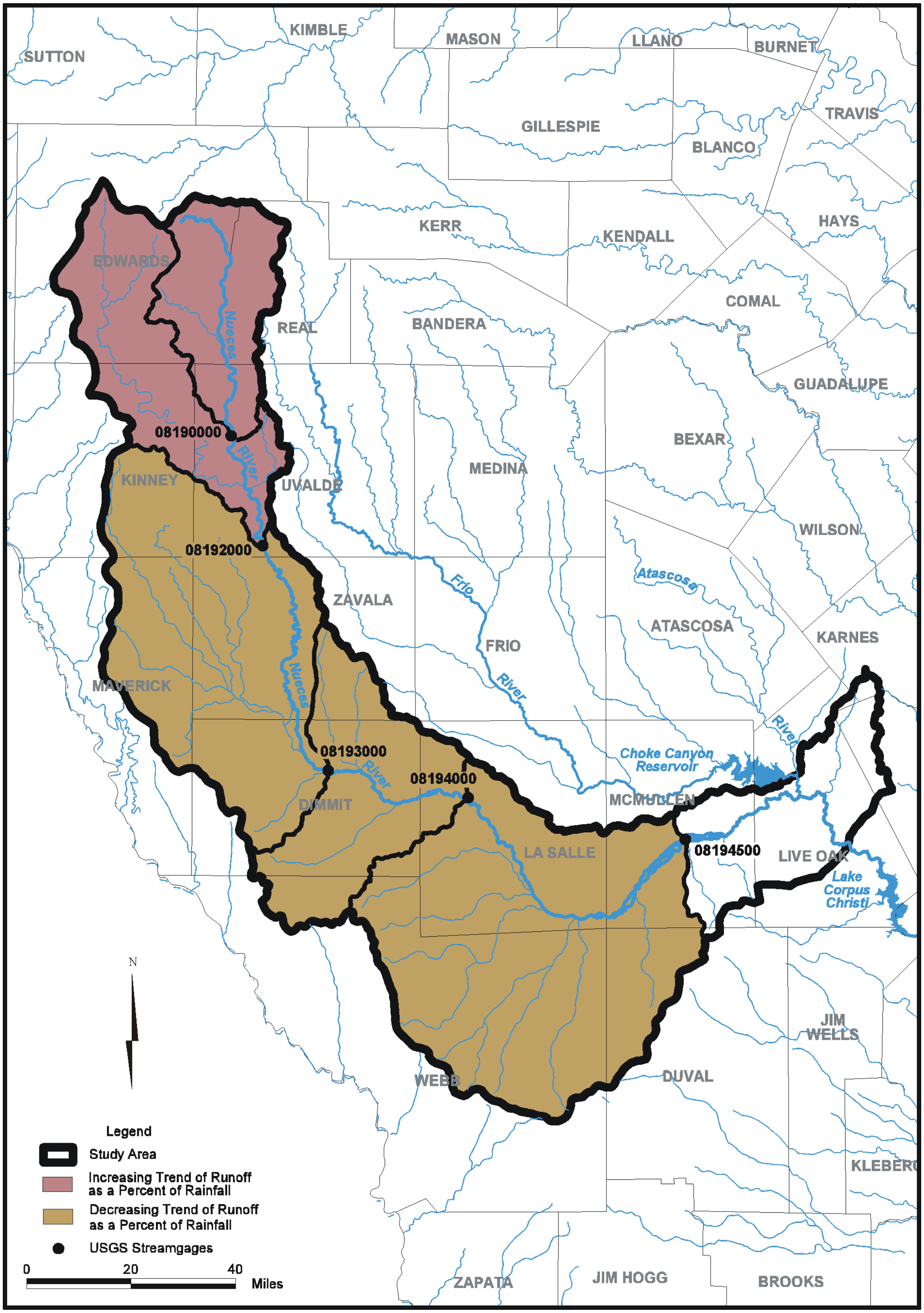


*Figure 5-5. Results of Statistical Analyses of Runoff as a Percentage of Rainfall*

### *5.6 Summary*

Average annual rainfall throughout the Nueces River Basin has generally increased between the earlier and latter portions of the last five or six decades. Causes of this trend are not known. Statistically, runoff as a percentage of rainfall in the Nueces River Basin is significantly increasing in two sub-basins in the Hill Country and decreasing in three downstream sub-basins at the 90 percent confidence level. The decreasing trend in the relationship between runoff and rainfall occurs in the sub-basins between the streamflow gages on the Nueces River at Uvalde (USGS #08192000) and Asherton (USGS #08193000), between the Nueces River at Asherton (USGS #08193000) and Cotulla (USGS #08194000), and between the Nueces River at Cotulla (USGS #08194000) and Tilden (USGS #08194500). The apparent trends may be attributed to the proliferation of brush in the watersheds and, possibly, to pumping from the Carrizo Aquifer throughout the 20$^{th}$ Century. Additional studies and field research are recommended for this sub-basin.

# Section 6
# Hydrologic Simulation

## 6.1 Methods

### 6.1.1 Watershed Characteristics

The Nueces River Watershed covers a large area of South Texas just north of the Rio Grande River Basin. It is within a semiarid climatic region with soils that are primarily Usterts and Ustalfs that generally have large cracks that persist for more than 3 months during the summer. This allows for deep infiltration of any significant rainfall during the summer months. The watershed generally runs northwest to east and drains into the junction with the Frio River just below Choke Canyon Lake. Based on the digital elevation map (DEM), the derived sub-basins are shown in Figure 6-1. Due to the fact that part of the watershed lies over the western part of the Edwards Aquifer recharge zone, the watershed was divided into the upper (Edwards) and lower Nueces. The lower corresponds to the 8-digit HRUs 12110103, 12110104, and 12110105. The streamgauge flows near Uvalde were input into SWAT for the Lower Nueces.

### 6.1.2 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 6-2. For each sub-basin, precipitation and temperature data are retrieved by the SWAT input interface for the climate station nearest the centroid of the sub-basin.

### 6.1.3 Topography

The outlet or “catchment” for the portion of the Upper and Lower Nueces River, simulated in this study, is Lake Corpus Christi, which is located just downstream of sub-basin number 105_1. The sub-basin delineation and numbers are shown in Figure 6-1. Roads (obtained from the Census Bureau) are overlaid in Figure 6-3.

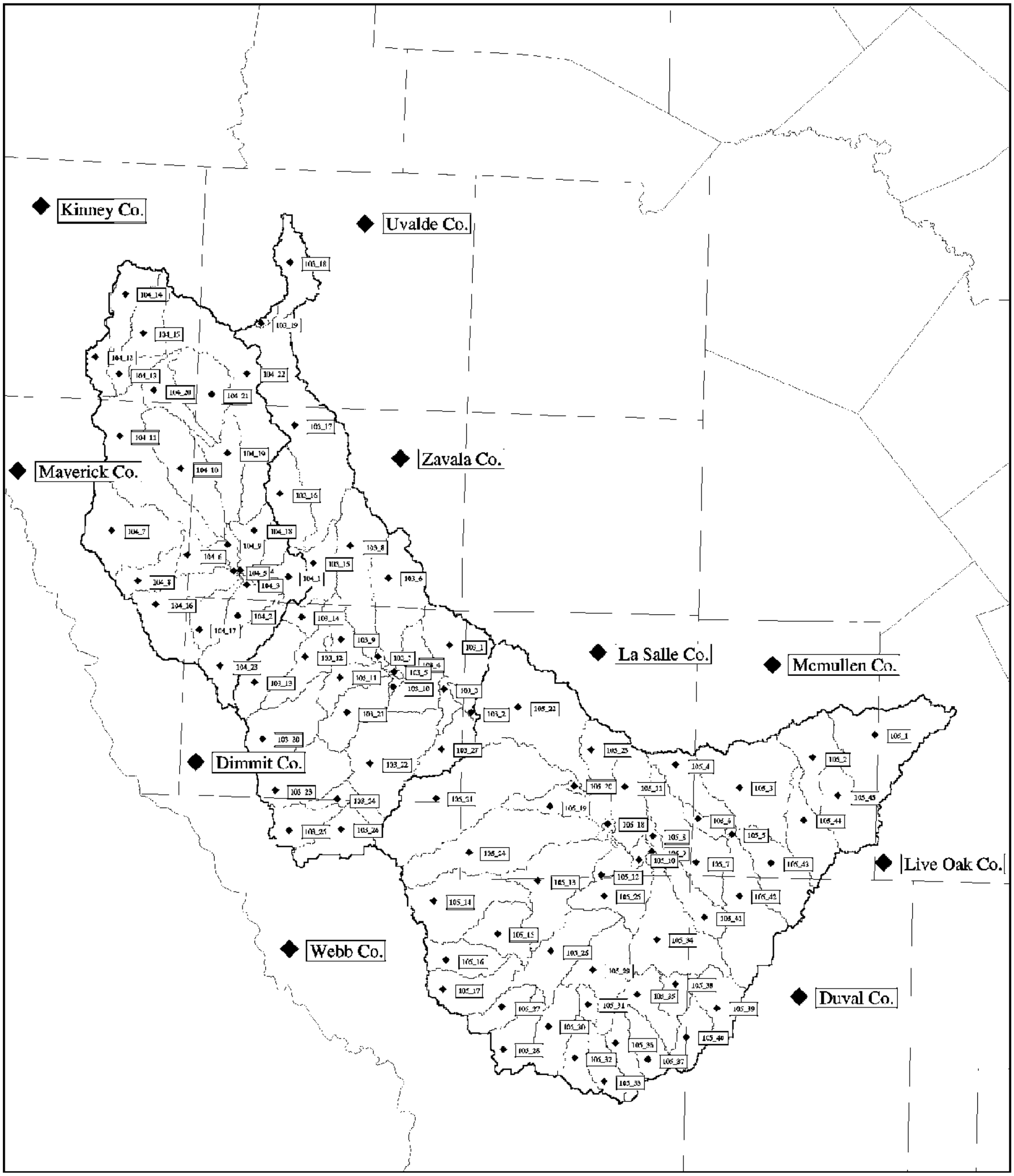


***Figure 6-1. Nueces River Watershed Sub-basin Map***

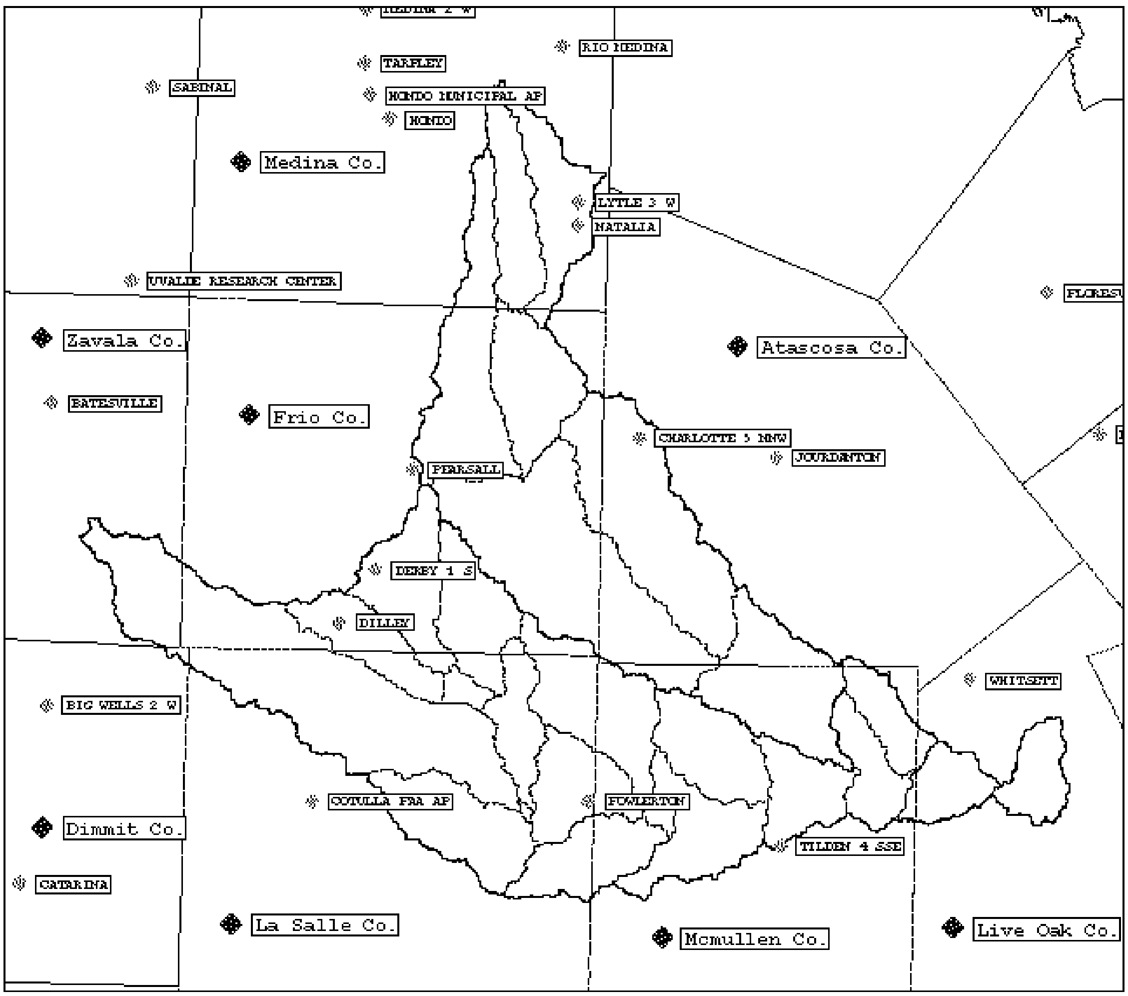


***Figure 6-2. Climate Stations in the Upper Nueces Watershed***

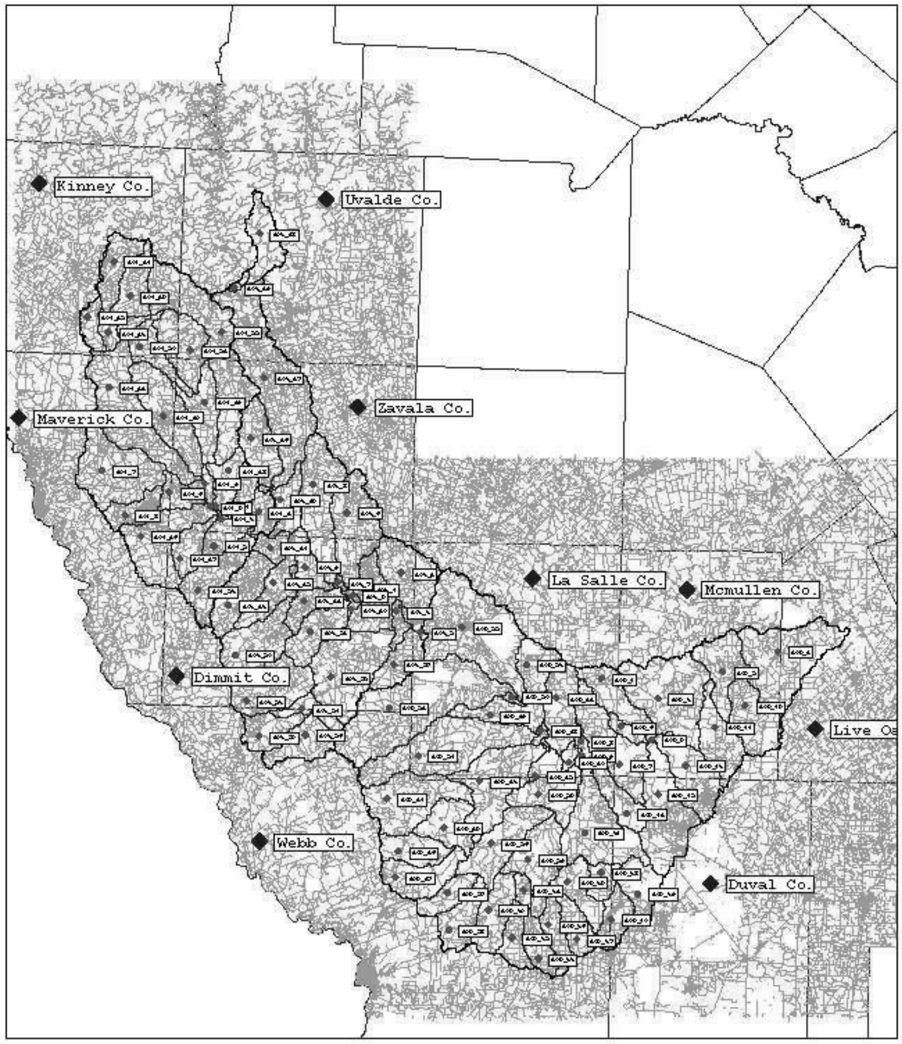


***Figure 6-3. Nueces River Watershed Roads Map***

### *6.1.4 Soils*

The dominant soil series in the Nueces River Watershed are Uvalde, Aguilares, Duval, Maverick, and Montell. These six soil series represent over 50 percent of the watershed area. A short description of each follows:

- ***Uvalde:*** The Uvalde series consists of deep, well-drained, moderately permeable soils formed in alluvium from limestone. These level to gently sloping or gently undulating soils are on alluvial fans or stream terraces. Slopes range from 0 to 3 percent.

- ***Aguilares:*** The Aguilares series consists of deep, well drained moderately permeable soils that formed in calcareous, loamy sediments. These soils are on uplands with slopes ranging from 1 to 3 percent.
- ***Duval:*** The Duval series consists of deep, well drained, moderately permeable soils that formed in sandy clay loams with interbedded sandstone on uplands. Slopes range from 1 to 5 percent.
- ***Maverick:*** The Maverick series consists of moderately deep, well drained soils formed in ancient clayey marine sediments. These soils are gently rolling. Slopes range from 0 to 10 percent.
- ***Montell:*** The Montell series consists of deep, moderately well drained, very slowly permeable soils that formed in ancient clayey alluvium. These soils are on nearly level to gently sloping uplands. Slopes range from 0 to about 3 percent.

### *6.1.5 Land Use/Land Cover*

Figure 6-4 show the areas of heavy and moderate brush in the Nueces River Watershed that is the area of brush removed or treated in the no-brush simulation. This corresponds to 74 percent of the total watershed area.

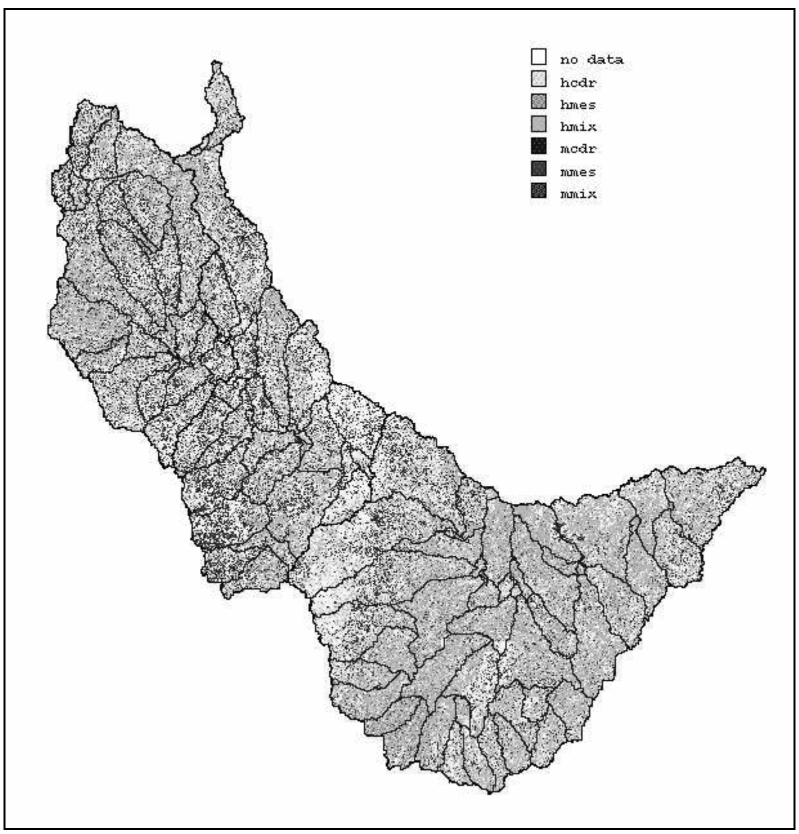


***Figure 6-4. Area of Heavy and Moderate Brush***

### 6.1.6 Model Input Variables

Significant input variables for the SWAT model for the lower Nueces River Watershed are shown in Table 6-1. Input variables for all sub-basins in the watershed were the same, with one exception.

It was assumed that 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 four units to account for the change from fair to good hydrologic conditions, and from brush to range conditions.

## 6.2 Nueces River Watershed Results

### 6.2.1 Calibration

SWAT was calibrated for the flow at streamgauges near Three Rivers. The results of calibration are shown in Figure 6-5. Measured and predicted average monthly flows compare reasonably well with a 4 percent difference between measured and simulated cumulative flow. Near Three Rivers, the measured and predicted monthly mean values are 34,340 and 29,386 acft, respectively. The coefficient of determination ($r^2$) was 0.99 between measured and simulated the Lower Nueces. Average baseflow for the entire watershed is 7 percent of total flow.

### 6.2.2 Brush Removal Simulation

The average annual rainfall is 22.47 inches for the Lower Nueces. Average annual evapotranspiration in the Lower Nueces is 21.00 inches for the brush condition and 18.57 inches for the no-brush condition. This represents 93 percent and 83 percent of precipitation for the brush and no-brush conditions, respectively in the Lower Nueces.

**Table 6-1. SWAT Input Variables for Nueces River Watershed**

| Variable | Brush Condition (Calibration) | No Brush Condition |
|---|---|---|
| Runoff Curve Number Adjustment | -15 | -15 |
| Soil Available Water Capacity Adjustment (%) | 0 | 0 |
| Soil Evaporation Compensation Factor ($in^3$ $in^{-3}$) | 0.85 | 0.85 |
| 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) | 5399 | 5399 |
| Heavy Cedar | 5399 | 5399 |
| Heavy Mesquite | 4697 | 4697 |
| Heavy mixed Brush | 5021 | 5021 |
| Moderate Cedar | 4697 | 4697 |
| Moderate Mesquite | 4157 | 4157 |
| Moderate Mixed Brush | 4427 | 4427 |
| Heavy Oak | 4697 | 4697 |
| Moderate Oak | 4157 | 4157 |
| Light Brush & Open Range/Pasture | 3617 | 3617 |
| Precipitation Interception (inches) | | |
| Heavy Cedar | 0.79 | N/A |
| Heavy Mesquite | 0 | N/A |
| Heavy Mixed Brush | 0.59 | N/A |
| Moderate | 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 & Moderate | 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 | 4 |
| Heavy Mixed Brush | 4 | 4 |
| 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 |
| Sub-basin Transmission Loss (inches/hour) | 0.015 | 0.015 |
| Fraction Trans. Loss Returned as Baseflow | 0.07 | 0.07 |

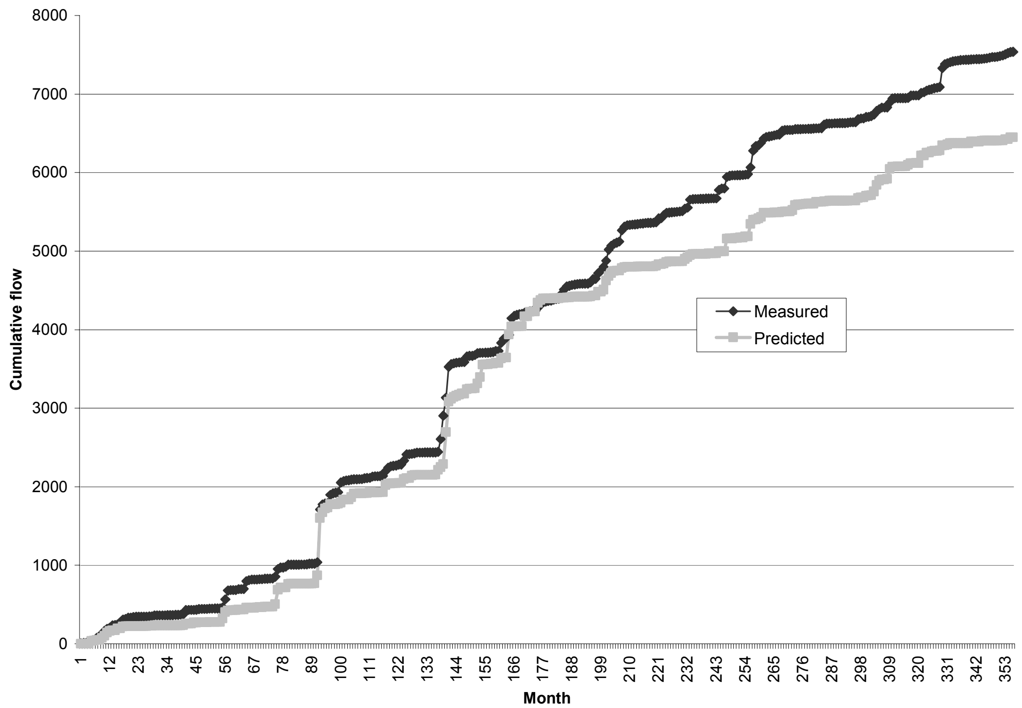


***Figure 6-5. Simulated and Measured Cumulative Flow at the Outlet of the Lower Nueces (Three Rivers)***

The increases in water yield by sub-basin for the Lower Nueces River Watersheds are shown in Figure 6-6 and 6-7, and Table 6-2. The amount of annual increase varies among the sub-basins and ranges from 16,058 gallons per acre of brush removed per year in sub-basin number 103-25 to 123,654 gallons per acre in sub-basin number 105-38. 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 sub-basins 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. In addition, Table 6-2 gives the total sub-basin area, area of brush treated, fraction of sub-basin treated, water yield increase per acre of brush treated, and total water yield increase for each sub-basin.

For the Lower Nueces, the increase is 105 percent or 653,618 acft. The average annual flow to Lake Corpus Christi could increase by 523,141 acft. The increase in volume of flow to Lake Corpus Christi is slightly less than the water yield because of stream channel transmission losses that occur after water leaves each sub-basin and the shallow soils that allow for percolation.

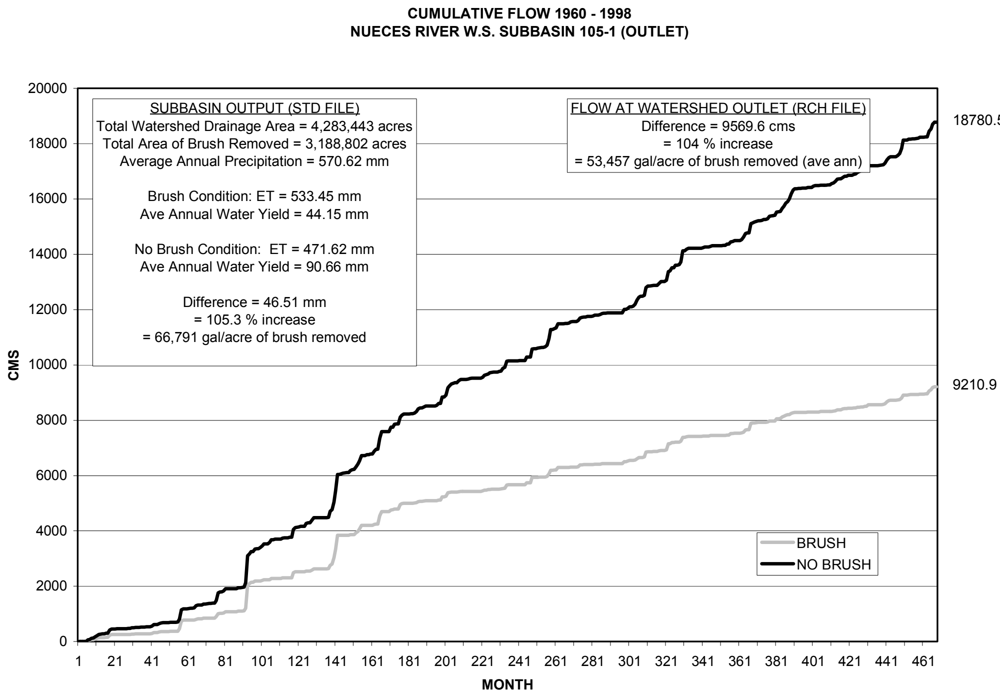


***Figure 6-6. Simulated Cumulative Flow at the Outlet for Brush and No Brush Conditions in the Lower Nueces***

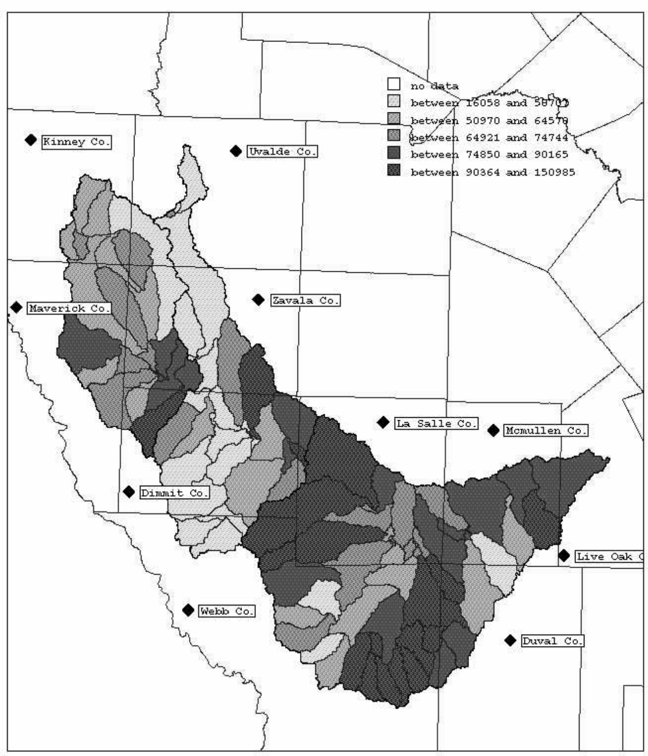


***Figure 6-7. Increase in Water Yield per Treated Acre (gallons/acre) due to Brush Removal from 1960 through 1998***

### *Table 6-2. Lower Nueces Acres and Water Yield*

| Sub-basin | Sub-basin Total Area (acres) | Brush Removal Area (acres) | Fraction of Sub-basin Containing Brush | Increase (gal/ac)Water Yield | Water Yield Increase (gallons/yr.) |
|---|---|---|---|---|---|
| 103-1 | 63206 | 16440 | 0.26 | 86026 | 1414267726 |
| 103-2 | 7952 | 2905 | 0.37 | 91684 | 266342739 |
| 103-3 | 10435 | 3910 | 0.37 | 89360 | 349396301 |
| 103-4 | 49891 | 31755 | 0.64 | 60416 | 1918521817 |
| 103-5 | 2320 | 1959 | 0.84 | 96361 | 188770359 |
| 103-6 | 77461 | 34494 | 0.45 | 90364 | 3117000052 |
| 103-7 | 2596 | 2024 | 0.78 | 50707 | 102630322 |
| 103-8 | 81937 | 66467 | 0.81 | 71825 | 4773980675 |
| 103-9 | 26377 | 14691 | 0.56 | 39080 | 574126071 |
| 103-10 | 2638 | 1887 | 0.72 | 45539 | 85931292 |
| 103-11 | 29579 | 19072 | 0.64 | 28137 | 536623176 |
| 103-12 | 38109 | 25874 | 0.68 | 50970 | 1318786059 |
| 103-13 | 52121 | 27671 | 0.53 | 74245 | 2054423493 |
| 103-14 | 14608 | 8938 | 0.61 | 38736 | 346226694 |
| 103-15 | 30070 | 16387 | 0.54 | 31701 | 519492019 |
| 103-16 | 47699 | 29903 | 0.63 | 45429 | 1358462299 |
| 103-17 | 157836 | 113634 | 0.72 | 46968 | 5337149321 |
| 103-18 | 39715 | 23948 | 0.60 | 45546 | 1090743834 |
| 103-19 | 1564 | 1148 | 0.73 | 70391 | 80808611 |
| 103-20 | 64402 | 38899 | 0.60 | 35081 | 1364605446 |
| 103-21 | 42963 | 27350 | 0.64 | 34343 | 939273365 |
| 103-22 | 97607 | 77509 | 0.79 | 55359 | 4290798955 |
| 103-23 | 66803 | 34210 | 0.51 | 22358 | 764873356 |
| 103-24 | 21043 | 21043 | 1.00 | 16613 | 349593030 |
| 103-25 | 32783 | 17089 | 0.52 | 16058 | 274419236 |
| 103-26 | 39488 | 39488 | 1.00 | 16506 | 651803262 |
| 103-27 | 34124 | 12007 | 0.35 | 67085 | 805495462 |
| 104-1 | 23402 | 13619 | 0.58 | 75226 | 1024497674 |
| 104-2 | 42361 | 25611 | 0.60 | 74850 | 1916984352 |
| 104-3 | 1650 | 1041 | 0.63 | 86486 | 90032375 |
| 104-4 | 212 | 127 | 0.60 | 88515 | 11241432 |
| 104-5 | 287 | 287 | 1.00 | 90753 | 26046089 |
| 104-6 | 21708 | 16102 | 0.74 | 70564 | 1136227556 |
| 104-7 | 89867 | 89867 | 1.00 | 90165 | 8102852553 |
| 104-8 | 26547 | 18771 | 0.71 | 64559 | 1211845963 |
| 104-9 | 9657 | 7453 | 0.77 | 70867 | 528173810 |
| 104-10 | 73755 | 50372 | 0.68 | 65478 | 3298248909 |

### *Table 6-2. Lower Nueces Acres and Water Yield (Continued)*

| Sub-basin | Sub-basin Total Area (acres) | Brush Removal Area (acres) | Fraction of Sub-basin Containing Brush | Increase (gal/ac)Water Yield | Water Yield Increase (gallons/yr.) |
|---|---|---|---|---|---|
| 104-11 | 120046 | 96431 | 0.80 | 52969 | 5107811496 |
| 104-12 | 18968 | 10916 | 0.58 | 62082 | 677691568 |
| 104-13 | 12335 | 7476 | 0.61 | 68298 | 510597399 |
| 104-14 | 37234 | 26098 | 0.70 | 62824 | 1639591212 |
| 104-15 | 37398 | 19570 | 0.52 | 63026 | 1233410500 |
| 104-16 | 76277 | 53800 | 0.71 | 72269 | 3888068842 |
| 104-17 | 27565 | 18268 | 0.66 | 60815 | 1110972842 |
| 104-18 | 27847 | 21759 | 0.78 | 77330 | 1682614641 |
| 104-19 | 43527 | 34290 | 0.79 | 61311 | 2102369549 |
| 104-20 | 31995 | 24694 | 0.77 | 63744 | 1574101832 |
| 104-21 | 55686 | 44098 | 0.79 | 64921 | 2862891543 |
| 104-22 | 134439 | 103047 | 0.77 | 47854 | 4931171272 |
| 104-23 | 53735 | 25029 | 0.47 | 96260 | 2409293865 |
| 105-1 | 109371 | 82739 | 0.76 | 87052 | 7202561755 |
| 105-2 | 48203 | 34224 | 0.71 | 89004 | 3046064695 |
| 105-3 | 107943 | 86808 | 0.80 | 84134 | 7303544423 |
| 105-4 | 41983 | 34774 | 0.83 | 74744 | 2599148716 |
| 105-5 | 1929 | 1632 | 0.85 | 85383 | 139344632 |
| 105-6 | 11213 | 11213 | 1.00 | 75080 | 841876886 |
| 105-7 | 75519 | 75521 | 1.00 | 80595 | 6086590297 |
| 105-8 | 8639 | 8639 | 1.00 | 72258 | 624237732 |
| 105-9 | 2705 | 2298 | 0.85 | 65399 | 150287923 |
| 105-10 | 6477 | 5370 | 0.83 | 73357 | 393925347 |
| 105-11 | 50691 | 50692 | 1.00 | 66719 | 3382120967 |
| 105-12 | 15675 | 12302 | 0.78 | 55455 | 682201622 |
| 105-13 | 85277 | 85277 | 1.00 | 72098 | 6148279055 |
| 105-14 | 81569 | 65835 | 0.81 | 82838 | 5453648088 |
| 105-15 | 41116 | 41116 | 1.00 | 46130 | 1896687373 |
| 105-16 | 35149 | 35150 | 1.00 | 64570 | 2269624484 |
| 105-17 | 47969 | 47969 | 1.00 | 65705 | 3151790312 |
| 105-18 | 4553 | 4552 | 1.00 | 57400 | 261284865 |
| 105-19 | 37543 | 37543 | 1.00 | 71071 | 2668235019 |
| 105-20 | 2290 | 2291 | 1.00 | 70720 | 162019147 |
| 105-21 | 175846 | 95449 | 0.54 | 96980 | 9256666848 |
| 105-22 | 147144 | 102589 | 0.70 | 92845 | 9524908246 |
| 105-23 | 33094 | 23046 | 0.70 | 79614 | 1834787913 |
| 105-24 | 119471 | 90822 | 0.76 | 99326 | 9021023218 |
| 105-25 | 45795 | 37941 | 0.83 | 60957 | 2312767883 |
| 105-26 | 62181 | 62181 | 1.00 | 56137 | 3490629992 |

### Table 6-2. Lower Nueces Acres and Water Yield (Continued)

| Sub-basin | Sub-basin Total Area (acres) | Brush Removal Area (acres) | Fraction of Sub-basin Containing Brush | Increase (gal/ac)Water Yield | Water Yield Increase (gallons/yr.) |
|---|---|---|---|---|---|
| 105-27 | 26283 | 26283 | 1.00 | 50768 | 1334325721 |
| 105-28 | 37437 | 37437 | 1.00 | 58788 | 2200841945 |
| 105-29 | 60783 | 39211 | 0.65 | 87816 | 3443341892 |
| 105-30 | 43329 | 43330 | 1.00 | 90954 | 3941034554 |
| 105-31 | 9277 | 7552 | 0.81 | 150985 | 1140239767 |
| 105-32 | 25423 | 13721 | 0.54 | 129783 | 1780757498 |
| 105-33 | 27684 | 18744 | 0.68 | 108253 | 2029101374 |
| 105-34 | 90967 | 72018 | 0.79 | 109176 | 7862632769 |
| 105-35 | 35258 | 28171 | 0.80 | 90717 | 2555591663 |
| 105-36 | 26392 | 17036 | 0.65 | 97566 | 1662131655 |
| 105-37 | 27975 | 27975 | 1.00 | 100503 | 2811565745 |
| 105-38 | 19082 | 14508 | 0.76 | 123654 | 1793966993 |
| 105-39 | 36866 | 36866 | 1.00 | 80169 | 2955517041 |
| 105-40 | 30285 | 30285 | 1.00 | 83890 | 2540594339 |
| 105-41 | 31636 | 25103 | 0.79 | 102475 | 2572420628 |
| 105-42 | 87664 | 71314 | 0.81 | 56299 | 4014900999 |
| 105-43 | 60634 | 44439 | 0.73 | 48209 | 2142356683 |
| 105-44 | 48690 | 40817 | 0.84 | 59198 | 2416289720 |

# Section 7
# Economic Analysis

## 7.1 Introduction

Amounts of the various types and densities of brush cover in the Nueces River Watershed were detailed in Section 6. 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 portion of the Nueces river watershed down stream of the Edwards Aquifer recharge zone.

## 7.2 Brush Control Costs

Brush control costs include both initial and follow-up treatments required to reduce current brush canopies to 5 percent or less, and maintain it at the reduced level for at least 10 years. Both types of treatments and 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 will vary with brush type-density categories. Present values 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. Table 7-1 presents present values of total control costs per acre for the northern portion of the region which consists of sub-basins with a 103 and 104 prefix. Present values of total costs range from $170.42 per acre for rootplowing with predozing for control of heavy mesquite or mixed brush, to $83.99 per acre for moderate mesquite or mixed brush that can be initially controlled with herbicide treatments. Similar information is presented in Table 7-2 for the southern portions of the region consisting of sub-basins with a 105 prefix. For this portion of the region, present

**Table 7-1. Cost of Water Yield Brush Control Programs by Type-Density Category (Northern Portion of Nueces River Watershed)**

| Year | Treatment | Treatment Cost ($/acre) | Present Value ($/acre) |
|---|---|---|---|
| **Heavy Mesquite — Chemical Herbicide[1]** | | | |
| 0 | Chemical Herbicide | 45.00 | 45.00 |
| 4 | Chemical Herbicide | 40.00 | 29.40 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 88.99 |
| **Heavy Mesquite — Rootplow[2]** | | | |
| 0 | Rootplow | 110.00 | 110.00 |
| 5 | Choice IPT or Burn | 30.00 | 20.42 |
| | | Total | 130.42 |
| **Extra Heavy Mesquite — Rootplow with Pre-Doze[3]** | | | |
| 0 | Pre-doze and Rootplow | 150.00 | 150.00 |
| 5 | Choice IPT or Burn | 30.00 | 20.42 |
| | | Total | 170.42 |
| **Heavy Mixed Brush — Chemical Herbicide[4]** | | | |
| 0 | Chemical Herbicide | 90.00 | 90.00 |
| 5 | Choice IPT or Burn | 35.00 | 23.82 |
| | | Total | 113.82 |
| **Heavy Mixed Brush — Chop Method[5]** | | | |
| 0 | Choice of Chop Method | 45.00 | 45.00 |
| 4 | Choice Chop, IPT, or Burn | 45.00 | 33.08 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 96.67 |
| **Heavy Mixed Brush — Rootplow[2]** | | | |
| 0 | Rootplow | 100.00 | 100.00 |
| 5 | IPT or Burn | 30.00 | 20.42 |
| | | Total | 120.42 |
| **Extra Heavy Mixed Brush — Rootplow with Pre-Doze[3]** | | | |
| 0 | Pre-Doze and Rootplow | 150.00 | 150.00 |
| 5 | IPT or Burn | 30.00 | 20.42 |
| | | Total | 170.42 |

***Table 7-1. Cost of Water Yield Brush Control Programs by Type-Density Category (Northern Portion of Nueces River Watershed) (Continued)***

| Year | Treatment | Treatment Cost ($/acre) | Present Value ($/acre) |
|---|---|---|---|
| ***Moderate Mesquite — Chemical Herbicide[1]*** | | | |
| 0 | Aerial or IPT Herbicide | 40.00 | 40.00 |
| 4 | Aerial or IPT Herbicide | 40.00 | 29.40 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 83.99 |
| ***Moderate Mixed Brush — Chemical Herbicide[1]*** | | | |
| 0 | Aerial or IPT Herbicide | 40.00 | 40.00 |
| 4 | Aerial or IPT Herbicide | 40.00 | 29.40 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 83.99 |

[1]Either aerial or individual chemical application may be used.
[2]Rootplow, rake, stack, and burn.
[3]Heavy tree-doze, rootplow, rake, stack, and burn. Note: canopy cover for this practice is 40% or greater.
[4]Choice of roller-chop, aerator method, or deep disking.

***Table 7-2. Cost of Water Yield Brush Control Programs by Type-Density Category (Southern Portion of Nueces River Watershed)***

| ***Year*** | ***Treatment*** | ***Treatment Cost ($/acre)*** | ***Present Value ($/acre)*** |
|---|---|---|---|
| ***Heavy Mesquite — Chemical Herbicide[1]*** | | | |
| 0 | Chemical Herbicide | 45.00 | 45.00 |
| 4 | Chemical Herbicide | 40.00 | 29.40 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 88.99 |
| ***Heavy and Extra Heavy Mesquite — Rootplow and Pre-Doze[2]*** | | | |
| 0 | Pre-Doze and Rootplow | 120.00 | 120.00 |
| 5 | Choice IPT or Burn | 30.00 | 20.42 |
| | | Total | 140.42 |
| ***Heavy Mixed Brush — Chemical Herbicide[1]*** | | | |
| 0 | Chemical Herbicide | 50.00 | 50.00 |
| 4 | Choice Chop, IPT, or Burn | 60 | 44.10 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 108.69 |
| ***Heavy Mixed Brush — Chop Method[3]*** | | | |
| 0 | Choice of Chop Method | 45.00 | 45.00 |
| 4 | Choice Chop, IPT, or Burn | 45.00 | 33.08 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 92.67 |
| ***Heavy and Extra Heavy Mixed Brush — Rootplow with Pre-Doze[2]*** | | | |
| 0 | Pre-Doze and Rootplow | 120.00 | 120.00 |
| 5 | IPT or Burn | 30.00 | 20.42 |
| | | Total | 140.42 |
| ***Moderate Mesquite — Chemical Herbicide[1]*** | | | |
| 0 | Aerial or IPT Herbicide | 40.00 | 40.00 |
| 4 | Aerial or IPT Herbicide | 30.00 | 20.42 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 76.64 |

***Table 7-2. Cost of Water Yield Brush Control Programs by Type-Density Category (Southern Portion of Nueces River Watershed) (Continued)***

| ***Year*** | ***Treatment*** | ***Treatment Cost ($/acre)*** | ***Present Value ($/acre)*** |
|---|---|---|---|
| ***Moderate Mixed Brush — Chemical Herbicide[1]*** | | | |
| 0 | Aerial or IPT Herbicide | 40.00 | 40.00 |
| 4 | Aerial or PIT Herbicide | 40.00 | 29.40 |
| 7 | Choice IPT or Burn | 25.00 | 14.59 |
| | | Total | 83.99 |

[1]Either aerial or individual chemical application may be used.
[2]Rootplow, rake, stack, and burn.
[3]Heavy tree-doze, rootplow, rake, stack, and burn. Note: canopy cover for this practice is 40% or greater.
[4]Choice of roller-chop, aerator method, or deep disking.

values of total costs range from $140.42 per acre for rootplowing with predozing for control of heavy mesquite or mixed brush, to $76.64 per acre for moderate mesquite that can be initially controlled with herbicide treatments. Costs of treatments, year those treatments are needed and treatment life for each brush type density category are detailed in Tables 7-1 and 7-2.

### 7.3 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 Nueces River Watershed are shown in Table 7-3 (sub-basins 103 and 104) and Table 7-4 (sub-basin 105). Data relating to grazing capacity was entered into the investment analysis model.

***Table 7-3. Grazing Capacity With and Without Brush Control (Acres/AUY) (Northern Portion of Nueces River Watershed)***

| | | Program Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Brush Type / Category*** | ***Brush Control*** | ***0*** | ***1*** | ***2*** | ***3*** | ***4*** | ***5*** | ***6*** | ***7*** | ***8*** | ***9*** |
| Heavy Mesquite | Control | 39.0 | 35.0 | 31.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 |
| | No Control | 39.0 | 39.0 | 39.1 | 39.1 | 39.2 | 39.2 | 39.2 | 39.3 | 39.3 | 39.4 |
| Heavy Mixed Brush | Control | 39.0 | 35.0 | 31.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 |
| | No Control | 39.0 | 39.0 | 39.1 | 39.1 | 39.2 | 39.2 | 39.2 | 39.3 | 39.3 | 39.4 |
| Moderate Mesquite | Control | 35.0 | 32.3 | 39.7 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 |
| | No Control | 35.0 | 35.2 | 35.4 | 35.5 | 35.7 | 35.9 | 36.1 | 36.2 | 36.4 | 36.6 |
| Moderate Mixed Brush | Control | 35.0 | 32.3 | 29.7 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 | 27.0 |
| | No Control | 35.0 | 35.2 | 35.4 | 35.5 | 35.7 | 35.9 | 36.1 | 36.2 | 36.4 | 36.6 |

***Table 7-4. Grazing Capacity With and Without Brush Control (Acres/AUY)***
***(Southern Portion of Nueces River Watershed)***

| | | ***Program Year*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Brush Type / Category*** | ***Brush Control*** | ***0*** | ***1*** | ***2*** | ***3*** | ***4*** | ***5*** | ***6*** | ***7*** | ***8*** | ***9*** |
| Heavy Mesquite | Control | 41.0 | 36.0 | 31.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| | No Control | 41.0 | 41.0 | 41.1 | 41.1 | 41.2 | 41.2 | 41.3 | 41.3 | 41.3 | 41.4 |
| Heavy Mixed Brush | Control | 38.0 | 34.0 | 30.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| | No Control | 38.0 | 38.0 | 38.1 | 38.1 | 38.2 | 38.2 | 38.2 | 38.3 | 38.3 | 38.4 |
| Moderate Mesquite | Control | 33.0 | 30.6 | 28.3 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| | No Control | 33.0 | 33.2 | 33.3 | 33.5 | 33.7 | 33.8 | 34.0 | 34.2 | 34.3 | 34.5 |
| Moderate Mixed Brush | Control | 33.0 | 30.6 | 28.3 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 | 26.0 |
| | No Control | 33.0 | 33.2 | 33.3 | 33.5 | 33.7 | 33.8 | 34.0 | 34.2 | 34.3 | 34.5 |

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. In the northern portion of the watershed, livestock grazing capacities range from about 27 acres per AUY for land on which mesquite is controlled, to 39 acres per AUY for land infested with heavy mixed brush. In the southern portion of the watershed, livestock grazing capacities range from about 26 acres per AUY for land on which mesquite is controlled, to 41 acres per AUY for land infested with heavy mesquite.

Livestock production practices, revenues, and costs representative of the watershed were obtained from personal interviews with a focus group of local ranchers. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into livestock production investment analysis budgets. This information for the livestock enterprises (cattle) in the project areas is shown in Table 7-5. It is important to note once again 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.

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, turkey, and quail being the most commonly hunted species. Therefore, wildlife costs and revenues were entered into the model as simple entries in the project period. For control of heavy brush categories, wildlife revenues are expected to increase by about $1.50 per acre (from $10.00 per acre to $11.50 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 7-5. Investment Analysis Budget, Cow-Calf Production***

| ***Revenue Item Description*** | ***Quantity*** | ***Unit*** | ***$ / Unit*** | ***Cost*** |
|---|---|---|---|---|
| **Partial Revenues** | | | | |
| Calves | 425.00 | Pound | .85 | 361.25 |
| Cows | 111.1 | Pound | .40 | 0 |
| Bulls | 250.0 | Pound | .50 | 0 |
| | | | Total | 361.25 |
| ***Variable Cost Item Description*** | ***Quantity*** | ***Unit*** | ***$ / Unit*** | ***Cost*** |
| **Partial Variable Costs** | | | | |
| Supplemental Feed | 400.0 | Pound | 0.10 | 40.00 |
| Salt & Minerals | 50.0 | Pound | 0.20 | 10.00 |
| Marketing | 1.0 | Head | 6.25 | 6.25 |
| Veterinary Medicine | 1.0 | Head | 12.00 | 12.00 |
| Miscellaneous | 1.0 | Head | 5.00 | 5.00 |
| Net Replacement Cows[3] | 1.0 | Head | 35.28 | 35.28 |
| Net Replacement Bulls[4] | 1.0 | Head | 3.09 | 6.09 |
| | | | Total | 114.62 |

Note: This budget is for presentation of the information used in the investment analysis only. Values herein are representative of a typical ranch in the Lower Frio and Nueces Watersheds. The budget is based on 1 cow-calf pair per animal unit. Variable costs listed here include only items which change as a result of implementing a brush control program and adjusting livestock numbers to meet changes in grazing capacity. Net returns cannot be calculated from this budget, for not all revenues and variable costs have been included, nor have fixed costs been considered.

With the information presented in Table 7-5, present values of the benefits to landowners were estimated for each of the brush type-density. In the northern portion of the watershed, they range from $19.73 per acre for control of moderate mesquite and mixed brush to $34.49 per acre for the control of heavy mesquite and mixed brush (Table 7-6). In the southern portion of the watershed, they range from $17.14 per acre for control of moderate mesquite and mixed brush to $36.53 per acre for the control of heavy mixed brush (Table 7-7).

***Table 7-6. Landowner / State Cost-Shares of Brush Control (Northern Portion of Nueces River Watershed)***

| Brush Type and Density | Control Practice | PV of Total Cost ($/acre) | Rancher Share ($/acre) | Rancher (%) | State Share ($/acre) | State (%) |
|---|---|---|---|---|---|---|
| Heavy Mesquite | Chemical | 88.99 | 34.9 | 0.39 | 54.5 | 0.61 |
| | Rootplow | 130.42 | 34.49 | 0.26 | 95.93 | 0.74 |
| | Doze and Plow[1] | 170.42 | 34.49 | 0.20 | 135.93 | 0.80 |
| Heavy Mixed Brush | Chemical | 113.82 | 34.49 | 0.30 | 72.33 | 0.70 |
| | Chop[2] | 92.67 | 34.49 | 0.37 | 58.18 | 0.63 |
| | Rootplow | 120.42 | 34.49 | 0.29 | 85.93 | 0.71 |
| | Doze and Plow[1] | 170.42 | 34.49 | 0.20 | 135.93 | 0.80 |
| Moderate Mesquite | Treatment Choice | 83.99 | 19.73 | 0.23 | 64.26 | 0.77 |
| Moderate Mixed Brush | Treatment Choice | 83.99 | 19.73 | 0.23 | 64.26 | 0.77 |
| Average | | 117.24 | 31.21 | 0.28 | 86.03 | 0.72 |

Note: Averages are simple averages, and do not reflect actual project averages based on the relative percent of each brush category. Rancher ability to pay is based on the net present value of a 10 year income stream which is realized by engaging in an production agriculture enterprise venture of 100% cow-calf cattle. In this region, 20% of typical ranch resources are assigned to wildlife production, but this budget is based on a 100% assignment of carrying capacity to the livestock operation.

[1]The (pre)doze and plow category is for extra heavy brush canopy cover classifications in excess of 40% canopy cover.

[2]The "Chop" category is for roller chopping, heavy disking, or for the use of heavy "aerator"-type treatments. This category is not for use in areas where mesquite or other plants which sprout from the root crown, unless additional means for controlling those plants are used.

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 northern portion of the project area range from $54.50 for control of heavy mesquite with chemical treatments to $135.93 for control of heavy mesquite and mixed brush by mechanical method. State per acre cost share of brush control in the southern portion of the project area range from $53.30 for control of heavy mesquite with chemical treatments to $104.73 for control of heavy mesquite brush by mechanical method. 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 Tables 7-6 and 7-7.

**Table 7-7. Landowner / State Cost-Shares of Brush Control (Southern Portion of Nueces River Watershed)**

| Brush Type and Density | Control Practice | PV of Total Cost ($/acre) | Rancher Share ($/acre) | Rancher (%) | State Share ($/acre) | State (%) |
|---|---|---|---|---|---|---|
| Heavy Mesquite | Chemical | 88.9 | 35.69 | .40 | 53.3 | 0.60 |
| | Doze and Plow[1] | 140.42 | 35.69 | 0.25 | 104.73 | 0.75 |
| Heavy Mixed Brush | Chemical (Chop)[2] | 108.69 | 36.53 | 0.34 | 72.16 | 0.66 |
| | Chop[3] | 92.67 | 36.53 | 0.39 | 56.14 | 0.61 |
| | Doze and Plow[1] | 140.42 | 36.53 | 0.26 | 103.89 | 0.74 |
| Moderate Mesquite | Treatment Choice | 76.64 | 17.14 | 0.22 | 59.5 | 0.78 |
| Moderate Mixed Brush | Treatment Choice | 83.99 | 17.14 | 0.20 | 66.85 | 0.80 |
| Average | | 104.55 | 30.75 | 0.30 | 73.80 | 0.70 |

Note: Averages are simple averages, and do not reflect actual project averages based on the relative percent of each brush category. Rancher ability to pay is based on the net present value of a 10 year income stream which is realized by engaging in an production agriculture enterprise venture of 100% cow-calf cattle. In this region, 20% of typical ranch resources are assigned to wildlife production, but this budget is based on a 100% assignment of carrying capacity to the livestock operation.

[1]The (pre)doze and plow category is for extra heavy brush canopy cover classifications in excess of 40% canopy cover. However, only one category of cost was included for all rootplow treatment options.. A cost average between heavy and extra heavy was used.

[2]This chemical treatment can be used in combinations of chemical or mechanical chop methods for retreatments.

[3]The "Chop" category is for roller chopping, heavy disking, or for the use of heavy "aerator"-type treatments. This category is not for use in areas where mesquite or other plants which sprout from the root crown, unless additional means for controlling those plants

## 7.4 Cost of Additional Water

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed 10-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 Section 6). 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 percent discount rate).

The cost of added water was determined to average $46.62 per acft for the entire Nueces Watershed (Table 7-8). Sub-basins range from costs per added acft of $17.91 to $210.72.

### *Table 7-8. Cost of Added Water From Brush Control By Sub-Basin (acft)*

| Sub-Basin | Total State Cost ($) | Average Annual Gallon Increase | Average Annual acft Increase | Added acft 10Yr. Disctd | State Cost per acft Added Water ($) |
|---|---|---|---|---|---|
| 103-1 | 1056370.14 | 1414267725.54 | 4340.23 | 33862.46 | 31.20 |
| 103-2 | 232591.4 | 266342739.08 | 817.38 | 6377.17 | 36.47 |
| 103-3 | 304834.22 | 349396300.51 | 1072.26 | 8365.76 | 36.44 |
| 103-4 | 2567728.32 | 1918521816.63 | 5887.73 | 45936.05 | 55.90 |
| 103-5 | 175906.72 | 188770359.24 | 579.31 | 4519.82 | 38.92 |
| 103-6 | 2703524.08 | 3117000052.05 | 9565.72 | 74631.76 | 36.22 |
| 103-7 | 159824.26 | 102630321.75 | 314.96 | 2457.32 | 65.04 |
| 103-8 | 5487458.5 | 4773980674.51 | 14650.81 | 114305.61 | 48.01 |
| 103-9 | 1140984.08 | 574126070.86 | 1761.93 | 13746.56 | 83.00 |
| 103-10 | 169528.08 | 85931291.87 | 263.71 | 2057.49 | 82.40 |
| 103-11 | 1573902.06 | 536623175.82 | 1646.84 | 12848.61 | 122.50 |
| 103-12 | 1984420.34 | 1318786059.44 | 4047.21 | 31576.30 | 62.85 |
| 103-13 | 2057829.56 | 2054423492.56 | 6304.79 | 49190.00 | 41.83 |
| 103-14 | 681075.02 | 346226693.95 | 1062.53 | 8289.86 | 82.16 |
| 103-15 | 1166706.14 | 519492019.20 | 1594.26 | 12438.44 | 93.80 |
| 103-16 | 2400807.46 | 1358462299.40 | 4168.97 | 32526.29 | 73.81 |
| 103-17 | 9283966.92 | 5337149321.29 | 16379.11 | 127789.81 | 72.65 |
| 103-18 | 2151308.64 | 1090743834.07 | 3347.37 | 26116.18 | 82.37 |
| 103-19 | 103136.32 | 80808610.53 | 247.99 | 1934.84 | 53.30 |
| 103-20 | 2772088.6 | 1364605446.00 | 4187.82 | 32673.37 | 84.84 |
| 103-21 | 2176805.26 | 939273365.13 | 2882.52 | 22489.45 | 96.79 |
| 103-22 | 6341224.36 | 4290798954.93 | 13167.98 | 102736.57 | 61.72 |
| 103-23 | 2525872.78 | 764873355.71 | 2347.31 | 18313.71 | 137.92 |
| 103-24 | 1755823.8 | 349593029.84 | 1072.86 | 8370.47 | 209.76 |
| 103-25 | 1291357.36 | 274419236.21 | 842.16 | 6570.55 | 196.54 |
| 103-26 | 3288577.6 | 651803261.83 | 2000.31 | 15606.42 | 210.72 |
| 103-27 | 345333.24 | 805495461.58 | 2471.97 | 19286.35 | 17.91 |
| 104-1 | 995370.46 | 1024497673.64 | 3144.07 | 24530.02 | 40.58 |
| 104-2 | 2036292.72 | 1916984351.55 | 5883.01 | 45899.24 | 44.36 |
| 104-3 | 80132 | 90032374.72 | 276.30 | 2155.69 | 37.17 |
| 104-4 | 10322.22 | 11241431.87 | 34.50 | 269.16 | 38.35 |
| 104-5 | 24505.08 | 26046089.33 | 79.93 | 623.63 | 39.29 |
| 104-6 | 1316272.96 | 1136227555.62 | 3486.95 | 27205.22 | 48.38 |
| 104-7 | 8073651.28 | 8102852553.30 | 24866.74 | 194010.32 | 41.61 |
| 104-8 | 1686386.64 | 1211845962.67 | 3719.02 | 29015.78 | 58.12 |
| 104-9 | 628099.24 | 528173810.22 | 1620.91 | 12646.31 | 49.67 |
| 104-10 | 4161225.54 | 3298248908.54 | 10121.95 | 78971.49 | 52.69 |
| 104-11 | 8663361.04 | 5107811496.10 | 15675.30 | 122298.67 | 70.84 |
| 104-12 | 836396.66 | 677691567.87 | 2079.76 | 16226.28 | 51.55 |
| 104-13 | 621123.34 | 510597398.72 | 1566.97 | 12225.47 | 50.81 |
| 104-14 | 2147678.32 | 1639591211.81 | 5031.72 | 39257.48 | 54.71 |
| 104-15 | 1758168.8 | 1233410499.62 | 3785.20 | 29532.11 | 59.53 |

***Table 7-8. Cost of Added Water From Brush Control By Sub-Basin (acft) (Continued)***

| Sub-Basin | Total State Cost ($) | Average Annual Gallon Increase | Average Annual acft Increase | Added acft 10Yr. Disctd | State Cost per acft Added Water ($) |
|---|---|---|---|---|---|
| 104-16 | 4454628.94 | 3888068842.33 | 11932.05 | 93093.82 | 47.85 |
| 104-17 | 1418228.74 | 1110972841.62 | 3409.45 | 26600.53 | 53.32 |
| 104-18 | 1792497.88 | 1682614640.70 | 5163.75 | 40287.61 | 44.49 |
| 104-19 | 2748009.96 | 2102369548.66 | 6451.94 | 50338.00 | 54.59 |
| 104-20 | 1941567.4 | 1574101831.77 | 4830.74 | 37689.44 | 51.51 |
| 104-21 | 3961764.32 | 2862891542.71 | 8785.89 | 68547.53 | 57.80 |
| 104-22 | 9257742.48 | 4931171271.75 | 15133.21 | 118069.30 | 78.41 |
| 104-23 | 1913725.1 | 2409293865.36 | 7393.85 | 57686.83 | 33.17 |
| 105-1 | 6403998.6 | 7202561754.64 | 22103.85 | 172454.24 | 37.13 |
| 105-2 | 2648937.6 | 3046064694.75 | 9348.03 | 72933.32 | 36.32 |
| 105-3 | 6718939.2 | 7303544422.78 | 22413.75 | 174872.12 | 38.42 |
| 105-4 | 2691507.6 | 2599148716.16 | 7976.49 | 62232.61 | 43.25 |
| 105-5 | 126316.8 | 139344631.70 | 427.63 | 3336.39 | 37.86 |
| 105-6 | 639014.4 | 841876886.09 | 2583.63 | 20157.44 | 31.70 |
| 105-7 | 4495546.8 | 6086590296.67 | 18679.06 | 145734.02 | 30.85 |
| 105-8 | 418966.2 | 624237731.85 | 1915.72 | 14946.41 | 28.03 |
| 105-9 | 178767.18 | 150287922.74 | 461.22 | 3598.41 | 49.68 |
| 105-10 | 417904.02 | 393925347.04 | 1208.91 | 9431.94 | 44.31 |
| 105-11 | 3939772.14 | 3382120967.48 | 10379.35 | 80979.67 | 48.65 |
| 105-12 | 956788.56 | 682201621.53 | 2093.60 | 16334.27 | 58.58 |
| 105-13 | 6646415.4 | 6148279054.56 | 18868.38 | 147211.07 | 45.15 |
| 105-14 | 4886169.3 | 5453648088.24 | 16736.63 | 130579.20 | 37.42 |
| 105-15 | 3198251.16 | 1896687372.85 | 5820.72 | 45413.26 | 70.43 |
| 105-16 | 2641917.55 | 2269624483.79 | 6965.22 | 54342.66 | 48.62 |
| 105-17 | 3732538.68 | 3151790312.35 | 9672.49 | 75464.76 | 49.46 |
| 105-18 | 352402.2 | 261284864.47 | 801.85 | 6256.06 | 56.33 |
| 105-19 | 2917719 | 2668235018.71 | 8188.51 | 63886.78 | 45.67 |
| 105-20 | 171190.3 | 162019146.73 | 497.22 | 3879.30 | 44.13 |
| 105-21 | 6995387.55 | 9256666847.58 | 28407.67 | 221636.62 | 31.56 |
| 105-22 | 7430127.3 | 9524908246.03 | 29230.87 | 228059.25 | 32.58 |
| 105-23 | 1783837.8 | 1834787912.96 | 5630.76 | 43931.17 | 40.61 |
| 105-24 | 6778096.7 | 9021023218 | 27684.50 | 215994.50 | 31.38 |
| 105-25 | 2951419.14 | 2312767883 | 7097.62 | 55375.66 | 53.30 |
| 105-26 | 4838710.32 | 3490629992 | 10712.35 | 83577.76 | 57.89 |
| 105-27 | 2052765.72 | 1134325721 | 3481.12 | 27159.68 | 75.58 |
| 105-28 | 2919049.92 | 2200841945 | 6754.14 | 52695.77 | 55.39 |
| 105-29 | 3034931.4 | 3443341892 | 10567.23 | 82445.51 | 36.81 |
| 105-30 | 3367436.22 | 3941034554 | 12094.59 | 94362.00 | 35.69 |
| 105-31 | 584524.8 | 1140239767 | 3499.27 | 27301.28 | 21.41 |
| 105-32 | 1062005.4 | 1780757498 | 5464.94 | 42637.49 | 24.91 |
| 105-33 | 1450863 | 2029101374 | 6227.08 | 48583.71 | 29.86 |

***Table 7-8. Cost of Added Water From Brush Control By Sub-Basin (acft) (Continued)***

| Sub-Basin | Total State Cost ($) | Average Annual Gallon Increase | Average Annual acft Increase | Added acft 10Yr. Disctd | State Cost per acft Added Water ($) |
|---|---|---|---|---|---|
| 105-34 | 5574193.2 | 7862632769 | 24129.53 | 188258.62 | 29.61 |
| 105-35 | 2180435.4 | 2555591663 | 7842.82 | 61189.70 | 35.63 |
| 105-36 | 1318586.4 | 1662131655 | 5100.89 | 39797.18 | 33.13 |
| 105-37 | 2165265 | 2811565745 | 8628.38 | 67318.61 | 32.16 |
| 105-38 | 1122919.2 | 1793966993 | 5505.48 | 42953.77 | 26.14 |
| 105-39 | 2853428.4 | 2955517041 | 9070.15 | 70765.30 | 40.32 |
| 105-40 | 2344059 | 2540594339 | 7796.80 | 60830.62 | 38.53 |
| 105-41 | 1942972.2 | 2572420628 | 7894.47 | 61592.65 | 31.55 |
| 105-42 | 5519703.6 | 4014900999 | 12321.28 | 96130.62 | 57.42 |
| 105-43 | 3439578.6 | 2142356683 | 6574.65 | 51295.43 | 67.05 |
| 105-44 | 3159235.8 | 2416289720 | 7415.32 | 57854.33 | 54.61 |
| 105-45 | 2832143.4 | 3413799468 | 10476.57 | 81738.17 | 34.65 |
| Total | 250310874.5 | | | 5369726.49 | |
| Average | | | | | $6.62 |

# Appendix A
# Brush/Water Yield Feasibility Studies

## A.1 Introduction

The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in eight 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 streamgauges, 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.

## A.2 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 streamflow, possibly due to increased evapotranspiration (ET).[1,2] A modeling study of the North Concho River Watershed[3] (Upper Colorado River Authority, 1998) indicates that removing brush may result in a significant increase in water yield.

During the 1998–1999 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

[1] Thurow, T. L. 1998. Assessment of Brush Management as a Strategy for Enhancing Water Yield. Proceedings of the 25th Water for Texas Conference.
[2] Dugas, W.A.; R. A. Hicks; and P. Wright. 1998. Effect of Removal of Juniperus Ashei on Evapo-Transpiration and Runoff in the Seco Creek Watershed. Water Resources Research, Vol. 34, No. 6, 1499-1506.
[3] Upper Colorado River Authority. 1998. North Concho River Authority—Brush Control Planning, Assessment & Feasibility Study.

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:

- To predict the effects of brush removal or treatment on water yield in each watershed.
- To prioritize areas within each watershed relative to their potential for increasing water yield.
- To determine the benefit/cost of applying brush management practices in each watershed.
- To determine effects of brush management on livestock production and wildlife habitat.

This report will only address the first two.

## A.3 Methods

### A.3.1 SWAT Model Description

The SWAT model[4] is the continuation of a long-term effort of nonpoint source pollution modeling by the USDA-Agricultural Research Service (ARS), including development of CREAMS[5] (Knisel, 1980), SWRRB[6] (Williams et al., 1985; Arnold et al., 1990), and ROTO[7] (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 (1) is physically based; (2) uses readily available inputs; (3) is computationally efficient to operate on large basins in a reasonable time; and (4) 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.

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[4] Srinivasan, R. and J. G. Arnold. 1994. Integration of a Basin Scale Water Quality Model with GIS. Water Resources Bulletin, Vol. 30, No. 3, June.
[5] Knisel, W.G. 1980. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. United States Department of Agriculture Conservation Research Report No. 26.
[6] Williams, J. R., A.D. Nicks, and J. G. Arnold. 1985. Simulator for Water Resources in Rural Basins. J. Hydraulic Eng., ASCE, 111(6): 970–986.
[7] Arnold, J. G., J. R. Williams, D. R. Maidment. 1995. A Continuous Water and Sediment Routing Model for Large Basins. American Society of Civil Engineers Journal of Hydraulic Engineering. 121(2): 171–183.

### A.3.2 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.[8] An interface was developed for SWAT using the Graphical Resources Analysis Support System (GRASS). 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.

### A.3.3 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.

#### A.3.3.1 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 A-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 A-1).

[8] Srinivasan, R. and B. A. Engel. 1991. A Knowledge Based Approach to Exact Input Data from GIS. ASAE Paper No. 91-7045, American Society of Agricultural Engineers, St. Joseph, MI.

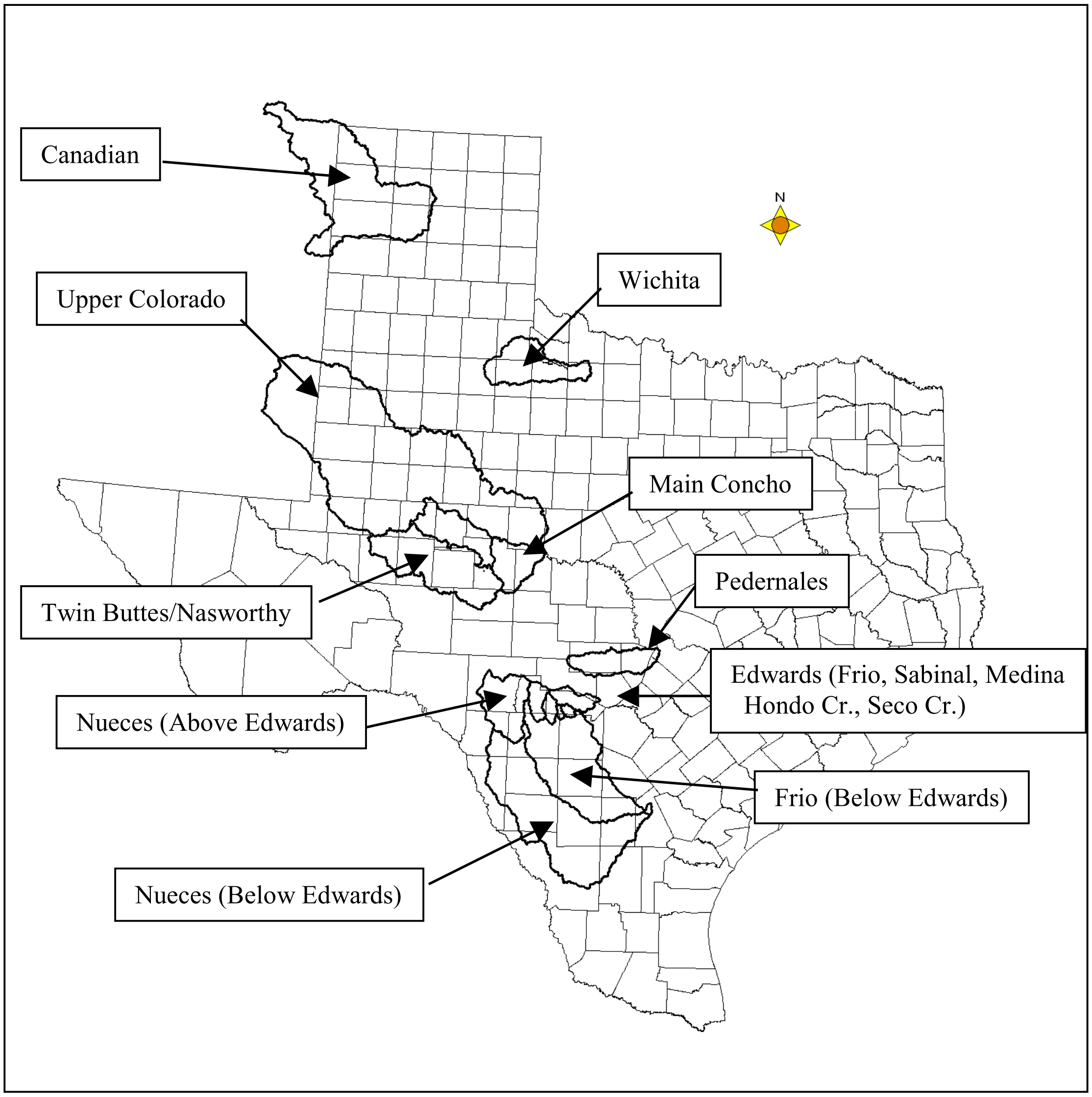


***Figure A-1. Watersheds included in the study area.***

**Table A-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 |

#### A.3.3.2 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 A-2.

#### A.3.3.3 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):

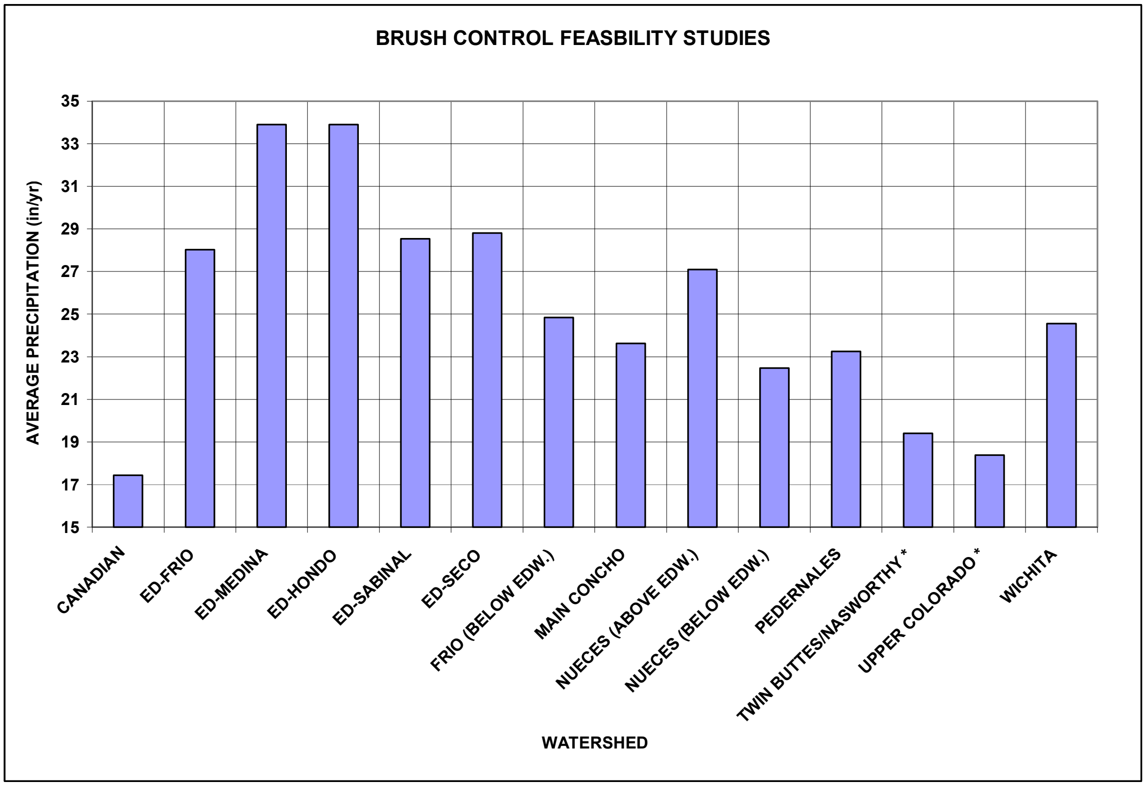


***Figure A-2. Average annual precipitation. Averages are for all climate stations in each watershed.***

1. **Computer-Based Mapping System (CBMS).** 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).** 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 percent 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. **State Soil Geographic (TATSGO).** 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.

#### *A.3.3.4 Land Use/Land Cover*

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 A-2).

**Table A-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 18 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 GCPs (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 shown in Table A-3:

***Table A-3.***

| | |
|---|---|
| Heavy Cedar, Mesquite, Oak, Mixed | Mostly pure stands of cedar (juniper), mesquite, oak and mixed brush with average canopy cover greater than 30%. |
| Moderate Cedar, Mesquite, Oak, Mixed | Mostly pure stands of cedar, mesquite, oak and mixed brush with average canopy cover 10 to 30%. |
| Light Brush | Either pure stands or mixed with average canopy cover less than 10%. |
| 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 percent – 80 percent. Table A-4 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 A-4.**
**Land Use and Percent Cover**

| Watershed | 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 (Above 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 |

*Percent of watershed where brush removal was planned.

### A.3.4 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 streamflows. 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. Groundwater 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.

### *A.3.5 Model Calibration*

The calibration period was based on the available period of record for streamgauges within each watershed. Measured streamflow 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.

### *A.3.6 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 A-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 streamflow 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 streamgauge data to estimate the location of

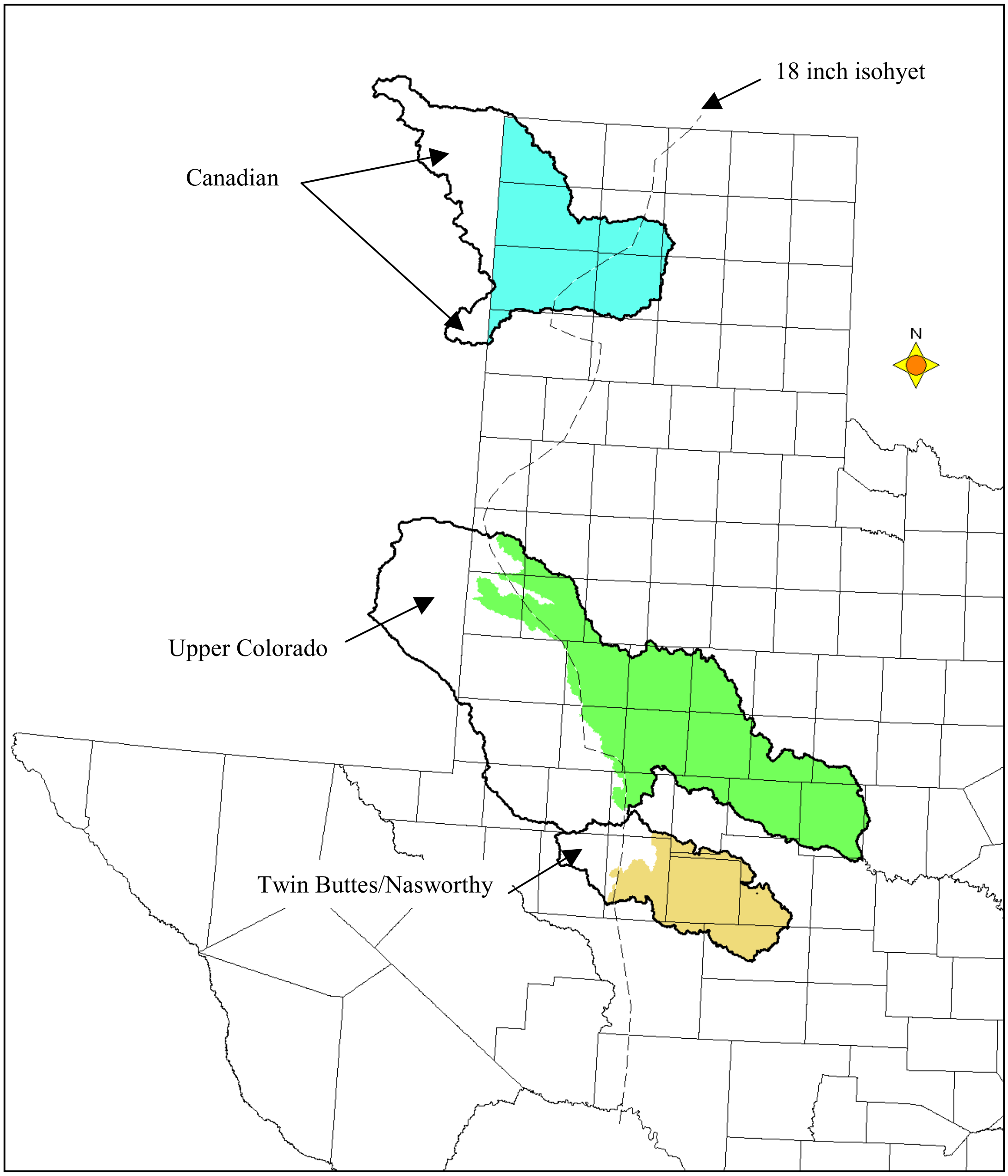


***Figure A-3. Areas where brush treatment was not planned (non-shaded portions of each watershed).***

These areas, most of which are west of the 18 inch isohyet. Brush treatment was not planned in these areas (Figure A-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 percent oak and 50 percent 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.

## A.4 Results

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

### A.4.1 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.

### A.4.2 Brush Treatment Simulations

Total area of each watershed is shown in Figure A-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 A-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.

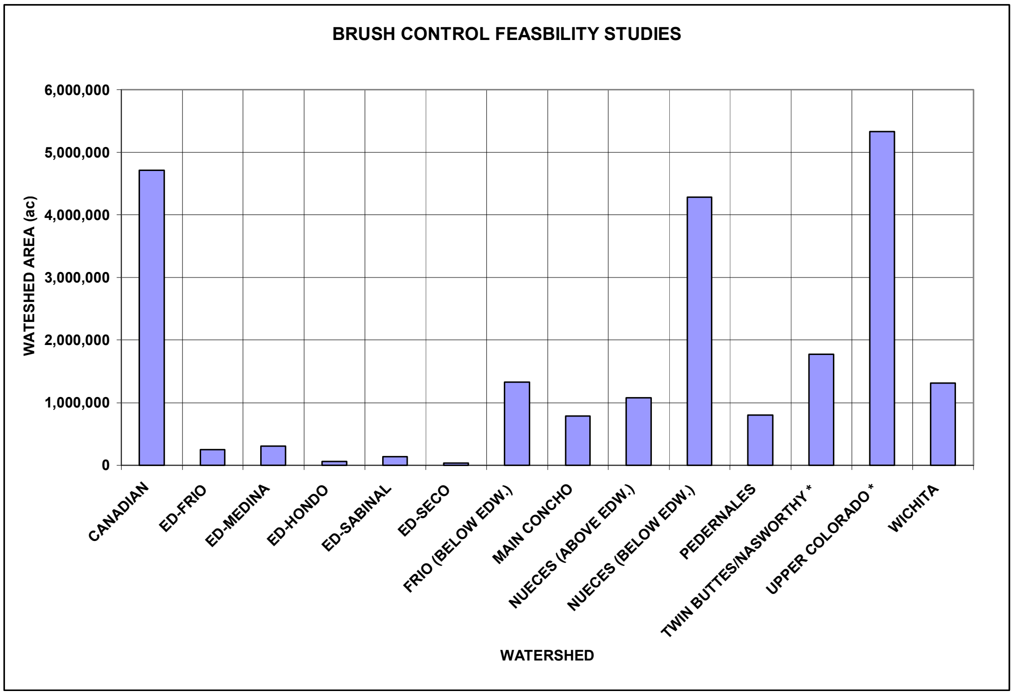


***Figure A-4. Watershed area. For watersheds that lie across the 18 inch isohyet, the area shown represents only the portion of those watersheds where brush treatment was planned and simulated.***

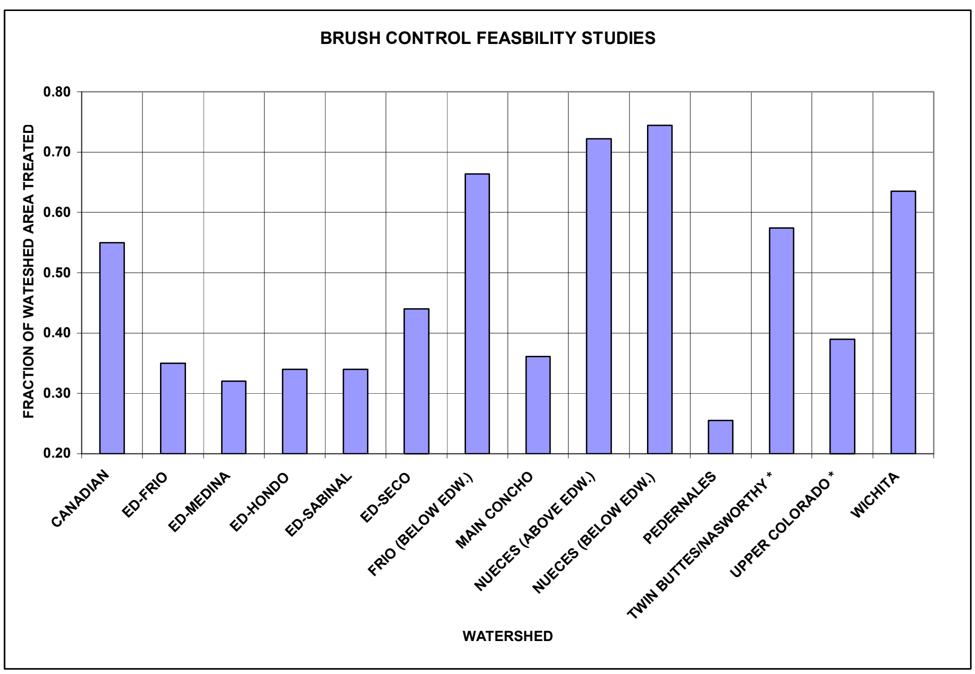


***Figure A-5. Fraction of watershed containing heavy and moderate brush that was treated. For watersheds that lie across the 18 inch isohyet, this is the fraction of the portion of the watershed where brush treatment was planned and simulated.***

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 A-6).

The average annual streamflow (acft) for the brush and no-brush conditions is shown for each watershed outlet in Figure A-7. Average annual streamflow 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 A-8). In some cases, the increase in streamflow 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 streamflow increase and precipitation (Figure A-9). The amount of streamflow increase was greater in watersheds with higher average annual precipitation.

Variations in the amount of increased water yield and streamflow 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 streamflows were most likely due to greater rainfall volumes as well as increased density and canopy of brush.

### *A.5 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 streamgauge 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

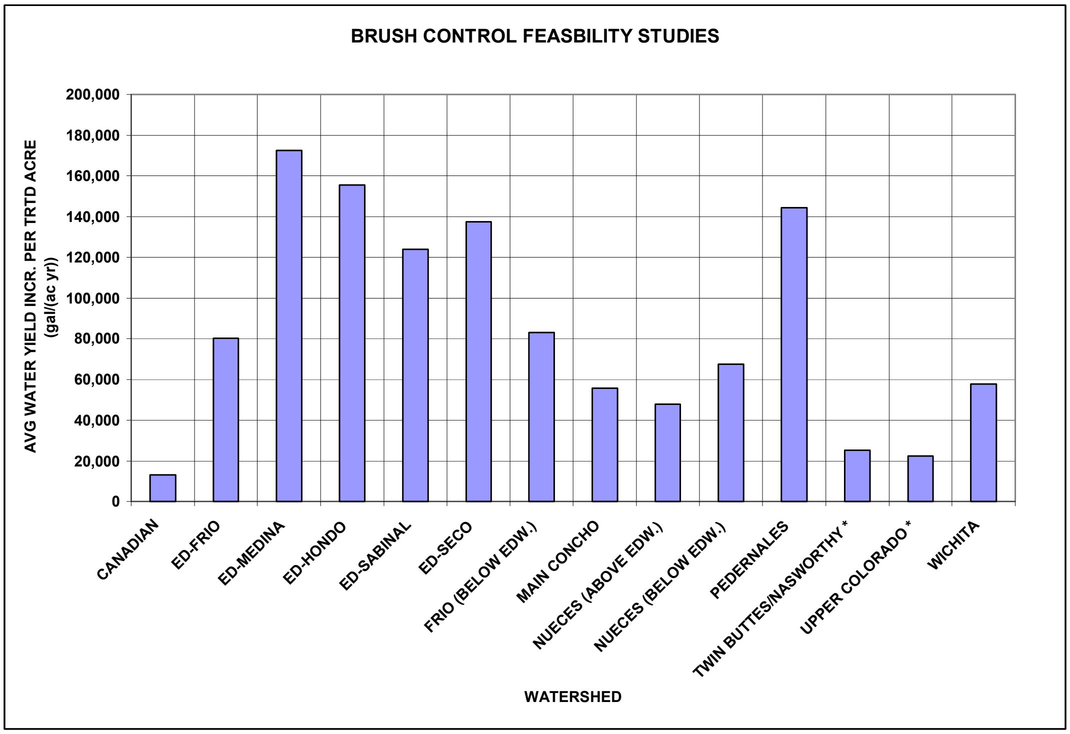


*Figure A-6. Average annual water yield increase, 1960 through 1998.*

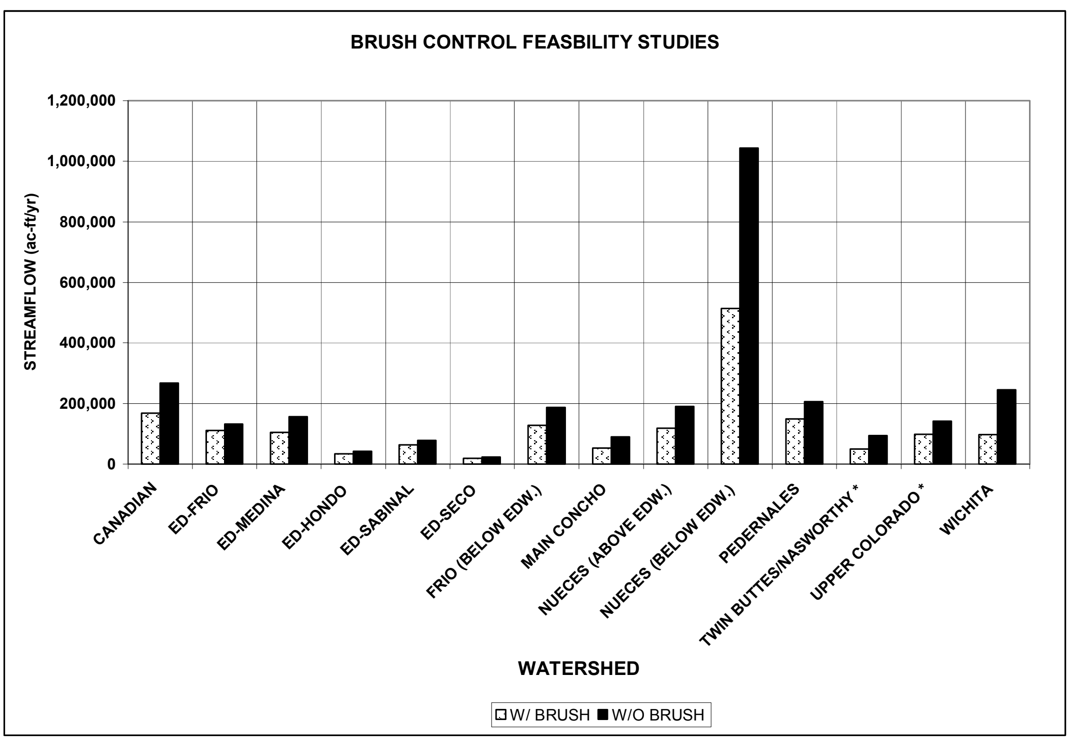


*Figure A-7. Average annual streamflow at watershed outlet, 1960 through 1998.*

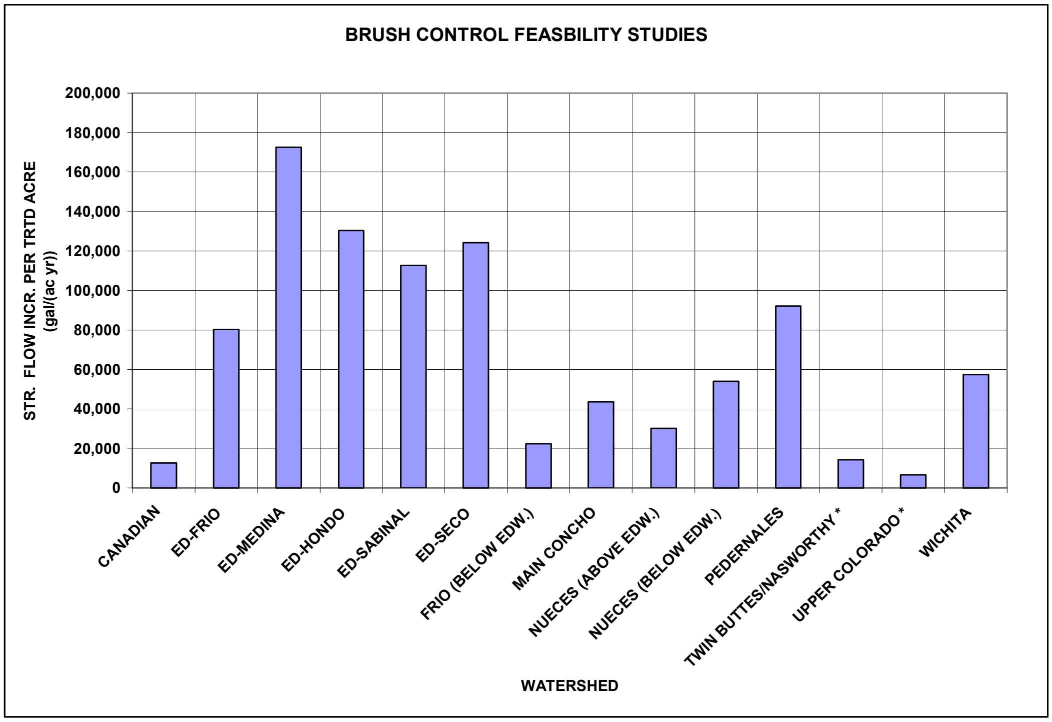


***Figure A-8. Average annual streamflow increase at watershed outlet, 1960 through 1998.***

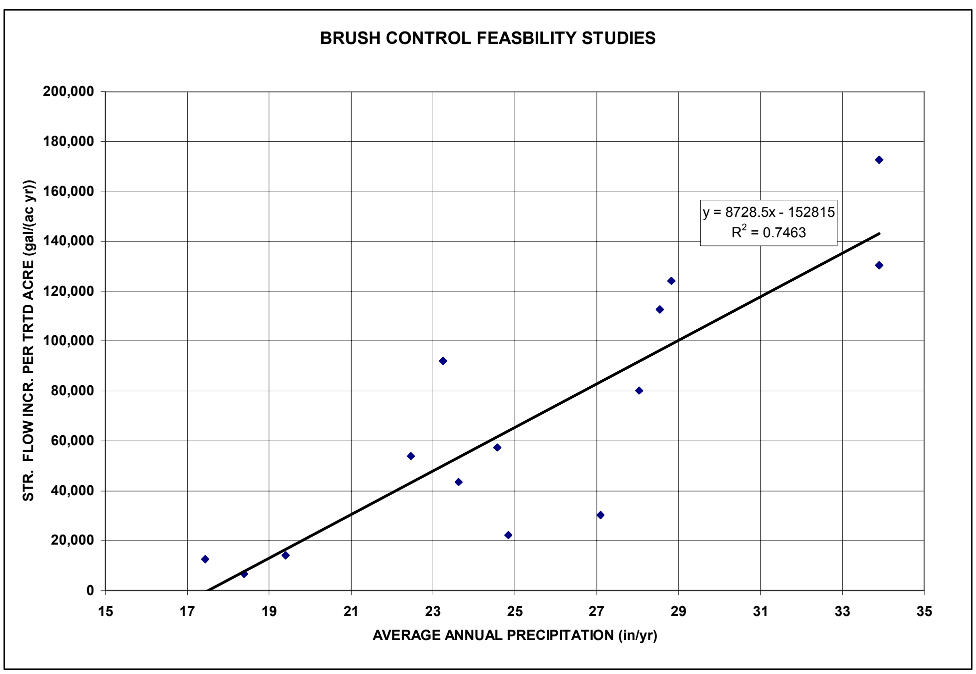


***Figure A-9. Average annual streamflow increase versus average annual precipitation, 1960 through 1998. Each point represents one watershed.***

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 percent 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 groundwater flow.

## LITERATURE CITED

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons. 1990. SWRRB: A Basin Scale Simulation Model for Soil and Water Resources Management. Texas A&M Univ. Press, College Station.

Arnold, J.G., J.R. Williams, D.R. Maidment. 1995. A Continuous Water and Sediment Routing Model for Large Basins. American Society of Civil Engineers Journal of Hydraulic Engineering. 121(2):171-183.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large Area Hydrologic Modeling and Assessment, Part1: Model Development. Journal of American Water Resources Association. 34(1):73-89.

Arnold, J.G., P.M. Allen, R.S. Muttiah, G. Bernhardt. 1995. Automated Base Flow Separation and Recession Analysis Techniques. GROUND WATER, Vol. 33, No. 6, November-December.

Dugas, W.A., R.A. Hicks, and P. Wright. 1998. Effect of Removal of Juniperus Ashei on Evapo-transpiration and Runoff in the Seco Creek Watershed. Water Resources Research, Vol. 34, No. 6, 1499-1506.

Knisel, W.G. 1980. CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. United States Department of Agriculture Conservation Research Report No. 26.

Nichols, J.D. 1975. Characteristics of Computerized Soil Maps. Soil Science Society of America Proceedings. Volume 39, No. 5.

National Oceanic and Atmospheric Administration. 1980. Climatology of the United States No. 20, Climatic Summaries for Selected Sites, 1951 – 1980, Texas.

Rewerts, C.C. and B.A. Engel. 1991. Answers on GRASS: Integrating a watershed simulation with a GIS. ASAE Paper No. 91-2621, American Society of Agricultural Engineers, St. Joseph, MI.

Srinivasan, R. and B.A. Engel. 1991. A Knowledge Based Approach to Exact Input data From GIS. ASAE Paper No. 91-7045, American Society of Agricultural Engineers, St. Joseph, MI.

Srinivasan, R. and J.G. Arnold. 1994 Integration of a Basin Scale Water Quality Model With GIS. Water Resources Bulletin, Vol. 30, No. 3, June.

Thurow T.L., and C.A. Taylor Jr. Juniper Effects on the Water Yield of Central Texas Rangeland. Proc. 24th Water for Texas Conference, Texas Water Resources Institute, Austin, Texas January 26-27, 1995; Ed. Ric Jensen.

Thurow, T.L. 1998. Assessment of Brush Management as a Strategy for Enhancing Water Yield. Proceedings of the 25th Water For Texas Conference.

Upper Colorado River Authority. 1998. North Concho River Authority – Brush Control Planning, Assessment & Feasibility Study.

U.S. Department of Agriculture, Soil Conservation Service, 1972. National Engineering Handbook, Section 4-Hydrology, Chapters 4-10.

U.S. Geological Survey. 1999. Water Resources Data, Texas, Water Year 1999. Volume 4.

U.S. Army. 1988. GRASS Reference Manual. USA CERL, Champaign, IL.

Williams, J.R., A.D. Nicks, and J.G. Arnold. 1985. Simulator for Water Resources in Rural Basins. J. Hydraulic Eng., ASCE, 111(6):970-986.

# *Appendix B*
# *Assessing The Economic Feasibility Of Brush Control To Enhance Off-Site Water Yield*

## *B.1 Introduction*

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 percent and 3 percent 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 acft averaged over each watershed.

As was reported in Appendix A 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 acft averaged over the entire North Concho basin[1].

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.

[1] Bach, Joel P. and J. Richard Conner. 1998. Economic Analysis of Brush Control Practices for Increased Water Yield: The North Concho River Example. In: Proceedings of the 25th Water for Texas Conference - Water Planning Strategies for Senate Bill 1. R. Jensen, editor. A Texas Water Resources Institute Conference held in Austin, Texas, December 1-2, 1998. Pgs. 209-217.

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 (Figure A-1). In addition to including a wide variety of soils, topography and plant communities, the eight watersheds included average annual precipitation zones from 15 to 26 inches and growing seasons from 178 to 291 days. The studies were conducted primarily between February and September of 2000.

### *B.2 Objectives*

This Appendix 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 Appendix A. 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 Appendix 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.

### *B.3 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.

### B.3.1 Brush Type-Density Categories

Land cover categories identified and quantified for the eight watersheds in Appendix A 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 to 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 B-1. Year 0 in Table B-1 is the year that the initial practice is applied while years 1 to 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.

### B.3.2 Control Costs

Yearly costs for the brush control treatments and the present value of those costs (assuming an 8 percent discount rate as opportunity cost for rancher investment capital) are also displayed in Table B-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.

### *B.3.3 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, turkey, 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 B-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 B-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 percent canopy cover (Table B-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 B-2. Grazing Capacity in Ac/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[2]. 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 B-3 for the control of moderate cedar in the Upper Colorado – West Watershed.

***Table B-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 B-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 B-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

[2] Conner, J.R. 1990. ECON: An Investment Analysis Procedure for Range Improvement Practices. Texas Agricultural Experiment Station Documentation Series MP-1717.

moderate mesquite in the Canadian Watershed to $52.12 per acre for control of heavy mesquite in the Edwards Aquifer Watershed.

***Table B-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.

### *B.3.4 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 B-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.

### *B.4 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 10-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 Section 6). 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 percent discount rate). Table B-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 acft 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 B-5, the Middle Concho analysis resulted in an estimated average cost across all its sub-basins of $204.05 per acft. Most of the watershed analyses, however, resulted in estimates of costs in the $40 to $100 acft range. Although the cost of added water from alternative sources are not currently known for the watersheds in the study, a high degree of 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.

***Table B-5 Cost Per Acft of Added Water from Brush Control by Sub-Basin – Wichita Watershed***

| Sub-Basin # | Total State Cost ($) | Added Gallons/Acre | Added Acft/Year | Total Acft/ 10-Years | Cost Per Acft ($) |
|---|---|---|---|---|---|
| 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.

## *B.5 Additional Considerations*

Total state costs and total possible added water discussed above are based on the assumption that 100 percent 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 percent 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 percent 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)[3] that indicated that only about 66 percent 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 percent 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.

[3] Thurow, A., J.R. Conner, T. Thurow and M. Garriga. 2001. Modeling Texas ranchers' willingness to participate in a brush control cost-sharing program to improve off-site water yields. Ecological Economics (in press).