CONCHO RIVER &
UPPER COLORADO RIVER BASINS

Brush Control Feasibility Study

Prepared By The:

UPPER COLORADO RIVER AUTHORITY

In Cooperation with

TEXAS STATE SOIL & WATER CONSERVATION BOARD

and

TEXAS A & M UNIVERSITY

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Cover Photograph:
Rocky Creek located in Irion County, Texas following restoration though a comprehensive brush control program. Photo courtesy of United States Natural Resources Conservation Services.

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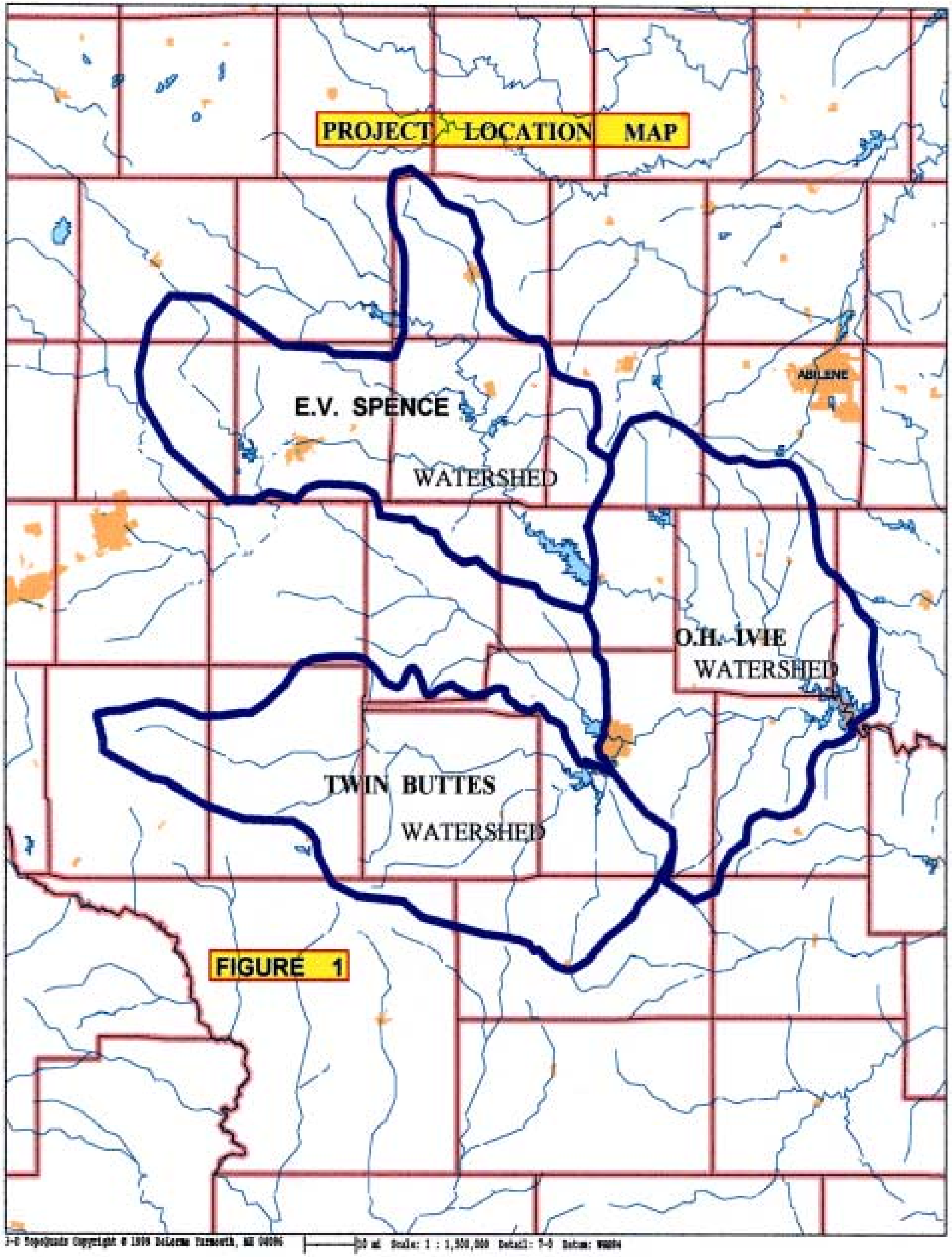
1.0 Introduction

West Texas landowners, range scientists and water supply professionals have long suspected that noxious brush, (primarily mesquite and juniper), have had, and continue to have, a major impact on water resources in the region. One of the most dramatic examples of this phenomenon has been at O.C.Fisher Reservoir. This reservoir was designed by the U.S. Army Corp of Engineers prior to WWII utilizing historical hydrologic data collected on the North Concho River since 1925. Construction was completed in the early 1950's. Since that time, the reservoir has never approached or experienced water levels or reservoir yields anticipated by its' designers. It has been determined from existing records that this disappointing performance is due to the watershed experiencing a dramatic shift in hydrologic characteristics beginning about 1960. The Texas Water Development Board (TWDB) funded "*North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study*, *1998*" concludes the following; brush control programs on the total watershed could restore watershed yields to near the historic 38,000 acre feet per year from the current average yield of near 8,000 acre feet per year. As a result of this recommendation, the Texas Legislature funded implementation of the first phase and the program began September 1, 1999. Present plans indicate that the program should be completed within a 10-year period.

The State Legislature has also funded brush control feasibility studies to be carried out on eight additional watersheds. These feasibility studies are currently being conducted by Texas A&M University and a number of River Authorities or other local entities and are to be completed by November 2000. One of the target locations for the feasibility studies is the Concho and Upper Colorado River watershed. This study, implemented by the Upper Colorado River Authority and Texas A&M University in contract with the Texas State Soil and Water Conservation Board, is the subject of this report. The study area includes the Concho River (Twin Buttes Reservoir watershed) and Upper Colorado River areas (O.H. Ivie Reservoir and E.V. Spence Reservoir watersheds). Initially, the area was designated as two projects but was later combined for cost savings and because of similarity of the areas. Figure "1" shows a location map for the Feasibility Study area.


PROJECT LOCATION MAP
E.V. SPENCE
WATERSHED
ABILENE
O.H. IVIE
WATERSHED
TWIN BUTTES
WATERSHED
FIGURE 1

Review of the watersheds in this study reveal similar historical patterns as compared to the North Concho River watershed hydrologic data. Degradation of watershed yields varies from area to area, but many display the same dramatic hydrologic changes beginning in the 1960's. Investigators involved in previous and recent studies have suggested that the sudden changes in the hydrologic characteristics of the watersheds are due to several factors:

1) In the 1950's brush infestations were complete, to the extent that we now recognize as "normal" conditions. In comparing aerial or ground based photography in 1960 to current photography only slight differences are observed. A dramatic change in vegetative types occurs when comparing the same 1960 photography to 1920 photography. The "normal" or "native" condition of much of the region could be characterized ecologically as a grassland prairie.
2) A historic drought was experienced during the 1950's seriously depleting surface and groundwater resources. Many historic springs stopped flowing during this period and have never recovered.
3) It is theorized that the hydrologic systems in many of the watersheds that include gaining streams and the critical relationship between the groundwater and surface water flows contained large storage volumes that were slowly being depleted with brush encroachment. Following the drought of the 1950's, the systems no longer had the capacity to recover because of the increased utilization of water by the brush. The 1998 study concluded that the loss of normal stream flows has greatly influenced the frequency, duration and intensity of rainfall runoff flows.

Because of the apparent critical historical element in watersheds experiencing reduced water yields due to water loving noxious brush, this evaluation utilizes historical hydrologic records as a benchmark in evaluating all other data or models. Historically, rainfall characteristics have not changed significantly within the region. If watersheds display reduced water yields and increased brush cover through time, it is reasonable to assume that the brush cover is likely responsible for the decrease and that the watersheds could theoretically produce pre-brush water yields following brush control.

In evaluating the effects of the invasion of woody brush (predominately juniper and mesquite) on water resources in the study area, historical rainfall and stream flow data is included in this report. This data is presented in a conventional manner and is representative of actual rainfall measurements as well as actual historical stream flows through time as measured at specific points within the watersheds. The previously cited "*North Concho River Watershed Brush Control Planning, Assessment & Feasibility Study"*, (UCRA 1998) and the current feasibility study examines the hydrologic record by several different analysis techniques while attempting to calibrate watershed models.
One of the techniques utilizes "Accumulated Flow Graphs", which represent changes in flow through time as breaks in the slope of the graph. Examination of these graphs indicates that there has been a significant reduction in the

frequency and magnitude of runoff events since 1960. Further interpretation of these graphs might lead one to conclude the following; there may have been a significant reduction in the frequency and magnitude of storm events over the watershed and that restoration of perennial stream flows in the North Concho or the present study streams through brush control will have little effect on total watershed yield. Both of these conclusions are in error and are not supported by historical rainfall records. The reason for this apparent apparition in the record is the debilitating effect of dry streambeds and depleted shallow aquifers on runoff potential. It was determined in the North Concho study, and confirmed in this study, that there is a direct correlation between floodplain alluvial aquifers, perennial stream flow and runoff potential. Hundreds of miles of dry streambeds in a watershed that historically had been perennial results in almost complete elimination of summer season runoff events from the records after 1960.

In addition, the hydrologic records for the watershed indicate numerous events during which significant runoff flows are measured at an upstream station and no runoff flows reaching a lower flow measuring station. Other numerous events resulted in a significant reduction in the runoff flows as they proceed downstream. In other words, the dry streambeds and depleted aquifers have impacted the frequency and intensity of rainfall runoff events. In the normal pre-1960 condition, where stream and tributary flows were common and completely dry streambeds were uncommon, any rainfall falling upon the watershed would likely increase stream flows. It is critical that this phenomenon be considered in any watershed modeling or evaluations to determine water yield improvements following brush control.

This study report has been organized following the watershed boundaries of the three major receptors of any increased watershed yields resulting from brush control. The evaluation includes a thorough review of historical hydrologic records and rationale developed to estimate pre and post 1960 norms for watershed yields. Developing the rationales for each watershed included a review of flow station locations, watershed controls through time and any significant historical ecological or other changes within the watershed. The examination of the historical data also allows theoretical projections of increased water yields based on yields prior to the breakdown of the hydrologic systems because of the brush infestations. The watershed modeling and economic analysis prepared by Texas A&M University is also included in this report.

The Texas Water Resources Institute, (Spring 1988, Volume 14, No. 1), quotes the Soil Conservation Service as estimating the following; 88.5 million acres of Texas range land were infested with brush and roughly half of that needed brush removal. It was also estimated that 10 million-acre feet (57% of all the water used in Texas in 1980 by the municipal, industrial and agricultural sectors) could be made available annually through a comprehensive brush management program.

2.0 Executive Summary

Unless profound and dramatic brush control methods are put into practice during the next two decades, specific communities of West Texas, including rural and some metropolitan areas, will not have sufficient water to meet existing demands for municipal, industrial and agriculture uses.

The evidence is overwhelming. More than 25 percent of once perennial streams in the Concho and Colorado basins stopped flowing after the drought of the 1950's when noxious brush such as mesquite, juniper and salt cedar began to culminate its' dominance over what was once grassland prairie. As a result, every 10 acres of moderate to heavy brush infestation now steals one acre foot of water annually (325,000 gallons).

With the drought of the late 1990's now entering the 21st century, additional perennial streams or major segments have stopped flowing and more than a dozen other streams on the Concho and Colorado basins have been impacted because brush has robbed not only groundwater supplies but stifled current and future recharges.

The Middle Concho River above San Angelo and Twin Buttes Reservoir is now non-perennial. Sections of the Main Concho below San Angelo and Spring Creek above San Angelo have also suffered the same fate. Tributaries of the Colorado and Concho Rivers above Ivie Reservoir have lost significant historical output which include Pecan Creek, Kickapoo Creek, Oak Creek, Valley Creek, Coyote Creek, Bluff Creek and Elm Creek due to brush infestation. **Predictions are, that unless brush control practices are enacted immediately, perennial flows from Dove Creek, Spring Creek and the South Concho River could cease. (See Summary of Report, Section 6.0)**

Static groundwater levels continue to deteriorate showing rapid a depletion of mining of once plentiful supplies for city, industrial and agriculture uses. **In many instances water wells that have produced for 75 years are now dry.**

The implications of this report are shocking because computer modeling performed by Blackland Research and Texas A&M and calculated by the Upper Colorado River Authority shows that the entire Colorado and Concho River basins could gain an additional 249,584 acre feet of water annually in groundwater recharge and surface flow into existing reservoirs. All of this is water now lost to the public, whether it is groundwater to recharge aquifers or surface flow into existing reservoirs….water that the people of Texas have lost and are losing every day to mesquite, juniper and salt cedar.

More than 75 percent of the water gained as a result of brush control in the Concho and Colorado basins would benefit the three main reservoirs located in the area: Twin Buttes, O.H. Ivie and Spence Reservoir. The remaining percentage would benefit the smaller reservoirs such as Oak Creek, Ballinger, Lake Winters, Champion Creek, Lake Colorado City and J. B. Thomas.

Two reservoirs basins….Twin Buttes and O. H. Ivie combined, could realize almost 155,000 acre feet of water annually in groundwater recharge and surface flow….more than half of the projected 249,584 acre feet annual increase anticipated from the computer model.

This report shows that this water can be produced for the Concho and Colorado basins at an average cost to the state for $74.63 per acre foot of water, which is less than half the normal costs to build reservoirs and related transmission facilities. For detailed and complete analysis, the Concho and Colorado basins were divided into 190 primary and tributary sub-basins. Individual modeling and calculations were performed on each sub-basin. In sub-basins that contain primarily mesquite, that can be controlled with herbicides and aerial spray, the cost to produce an additional acre foot of water annually ranges from a state cost of $28 to $30. An acre foot of water is 325,000 gallons. In other areas that contain heavy juniper or mixed mesquite and juniper, the cost per acre foot of water increases because of mechanical treatments required. But when averaged, the state and public cost is $74.63 per acre foot of new water produced for the Concho and Colorado River basins.

Contained in the summary and conclusion of the report are recommendations by the Upper Colorado River Authority for implementation. Of the 2.8 million acres modeled in the Concho and Colorado River basins, **UCRA is recommending that approximately 1.4 million acres on those watersheds be targeted for brush control for a total cost of $72.5 million. It is further recommended that the program be funded over 10 years or five legislative bienniums.**

The first funding biennium, effective September 1, 200l would require $11,274,528 in appropriations for the Concho and Colorado basins, with the remainder funded over the following eight years (four bienniums). UCRA also recommends that the state continue the authorized 70 per cent cost share with landowner paying 30 percent as current state law allows and is also consistent with costs share utilized in the North Concho River brush control project now underway. Also included in this report are analyses of sub-basins and projected water yields per sub-basin. **UCRA strongly urges that implementation by the Texas State Soil & Water Conservation Board be done on a sub-basin basis, which have prudent conservation planning and water yield results and have 50 percent or greater landowner sign-up and landowner participation.**

The Upper Colorado River Authority has independently developed a priority rating system for watershed reservoirs based upon six objective criteria. That criteria rating system was then reviewed and verified by an independent water engineering consulting firm to determine objectivity. **Twin Buttes Reservoir graded the highest because of its multi-faceted uses, impoundment history, current condition, reservoir significance and watershed yield. However, other reservoirs in the region were close behind which proved the dramatic extent to which each has been impacted by brush infestation.**

This report also includes a multitude of tables, graphs and illustrations which support the frightening conclusion that without brush control, West Texas will be void of vital water supplies for the future.

Successful brush control on the Concho and Colorado River basins will insure their stability and use for future generations, helping also to maintain a viable eco-system. Without that control, the water future of West Texas is bleak.

Indeed, there is no greater environmental devastation or impact than a dry creek, river bed or empty reservoir.

3.0 Defining the Problem

The chances of a drop of rainfall serving a beneficial purpose is in large part determined by the type of vegetation and soil on which it falls. Common sense tells us that rain falling on bare ground has the greatest chance of becoming runoff and thereby entering our streams and rivers and filling the reservoirs. We see this truth demonstrated within cities and developed areas as pavement and concrete increase the runoff capacity of urban watersheds and create problems with urban flooding. Unfortunately, bare ground lends itself to erosion and increased runoff carries with it greater loadings of sediment to streams and reservoirs. Bare soils dry out much faster and deeper after a rain. The tendency is the formation of a "*hardpan*" (packed soil) only a few inches below the surface, which blocks the infiltration of rainwater deep into the soil and eventually to underground water storage. The hardpan and poor infiltration characteristics do not enable the soils to store much water, or withstand the erosive forces of falling and moving water. Runoff from bare soils ruins stream channels and fills reservoirs with sediment.

Having established the fact that barren soils are not a desirable characteristic for water resource management, the question naturally emerges as to the most desirable type of plant cover within our watersheds. It is reasonable to assume that plants with the most efficient water use characteristics would be of the greatest benefit in returning water to our streams, reservoirs and aquifers. It has long been established by botanists and range experts that the most efficient water users and the most efficient plants in protecting soils from erosion are grass species. By comparing plant species common within the region, it is also well established that approximately three times as much water is required to produce one pound of foliage on a honey mesquite, as it is to produce one pound of a desirable range grass such as blue gramma. On a larger scale, one acre foot (325,830 gallons) of water will produce 4,561 pounds of blue gramma as compared to 1,576 pounds of mesquite. A supplement published by the San Angelo Standard Times in the 1970's entitled "*Brush, The Water Thief*" cites statistics from the U.S. Department of Agriculture that indicate the following common plant production rates in pounds from 50 gallons of water: Blue Gramma - 0.70, Honey mesquite - 0.24, Catclaw - 0.17, Buffalo Grass -1.3, Arizona Grass - 0.76, Cottontop - 0.76, and Sideoats Gramma - 0.59. In addition to being inefficient, most of the woody brush plants in the region are undesirable grassland invaders. Most of these have little economic value from a forage standpoint, while the more efficient grasses are prized and sought by livestock raisers.

Plants gather water for sustaining life through their root systems. If you were to carefully remove a block of grass from the ground and examine the root system, you would find a dense fibrous mass penetrating all of the soil pores. Roots of the deepest rooted grass species rarely extend deeper than 9 feet. Most grass species have shallow root systems affecting soil depths of one foot or less.

Roots on woody brush species vary but generally are much deeper. The Texas Water Resources Institute, (Spring 1988, Volume 14, No. 1) reports that Honey Mesquite has a dual root system: lateral roots are only a few feet below the surface but extend out to 30 feet or greater, and a tap root that penetrates as much as 65 feet beneath the surface. Other sources cite mesquite tap roots as penetrating to greater depths. The San Angelo Standard Times Supplement cited above reports root depths of 80 feet. When water is plentiful, mesquite grows rapidly and consumes excessive amounts of water from shallow depths. During dry periods, mesquite uses the tap root to pump water from deep below the surface. Many mesquites, particularly those growing along the flood plains of creeks and streams, are thriving with their roots in the aquifer. Not only do they intercept several times more water than grass, they also pump water directly from the aquifer, just as water well pumps do. Trees with this capability are called "*Phreatophytes*", which literally means, "well (as in water well) plants".

3.1 Identification of Noxious Brush & Its' Effects

Besides the Honey Mesquite, there are many other species of woody plants that are Phreatophytes and favor the riparian zone. These include Salt Cedar, Cottonwood, and Sycamore. Other range plants that seriously effect runoff and infiltration are the Redberry and Ash Juniper. Three of the plant species, juniper, mesquite and salt cedar predominate in existence in the region and are implicated by published literature as being the most problematic in affecting water resources. The ecology of each and a discussion of the hydrologic effects are as follows:

- **Juniper (Both Species)**
  Juniper is a native Texas range plant common in the study area and currently occupies several million acres within the various watersheds. The plant has an extensive lateral root system that assists in its dominance on shallow rocky soils along hillsides in the Edwards Plateau and much of the region. Characteristically, mesquite will dominate within the riparian areas and the juniper will dominate in the upland areas. This plant species has apparently increased its' dominance in north, central and west Texas range lands within the last 50 years. This dominance has often been associated with the disappearance of springs and seeps on many ranches.

  Texas A&M University, Department of Rangeland Ecology and Management *Watershed Management*, and research at the Texas Agricultural Experiment Station at Sonora, Texas, *Assessment of Brush Management as a Strategy for Enhancing Water Yield*, Thomas L. Thurow, Department of Rangeland Ecology and Management, Texas A&M University indicates that juniper and its' associated litter have an annual interception loss averaging 73% of precipitation, (compared with 46% interception loss for live oak and 14% interception loss for grass). It was found that on rangelands with dense juniper cover, that essentially all of the rainfall is returned to the atmosphere either by evaporation (in the form of interception loss) or transpiration (i.e., the small amount of water that does reach the soil is taken up by the trees).

- **Honey Mesquite**

  The Texas Water Resources Institute reports that Honey Mesquite is the most prominent brush species in Texas. It is naturally occurring and can be found from the gulf coast to New Mexico. It is seldom found above 5,500 feet because it is vulnerable to cold weather and does best below 4,500 feet. The Honey Mesquite can survive in desert conditions and exists in areas with 6 to 30 inches of annual rainfall. It can grow to 60 feet high with trunk diameters of 36 inches or greater. As stated previously, the tree has a dual root system and will consume excessive amounts of water from shallow depths when available and literally pumps water from shallow aquifers in the riparian zone through deep tap roots. The mesquite is a very successful invader and has gradually replaced grass as the predominant plant species in much of Texas (particularly within the study area). Most experts agree that the factors responsible for mesquite's success include the following; 1) It "out competes" grasses 2) Cattle have spread the seeds through their dung; and 3) Wild fires which tend to limit young tree numbers are much less common.

  The primary detrimental effects of the mesquite appears to be related to its' water consumption and competition with grasses. A paper describing the ecology of Mesquite prepared by the Texas Agricultural Experiment Station at Vernon, Texas, R.J. Ansley, J.A. Duddle and B.A. Kramp, reports that a 8 to 12 foot mesquite will consume up to 20 gallons of water per day during mid-summer growing conditions. Considering an estimate of hundreds of millions of mesquite trees within the study watersheds, it can be calculated that a daily loss of water resources during mid-summer is on the magnitude of multiple billions of gallons per day. The researchers reported that the mesquite canopy exerts a profound influence on neighboring vegetation, soils, sub-canopy microclimate, wildlife and insect populations. High densities of mesquite (>25% canopy cover) suppress grass growth and may reduce understory species diversity.

  Many studies have indicated that grass production increases following mesquite control. In addition, mesquite is a nitrogen fixer and may modify soil fertility. Soil nitrogen can be 3-7 times greater beneath mesquite canopies than in interspaces between mesquites. It has been reported that understory vegetation is distributed into zones with taller grass species beneath mesquite canopies and short grass species in the interspaces. Control of mesquite provides regions of enhanced soil "N" and "C" which are temporarily exploited by associated grasses. In the long term, however, mesquite in low densities may enhance recruitment of grasses into the landscape at a greater rate than mesquite free areas (or conversely in mesquite infested areas).

Mesquites do offer some beneficial effects. They provide cover and support for wildlife (though adult mesquite is not considered palatable and is not extensively browsed by mammals). It may also be considered a resource in production of charcoal, fuel, lumber (primarily for furniture and flooring), flour, tea and fermented drinks that can be produced from its fiber and fruit.

- **Salt Cedar (Tamarix sp.)**
  Salt Cedar was introduced into the United States in the 1800's. It was initially thought that the Spanish were responsible for the introduction, but it appears that the first plants were sold to a nursery in Philadelphia. The genus *Tamarix* was named after the Tamaris River in Spain that contains many small shrubs and trees native to Europe. The genus consists of approximately 90 different species, 8 of which have been introduced into the United States. The plants are commonly found in the Southwest, including Texas. They are deciduous shrubs/small trees that grow most successfully along streams and/or edges of water bodies.

  It has been described as a "*Facultative Phreatophyte*" meaning that its' roots extend deep and depend upon ground water for water supply, but has the capacity to obtain water from other sources by sending out advantitious roots. The plants get their common name from their ability to readily take up solutes from the soil and dump them above ground from salt glands or by dropping its' leaves. Jason Hart, (*Invasive Species of the Southwest,* May 1999), describes this effect as "allelopathic" as surrounding plants are unable to thrive in these high salt concentrations. Hart also reported that salt cedars can grow in soil salt salinity conditions of 36,000 ppm, and other floodplain species such as willows or cottonwood can tolerate salt salinity up to approximately 1500 ppm.

  Salt cedar is reported by Hart to have four main impacts on the local environment once it is established: 1) increased soil salinity 2) increased water consumption 3) increased wildfire frequency and, 4) increased frequency and intensity of flooding. The last of these appears to be the most serious concern with the plants in the study area. Once established, the plants tend to dominate the flood plains. Dense stands narrow channels that carry flood flows, which increases flooding threats. Water flows are often diverted by the tree stands to areas that do not normally carry flood waters. The results often include increased erosion and sedimentation, which also contribute to the chances of flooding.

Salt cedar has currently invaded the study areas that include extensive growths in the Twin Buttes and Colorado River systems. Smaller infestations can be found within almost every other waterway within the study area (salt cedar has not been found to be problematic within the hill country streams that include perennial streams above San Angelo). Due to its' general confinement within stream and lakebeds the aerial extent of the plants within the study area is limited, and could be measured in the thousands of acres.

Evaluation of the effects of the three invasive plant species in the potential increase of useable water resources within the study area easily recognizes that mesquite and juniper are the greatest consumers of water. The amount of acreage infested in salt cedar compared to the total acreage of mesquite and juniper is very small. Current brush control procedures under existing law require landowner contracts and landowner application of control methods and techniques. Few landowners are willing to apply existing control methodologies for this plant to streambeds or lakebeds generally owned by the state. It also appears that potential environmental liabilities from control methodologies at close proximity to surface waters tend to discourage landowner participation. Of particular note in this study is the Federal ban on the use of the most promising control method for salt cedar (Arsenol) within Tom Green or Coke Counties. For these reasons, brush control evaluation for increasing water supplies within the study area will largely consider the effects and economics of controlling juniper and honey mesquite.

3.2 Historical Brush Control Efforts & Implications For This Study

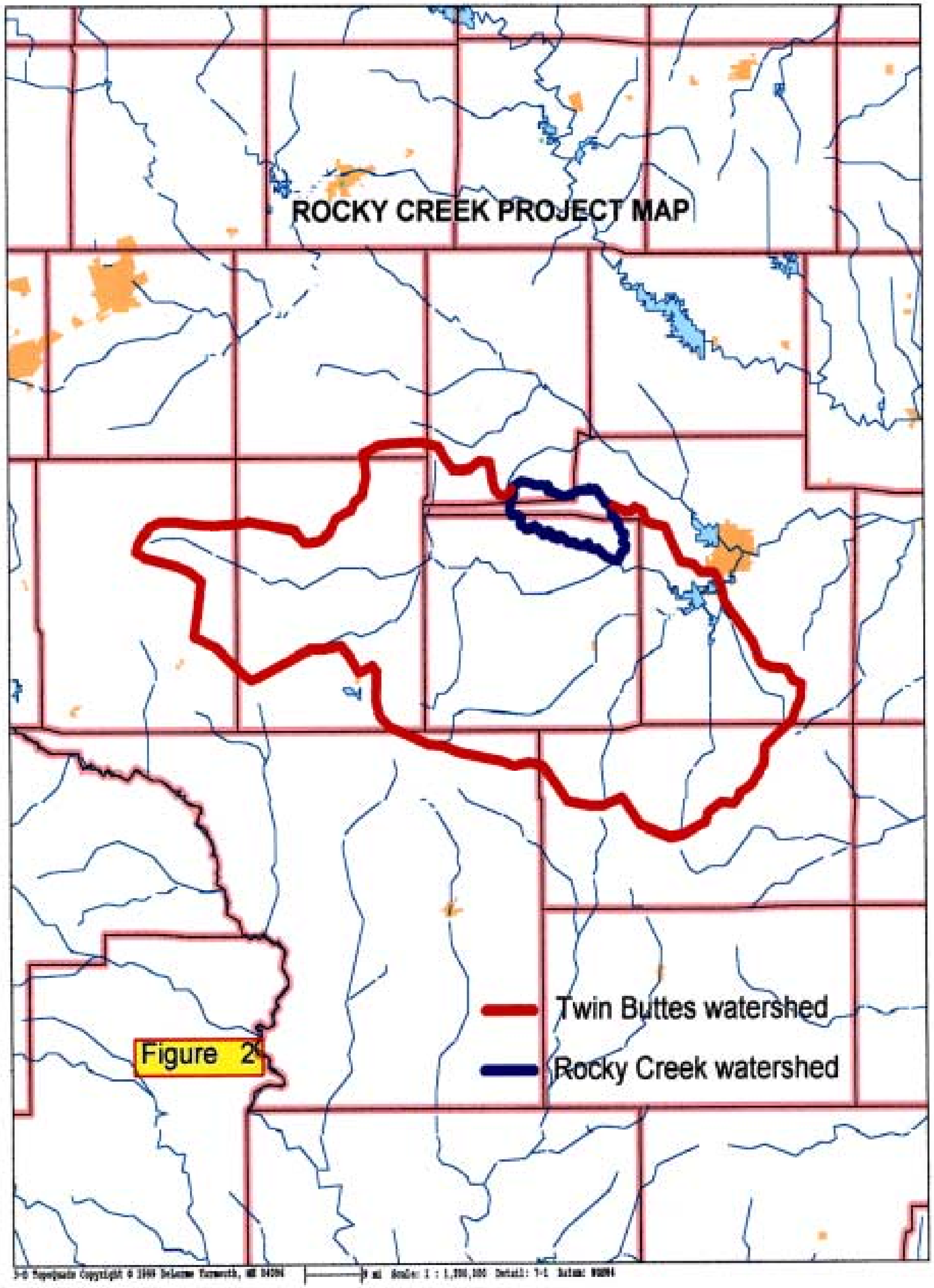
Brush control efforts within the United States and Texas can be divided into two broad categories: **plot sized** (or small watershed research projects) and **larger projects** that encompass thousands of acres. There have been a number of these types of projects within the United States and Texas in the last 30 years in the first category that have produced much needed data. Texas research very likely dominates this area. Many of the research project results are cited within this report. In the second category, there have been few large-scale projects, particularly those that could find a parallel in Texas or within the study area.

It is apparent, considering the obvious importance of this issue, that there has been very little scientifically documented information on the effects of brush control on water yield. According to Thurow (in the previously cited study regarding the effects of brush control as a strategy for enhancing water yield), the reason for lack of scientific data is that watershed research is time consuming and expensive. This type of research has many built-in issues that contribute to these problems such as replication of study sites and long-term interdisciplinary commitments. Currently, Texas A&M University and the Upper Colorado River Authority (under contract with the Texas State Soil and Water Conservation Board) are monitoring the North Concho River Brush Control Project. This is being implemented through a long term, multi-task, multi-disciplinary approach that will hopefully provide additional scientifically valid data regarding water yields through brush management.

In previous program discussion, most sources cite work in California, the Central Arizona Project, a Texas / New Mexico salt cedar project along the Pecos River and the Rocky Creek Project near San Angelo. The Central Arizona project is the largest project. It began in 1956 as a cooperative effort between the State of Arizona, the U.S. Forest Service and other Federal agencies interested in recovering a greater percentage of rainfall on the 13,000 square mile Salt and Verde River watersheds. The goal was to convert worthless vegetation to a more valuable plant cover. Most of the land within the project area (90%) was publicly owned and there were a multitude of experimental projects that included the removal of juniper, pinion and chaparral, re-seeding of beneficial grasses and controlled burning of brush.

A multitude of results occurred. Some projects increased water resources and some did not. In the Three-Bar Wildlife area west of Roosevelt Lake, the area was re-seeded following a wildfire and brush was controlled with annual chemical treatments for five years. "*The watershed has shown a sevenfold increase in water yield for equal quantities of precipitation"* (Joseph Arnold, Arizona State Land Department, Watershed Management Division, San Angelo Standard Times Supplement). In 1979, 54,000 acres of salt cedar were removed from the Pecos River in West Texas and New Mexico. It has been reported that water yields did not significantly increase. Additional work in this area is currently under way and preliminary results indicate that the program is now successful in restoring water yields.

One of the major brush control projects occurred within a study area in the Twin Buttes watershed and the outcome has had a direct effect on the future planning and conclusions of this report. Rocky Creek is a tributary to the Middle Concho River above Twin Buttes Reservoir and west of San Angelo, Texas. Its' watershed is typical of the majority of the remaining Middle Concho River in most every respect including soil types, geology, brush types and hydrological history. The location of this watershed is shown on Fig. 2. This completed project is a living model of what can be


ROCKY CREEK PROJECT MAP
Twin Buttes watershed
Rocky Creek watershed
Figure 2

Conservation Service (this agency is presently named the Natural Resources Conservation Service). NRCS photographs on the following page illustrate the “before and after” appearance of the watershed ecology as a result of the brush control program.

This project resulted in the restoration of perennial flows to Rocky Creek. The creek has continued to flow for almost 40 years to the date of this writing. During that period (including 1998 & 1999) severe droughts have periodically ceased flows on most of the area rivers and creeks. Perennial flows in excess of 5 cubic feet per second are routinely measured near the confluence of the creek with the Middle Concho and in recent years, runoff flows to Twin Buttes, which have been lacking from other sources, have occurred from this watershed.

Rocky
Creek
Beautifully
Restored

3.3 Factors Effecting Water Resource Enhancement

In examination of previous studies, reports and pilot projects, there appears to be several factors to examine when making determinations regarding potential significant water resource enhancement through control of noxious brush in any given location. Several of the significant factors are described below:

Historical Records:
Locations in which brush control activities will be successful in enhancing water resources must demonstrate a history of decreasing watershed yields and dramatic ecological changes. Other areas may benefit from brush control, but these activities should follow detailed hydrologic and feasibility studies to define mechanisms of the improvements, potential benefits and associated cost/benefit analysis.

Stream Characteristics:
Successful watersheds must contain main streams and tributaries, a significant portion of which can be classified as "gaining". This means that perennial flows were prevalent due to de-watering of shallow alluvial aquifers in intimate contact with the streambeds. The existing condition of the streams would be defined as normally dry except during wet periods particularly during winter months when evapotranspiration rates are low.

Ecological Characteristics:
Successful watersheds will contain significant numbers of mature noxious plants, predominantly mesquite located within the lowland areas associated with the floodplains and juniper located within the upland areas. Mesquites in these areas will literally pump water directly from the shallow aquifers. These trees are deep rooted and can be extremely inefficient in water use. Extensive juniper canopy in the uplands will prevent aquifer recharge and rainfall runoff. Shallow rooted native grasses are reported to utilize only one third to one half of the quantities of water in production of identical weights of plant foliage as compared to woody brush.

Land Uses & Funding:
Successful watersheds will be those identified by the Texas Soil and Water Conservation Board through feasibility studies as benefiting from brush control activities and cost share funds deposited in the State Brush Control Fund. One of the factors evaluated in the studies is economic benefit vs. program cost. The funds are administered and the program conducted pursuant to Chapter 203 of the Agricultural Code. Local Soil and Water Conservation Districts contract with landowners to perform the work consistent with individual brush control plans. It has been theorized

that those areas primarily utilized for livestock pasture and consisting of larger properties will be the most successful. Smaller operators and/or tracts primarily utilized for recreation may not be as receptive to brush control plans and contracts.

On-Going & Long Term Programs:
Successful watersheds will have long term and on-going brush control programs in place. It has been recognized that previous private local programs have not been as successful as they might have been due to the lack of follow-up treatment. Initial chemical treatment of brush is not normally better than 85% efficient, and could be considerably less dependent upon conditions and circumstances. Invariably, follow-up treatment will be required within three years. As the tenth year following treatment approaches it is important that additional treatment be performed if required.

Climate:
It has been reported that climate plays a critical role in predicting brush control success. In a paper entitled *Assessment of Brush Management as a Strategy for Enhancing Water Yield,* Thomas L. Thurow, Associate Professor of Rangeland Ecology and Management, Texas A&M University states; "*In general, conversion from brush to grass does not have any influence on water yields on sites that receive less than 18 inches/year because the extra water that reaches the ground (due to reduced interception loss) and the reduced transpiration loss (associated with grasses instead of trees) will be offset by the high evaporation rate from the soil."* The watershed yield analysis provided in this report for the study area generally recognizes this concept. Anticipated yields appear to decline rapidly with decreasing annual rainfall amounts. The record also appears to indicate that significant benefits can be realized with 18 inches of rainfall (such as the upper North Concho watershed) and has been demonstrated in areas with rainfalls near 18 inches (such as the previously cited Rocky Creek project). It is likely safe to conclude that climate has an effect on success of brush control activities designed to improve water resources. This conclusion should then be applied as a general principle with considerable care in evaluating marginal areas of rainfall. Fig. 3 in this report is a map of Texas with average rainfall contours plotted for the period of 1961 to 1990.

Environmental Concerns:
Available literature concerning brush control issues often contain lists of known or potential environmental concerns. Most often cited are wildlife habitat removal, initial increases in erosion following brush removal (mechanical), risks to endangered plants, birds or fish, use of chemical treatment in riparian zones or adjacent to cultivation and water rights issues. All of these issues have been addressed in the on-going North Concho River Brush Control Program. This program will be typical of any

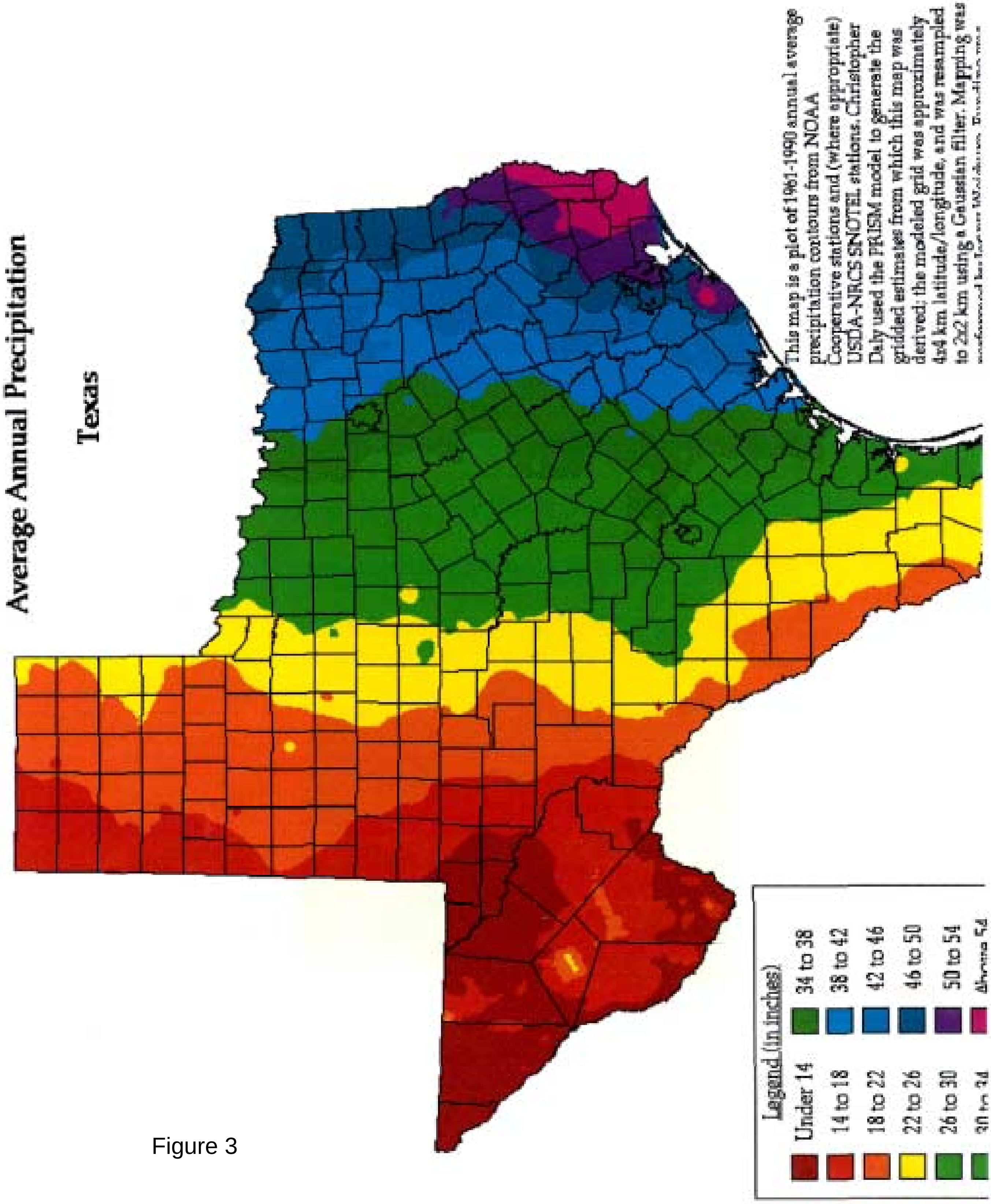

Average Annual Precipitation
Texas
This map is a plot of 1961-1990 annual average precipitation contours from NOAA Cooperative stations and (where appropriate) USDA-NRCS SNOTEL stations. Christopher Daly used the PRISM model to generate the gridded estimates from which this map was derived; the modeled grid was approximately 4x4 km latitude/longitude, and was resampled to 2x2 km using a Gaussian filter. Mapping was
Legend (in inches)
Under 14
14 to 18
18 to 22
22 to 26
26 to 30
34 to 38
38 to 42
42 to 46
46 to 50
50 to 54

Figure 3

future programs occurring in the study area. Initial program planning included participation by a broad range of representatives that involved the Texas Parks & Wildlife Department, Texas State Soil and Water Conservation Board, Texas Natural Resource Conservation Commission, Texas Water Development Board, Upper Colorado River Authority, Texas A&M Agricultural Extension Service, Natural Resources Conservation Service, United States Geological Survey, Underground Water Conservation Districts, Local Officials and landowners. Within the approximate one million-acre North Concho River Project, (typical of most candidate areas in the study), the work is being conducted within the rules of the Texas State Soil and Water Conservation Board. Strict conservation plans have been prepared for each specific tract. These plans detail control methods, the areas to be controlled, erosion control (if required) and any other pertinent environmental issues. To date, no serious environmental concerns that have precluded landowner contracts for work have occurred.

4.0 Description of the Study Area

4.1 Watershed Boundaries & General Hydrologic Description

Figures 4, 6, and 8 locate the general boundaries of the three primary study area receptor watersheds: Twin Buttes Reservoir, O.H. Ivie Reservoir and E.V. Spence Reservoir. A general description of the hydrology of each of the watersheds follows:

Twin Buttes Reservoir :
Twin Buttes Reservoir is owned by the City of San Angelo and is a primary source of domestic supply to the city. This study area watershed is inclusive of the sub-watersheds of four major streams and one minor stream (Pecan Creek). The watershed has been included in this study area although technically it confluences immediately below Twin Buttes and into Lake Nasworthy. The four major streams are the Middle Concho River, Spring Creek, Dove Creek and the South Concho River. The USGS reports that the total area of this watershed is 3,868 sq. mi. (2,475,520 acres).

Historically, all four of the major streams are perennial, although within recent memory the Middle Concho River has rarely displayed perennial characteristics. The South Concho, Spring Creek and Dove Creek have their perennial origins in spectacular historic springs and continue to be normally perennial. The springs on the South Concho located at the head of the River Ranch have historically been the most prolific of the three in regard to flow quantities. The main springs on Spring Creek are located immediately upstream of Mertzon and continue to be major contributors of stream flow, although springs located upstream from the main springs have largely ceased flowing in recent years.

The Dove Creek springs are located approximately 10 miles southwest of Knickerbocker, and flow records collected at the spring and maintained by the USGS since 1944 indicate little change in flows since the records began. The spring flow at this site has varied from year to year dependent upon rainfall conditions and has been quite reflective of extended drought periods. All three of these streams (and springs) are fed by water from outcropping limestone formations recharged to the south in the high plateau areas primarily in Schleicher County. This same region also provides the origins for the Devils River, the North Llano River and the San Saba River.

The perennial characteristics of the Middle Concho River were derived from a completely different hydrogeologic condition in comparison to the other three main tributaries. Middle Concho historic flows were derived from within the stream's watershed itself. This consisted of dewatering of the floodplain alluvial deposit aquifer as the stream bed (and tributaries) were in intimate contact with the top of the saturated zone. It is within this watershed that the successful 74,000 acre brush control project on Rocky Creek produced such dramatic results in restoring perennial flows to this tributary to the Middle Concho River. This watershed contains the largest portion of the Twin Buttes watershed, encompassing an area that is near equal to the remaining watershed. However, much of the watershed is non-producing and/or located within the arid regions in Upton and Midland Counties. The limits of the historically perennial portions of the Middle Concho are likely near the Reagan/Irion County line.

Twin Buttes Reservoir's impoundment of the Middle Concho River, Spring Creek and South Concho River began in 1962 with dam completion following in 1963. A 3.22 mile equalization channel connects the South Concho and Middle Concho –Spring Creek pools. Conservation storage is 186,200 acre-feet at an elevation of 1,940.2 feet and is the sum of the two pools. Below the level of the equalization channel (1926.5 feet) the capacity of the South Concho Pool is 5,440 acre feet (dead storage). Principal uses of Twin Buttes include flood control, irrigation and municipal water supply.

A USGS Gauging Station above Tankersley records flow into Twin Buttes from the Middle Concho River. Daily mean discharges have been recorded from 1961 to 1995 in the 1,116 square mile contributing drainage area. Prior to 1961 the gauging station was located a few miles downstream with an increased drainage area of 569 square miles. Records for this station on the Middle Concho date back to 1930. Spring Creek measurements for daily mean discharge date from 1930 to 1995. From 1930 to 1960 the gauging station recorded discharge for a 671 square mile contributing drainage area. In 1960, the USGS Gauging Station relocated upstream to the FM 2335 bridge above Tankersley. The contributing drainage area decreased to 405 square miles after this move. Dove Creek contributes flow to Spring Creek. Records for USGS Gauging Station on Dove Creek near Knickerbocker covered a 218 square mile contributing drainage area. The station located at FM 2335 bridge, 9 miles downstream from the spring recorded discharges for 1960 to 1995. The USGS Gauging Station (South Concho at Christoval) measured daily mean discharges for a 412 square mile drainage area from 1930 to 1995.

The gates were closed on Twin Buttes Reservoir in 1962. Since that time, the reservoir has had a varied and eventful past as related to its' impoundment history. Figure 5 is a summary of the impoundment history of Twin Buttes utilizing the USGS water year and the mean annual contents in acre feet.

O.H. Ivie Reservoir:

O.H. Ivie Reservoir is owned by the Colorado River Municipal Water District and is an integral part of the water supply planning for the entire region. The region includes the numerous municipalities of San Angelo, Abilene, Midland, Big Spring and many others. The primary feeding tributaries to this reservoir are the Colorado River below E.V. Spence Reservoir, Elm Creek and the Concho River below San Angelo. The main stem streams of these tributaries are normally perennial and can be classified as “gaining” streams (stream flows normally increase downstream). These perennial flows generally originate from dewatering of associated shallow alluvial aquifers that are in intimate contact with the streams.

Current perennial flows experienced by the Colorado River below E.V. Spence largely result from required controlled releases from the reservoir. Recent hydrologic studies and ground water modeling along the Concho River below San Angelo indicate that the Concho historically receives an average of approximately 7,000 acre feet of water per year (1915-1998) from dewatering of the Leona Aquifer in Tom Green and Concho Counties. These flows have decreased significantly in recent years due to the severe and prolonged drought experienced by the region. Several tributaries to the Concho have been observed to be historically perennial but have ceased flowing as the sub-watershed hydrologic systems were altered due to extreme brush infestations. Most notably, is Kickapoo Creek which once supported an impressive aquatic environment, finally terminating during the drought of the 1950’s. The creek, which originates from historic headwater springs, can currently be described as intermittent with wet weather perennial flows generally confined to the upper reaches of the sub-watershed.

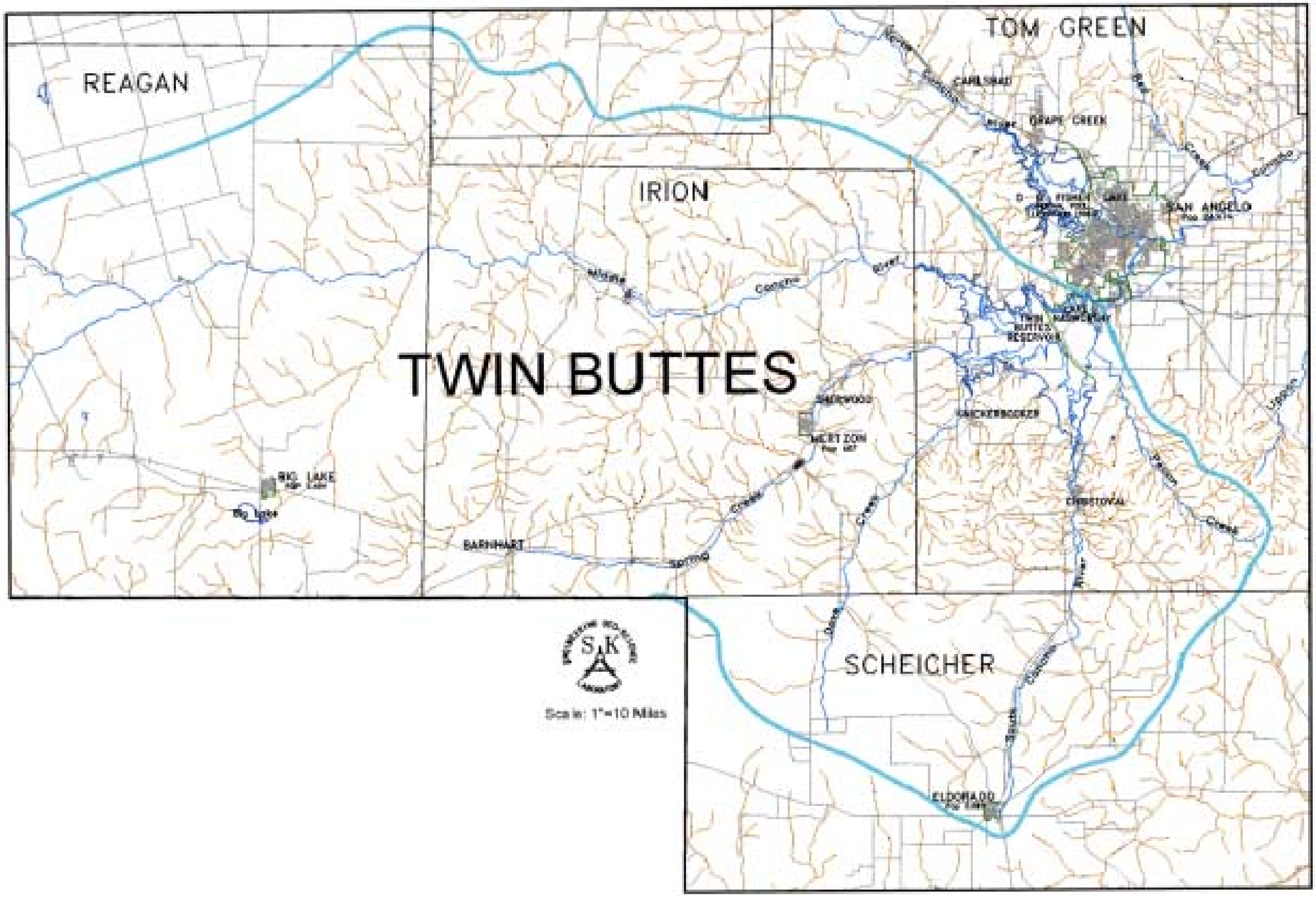
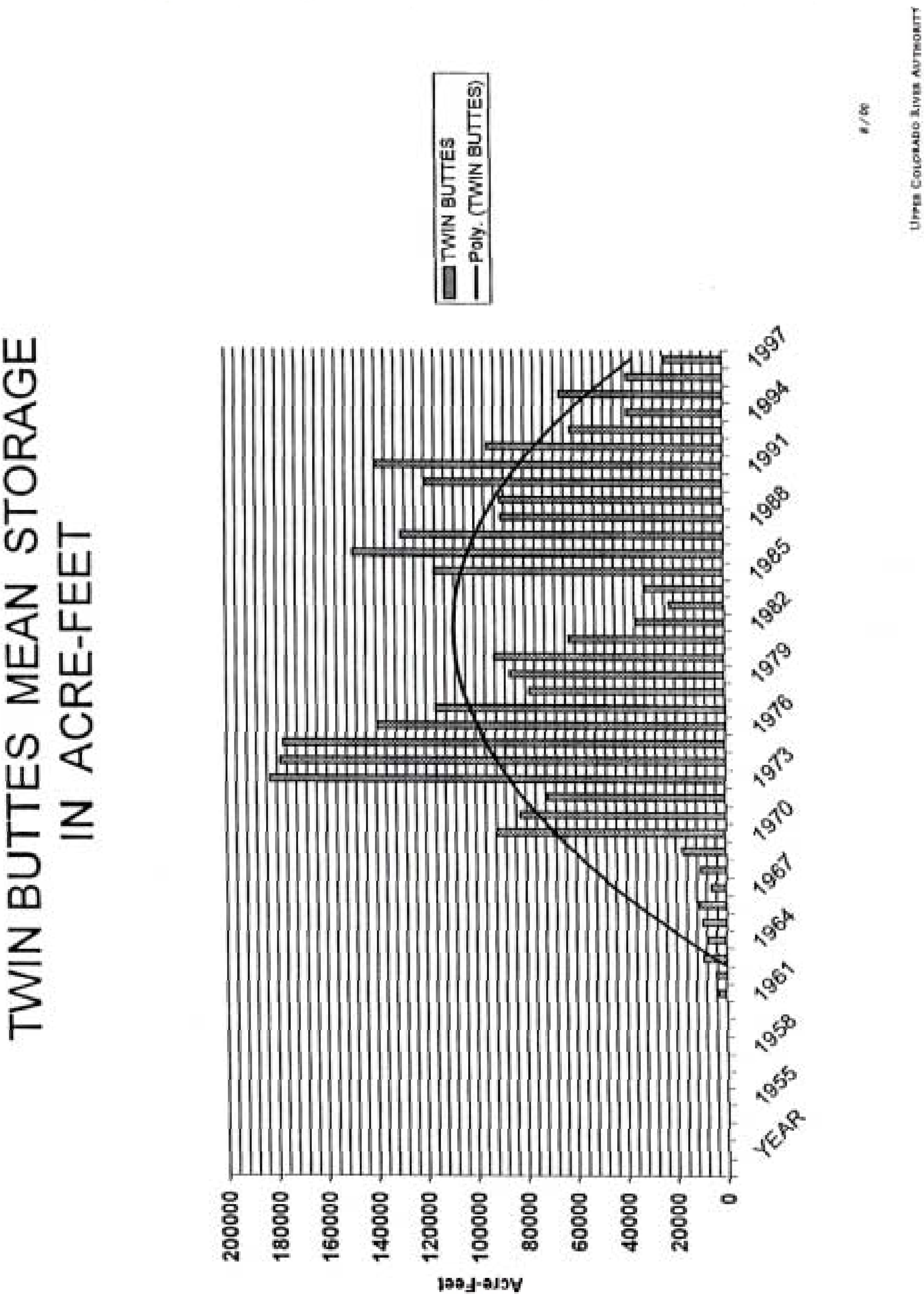

REAGAN
TOM GREEN
IRION
TWIN BUTTES
SCHEICHER
BIG LAKE
BARNHART
MERTZON
CHRISTOVAL
ELDORADO
SAN ANGELO
CARLSBAD
GRAPE CREEK
KNICKERBOCKER
TWIN BUTTES RESERVOIR

Figure 4



TWIN BUTTES MEAN STORAGE
IN ACRE-FEET
TWIN BUTTES
Poly. (TWIN BUTTES)
Acre-Feet
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
YEAR
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
Upper Colorado River Authority

Figure 5

In 1990 impoundment of the 12,647 square mile contributing drainage area began for Ivie Reservoir. Several large West Texas municipalities draw municipal water from Ivie Reservoir. Designed conservation storage is 554,300 acre-feet. Examination of the Colorado River below E.V. Spence Reservoir and the Concho River downstream of San Angelo provides an estimate of water flowing into Ivie Reservoir not regulated by upstream lakes.

The Concho and Colorado Rivers flow into O.H. Ivie Reservoir. Ivie Reservoir was not complete until 1990. By examining the present and historical records from USGS Gauging Stations, however, the volume of water that would have potentially been delivered into the lake basin can be computed for pre and post 1960 amounts.

The USGS Station on the Concho River at San Angelo lies 0.4 miles downstream of the confluence of the North and South Concho Rivers. Records on daily mean discharge are available from 1915 to present. Records are also available for the same time period for the USGS Gauging Station Concho River at Paint Rock. This Station gathers data on 1032 square miles of drainage. Water diversions for this area include irrigation, industrial use and municipal supply.

The USGS Station on the Colorado River at Robert Lee has a sporadic historical record of daily mean discharge. The station first collected data from 1923 to 1927, again from 1939 to 1956 and finally from 1968 to present, (after the construction of Spence Reservoir). The station is located at State Highway 208 Bridge and drains 5,047 square miles. Withdrawals include municipal, mining, agricultural, and industrial. The USGS Gauging Station on the Colorado River near Ballinger has been located at FM 2111 since 1979. From 1907 until 1979 the station was located in Ballinger. Six thousand ninety-eight square miles of contributing watershed lie upstream of the Ballinger Station.

O.H. Ivie Reservoir began impoundment in October of 1990 and Figure 7 is a summary of reservoir contents in acre feet and the USGS water year.

E.V. Spence Reservoir :

E.V. Spence was completed in 1969 and stores 488,800 acre-feet at conservation pool. Five thousand eighteen square miles drain into Spence Reservoir. However, flow is partially regulated by Lake B.J. Thomas, Champion Creek Reservoir, and Lake Colorado City. Three gauging stations on the Colorado River between Lake Thomas and Spence Reservoir provide an estimate of present and historical flow through the area. The river location of the USGS gauging station near Ira drains 2,371 square miles and the station at Colorado City adds 473

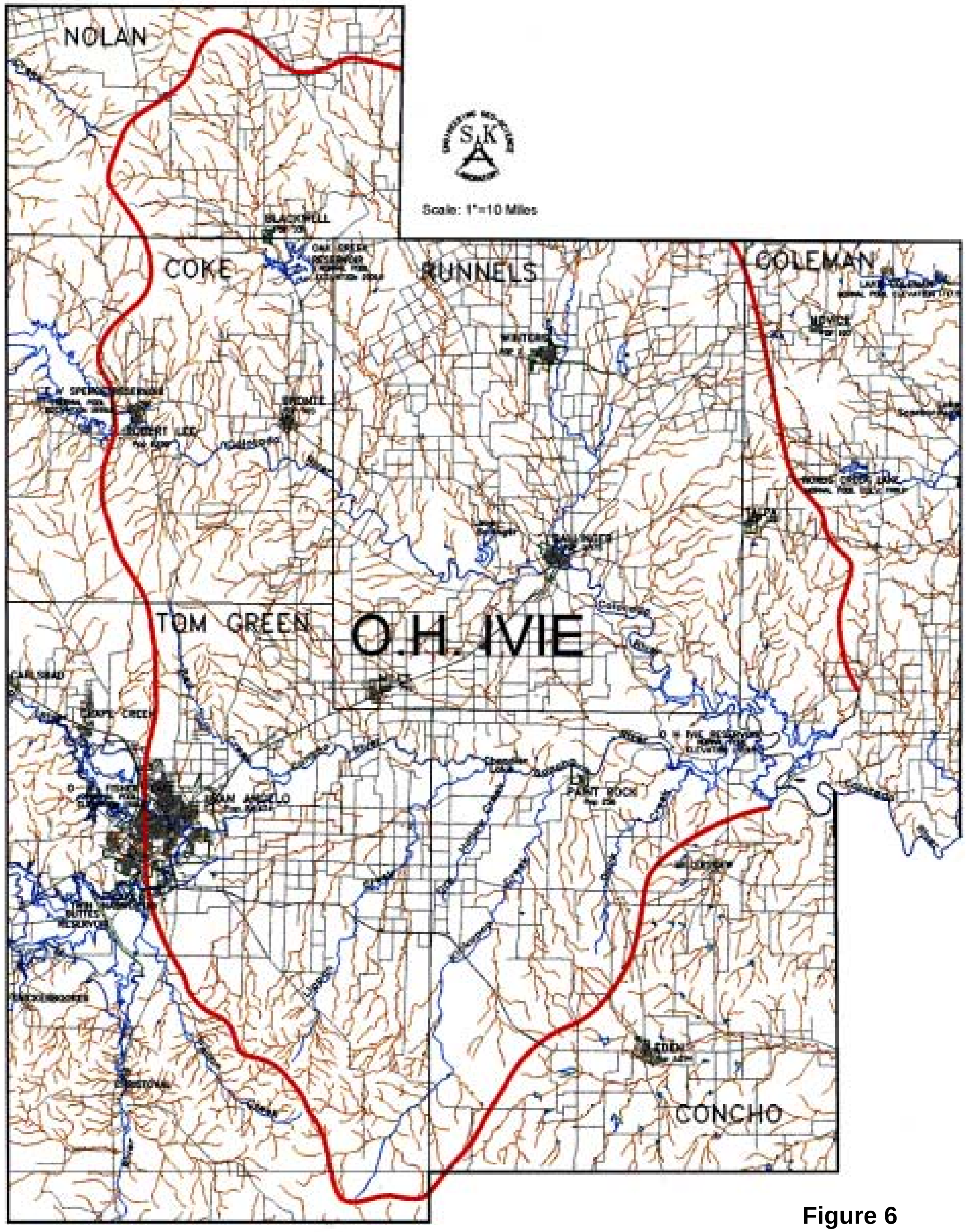

NOLAN
Scale: 1"=10 Miles
COKE
RUNNELS
COLEMAN
TOM GREEN
O.H. IVIE
SAN ANGELO
PAINT ROCK
EDEN
CONCHO

Figure 6

OH IVIE MEAN STORAGE IN ACRE-FEET

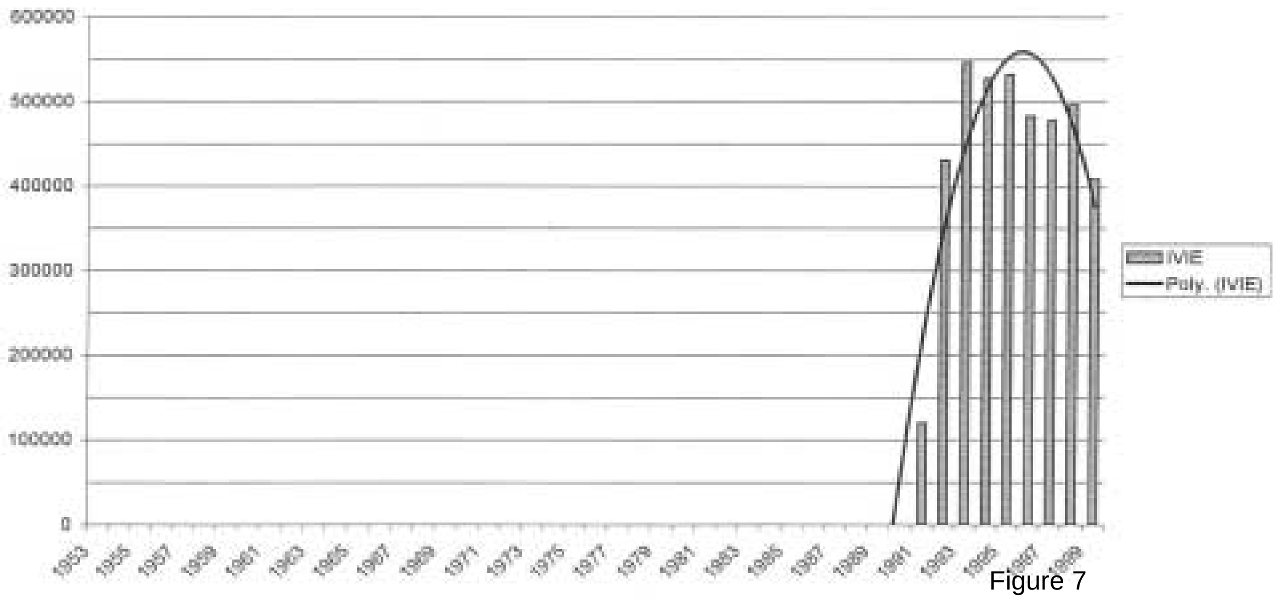


Figure 7

square miles of drainage. The station near Ira is located on the State Highway 350 Bridge and has collected daily mean discharge since 1958. The station in Colorado City, located at State Highway 377 Bridge, first collected data from 1923 until 1935 and presently records daily mean discharges (beginning in 1946). In addition, a USGS station is located on the Colorado River near Silver, Texas immediately upstream from the reservoir. Flow records are available from 1970 to the present. The contributing draining area for this station is approximately 1954 sq. miles.

Two sub-watersheds in the area include Beals Creek and Morgan Creek. The USGS Station on Morgan Creek near Colorado City provides historical flows from 1947 to 1949 for the 313 square mile drainage area. The USGS Gauging Station on Beal's Creek near Westbrook, located on state highway 163 bridge, drains 1988 square miles. The station has been continuously collecting daily mean discharge since 1958.

Figure 9 is a summary of the storage history of E.V. Spence Reservoir. The year indicated is the USGS water year and the mean content is in 'acre feet'.

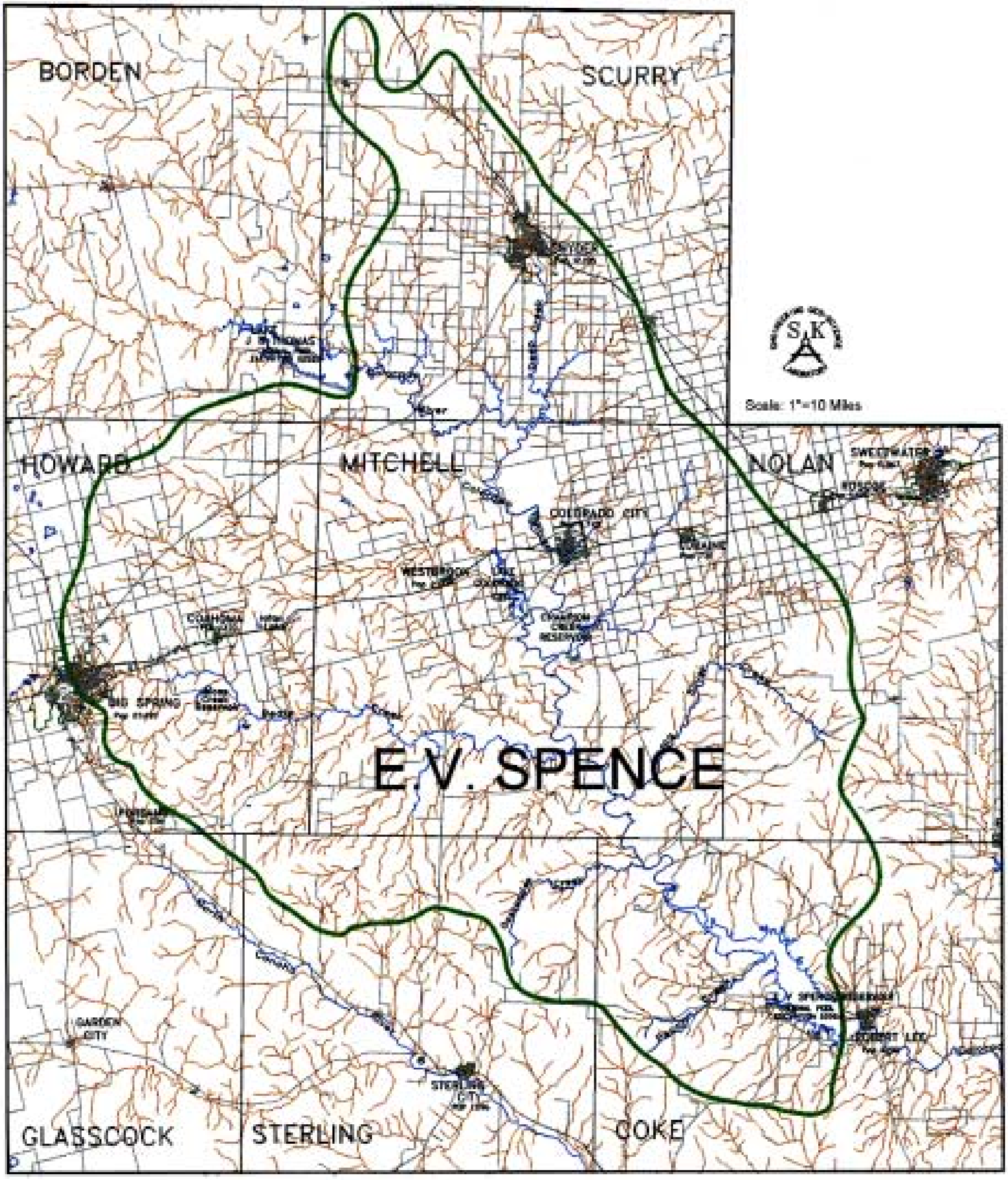

BORDEN
SCURRY
HOWARD
MITCHELL
NOLAN
SWEETWATER
COLORADO CITY
WESTBROOK
BIG SPRING
E.V. SPENCE
GARDEN CITY
STERLING CITY
ROBERT LEE
GLASSCOCK
STERLING
COKE
Scale: 1"=10 Miles

Figure 8

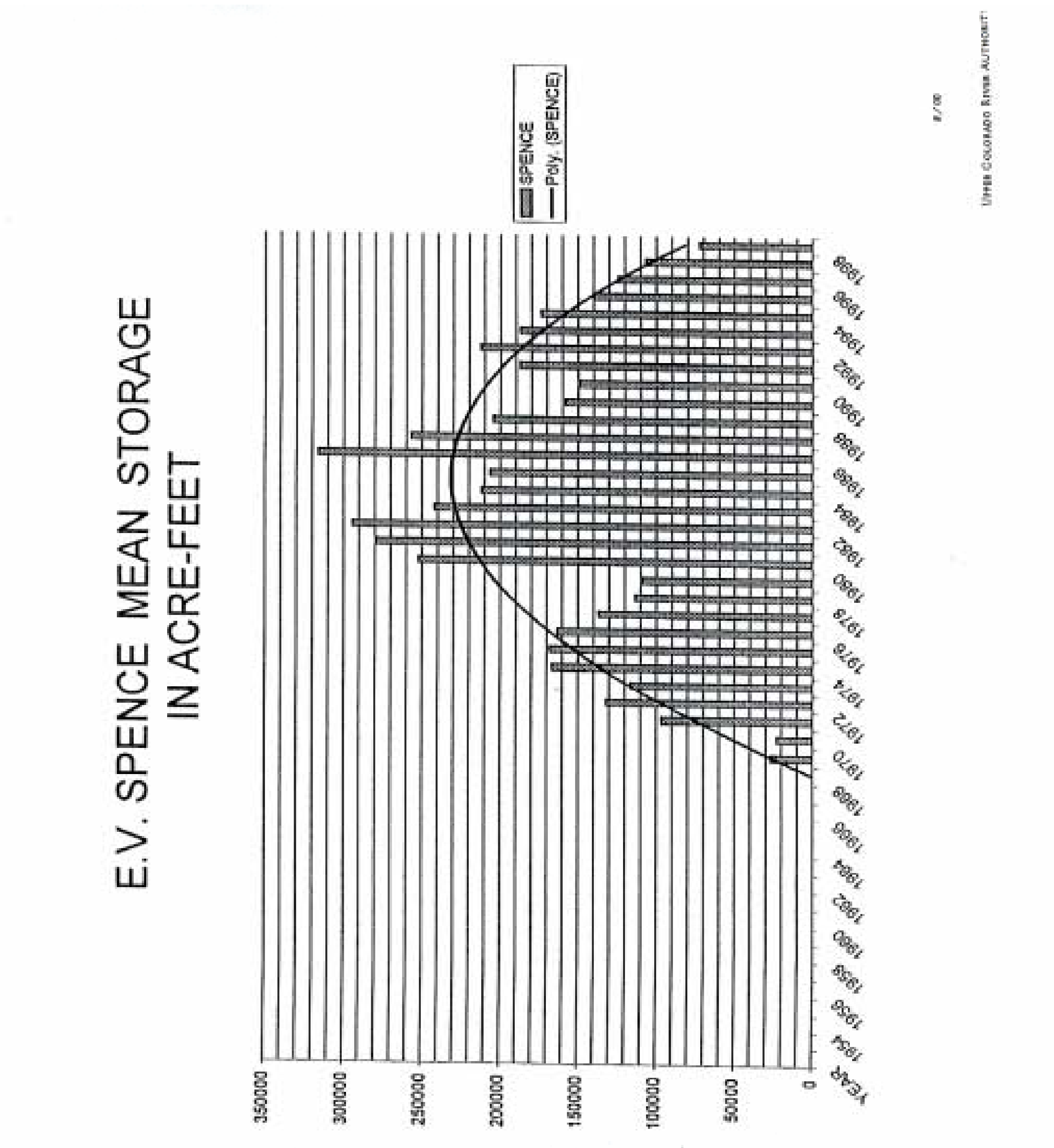


Figure 9

4.2 Historical Considerations

The previously cited 1998 North Concho River Watershed Brush Control Study Report contains a comprehensive regional ecological historical summary. This summary has been included as it provides an accurate description of the historical considerations regarding ecological changes of much of the study area, particularly that portion of the area most likely to benefit from brush control. Pages 12-16 of the study reports the following regional historical ecological chronology:

Ecological History :
A significant reference used in the preparation of this ecological study is a dissertation by Terry Clyde Maxwell entitled *Avifauna of the Concho Valley of West-Central Texas with Special Reference to Historical Change*, submitted to the Graduate College of Texas A&M University in May of 1979. Though the observations cited in the dissertation are of West Central Texas in general, the conditions of these areas are considered to be representative of the area actually within the watershed. Other sources used are *Personal Narrative of Explorations and Incidents in Texas, New Mexico, California, Sonora and Chihuahua, 1850-1883*, by John Russell Bartlett (also cited by Maxwell) and interviews conducted with local residents.

The sources of the information provided in this section are divided into three time periods: *Prior to 1849*, *1849 to 1885* and *1885 to 1950*. This allows for a chronological evaluation of the course of brush infestation, as well as a means of comparing past conditions with present conditions.

Prior to 1849:
Accounts from a Mendoza expedition in 1683 describe the Concho Valley, at the mouth of Kiowa Creek. Kiowa Creek is located in southern Sterling County, approximately ten miles south of the head of Mulberry Creek. One entry in the record of the expedition states:

"In this place were the first pecan trees we saw, for its bottoms have many groves of them; many nuts were gathered, ... It also has shells, a variety of fish, and very lofty live oaks, so large that carts and other bulky things can be made of them. There is a great variety of plants and of wild hens, which make noise at dawn. The river bottoms are very extensive and fertile, in its groves are many grape vines and springs, and many prickly pear patches; and all of the foregoing are on both sides of the river."

Maxwell makes note of the fact that Mendoza makes no mention of mesquite, and that the expedition would have passed the river bottom with difficulty if mesquite were present in the density that it is currently found. Another entry reads: "The place is in a plaza which has several great groves of very tall pecan and live oak trees. There are a number of wild hens and other kinds of game." This area currently looks much as described by Mendoza, except for the dense mesquite woodland that now occupies it. Maxwell points out that the wild hens, referred to by Mendoza, preferred a habitat of tall grasses and short shrubs. An area of dense mesquite woodland would not be a suitable habitat for these birds.

1849 – 1885:
One of the references used by Maxwell for this time period was an 1849 report of Lt. F.T. Bryan of the U.S. Army Topographical Engineers. The march from the South Fork of Brady Creek to the head of Brady Creek was described: "... marched through a beautiful country to the headwaters ... through a prairie covered with scattered mesquite and mesquite grass. There is abundance of wood for culinary purposes and the grass is abundant and good for grazing." Bryan went on to describe the route to Kickapoo Creek as being "...over an open, level, mesquite prairie requiring nothing but traveling to make a road in any direction." Maxwell's study of the area during the 1970s showed dense mesquite growth approaching woodlands, except for areas being cultivated.

From Kickapoo Creek, Bryan traveled to Lipan Creek. Bryan described the area as open grassland, with pecan and live oak trees being "very heavy" along the creek. Maxwell described the area currently as having dense mesquite, live oak and juniper. Toward Pecan Creek, Bryan observed the vegetation to be consisting of mesquite grass in the valleys. He noted that timber on the banks of Pecan Creek to be "pretty large."

Describing the journey from Pecan Creek, past the South Concho River and to Dove Creek, Bryan wrote:

"There is an almost total absence of timber. Now and then there is a solitary live oak and to the right (north toward Lipan Flat) may be seen some scattering of mesquite. (at South Concho)...crossed here easily after cleaning the brush from the banks. (at Dove Creek)...crossing effected without any difficulty after cutting out the brush from its banks. Both of these streams have heavy timber immediately on their banks but no farther...grazing is only tolerable, the grass being old and dry. Pecan timber of large size is found."

As Bryan traveled toward the Middle Concho River, crossed Spring Creek and passed Lopez Creek, he noted the area to be rolling prairies. Maxwell compares the area currently as juniper savannah.

Another source used by Maxwell was an 1853 description by John R. Bartlett, United States Commissioner of the United States-Mexican Boundary Survey. Of the land between Brady Creek and Kickapoo Creek, he wrote: “The country today has been flat...few trees except the mesquite now and then a little mot (sic) of live oaks was to be seen.” Traveling west past Kickapoo Creek, Bartlett noted that the hills were entirely barren of trees and shrubs.

As Bartlett passed the South Concho River and continued in the direction of Dove Creek, he described the area as being a "flat prairie interspersed with stunted mesquite." He wrote of the land between Spring Creek and Lopez Peaks and west of Kiowa Creek as barren and having only stunted mesquite, though Maxwell now finds the land to be covered with juniper.

Another of Maxwell’s sources was an 1867 army topographical map that contained vegetation notations. It noted the Middle Concho River bottoms to be grassland. Maxwell points out that mesquite was probably uncommon, because areas where mesquite was found were specifically noted on the map. The Grape Creek area was noted to have grass, with small mesquite in a small area, some scrubby oak, and juniper. The area is currently covered with very dense stands of mesquite trees and shrubs that blended with juniper.

Maxwell summarized the vegetation of the Concho Valley during the 1849-1885 time period as dominantly grassland. The prairies of Lipan Flat and the High Plains were grasslands with scattered old mesquite trees and low mesquite bushes. He wrote that the "undulating hills of the Eldorado and Colorado divides had scattered growth of live oaks and mesquite in some locations, and only 'barren' grassland in others." Juniper was uncommon. Large pecan trees and live oaks with dense undergrowth lined the stream banks.

1885 – 1950:

Several references describing the vegetation during this time period were used by Maxwell. Harvard wrote of dense thickets of mesquite in 1885, and Lloyd wrote, in 1887, "...It was once treeless, but now is being rapidly covered with dwarf mesquite..." Maxwell also made reference to an 1899 writing of Vernon Bailey, a biologist with the Bureau of Biological Survey. He described much of the land from San Angelo to Big Spring as being covered with a scattered growth of small mesquites. Bailey also described the buttes near Water Valley and Sterling City as being covered with shin oak and some juniper. In 1901, Harry Oberholser, with the Bureau of Biological Survey, observed chaparral around San Angelo, and the hills between San Angelo and Sherwood to be covered with oak and juniper. He noted the abundance of mesquite "everywhere."

During his study in the 1970s, Maxwell interviewed residents of the Concho Valley. Percy Turner, a Water Valley rancher recalled that mesquite was common in draws near the North Concho River before 1920, and that dense mesquite developed in the late 1940s and early 1950s. Alvin Counts said when he moved to a ranch at the top of the Colorado Divide in 1903, he could count the individual mesquite trees, which were large, old trees. The density of the mesquite increased in the early 1950s.

Interviews conducted specifically for this study in May 1998 yielded similar information. Ralph Davis, a resident of Sterling City who moved to the area in the early 1920s, recalled a definite increase in the density of mesquite since moving to the area. He stated that the brush had spread from the banks of creeks to the plains. James Weddell, Sr., who owns a ranch near Water Valley, described having to clear mesquite from approximately 900 acres on his ranch in the late 1950s. This mesquite had developed since his father obtained ownership of the ranch, around the beginning of the 1900s. The area cleared of mesquite in the late 1950s has since been inundated by dense mesquite growth.

Maxwell also interviewed people who recalled the spread of juniper in the late 1800s and early 1900s. Drew McInteer, who moved to Mertzon in 1911, remembered juniper as being confined to ravines along the Middle Concho River. Henry Linley said that in 1912 the juniper on his ranch just west of Mertzon was confined to heads of draws. After a period of drought between 1916 and 1918, the junipers began to spread rapidly.

It can be concluded that the vegetation surrounding and within the North Concho River watershed has changed significantly since the time of the first recorded observations of the area. Before 1849, there were no noticeable growths of mesquite, juniper or other noxious brush. Between 1849 and 1885, the area was dominantly grassland, with some growths of mesquite. From 1885 to the beginning of the twentieth century, however, mesquite began to infest the plains. It spread from the banks of streams and rivers to the grasslands, growing most rapidly during the late 1940s and early 1950s."

4.3 Geologic and Hydrogeologic Considerations

4.31 Twin Buttes Reservoir Watershed

The geological formations exposed at the surface within the Twin Buttes Reservoir Watershed predominately consist of Cretaceous and Quaternary sedimentary deposits. The Quaternary deposits are present in the stream valleys and the Cretaceous rocks form the hills and sloped terrain. A generalized lithological description of each of these follows:

The Cretaceous rocks consist primarily of the Fredericksburg Group (mostly limestones) and the Antlers Formation (castic sediments). Formations within the Fredericksburg Group, in descending geologic order, include the Segovia Formation, Fort Terrett Formation, Edwards Limestone, Comanche Peak Limestone, and the Walnut Formation. Herein, these formations are referred to as the "Undifferentiated Cretaceous limestones". The Antlers Formation is referred to herein as the "Antlers sand".

Lithologically, the Undifferentiated Cretaceous limestones consist of light to dark gray, to grayish brown and yellow massive to thinly bedded limestone with some dolomite. Limestones are fossiliferous and argillaceous in part. Irregularly bedded nodular chert layers are present throughout. Thin irregularly bedded clays, shales, and minor amounts of sand exist in lower beds. The Undifferentiated Cretaceous limestones exist in thickness up to approximately 350' thick within the watershed. They gently dip toward the southeast, as does the water table.

Lithologically, the Antlers sand consists of fine to coarse grained unconsolidated sands, fine to coarse grained poorly bedded friable to well cemented sandstones and quartzites. Colors vary from white to brown, gray, and yellow. The formation is conglomeratic at its base. The formation is up to approximately 100' thick within the watershed.

The Quaternary Alluvium consists of mainly floodplain and terrace deposits of sands, silts, gravels, and caliche. Alluvial deposits are also present in the form of gently sloping areas and alluvial fans located along the edges of the dissected Cretaceous limestones and Antlers sand.

Permian aged rocks unconformably underlie the Cretaceous rocks. These dip to the west toward the Midland Basin.

Within the Twin Buttes Reservoir watershed, the five principal waterways are the Middle Concho River, Spring Creek, Dove Creek, the South Concho River, and Pecan Creek. Of these, the drainage area of the Middle Concho River by far has the longest reach and the largest area. The erosional valleys that have developed in the Middle Concho River Valley cover much more area and contain a greater volume of alluvial deposits than do the other waterways in the Twin Buttes Reservoir watershed.

The other waterways are characterized by much narrower and steeper erosional canyons than is the Middle Concho River waterway. Only the lower reaches of these waterways contain significant alluvial deposits. In the mid to upper reaches of these waterways where erosion has incised into the Cretaceous limestone far enough down and far enough laterally to intersect the Edwards-Trinity (Plateau) Aquifer water table, springs issue forth. This phenomenon is exhibited in the Dove Creek, Spring Creek and the South Concho River, all of which are typically spring fed waterways.

Because of the larger volume of alluvial deposits that occur in the Middle Concho River watershed, it is considered likely that this portion of the Twin Buttes Reservoir Watershed would more readily respond to brush control efforts than the other sub-watersheds. However, it is considered likely that the alluvial deposits located in the lower reaches of the other waterways provide sufficient groundwater storage to locally respond to brush control efforts.

4.32 O.H. Ivie Reservoir Watershed

The O.H. Ivie Reservoir Watershed consists of the Concho River Watershed below San Angelo and the Colorado River Watershed below Robert Lee. The geological formations exposed at the surface in the Colorado River watershed vary significantly from those exposed in the Concho River Watershed. In the Concho River watershed, Quaternary alluvial deposits of the Leona Formation predominate, while in the Colorado River watershed, Permian aged rocks of various formations are the most prevalent.

The Quaternary Leona Formation of the Concho River watershed is comprised of up to approximately 125 feet of flood plain and terrace alluvial deposits that consist of gravel, clay, fine-grained sand, and conglomerate. These unconformably overlie Permian aged rocks that dip west into the Midland Basin. The Leona Formation and the up dip portions of the Permian rocks, principally the Choza Formation and the Bullwagon Dolomite, are hydrologically connected and comprise the Lipan Aquifer. The Lipan Aquifer is recognized as a Minor Aquifer of Texas and supplies irrigation water to farmers in the Lipan Flats area located in eastern Tom Green, western Concho, and southern Runnels counties. The Leona Formation contributes water to the Concho River and its’ tributaries, i.e. Lipan, Dry Hollow, and Kickapoo creeks.

The upper reaches of Kickapoo Creek extend to the Cretaceous limestones of the Edwards-Trinity (Plateau) Aquifer and may receive minor amounts of water from spring flow in wet seasons. Permian rocks are exposed east of Lipan Flats. Duck Creek, a tributary of the Concho River traverses exposed Permian rocks, as does a portion of Kickapoo Creek.

As previously mentioned, the predominant surficial deposits in the Colorado River watershed consist of Permian aged rocks. The exposed Permian rocks exist in northeast-southwest oriented bands that dip westward toward the Midland Basin. The oldest Permian rocks exist in the eastern most area of the watershed and the youngest Permian rocks are in the west. The Permian formations exposed in the watershed, in order from youngest to oldest include the Whitehorse Sandstone, Cloud Chief Gypsum, Blaine Formation, San Angelo Formation, Clear Fork Group, Lueders Formation, Talpa Formation, Grape Creek Formation and the Bead Mountain Formation. The youngest four formations listed consist predominantly of evaporite and clastic deposits, and the oldest four formations consist primarily of limestone deposits. The Clear Fork is transitional between the two. Their lithologies are described below.

The Whitehorse Sandstone consists predominantly of thin bedded to massive sand, sandstone, and shale with interbedded gypsum and selenite. The Cloud Chief Gypsum is similar in composition. It is comprised of thin beds to massive gypsum and selenite with thin discontinuous beds of dolomite and a basal conglomerate. The Blaine Formation also consists of interbedded thin to massive shale, sandstone, gypsum, selenite, shale, and dolomite. The San Angelo Formation consists of thin bedded to massive fine-grained sandstone and shale with a conglomeratic base. The contacts between these formations are locally indefinite.

The Clear Fork Group (undivided) consists mostly of mudstone and shale with thin beds of limestone and dolomite. The Lueders Formation consists predominantly of alternating beds of limestone and shale with progressively less shale southward. The Talpa, Grape Creek, and Bead Mountain formations consist of mostly distinct fossiliferous limestone beds with thin shale interbeds. They vary in thickness of beds and in their fossil assemblages. Locally, they are all quarried for limestone and road building materials.

A narrow band of alluvial flood plain and low terrace deposits exist on either side of the Colorado River and its tributaries. Other quaternary alluvial deposits exposed in the watershed consist of mostly caliche and windblown sand and silt. Because of their limited thickness and aerial extent, they likely do not provide a significant amount of groundwater storage capacity except on a local basis.

Cretaceous limestone outliers are present in the northernmost portion of the watershed.

The main tributaries of the Colorado River watershed portion of the O.H. Ivie Watershed include, from east to west, include Oak Creek, Valley Creek, Elm Creek and Mustang Creek. Neither a recognized major nor minor aquifer is located in this watershed.

Groundwater occurrence in the watershed is typically in the narrow bands of alluvial deposits along the rivers and streams, in shallow soils above bedrock, or in permeable zones within the upper portions of the Permian rocks. The shallow groundwater contributes water to the tributaries and supports stream flow after rainfall events.

4.33 E.V. Spence

The geological formations exposed at the surface within the E.V. Spence Reservoir Watershed predominantly consist of Tertiary, Triassic, and Quaternary aged sedimentary rocks. Minor occurrences of Permian aged rocks also exist.

Surface exposures of the Dockum Group (Triassic in age) are by far the most prevalent in aerial extent within the watershed. The Dockum Group consists of mostly fine to coarse grained, thin bedded to massive silty sand and clay, commonly red in color. Interbedded with the sand and clay is irregularly bedded conglomerate. The Dockum Group underlies the Ogallala Formation of Tertiary age.

The Ogallala (Tertiary in age) is present at the surface in the northeastern portion of the watershed. It consists of sand, silt, clay, gravel and caliche. The caliche is indurated and produces a hard, resistant caprock where exposed and in the subsurface at the contact with the Quaternary deposits.

The Quaternary aged rocks located within the watershed consist of mainly sand, clay, caliche, and gravel. In dissected areas, the deposits are gently sloping alluvial fans and low fluviatile terraces. Alluvium and floodplain deposits are present in narrow bands along the main waterways. Playa lakes and wind blown dunes and sheets are also present.

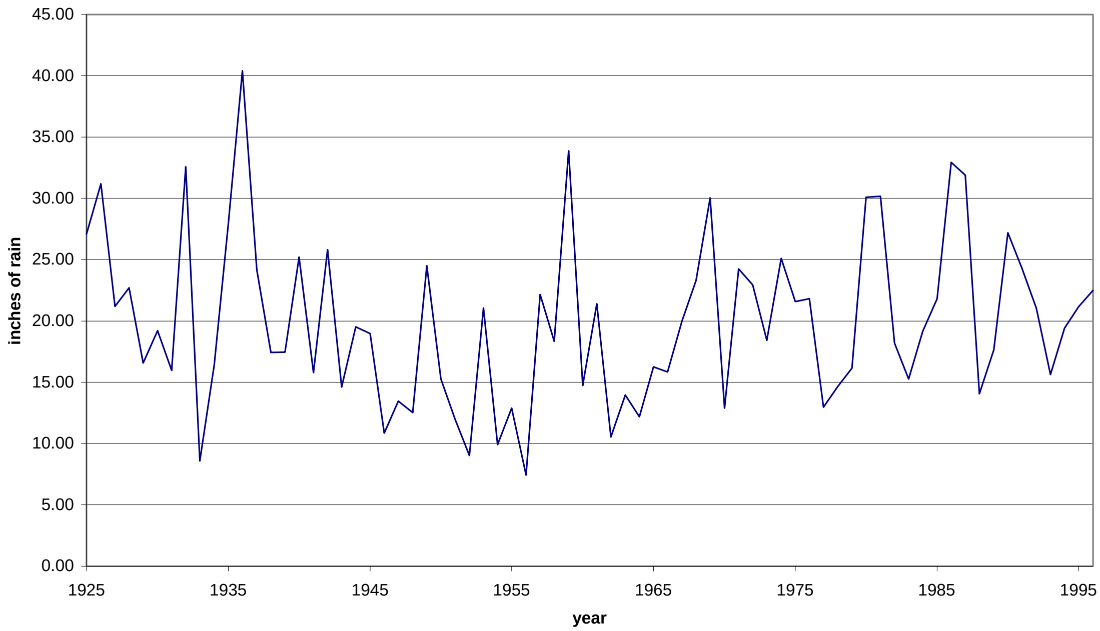
The Permian rocks exposed at the surface within the watershed are present only along the Colorado River near E.V. Spence Reservoir. These rocks are mainly composed of the Quartermaster Formation that consists mostly of shale, silt, and fine-grained sandstone, red in color, with interbedded gypsum and dolomite.

The water bearing zones of the Dockum Group forms the Dockum Aquifer, a recognized Minor Aquifer of Texas. The primary water-bearing zone is the Santa Rosa. The Dockum Aquifer is present at the surface throughout most of the E.V. Spence Watershed. It exists under the Ogallala Formation along the northeastern edge of the watershed. In the subsurface west and northwest of the watershed, the Dockum Aquifer and the Ogallala Aquifer are hydrologically connected and form one aquifer system. The salinity of groundwater produced from the Dockum Aquifer is widely variable. The freshest water is produced from its outcrop, which is located predominantly within the watershed area.

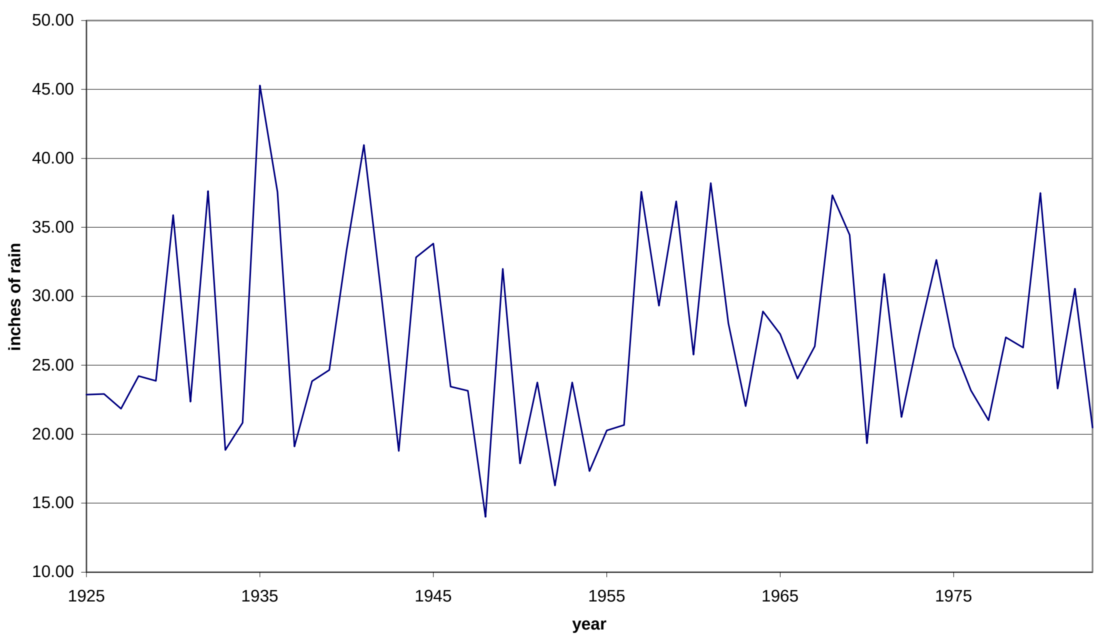
4.4 Existing Hydrologic Record

The following section examines and describes the historical hydrologic record of streams within the study area. The historical flow data is provided and analyzed to determine changes through time in stream discharge and reservoir yields. Evaluations of enhanced reservoir yields that follow in this report have assumed that there have not been any significant climatic changes during the period of record. A review of historical rainfall records for two area locations tend to confirm that this is a valid assumption. The graphic displays on the following page show rainfall experienced in San Angelo and Coleman, Texas and are representative of the area and actually indicate a slight increase in rainfall for the area since 1960.

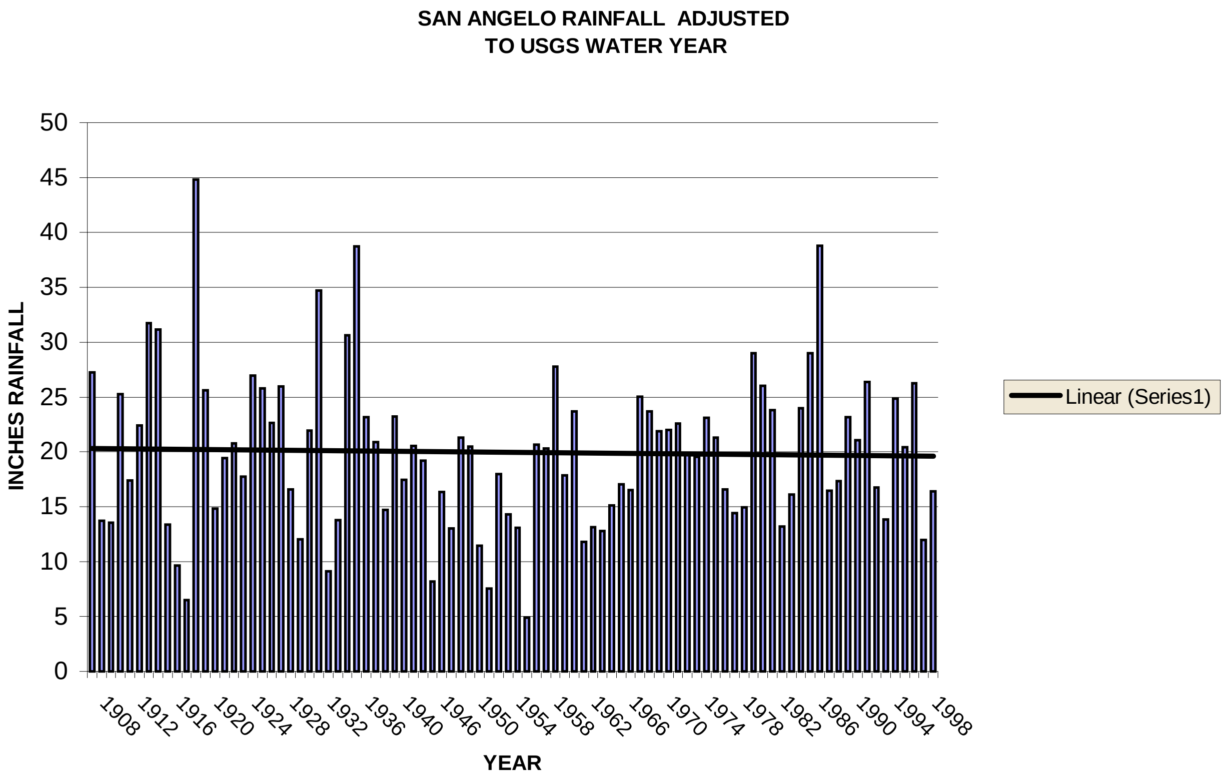
Rainfall Record for San Angelo weather station: 1924 - 1996
average recorded rainfall for 1925 to 1959 (in.): 19.48
average recorded rainfall for 1960 to 1996 (in.): 20.31



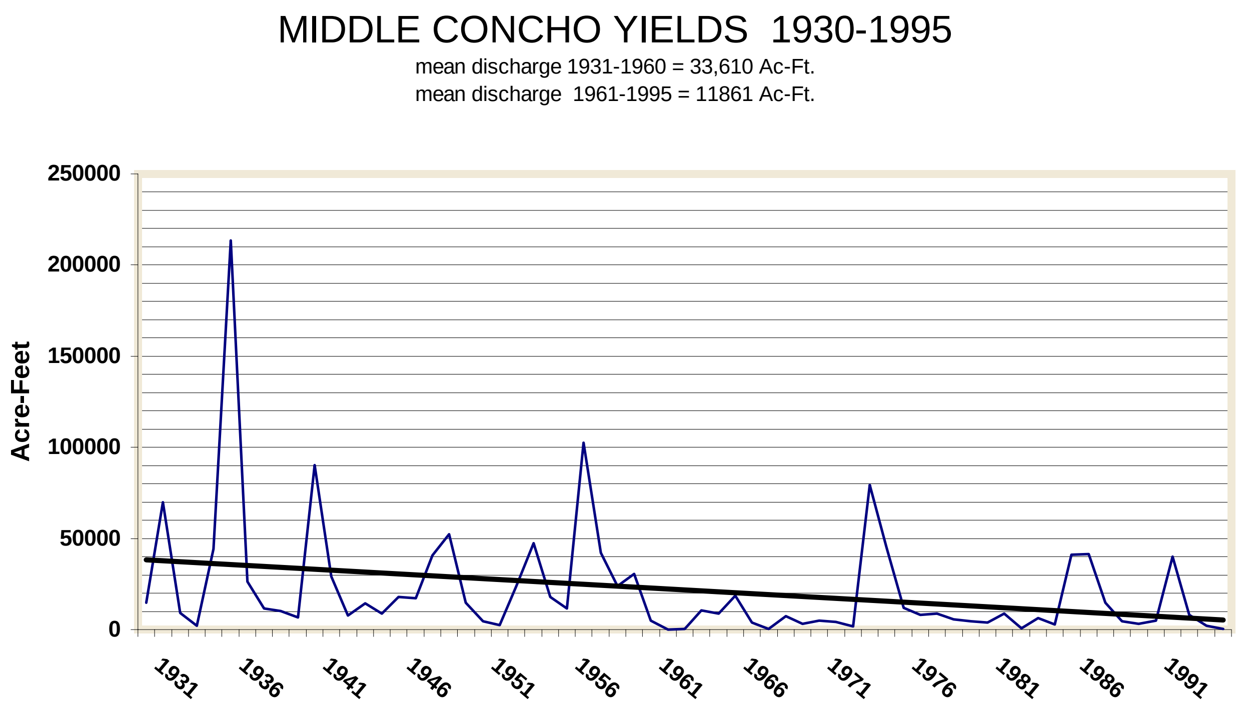
Rainfall Record for Coleman weather station: 1925-1983
average recorded rainfall for 1925 to 1959 (in.): 26.51
average recorded rainfall for 1960 to 1983 (in.): 27.51

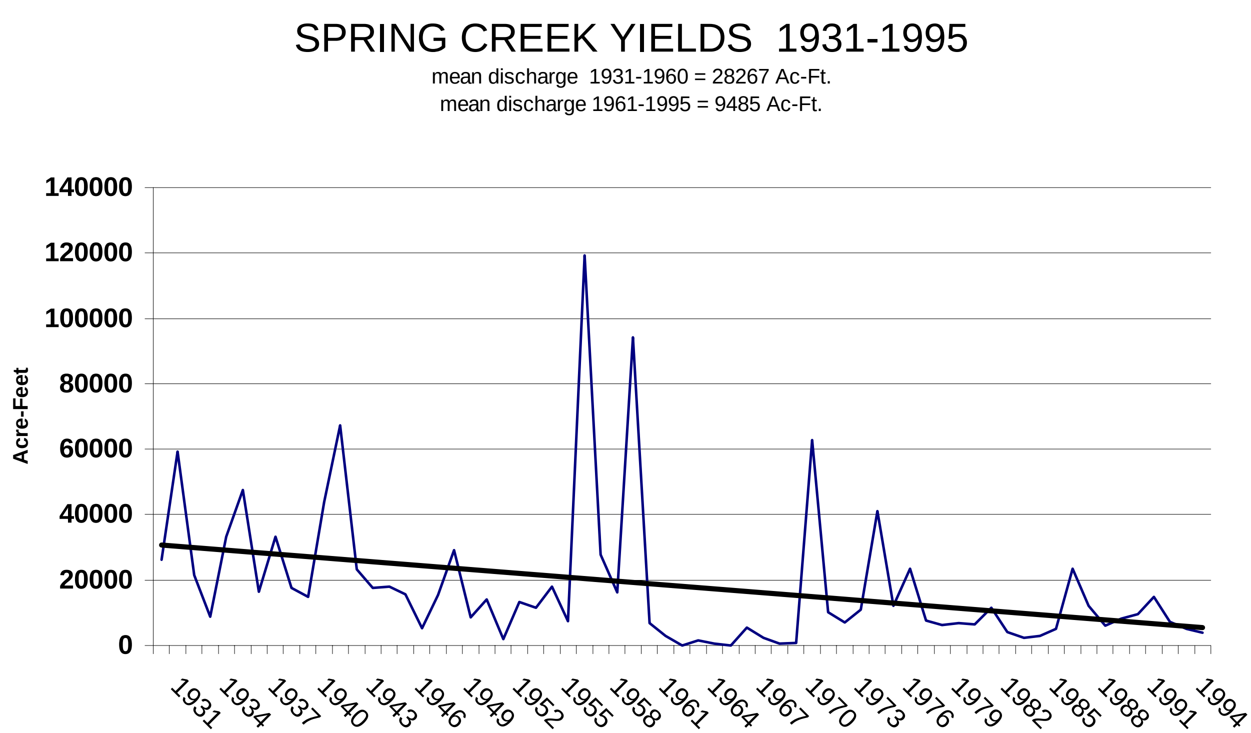


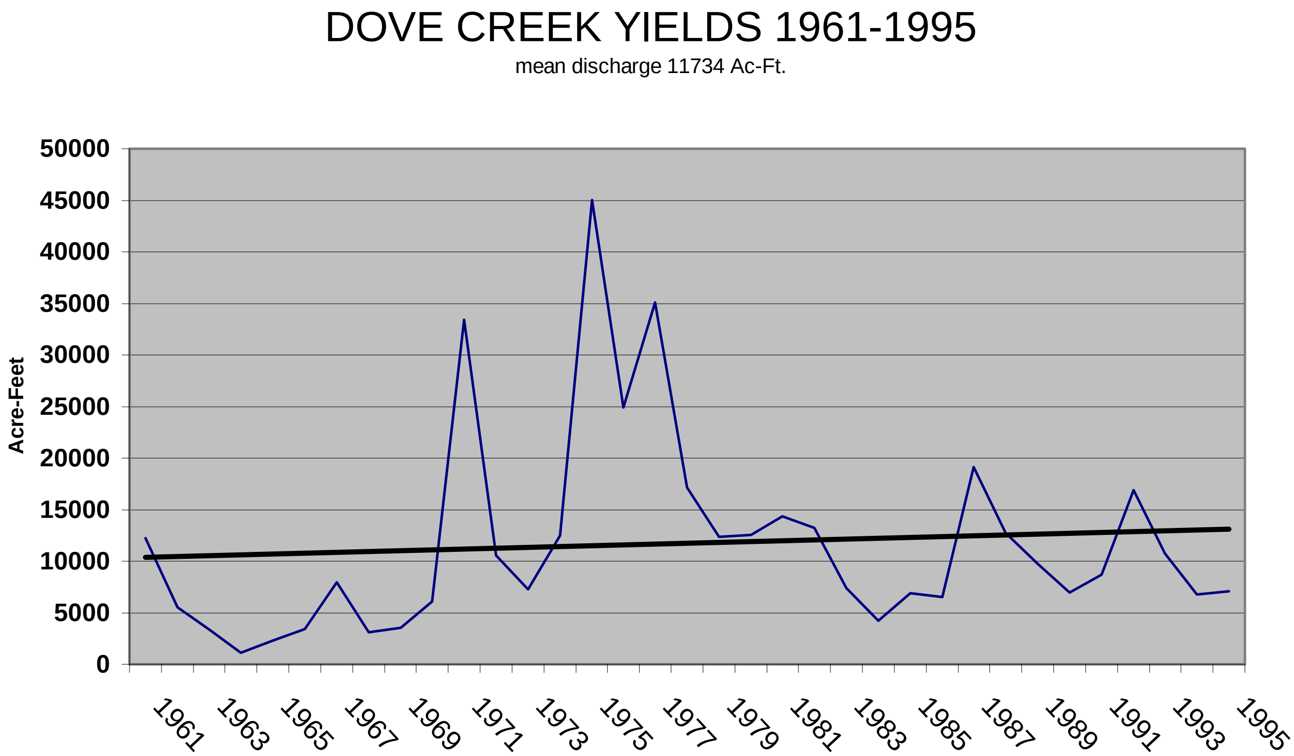
Following is a graphic display of the long-term rainfall record for the San Angelo area correlated to the USGS water year (October 1 to September 30). This record indicates that the mean annual rainfall for the area has been near 20 inches per year for the last 90 years and has remained remarkably constant.



Streams Above Twin Buttes Reservoir:
The following stream flow graphs indicate the historic hydrologic conditions experienced by the tributaries to Twin Buttes Reservoir.

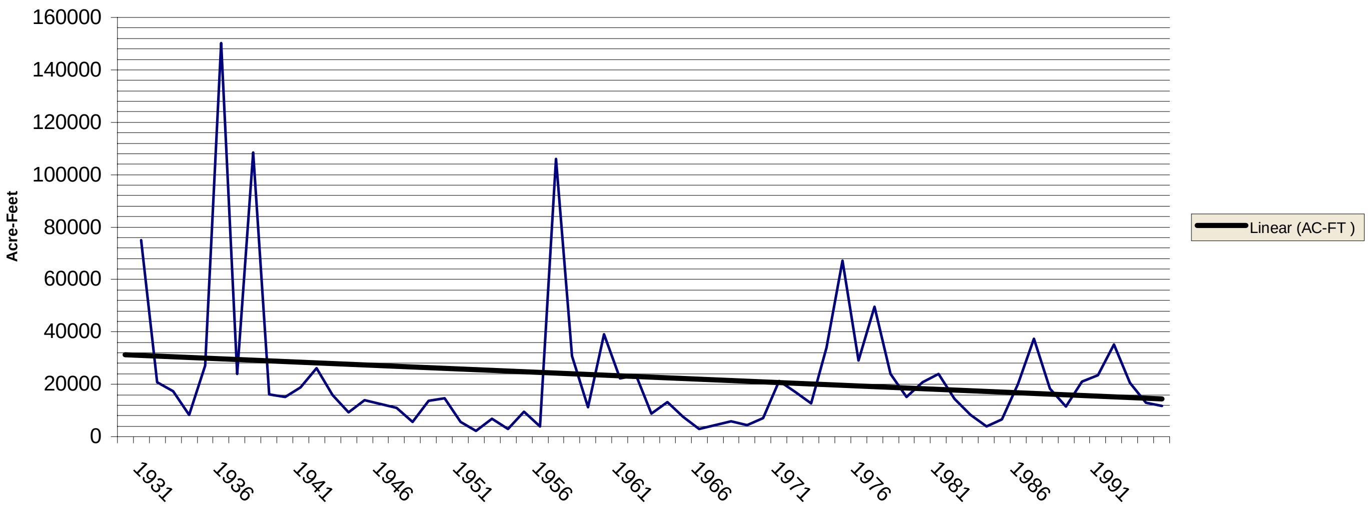





DOVE CREEK YIELDS 1961-1995
mean discharge 11734 Ac-Ft.
Acre-Feet
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995

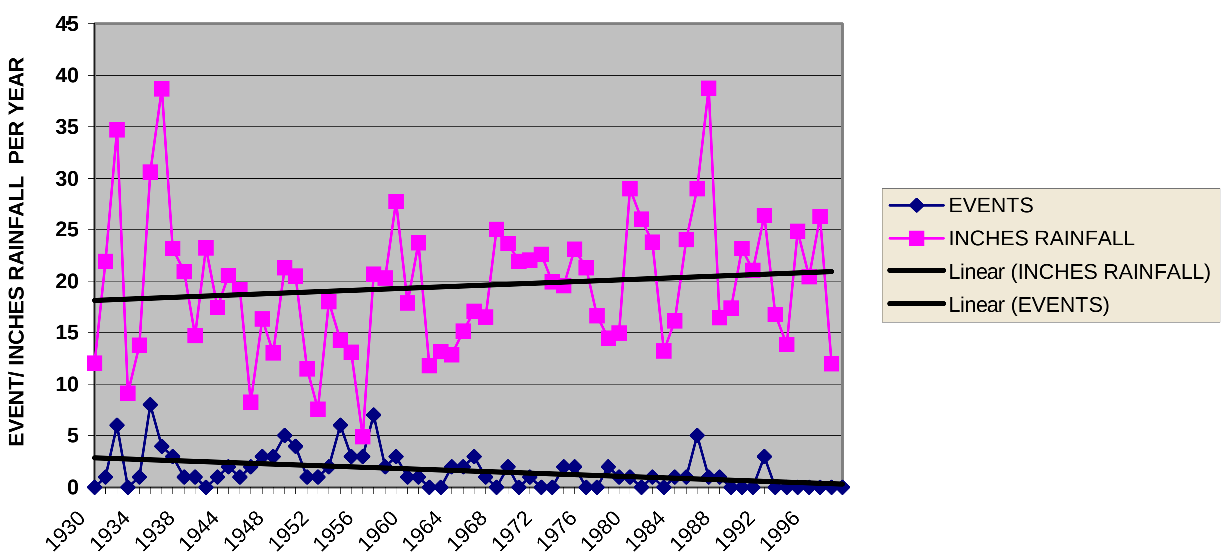
SOUTH CONCHO YIELDS 1931-1995

mean discharge1931-1960 = 27399 Ac-Ft.
mean discharge 1961-1995 = 18806 Ac-Ft.



In addition to the discharge summaries for the Twin Buttes Reservoir watershed as shown above, hydrologic data was also analyzed for this watershed to further demonstrate the effect of brush infestations and the loss of perennial flows on watershed yields. This analysis was conducted on the Middle Concho River stream flow data due to the complete loss of perennial flows on this stream with time. The following graphic shows the decline with time of the number of rainfall runoff events including stream flows of 500 cfs or greater. The annual rainfall for the same period is also included on the graph to demonstrate that the rainfall frequency and intensity has not declined. An examination of this data indicates that since 1930 the mean number of 500 cfs or greater rainfall runoff events on the Middle Concho River has declined from near 3 events per year to the present time when the number of events per year is approaching zero.

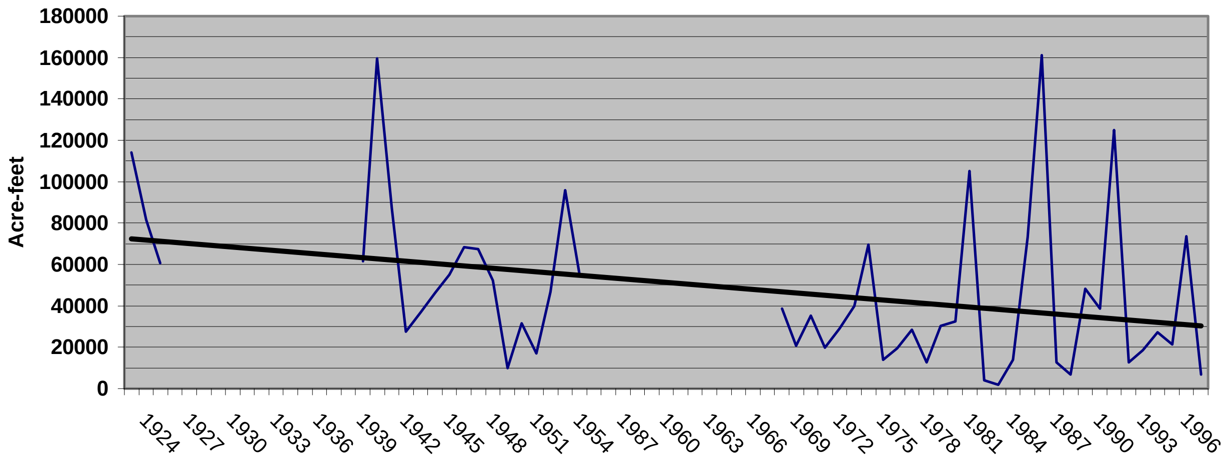
SAN ANGELO RAINFALL *VS* MIDDLE CONCHO 500+ CFS EVENTS



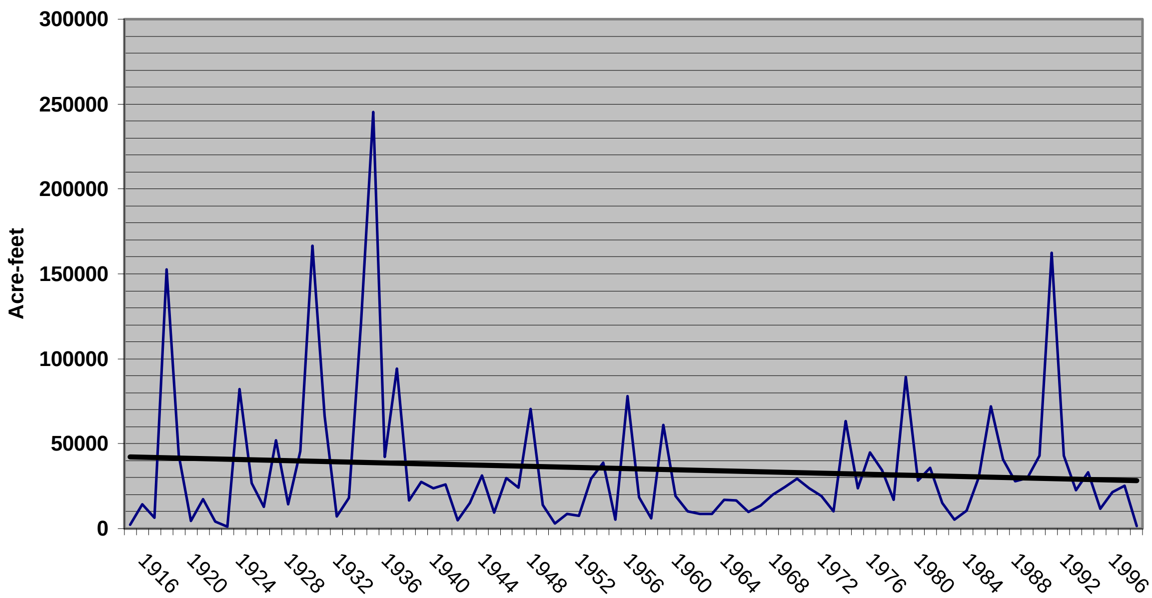
***1941-1942 not included due to missing data**

Concho And Colorado Rivers Above O.H. Ivie Reservoir
The following graphs summarize the historical stream flows for the Concho River below San Angelo, the Colorado River below Robert Lee and Elm Creek.

COLORADO RIVER, O.H. IVIE WATERSHED
BELOW E.V. SPENCE
MEAN DISCHARGE 1940-1951 = 57467 AC-FT
MEAN DISCHARGE 1968-1998 = 38010 AC-FT



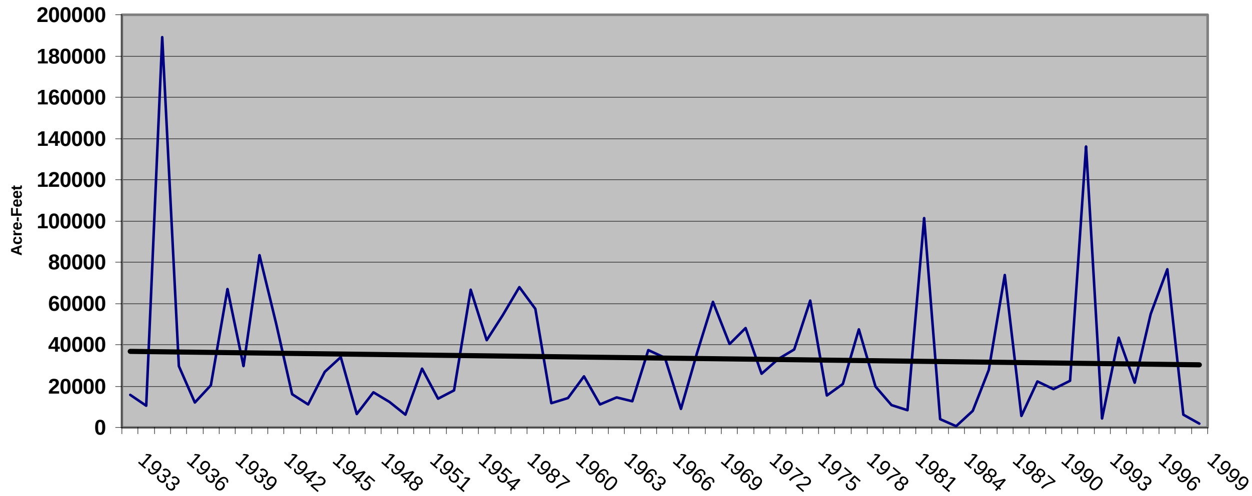
Concho River between USGS gaging station at San Angelo and USGS station at Paint Rock-Water year 1916-1999
mean discharge 1916-1960 (ac-ft/yr) = 40674
mean dishcarge 1961-1999 (ac-ft/yr) = 29816



ELM CREEK YIELDS 1933-1999

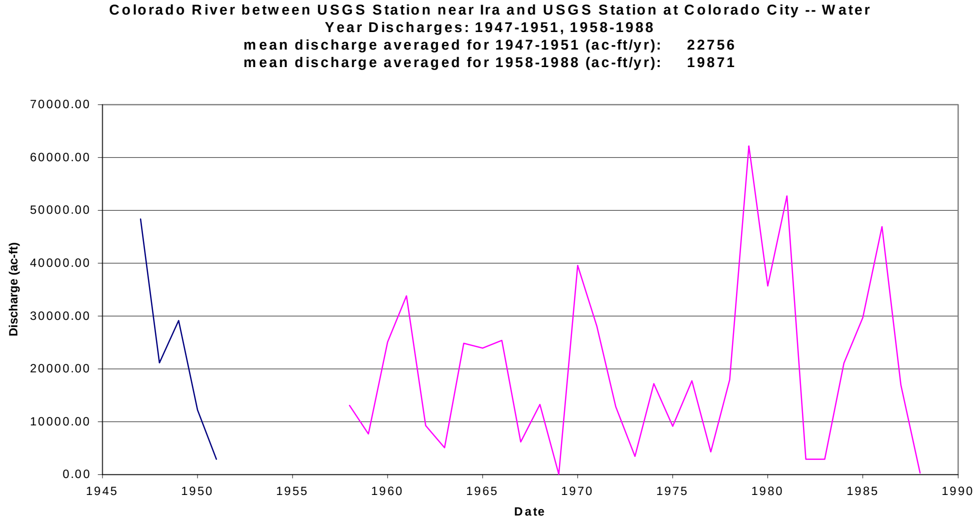
mean dishcarge 1933-1960 = 34947 ac-ft

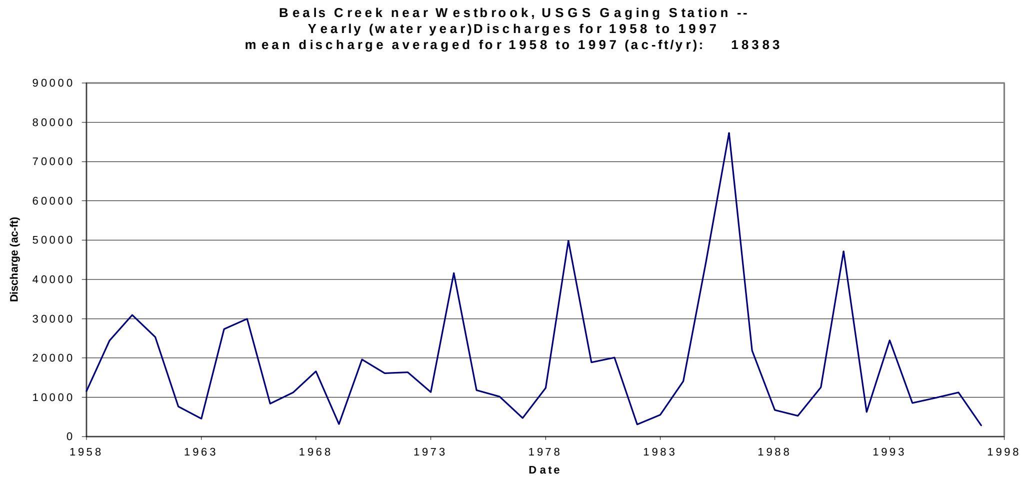
mean discharge 1961-1999 = 31786 ac-ft

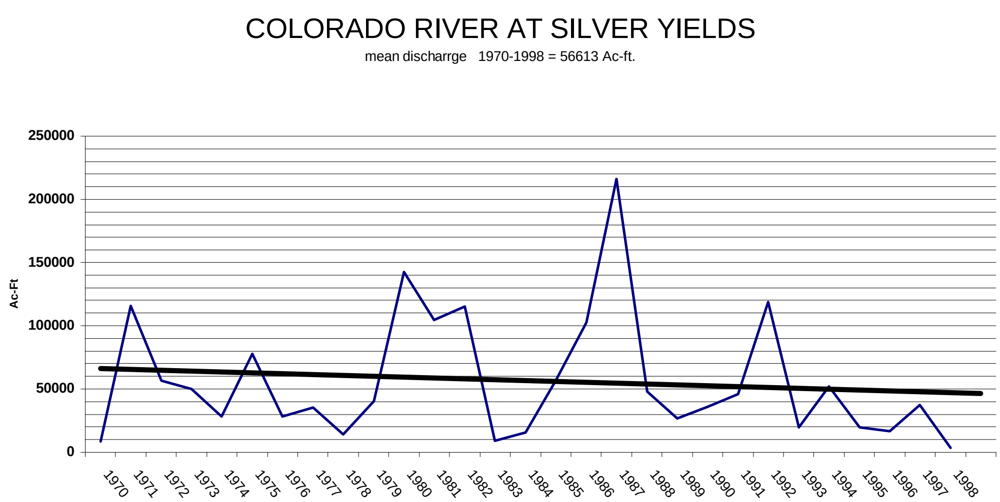


- **Colorado River and Other Streams Above E.V. Spence Reservoir**

  The following graphics display the historic stream flows experienced within the E. V. Spence watershed







5.0 Hydrologic Evaluation

The purpose of this report section is to examine and analyze the existing hydrologic record for the study watersheds and to utilize that data to predict water yields from these watersheds following a comprehensive brush control program. Some of the watersheds have long term flow records that will allow direct comparisons based on selected target periods. The target periods selected for evaluation of pre and post brush control is pre and post 1960. Almost all of the available hydrologic data for the watersheds indicate a pivot point in the data sets and dramatic hydrologic changes beginning in or about 1960. In come cases, complete hydrologic records for the comparative periods do not exist for watersheds or sub- watersheds. If identical or similar ecologic changes that have been observed regionally have occurred within a watershed, then it has been assumed that the watershed yields have diminished. Since most of these watersheds have current flow data, then the pre 1960 mean flows have been assumed by comparison to the measured multiple of change within adjacent or nearby watersheds. Peculiar situations within watershed or within data sets may require additional assumptions to accurately predict watershed yields based on the hydrologic data.

It is important to independently estimate watershed yields following brush control apart from the concurrent watershed modeling that has occurred. Modeling is a complex process that involves complicated factors related to a multitude of input variables and if not precisely conducted may result in grossly erroneous outputs. The best measure of modeling accuracy is the assumption that if watershed yields have declined through time due to ecological change, and the changes are reversed, the hydrologic system will return to the pre-change condition as related to yields.

In the discussions below, the hydrologic record of the streams and major tributaries of the three major watershed receptors are analyzed to estimate yields for pre and post brush control periods. A summary is also provided to tabulate the anticipated yields resulting from comprehensive brush control within the watersheds.

5.1 Twin Buttes Reservoir

The Middle Concho River, South Concho River, Dove Creek and Spring Creek contribute to Twin Buttes Reservoir. Mean daily flow data for the South Concho River USGS Gauging Station at Christoval were processed and plotted by pre and post 1960 time period. The Middle Concho River at Tankersley and Spring Creek near Tankersley were treated in similar fashion. Both USGS Gauging Stations moved upstream in the early 1960s. The decrease in drainage area was accounted for in calculating post-1960 discharge per drainage area. Depth of discharge for the watershed is calculated by summing the average discharges per year for the desired time duration and dividing by the area of the watershed for the time duration.

Summing the inflows for the gauging stations on the Middle and South Concho River and Spring Creek provide a reasonable estimate of water yield previously and presently available to Twin Buttes Reservoir. Percentage of contributing watershed area for each river was calculated by dividing the contributing area of the inflowing stream by the total contributing area of the lake. To calculate the projected yield for brush control; multiply the percentage of contributing watershed by the pre-1960 depth of discharge per watershed area resulting in the projected yield for the brush cleared reservoir watershed. Before 1960 the hydrologic effects of the noxious brush growth in the area was limited. The post-1960 value for depth of discharge per watershed was used to calculate present discharge available to the reservoir.

Historical records for Dove Creek prior to 1960 are not available, but similarities in topography, hydrology and land use allow application of historical South Concho flows and the multiple of change to the Dove Creek watershed.

Watershed	Comments	Total Drainage Area	Contributing Drainage Area (sq. miles)	Average Discharge over Contributing Area Ac. Ft.		Inches of Discharge over Contributing Area		Multiple of Change	Projected Reservoir Yield Ac. Ft.	
				Pre 1960	Post 1960	Pre 1960	Post 1960		Present	Brush Control
Twin Buttes Reservoir Conservation pool: 186,200 ac-ft		3,888							64,262	106,529
Middle Concho River above Tankersley	Station moved upstream on 10-1960. Estimated to cover 61% of contributing watershed.	2,653 2,084	1,685 1,116	33,610 ---	17,973 11,861	0.37 ---	--- 0.20	1.70		
Spring Creek above Tankersley	Station moved upstream on 10-1960. Estimated to cover 24% of contributing watershed.	425	671 405	28,267 ---	15,746 9,485	0.78 ---	--- 0.44	1.47		
Dove Creek at Knickerbocker	Multiple of change based on South Concho due to similarities in land use & geography. Pre-1960 values estimated for Dove Creek.	226	218	17,253	11,737	1.48	1.01			
S. Concho River at Christoval	Estimated to cover 15% of contributing watershed	471	413	27,399	18,806	1.25	0.85	1.47		

5.2 O.H. Ivie Reservoir

To examine Concho River inflows into Ivie Reservoir and discount the influence of Lake O.C. Fisher and Twin Buttes Reservoir and stream flows prior to lake construction, mean daily flows from the USGS Gauging Station below San Angelo were subtracted from the data collected at the USGS Gauging Station on the Concho River near Paint Rock.

Application of the same principle provided mean flows for the area of the Colorado River drainage below E.V. Spence Reservoir. Data from the USGS Gauging Station in Robert Lee was subtracted from data from the USGS Gauging Station at Ballinger. The USGS Gauging Station at Ballinger moved upstream during the observation period of historical records. However, the decrease in drainage area affecting post 1960 data was not determined to have a significant effect on flow and provides an adequate estimation of water volume lost to noxious brush.

The Elm Creek sub-watershed within the Colorado River watershed between Spence and Ivie Reservoirs was also analyzed. Daily mean discharge of the sub-watershed of Elm Creek at Ballinger has been recorded since 1932. The station records the discharge from the 514 square mile watershed. Because of the similarities in topography and land use between Elm Creek and other sub-watersheds, such as Oak Creek, Elm Creek is a model for discharge per drainage area.

By subtracting out the area above Spence, Fisher, and Twin Buttes Reservoirs, the contributing watershed area for Ivie is isolated. In utilizing this method, a projected yield due to brush control for the area contributing only to Ivie was calculated. The actual and contributing drainage area was calculated to be near 3,404 square miles. This matches with the case of the area between USGS Stations Colorado at Robert Lee and near Ballinger and Elm Creek. In these areas all of the drainage area is contributing. Percentage of contributing watershed area for each river was calculated by dividing the contributing area of the inflowing stream by the total contributing area of the lake. However, this method was determined not to be representative of the drainage area. A visual inspection of watershed drainage maps determined the following estimates for watershed contributing area: Colorado River 55%, Concho River 45%; Elm Creek makes up approximately 6% of the Colorado River watershed.

To calculate the projected yield for brush control, the percentage of contributing watershed is multiplied by the pre-1960 depth of discharge per watershed area resulting in the projected yield for the brush cleared reservoir watershed. Before 1960 the effects of the noxious brush growth in the area was limited. The post-1960 value for depth of discharge per watershed was used to calculate present discharge available to the reservoir. The total volume of water available to Ivie includes the water discharging from the area contributing to Ivie only plus any releases from upstream reservoirs. The following table has been prepared based on the actual stream flow conditions as reported by the USGS.

Watershed	Comments	Total Drainage Area	Contributing Drainage Area (sq. miles)	Average Discharge over Contributing Area Ac. Ft.		Inches of Discharge over Contributing Area		Multiple of Change	Projected Reservoir Yield Ac. Ft.	
				Pre-1960	Post 1960	Pre 1960	Post 1960		Present	Brush Control
O.H. Ivie Reservoir Consv. Pool at 554,300 acre feet	Excludes area above Spence, Twin Buttes and Fisher	3,404	3,404						115,422	150,479
Colorado River between Robert Lee & Ballinger	Estimated to represent 49% of Ivie Watershed area	1,051	1,051	57,469	38,010	1.03	0.68	1.51		
Elm Creek @ Ballinger	Estimated to comprise 6% of Ivie watershed area	514	514	34,947	31,786	1.28	1.16	1.09		
Oak Creek (estimated)	Estimate to be 50% the size of Elm Creek w/similar geographic & land use characteristics	256.75	256.75	17,391	15,810	1.28	1.16	1.09		
Concho River between San Angelo & Paint Rock	Estimated to represent 45% of Ivie watershed area	1,032	1,032	40,674	29,816	0.74	0.54	1.36		

5.3 E.V. Spence Reservoir

Records for USGS Gauging Stations above Spence Reservoir require more extrapolation and estimation than the data for O.H. Ivie Reservoir. USGS Gauging Stations in this area are sparser spatially and temporally. Time periods for many stations do not overlap and stations are not located in a way to allow easy analysis of contributions to the watershed. In addition, much of the total watershed is controlled through diversions or reservoirs such as J.B. Thomas, Lake Colorado City and Champion Creek Reservoir. A recent draft report prepared by Freese and Nichols, Inc. (July 2000) for the E.V. Spence TMDL Project indicated a total watershed of 15,278 square miles of which approximately 1954 square miles (1,250,560 acres) was uncontrolled by upstream diversion. A USGS stream flow station is located near Silver immediately upstream from the reservoir. Records available indicate that for the period from 1970 until 1998 the stream produced an average of 56,613 acre feet per year inflow into E.V. Spence. This average has been assumed to be typical of post-1960 watershed yields and has been calculated to be approximately 0.54 inches per year. For estimation of the pre-960 average watershed yields based on the rationale discussed previously, the multiple of change calculated for the Colorado River below E.V. Spence Reservoir has been applied to the measured data. This assumption results in a pre 1960 watershed yield of 0.82 inches of water per year or 85,486 acre feet per year.

Watershed	Comments	Total Drainage Area	Contributing Drainage Area (sq. miles)	Average Discharge over Contributing Area Ac. Ft.		Inches of Discharge over Contributing Area		Multiple of Change	Projected Reservoir Yield Ac. Ft.	
				Pre 1960	Post 1960	Pre 1960	Post 1960		Present	Brush Control
E.V. Spence Reservoir Conservation pool 488,800 ac-ft	Excludes area above Thomas	11,889	4,000						56,613	85,486
Colorado River @ Silver			1954	85,486	56,613	0.82	0.54	1.51		

5.4 Hydrologic Evaluation Summary

Utilizing the historical hydrologic records and various assumptions described within the appropriate section above, pre and post 1960 watershed yields have been calculated for the primary receptors and beneficiaries of any increased watershed yields resulting from a comprehensive brush control effort. In addition, yields from the primary contributing streams to each reservoir have been made where possible. As described previously, the pre-1960 average watershed yields either estimated or measured is assumed to approximate the historical and theoretically possible watershed yields. The decline in yields to the present is assumed to relate to the ecological changes due to increases in brush within the watersheds. The following is a summary of the evaluation results described above:

Stream or Receptor	**Post 1960 Yields Acre Feet/Year**	**Pre-1960 Yields Acre Feet/Year**	**Net Gain Acre Feet/Year**
Middle Conch River	17,973	33,610	15,637
Spring Creek	15,746	28,267	12,521
Dove Creek	11,737	17,253	5,516
S. Concho River	18,806	27,399	8,593
Twin Buttes Totals	*64,262*	*106,529*	*42,267*
Colorado River	38,010	57,467	19,457
Elm Creek	31,786	34,947	3,161
Oak Creek	15,810	17,391	1,581
Concho River	29,816	40,674	10,858
O.H. Ivie Totals	*115,422*	*150,479*	*35,057*
Colorado River (Silver)	56,613	85,486	28,873
E.V. Spence Totals	*56,613*	*85,486*	*28,873*
Total All Receptors	**236,297**	**342,494**	**106,197**

This summary has been prepared based on historical stream flow data and focused on the three primary receptors within the region. It is recognized that there are additional reservoir receptors and potential beneficiaries of increased stream flows within the study area. Estimates of benefits to these receptors will be identified in the following report sections. Also within the following report sections, the increased water yields as indicated by the watershed modeling will be discussed.

6.0 Summary & Conclusions

Previous sections of this report have explored the mechanics of the hydrologic problems caused by brush infestations, the study area has been defined as to location, hydrology, geology and history, and a hydrological evaluation prepared based on the available data. The output from the watershed modeling and economic analysis is reported in the appendix to this report. Based on a careful analysis of the information contained herein and identified above, the following conclusions have been reached:

Study Area ***:***
The study area has included the Concho and Upper Colorado River Basins encompassing approximately 8.593 million acres. Several major reservoirs exists within the area, including O.H. Ivie, Twin Buttes, E.V. Spence and J.B. Thomas. Smaller significant impoundments within the study area include Lake Colorado City, Champion Creek, Oak Creek, Winter's Lake (including Elm Creek Reservoir) and Ballinger Lake. Water from these reservoirs provide potable water for numerous municipalities including the cities of San Angelo, Odessa, Abilene, Big Spring, Snyder, Sweetwater, Colorado City, Robert Lee, Bronte, Winters and Ballinger. Other significant uses of the study area water resources have been determined and include electrical power generation, fish and wildlife propagation, agricultural uses, recreational uses and environmental mitigation. Major streams and watersheds studied included the Colorado River, Beals Creek, Main Concho River, Middle Concho River, South Concho River, Spring Creek and Dove Creek. Numerous smaller streams and tributaries were also studied. The watershed modeling effort utilized a total of 190 sub-basins within the study area.

Ecological Changes:
Dramatic and profound changes in the study area ecology have occurred within the last 100 years and have accelerated within the last 50 years. While these changes have been manifested in a multitude of ways, the most obvious change is plainly visible with the domination of brush into what has formerly been primarily a grassland prairie. The most prolific of the invader brush species are Honey Mesquite, Juniper and Salt Cedar. These brush species are also known to be the most efficient phreatophytes, (literally, "well plants") and should be the target of brush control within the study area.

Geology and Hydrogeology:
Section 4.3 of this report presents a detailed description of geology and hydrogeology for the study area. While the large area encompasses a very diverse geology, several general conclusions can be made regarding the relationship between existing geological conditions and the water resources for the study area:

- Many of the study area streams and tributaries are perennial. A significant number of streams that were historically perennial are now dry water courses except during wet winter periods.
- The source of perennial flows is from dewatering of groundwater aquifers that intersect the streambeds. This is characteristically from limestone or sandstone aquifers in the upland areas and from floodplain alluvial deposits in the lowlands.
- Characteristically, the upland aquifers and the lower alluvial aquifers are hydrologically connected and tend to function as a single hydrologic unit.
- Generally, all of the streams and tributaries within the study area can be classified as “gaining” streams in that stream flow tends to increase downstream. While this characteristic is the natural geologic condition, it has been altered in much of the area by declines in the groundwater hydraulic gradient. The declines are generally due to mesquite proliferation within the riparian zones. One exception appears to be the noted declines within the “Lipan Flat” area of eastern Tom Green and western Concho Counties which is likely due to irrigation pumping from the Lipan aquifer.

Study Area Hydrology:
One of the best “verification checks” on the SWAT watershed modeling effort is likely to be found in the historical stream flow records. As previously reported in this document, most long term stream flow data sets that are available within the region indicate a dramatic change in watershed yields beginning about 1960. Comparing pre and post 1960 stream flow data may be a good indication of the quantities of water currently being wasted by brush infestations.

The primary problem in utilizing this phenomenon as verification is the lack of good long term data sets where they are needed. In examining the available hydrologic data it was determined that hydrological evaluations could be made on the three primary watershed receptors in the study area: Twin Buttes, O.H. Ivie and E.V. Spence Reservoir. The evaluations are found in Section 4.4 of this report. The evaluations indicate a significant decrease in watershed yields when comparing pre and post 1960 records.

It has been theorized by the investigators that watershed modeling yields through brush removal should be greater than indicated yields from the historical record. This is due to the overlapping in the pre-1960 period in which brush infestations were already problematic. This would be particularly true of juniper brush that interferes directly with rainfall runoff and the effect would be manifested immediately upon the presence of the brush in the watershed. Riparian zone mesquite infestations have a greater effect upon the groundwater and its’ interaction with the surface water production through time. It is likely that the 1960 pivot point in the hydrologic record is due in large part to the regional record drought of the 1950’s and the final removal of the shallow groundwaters from the watershed hydrologic systems. Following this period (1960), the systems were unable to recover due to the now prolific mesquite brush in the lowlands. Comparison of the anticipated watershed yields following brush removal based on the SWAT model and the anticipated yields based on the historical record tends to confirm this theory, with historical yields being approximately 54% of the water yields indicated by the modeling. This comparison is shown in the table below:

Reservoir Name	Annual Water Increase (Ac.Ft) from Modeling*	Annual Water Increase (Ac.Ft.) from Record
Twin Buttes	76,702	42,267
O.H. Ivie	79,404	35,057
E.V. Spence	41,000	28,873
Totals	**197,106**	**106,197**

**This number is the sum of the total watershed sub-basin yields and represents the total increased water produced within the sub-basins as calculated by the UCRA based on implementation of priority system.*

Examination of the historical stream flow data is also useful in determining trends in the hydrologic performance of the watersheds and to assist in projecting the future hydrologic performance if brush control measures are not put into place. For example, the flow hydrograph for Spring Creek dating back to 1930 indicates a mean annual flow of near 30,000 ac. ft. per year. Currently, the mean annual flow is near 5,000 acre ft. per year. This represents a decline of 25,000 ac. ft. per year in seven decades, or a decline of approximately 3,500 Ac.Ft. annually per decade. It is apparent that the Spring Creek sub-watershed of Twin Buttes Reservoir will become virtually non-productive in two decades. The hydrograph of the Middle Concho River is very similar as are many within the Concho and Upper Colorado River basins. Report Section 4.4 also contains a graphic display of the number of 500 cfs rainfall runoff events per year occurring on the Middle Concho River from 1930 until the present time. This graphic indicates that the number of events has declined from near 3 events per year to near 0 events per year. This graphic also indicates that annual rainfall characteristics have not declined during the period. The conclusions from this data are obvious. Even when the current drought has ended and rainfall patterns return to near normal, the watersheds will not recover sufficiently to produce historical water yields. In addition, if brush control efforts do not reverse the current hydrologic trends, this region's water resources will not support the current populations water use.

Modeling Output and Economic Analysis

The watershed modeling output and the economic analysis as prepared by the Texas A&M University Extension Service and the Blackland Research Facility (USDA NRCS) in Temple, Texas, is presented in the appendix to this report. Contained within this section is a description of the model, sources of input values and a list of input variables for each watershed modeled. In addition, the sub-basins modeled within each watershed are located by map and the sub-basin data and increased water yields through brush removal included. The landowner and state costs for the brush removal is also calculated and included.

The Upper Colorado River Authority has closely examined this process during preparation of the data as well as the data contained in the final report. Based on this review, the following conclusions have been reached:

- The SWAT (Soil and Water Assessment Tool) watershed model utilized to predict increased water yields due to brush removal appears to be a valuable tool in basin scale simulations for soil and water resources management.
- As with any computer application, the accuracy of the model output is dependent upon the accuracy of the input data.
- The accuracy of the output from the models performed on the Concho and Upper Colorado River basins could have been improved through greater involvement and advice from local professionals regarding hydrologic and geologic conditions of the area.
- Based on a thorough review of the historical hydrological records available for the study area and for all adjacent River basins, it appears that the input variables utilized in the modeling may result in two inherent errors. First, the over estimation of the water yields from elimination of direct interception, primarily by Juniper. The modeled value of Juniper interception was 0.8 inches per year. Second, the modelers failed to consider the hydrologic interactions between shallow alluvial aquifers and surface flows that predominate the region. The historical record plainly indicates that the declines in watershed water production is related to the elimination of main stem and tributary losses of perennial flows. Field observations of rapid recovery of perennial flows following removal of riparian mesquite and seasonal observations of perennial flows rapidly established following loss of evapotranspiration from riparian mesquite due to first frost indicate that removal of mesquite from riparian areas will mitigate transmission losses quickly following brush removal. For this reason, in calculating and reporting water yields, the following report section will utilize only sub-basin water increases summed for each receptor to report potential receptor gains.
- The economic analysis provided in the Appendix for the Concho and Upper Colorado River basins utilized a state cost share of 70% of total costs for the upper Colorado watershed and 80% for the Main Concho and Twin Buttes watersheds. In addition, the present on-going brush control project on the North Concho River watershed (which is immediately adjacent to the study area) is utilizing a 70% state share in implementation. Through considerable landowner input and a desire to standardize the total regional program, the UCRA will provide alternative sub-basin total state costs numbers consistent with a regional 70% state cost program. These revised numbers and analysis are found in the following report section.

- The modeling output and economic analysis found in the Appendix contains all of the sub-basins modeled irregardless of sub-basin water production or costs of brush removal. Since it is apparent that funds to implement a total basin program will not be immediately available and that some sub-basins should not be considered in the program due to excessive costs and lack of water production, the UCRA has proposed (in the following report section), a priority system that will assist in implementation planning. The initial step in the priority system is the immediate elimination of sub-basins modeled that indicate a cost per acre foot of water production in excess of $250.00. This initial step is included in the revised economic analyses reported by watershed receptors found in the following report section.
- The SWAT modeling performed on the Concho and Upper Colorado River basins has indicated a substantial increase in watershed water production. A summary of these increases by study area reservoir are as follows. The values reported are in acre feet per year and represent the total water produced within the sub-basins. In addition, the state cost share per acre feet of water produced for the reservoir is shown in parenthesis :

  J.B. Thomas Reservoir– 17,739 ($147)
  Lake Colorado City – 2,703 ($133.37)
  Champion Creek Reservoir- 3,905 ($68.17)
  E.V. Spence Reservoir- 41,000 ($81.84)
  Lake Winters/Elm Creek Reservoir- 4,873 ($70.45)
  Oak Creek Reservoir- 14,002 ($55)
  Ballinger Reservoir- 9,256 ($44.11)
  O.H. Ivie Reservoir- 79,404 ($52.38)
  Twin Buttes Reservoir/ Lake Nasworthy- 76,702 ($74.14)

  Total of all increased inflow- 249,584 ($74.63)

7.0 Program Implementation Plan For the Concho & Upper Colorado River Basins

Based on conclusions discussed in the previous report section and all of the accumulated observations and data reported throughout this report, the UCRA has formulated a program implementation plan. This plan consists of the following elements:

- **State Cost Share –** The Twin Buttes and Main Concho watersheds economic analysis reported in the Appendix has calculated a 80% state cost share based on the cost of landowner benefits. The remainder of the study area and existing brush control programs within the adjacent North Concho River watershed has utilized a 70% state cost share. In order to make the most of any state cost share funds that are appropriated and to provide for a coordinated and identical brush removal program within the study area and region, the UCRA proposes to utilize the 70% state cost share through out the area. This decision has been made through considerable landowner consultation and advice. Toward implementation of this recommendation, revised sub-basin and total state cost share calculations have been made and are found in table xx.

- **Excessive Sub-basin Costs / Non Producing Areas –** Upon examination of data from the modeling and economic analysis contained in the Appendix, it is apparent that many sub-basins listed as modeled are not good candidates for brush removal due to a lack of increased water yield and/or excessive costs for brush removal. As an initial step within a priority system, the UCRA has eliminated all areas from the modeled sub-basins that report state share costs greater than $250.00 per acre feet. The sub-basins that display excessive costs to produce water are generally those that display a lack of increased water yield. The sub-basins selected for implementation are found in table xx. Table xx is a summary of total sub-basin water increases, water production rates, total acres treated, and state cost share by watershed receptors (reservoirs).

- **Implementation Priority System And Cost Analysis –** It is apparent (due to the total cost of 100% brush removal from the selected sub-basins of the study area) that the entire state cost share will not be provided for the initial program period. It is also unlikely that 100% of the brush from the selected sub-basins can be removed through landowner contracts. It is not unrealistic to expect, (based on experience in the existing North Concho brush removal program), that 50% of the area can be placed under contract. Since the total selected project cost has been calculated to be near $145 million, then a basin wide long term (ten year) program of approximately $72.5 million is reasonable. Also, because some sub-basins are much more productive than others, a 50% reduction in the total acreage selected may not result in a 50% reduction in water yield. Sound implementation planning can result in a long term program that addresses 50% of the selected watershed for brush removal while maintaining a very high percentage of the projected water yield.

Program implementation in the initial contract period also presents a problem in watershed(s) selection within the program area to solicit landowner contracts from with only 10% of the state cost share available. It is imperative that the TSSWCB utilize a selection system that is as objective as possible. The UCRA has prepared an implementation priority system that focuses on watershed receptors of additional water and utilizes a rating system based on critical water needs, cost of production and water production. Upon initial funding, the UCRA recommends that this system be utilized by the TSSWCB to target brush removal funds within the program area. It is also recommended that the Concho and Upper Colorado River basin study area continue to be considered as a program unit. The implementation priority system is shown on table xx.

- **Other Implementation Recommendations –** The TSSWCB may wish to review its' existing program rules prior to implementation of any new brush removal programs. The on-going North Concho brush removal program has created considerable staff experience in program implementation and this experience may provide opportunities for improvement. In addition, the Board may wish to consider rules that require 50% sub-basin landowner participation prior to any work accomplished within the sub-basin. Specific area targeting such as riparian zone heavy mesquite could also be explored to maximize water production and minimize costs. This could be accomplished through landowner guidance and encouragement during conservation plan preparation. It might also have to be accomplished through specific landowner contacts to encourage participation in critical areas.

Subbasin	Total State Cost (Millions)	State Cost / Ac-Ft (10yr. Disc.)	1000 gal / ac brush removal	Avg. annual A

LAKE J.B. THOMAS

UC 12	2.96	221.16	8.30	1716.86
UC 13	1.47	179.95	8.75	1076.84
UC 18	0.26	173.54	7.94	195.12
UC 34	4.80	180.63	9.95	3409.11
UC 45	2.87	127.79	13.31	2874.48
UC 47	6.54	130.46	13.65	6420.11
UC 48	1.44	90.38	19.74	2046.82
TOTALS	20.34	146.99	11.66	17739

LAKE COLORADO CITY

UC 44	2.81	133.37	12.34	2073

CHAMPION CREEK RESERVOIR

UC 60	2.08	68.17	31.53	3905

E V SPENCE RESERVOIR

UC 43	8.59	69.59	26.67	15829.53
UC 49	1.48	77.84	23.11	2429.79
UC 50	2.54	78.34	26.24	4160.36
UC 51	0.62	114.01	15.45	701.05
UC 52	0.10	100.55	21.41	124.78
UC 53	0.77	117.57	19.77	512.96
UC 54	0.91	189.33	10.37	615.57
UC 55	0.30	119.02	18.37	321.43
UC 56	1.57	191.05	10.51	1053.11
UC 57	0.57	88.53	17.87	783.46
UC 58	0.62	89.89	25.55	797.41
UC 59	0.78	201.65	11.14	498.41
UC 61	5.66	76.24	26.21	9516.53
UC 71	1.67	58.39	37.08	3654.84
TOTALS	26.18	81.84	20.70	41000

O.H. IVIE RESERVOIR

Subbasin	Total State Cost (Millions)	State Cost / Ac-Ft (10 yr. Disc.)	1000 gal / ac brush removal	Avg. annual A
UC 64	6.71	88.31	30.57	9740.66
UC 65	2.67	99.05	25.29	3454.28
UC 66	1.11	57.19	43.10	2482.69
UC 68	4.85	70.45	37.59	8820.11
UC 69	0.47	129.98	20.59	461.49
UC 70	2.54	55.13	40.87	5910.94
CR 1	0.92	43.43	48.99	2703.32
CR 2	0.90	45.88	49.10	2514.17
CR 3	0.39	69.77	32.28	720.36
CR 4	0.05	34.71	63.78	192.75
CR 5	0.41	65.38	33.84	795.36
CR 6	1.15	76.74	22.53	1920.65
CR 7	1.00	61.54	34.06	2082.75
CR 8	2.42	21.31	89.89	14537.84
CR 9	0.70	55.58	37.15	1612.39
CR 10	0.19	64.50	34.86	355.05
CR 11	0.19	73.74	33.61	319.97
CR 12	0.44	42.90	54.11	1313.53
CR 13	0.06	60.12	36.81	131.82
CR 14	0.56	37.85	61.71	1893.89
CR 15	0.24	27.86	80.91	1117.30
CR 16	0.15	27.28	81.13	707.58
CR 17	0.03	25.93	87.01	123.37
CR 18	0.20	28.90	80.98	900.94
CR 19	0.06	27.95	80.24	268.42
CR 20	0.02	25.93	80.04	95.31
CR 21	0.07	28.72	81.23	311.23
CR 22	0.25	34.51	63.59	698.97
CR 23	0.45	27.81	69.69	2080.86
CR 24	0.27	28.10	69.85	1242.78
CR 25	0.26	30.72	62.29	1090.32
CR 26	0.05	34.63	63.27	198.47
CR 27	0.30	38.08	56.72	1017.21
CR 28	0.07	30.79	70.94	277.43
CR 29	0.22	31.57	69.14	899.57
CR 30	0.14	37.51	52.87	481.31
CR 31	0.45	56.08	36.41	1085.36
CR 32	0.33	36.21	55.36	1161.22
CR 33	0.74	44.49	45.34	2119.18
CR 34	0.07	46.29	46.59	198.28
CR 35	0.02	27.85	79.54	71.71
CR 37	0.34	31.13	66.82	1388.04

TWIN BUTTES RESERVOIR

Subbasin	Total State Cost (Millions)	State Cost / Ac-Ft (10yr. Disc.)	1000 gal / ac brush removal	Avg. annual ac.ft
MC 8	0.05	228.22	8.86	28.86
MC 9	0.43	187.99	10.31	292.63
MC 12	0.87	209.56	8.30	529.97
MC 13	0.83	163.09	10.92	653.48
MC 14	0.39	157.97	11.23	318.09
MC 15	0.23	187.64	9.47	159.31
MC 16	1.84	205.05	9.23	1147.64
MC 17	1.00	128.76	13.03	990.03
MC 18	1.53	174.01	10.50	1122.74
MC 19	0.43	191.42	9.81	287.20
MC 20	0.05	208.74	9.05	30.95
MC 21	1.46	220.43	9.16	848.92
MC 22	0.96	186.73	10.99	658.69
MC 23	3.07	138.46	14.78	2841.34
MC 24	1.94	150.65	15.08	1575.72
MC 25	1.96	152.23	14.00	1720.77
MC 26	2.38	181.51	10.62	1681.90
MC 27	2.96	214.58	10.05	1765.91
SC 1	1.49	64.43	30.14	2950.29
SC 2	0.82	36.14	48.34	2900.15
SC 3	1.16	34.27	54.40	4344.69
SC 4	0.47	34.00	61.18	1753.06
SC 5	0.01	76.37	26.78	13.51
SC 6	0.53	49.37	41.19	1372.42
SC 7	0.64	50.11	39.54	1628.70
SC 8	0.23	62.40	30.60	465.50
SC 9	0.51	63.35	34.19	1033.26
SC 10	0.52	61.64	34.22	1083.81
SC 11	0.87	49.49	40.78	2250.85
SC 12	0.94	48.52	42.51	2479.52
SC 13	0.50	44.98	47.65	1410.43
SC 14	0.77	50.14	40.98	1952.91
SC 15	0.74	60.31	34.59	1572.91
SC 16	0.69	62.26	36.27	1410.37
SC 17	0.53	64.14	33.99	1059.73
SC 18	0.45	80.63	26.46	717.51
SC 20	0.76	100.09	21.16	976.30
SC 21	0.60	59.26	34.20	1290.93
SC 23	0.29	77.59	27.77	481.42
SOC 2	0.12	34.21	59.41	463.68
SOC 3	0.54	36.59	50.04	1872.35
SOC 4	0.37	41.89	43.88	1124.62
SOC 5	0.37	40.12	47.89	1172.47
SOC 6	0.06	54.97	33.72	144.98
SOC 7	0.26	36.56	49.49	896.67
SOC 8	0.23	35.83	49.54	803.92
SOC 9	0.32	52.54	37.16	770.30
SOC 10	0.40	57.30	35.02	901.88
SOC 11	1.14	35.63	51.33	4096.06
SOC 12	0.41	43.02	43.52	1206.61
SOC 13	1.27	53.19	36.57	3050.71
SOC 14	0.03	47.59	39.83	81.44
SOC 15	0.69	43.37	46.83	2078.80
SOC 16	0.84	48.47	41.65	2216.62
SOC 17	0.59	47.47	39.75	1598.95
PC 1	0.70	36.04	53.42	631.70
PC 2	0.13	46.77	46.28	346.80
PC 3	0.19	68.92	31.54	351.70
PC 4	0.16	65.77	33.35	321.60
PC 5	0.58	56.88	37.94	1309.30
PC 6	0.11	42.86	49.63	318.90
PC 7	0.23	56.91	35.32	515.70
PC 8	0.12	41.93	46.29	353.10
PC 9	0.13	94.73	22.26	174.60
PC 10	0.04	131.99	16.52	41.20
PC 11	0.05	137.93	15.33	45.60
TOTAL	45.93	74.14	31.08	76702

Upper Colorado & Concho River Watershed Receptors

Subbasin	*Total State Cost (Millions)*	*State Cost / Ac-Ft (10yr. Disc.)*	*1000 gal / ac brush removal*	*Avg. annual A*
JB THOMAS	20.34	146.99	11.66	17739
LAKE COLORADO CITY	2.81	133.37	12.34	2073
CHAMPION CREEK RES.	2.08	68.17	31.53	3905
EV SPENCE RES.	26.18	81.84	20.70	41000
LAKE WINTERS/E.C. RES	6.34	70.45	37.59	4873
OAK CREEK RES.	6.01	55.00	47.22	14002
BALLINGER LAKE	3.19	44.11	55.35	9256
OH IVIE RES.	32.45	52.38	54.29	79404
TWIN BUTTES RES.	45.93	74.14	31.08	76702
TOTAL / AVG.	145.33	74.63	33.52	249584

Scoring Category & Criteria

120 Pts. Possible

1. **Water Uses: (20 pts. possible)**
   Sole Source Municipal Supply & Power Generation – 20 pts
   Sole Source Municipal Supply – 17 pts
   Municipal Supply & Power Generation – 15 pts
   Municipal Supply Only – 10 pts
   Power Generation Only – 5 pts
   Recreational Only – 2 pts

2. **Impoundment History, Brush Impacts on Reservoir Design (20 pts possible)**
   Severe – 20 pts
   Moderate – 15 pts
   Slight – 10 pts

3. **Current Reservoir Contents: (20 pts possible)**
   Greater than 50% - 5 pts
   25-50% - 10 pts
   10-25% - 15 pts
   Less than 10% - 20 pts

4. **Reservoir Significance: (20 pts. Possible)**
   Major (+100,000 acre ft) – 20 pts
   Medium (+50,000 acre ft) – 15 pts
   Minor (-50,000 acre ft) – 10 pts

5. **Average Watershed Yield Increase (in/ac): 20 pts possible**
   More than 2.0 in – 20 pts
   1.5 – 2.0 in – 18 pts
   1.25 – 1.5 in – 16 pts
   1.0 - 1.25 in – 14 pts
   0.75 - 1.0 in – 12 pts
   0.5 – 0.75 – 10 pts
   0.25 – 0.5 in – 8 pts
   0.1– 0.25 in – 6 pts
   less than 0.1 in – 4 pts

6. **Average Watershed State Costs in $/acre ft.**
   $50 or less – 20 pts
   $51 to $75 – 17 pts
   $76 - $100 – 14 pts
   $101 - $125 – 11 pts
   $125 - $ 150 – 8 pts
   greater than $150 – 5 pts

Table 3, cont.

Brush Control Priority System Based on Watershed Receptors (reservoirs)
(Preliminary Example Scoring)

Scoring Category & Criteria 120 Pts. Possible	J. B. Thomas Reservoir	Lake Colorado City	Champion Creek Reservoir	E.V. Spence Reservoir	Oak Creek Reservoir	Winters Lake & Elm Creek Reservoir	Ballinger City Lake	O.H. Ivie Reservoir	Twin Buttes Reservoir
1. Water Uses: (20 pts. possible) Sole Source Municipal Supply & Power Generation – 20 pts Sole Source Municipal Supply – 17 pts Municipal Supply & Power Generation – 15 pts Municipal Supply Only – 10 pts Power Generation Only – 5 pts Recreational Only – 2 pts	10	15	15	10	10	17	17	10	15
2. Impoundment History, Brush Impacts on Reservoir Design performance: (20 pts possible) Severe – 20 pts Moderate – 15 pts Slight – 10 pts	10	15	15	15	15	10	15	10	20
3. Current Reservoir Contents: (20 pts possible) Greater than 50% - 5 pts 25-50% - 10 pts 10-25% - 15 pts Less than 10% - 20 pts	20	5	20	15	20	10	10	5	20
4. Reservoir Significance: (20 pts. Possible) Major (+100,000 acre ft) – 20 pts Medium (+50,000 acre ft) – 15 pts Minor (-50,000 acre ft) – 10 pts	20	10	10	20	10	10	10	20	20
5. Average Watershed Yield Increase (in/ac): 20 pts possible More than 2.0 in – 20 pts 1.5 – 2.0 in – 18 pts 1.25 – 1.5 in – 16 pts 1.0 - 1.25 in – 14 pts 0.75 - 1.0 in – 12 pts 0.5 – 0.75 – 10 pts 0.25 – 0.5 in – 8 pts 0.1– 0.25 in – 6 pts less than 0.1 in – 4 pts	6	8	14	12	18	16	20	20	14
6. Average Watershed State Costs in $/acre ft. $50 or less – 20 pts $51 to $75 – 17 pts $76 - $100 – 14 pts $101 - $125 – 11 pts $125 - $ 150 – 8 pts greater than $150 – 5 pts	5	8	17	17	17	17	20	20	14
Total Scoring Points:	**71**	**61**	**91**	**89**	**95**	**80**	**92**	**85**	**103**

Modeling Description
CHAPTER 1
BRUSH / WATER YIELD FEASIBILITY STUDIES

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

BACKGROUND

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

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

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

This report will only address the first two.

METHODS

SWAT Model Description

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

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

Geographic Information System (GIS)

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (e.g., soils, land use, and topography) for comprehensive simulation models and spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS (Srinivasan and Engel, 1991; Rewerts and Engel, 1991). An interface was developed for SWAT (Srinivasan and Arnold, 1993) using the Graphical Resources Analysis Support System (GRASS), (U.S. Army, 1988). The input interface extracts model input data from map layers and associated relational databases for each sub-basin. 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 sub-basin from a GIS map. The study was performed using GRASS

GIS integrated with the SWAT model, both of which operate in the UNIX operating system.

GIS Data

Development of databases and GIS layers was an integral part of the feasibility study. The data was assembled at the highest level of detail possible in order to accurately define the physical characteristics of each watershed.

Topography. The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of a watershed as a topographical database. The DEM available for the project area is the 1:24,000 scale map (U.S. Geological Survey, 1999). The resolution of the DEM is 30 meters, allowing detailed delineation of sub-basins 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 Fig 1.

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

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

Table 1. Sub-basin Delineation

Climate. Daily precipitation totals were obtained for National Weather Service (NWS) stations within and adjacent to the watersheds. Data from nearby stations were substituted for missing precipitation data in each station record. Daily maximum and minimum temperatures were obtained for the same NWS stations. A weather generator was used to generate missing temperature data and all solar radiation for each climate station. The average annual precipitation for each watershed for the 1960 through 1998 period is shown in Figure 2.

Soils

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

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

1. The majority of the information was a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. This database was known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) soils data. The CBMS database differs from some grid GIS databases in that the attribute of each cell was determined by the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell. This method of cell attribute labeling had the advantage of a more accurate measurement of the various soils in an area. The disadvantage was for any given cell the attribute of that cell may not reflect the soil that actually makes up the largest percentage of that cell.

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

3. The soils data base currently available for all of the counties of Texas is the State Soil Geographic (STATSGO) 1:250,000-scale soils database. 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.

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 2).

Table 2. Characteristics of Landsat-7

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

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

Portions of eighteen Landsat-7 scenes were classified using ground truth points collected by NRCS field personnel. The Landsat-7 satellite images used a spectral resolution of six channels (the thermal band (6) and panchromatic band (Pan) were not used in the classification). The imagery was taken from July 5, 1999 through December 14, 1999 in order to obtain relatively cloud-free scenes during the growing season for the project areas. These images were radiometrically and precision terrain corrected (personal communication with Gordon Wells, TNRIS).

Over 1,100 ground control points (GCP) were located and described by NRCS field personnel in November and December 1999. Rockwell precision lightweight Global positioning System (GPS) receivers were utilized to locate the latitude and longitude of the control points. A database was developed from the GCP's with information including the land cover, estimated canopy coverage, areal extent, and other pertinent information about each point. This database was converted into an ArcInfo™ point coverage.

ERDAS's Imagine™ was used for imagery classification. The Landsat-7 images were imported into Imagine (GIS software). Adjoining scenes in each watershed were histogram matched or regression corrected to the scene containing the highest number of GCP's (this was done in order to adjust for the differences in scenes because of dates, time of day, atmospheric conditions, etc.). These adjoining scenes were then mosaiced and trimmed into one image that covered an individual watershed.

The ArcInfo coverage of ground points was then employed to instruct the software to recognize differing land uses based on their spectral properties. Individual ground control points were "grown" into areas approximating the areal extent as reported by the data collector. Spectral signatures were collected by overlaying these areas over the imagery and collecting pixel values from the six imagery layers. A supervised maximum likelihood classification of the image was then performed with the spectral signatures for various land use classes. The ground data was used to perform an accuracy assessment of the resulting image. A sampling of the initial classification was further verified by NRCS field personnel.

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

Heavy Cedar, Mesquite, Oak, Mixed	Mostly pure stands of cedar (juniper), mesquite, oak and mixed brush with average canopy cover greater than 30 percent.
Moderate Cedar, Mesquite, Oak, Mixed	Mostly pure stands of cedar, mesquite, oak and mixed brush with average canopy cover 10 to 30 percent.
Light Brush	Either pure stands or mixed with average canopy cover less than 10 percent.

Open Range	Various species of native grasses or improved pasture.
Cropland	All cultivated cropland.
Water	Ponds, reservoirs and large perennial streams.
Barren	Bare Ground
Urban	Developed residential or industrial land.
Other	Other small insignificant categories

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

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

Table 3. Land Use and Percent Cover

	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 (Below Edwards)	62	17	19	< 1	1	< 1
Pedernales	25	50	7	16	1	1
Twin Buttes/Nasworthy *	57	2	31	5	3	2
Upper Colorado *	41	3	21	14	20	1
Wichita	63	4	15	9	7	2

* Percentage of watershed where brush removal was planned

Model Inputs

Required inputs for each sub-basin (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 sub-basin into a maximum of 30 virtual sub-basins or hydrologic response units (HRU). A single land use and soil were selected for each HRU. The number of HRU's within a sub-basin was determined by: (1) creating an HRU for each land use that equaled or exceeded 5 percent of the area of a sub-basin; 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 sub-basins and the variability of the land use and soils within the watershed. The soil properties for each of the selected soils were automatically extracted from the model-supported soils database.

Surface runoff was predicted using the SCS curve number equation (USDA-SCS, 1972). Higher curve numbers represent greater runoff potential. Curve numbers were selected assuming existing brush sites were fair hydrologic condition and existing open range and pasture sites with no brush were good hydrologic condition. The precipitation intercepted by canopy was based on field experimental work (Thurow and Taylor, 1995) and calibration of SWAT to measured stream flows. The soil evaporation compensation factor adjusts the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracks. A factor of 0.85 is normally used, but lower values were used in dry climates to account for moisture loss from deeper soil layers.

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

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

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

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

Model Calibration

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

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

Brush Removal Simulations

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

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

In order to simulate the "treated" or "no-brush" condition, the input files for all areas of heavy and moderate brush (except oak) were converted to native grass rangeland. Appropriate adjustments were made in growth parameters to simulate the replacement of brush with grass. We assumed the shallow aquifer re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and opportunity for re-evaporation from the shallow aquifer is higher. All other calibration parameters and inputs were held constant.

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

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

RESULTS

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

Watershed Calibration

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

Brush Treatment Simulations

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

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

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

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

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

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

SUMMARY

The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in 8 watersheds in Texas for 1960 through 1998. Landsat7 satellite imagery from 1999 was used to classify current land use and cover for all watersheds. Brush cover was separated by species (cedar, mesquite, oak, and mixed) and by density (heavy, moderate, light). After calibration of SWAT to existing stream gauge data, brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Removal of light brush was not simulated.

Simulated changes in water yield resulting from brush treatment varied by sub-basin, with all sub-basins showing increased water yield as a result of removing brush. Average annual water yield increases ranged from about 13,000 gallons per treated acre in the Canadian watershed to about 172,000 gallons per treated acre in the Medina watershed.

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

The hydrologic response of each watershed is directly dependent on receiving precipitation events that provide the opportunity for surface runoff and ground water flow.

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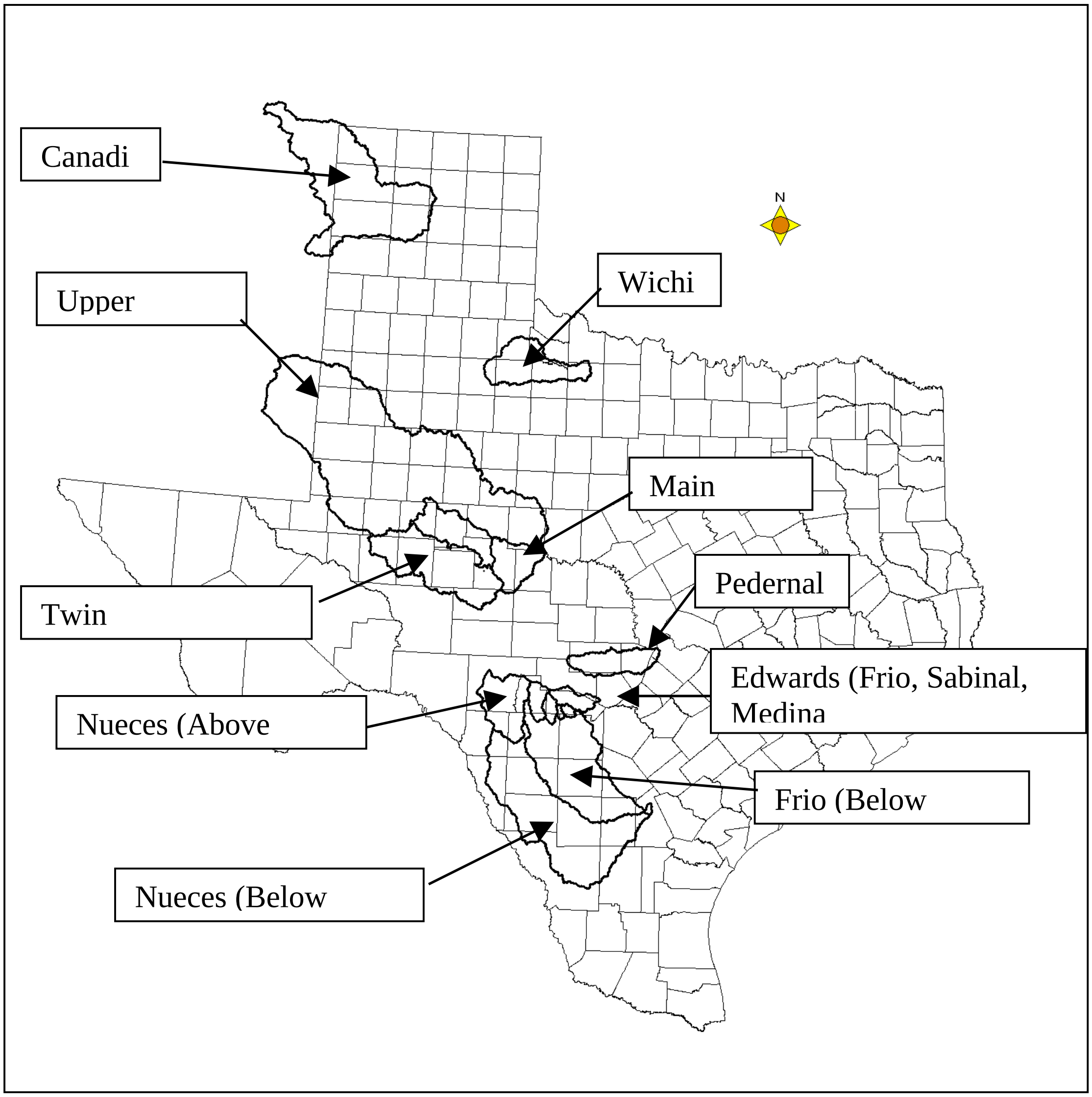

Figure 1. Watersheds included in the study area.

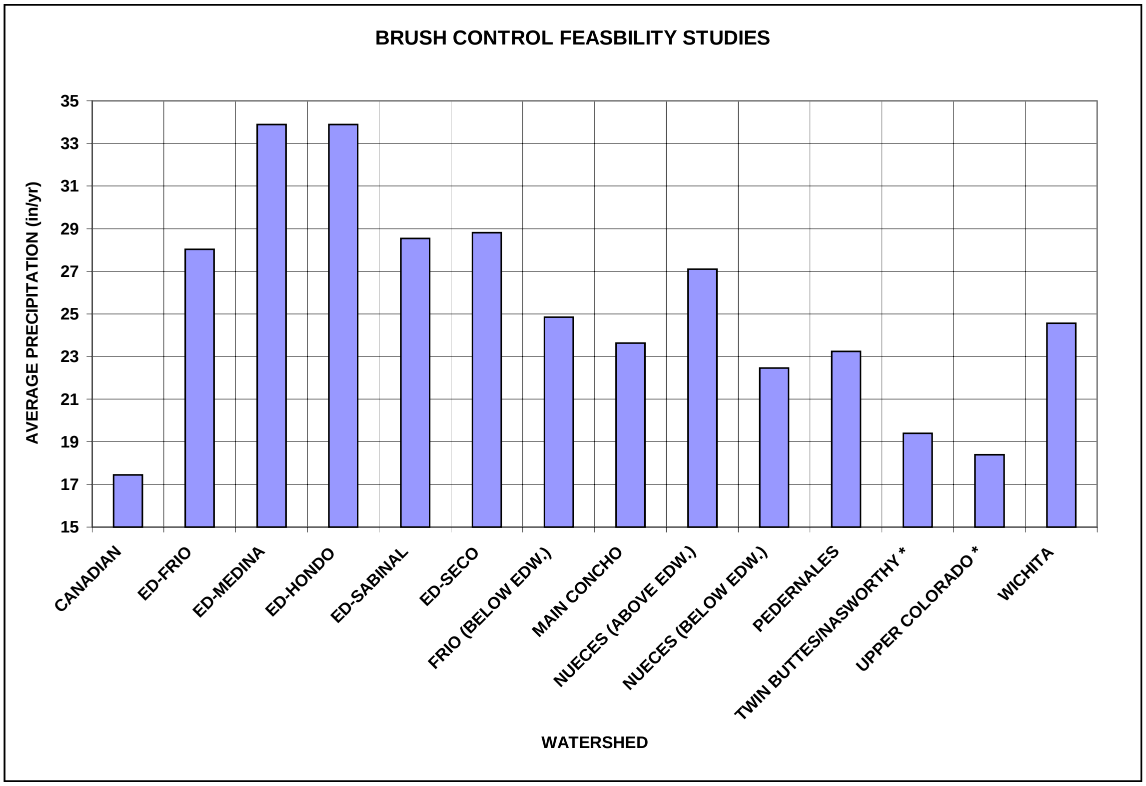

Figure 2.
Average annual precipitation.
Averages are for all climate stations in each watershed.

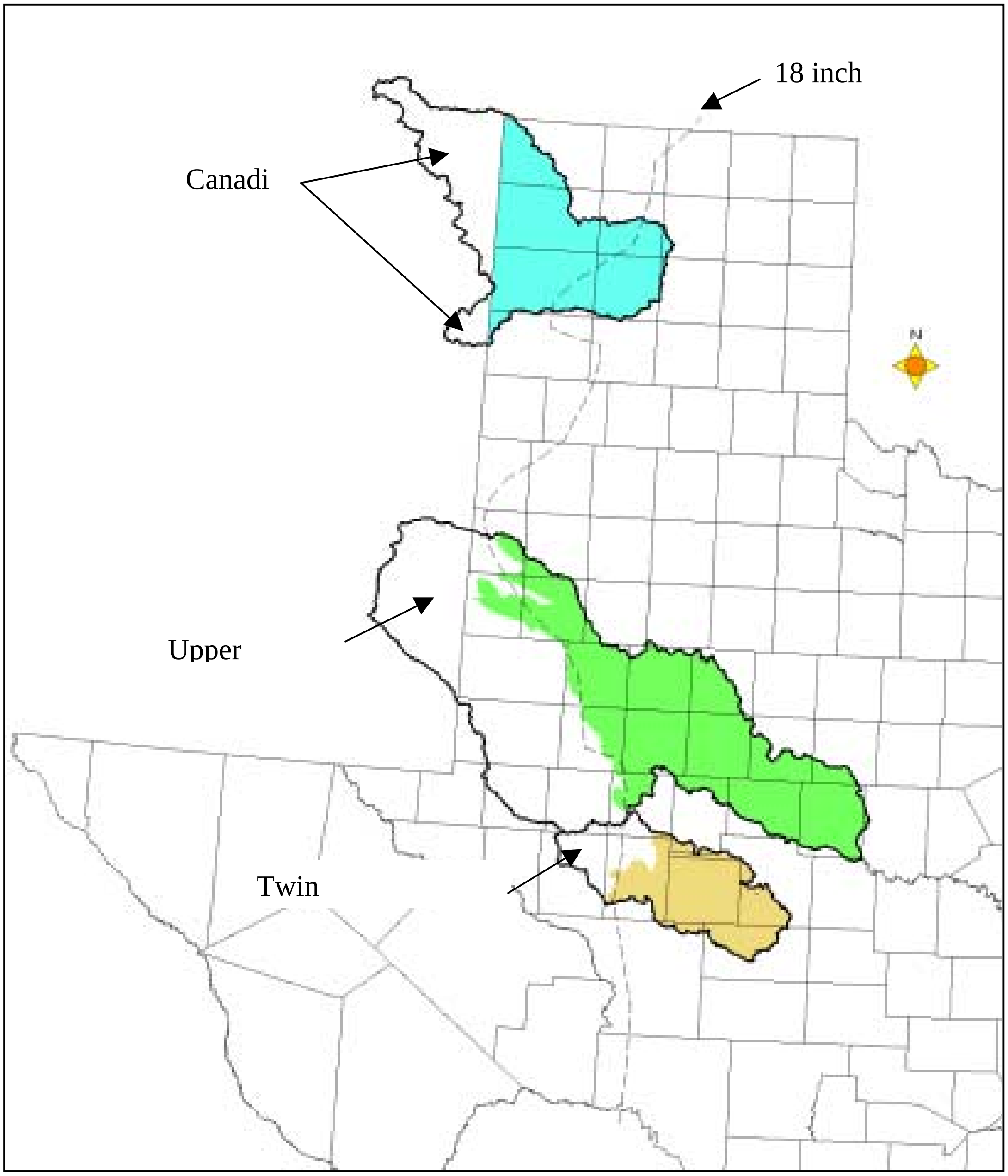

Figure 3.
Areas where brush treatment was not planned
(non-shaded portions of each watershed).

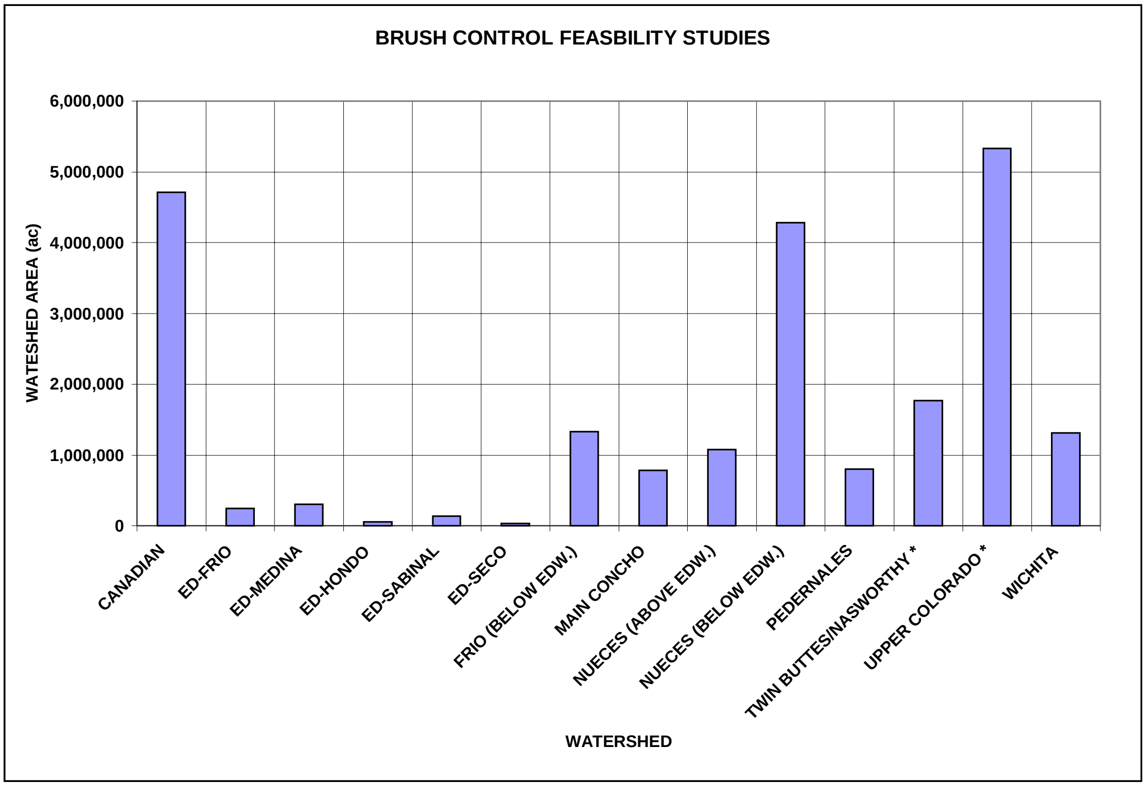

Figure 4.
Watershed area
For watersheds that lie across the 18 inch isohyet, the area shown represents only the portion of those watersheds where brush treatment was planned and simulated.

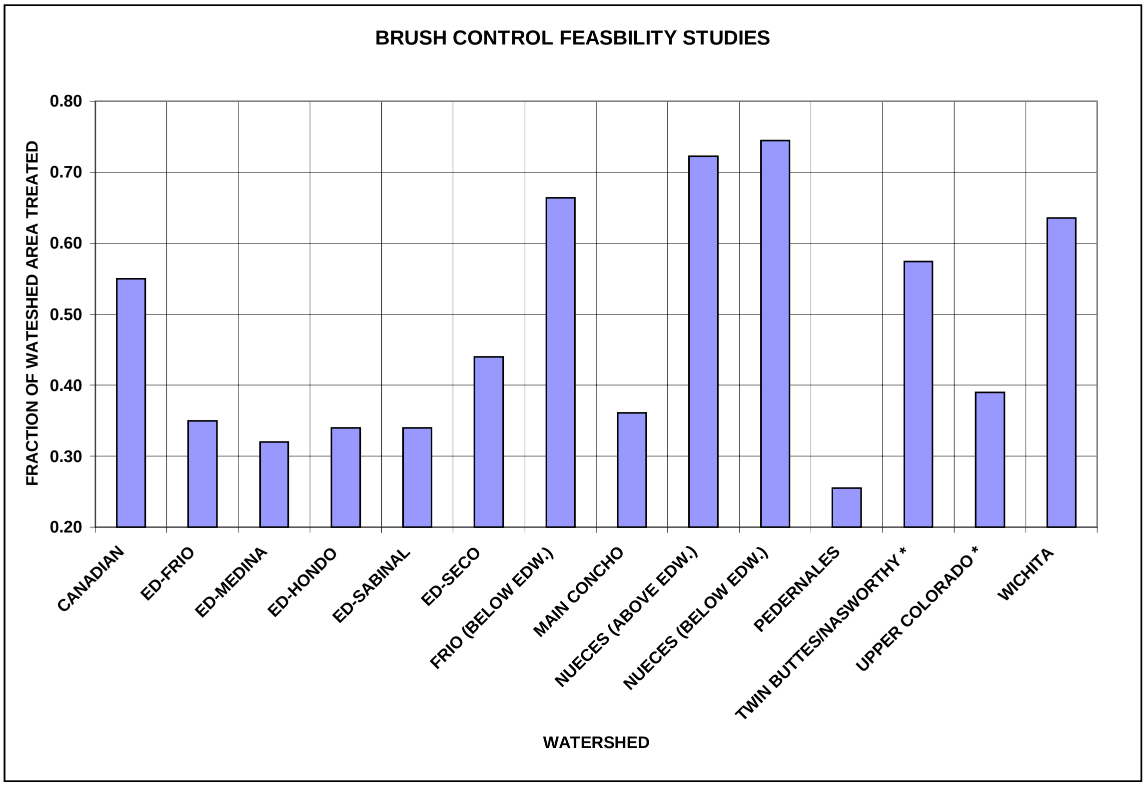

Figure 5.
Fraction of watershed containing heavy and moderate brush that was treated. For watersheds that lie across the 18 inch isohyet, this is the fraction of the portion of the watershed where brush treatment was planned and simulated.

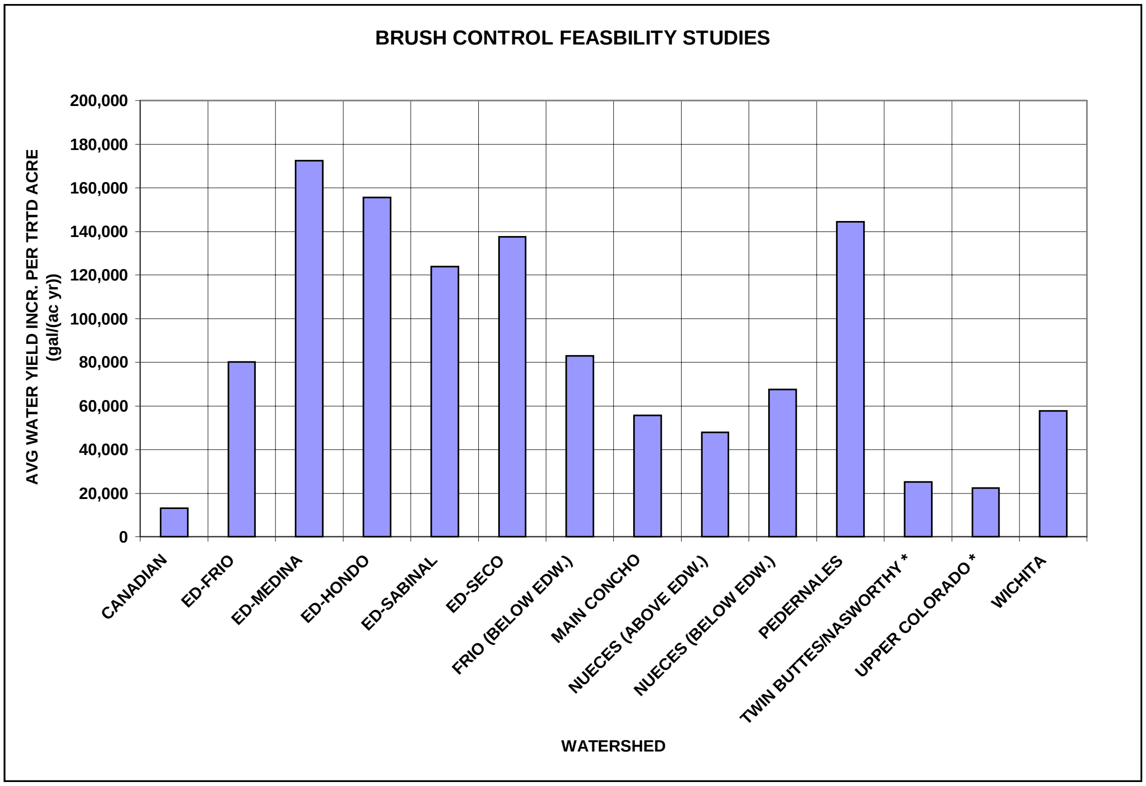

Figure 6. Average annual water yield increase, 1960 through 1998.

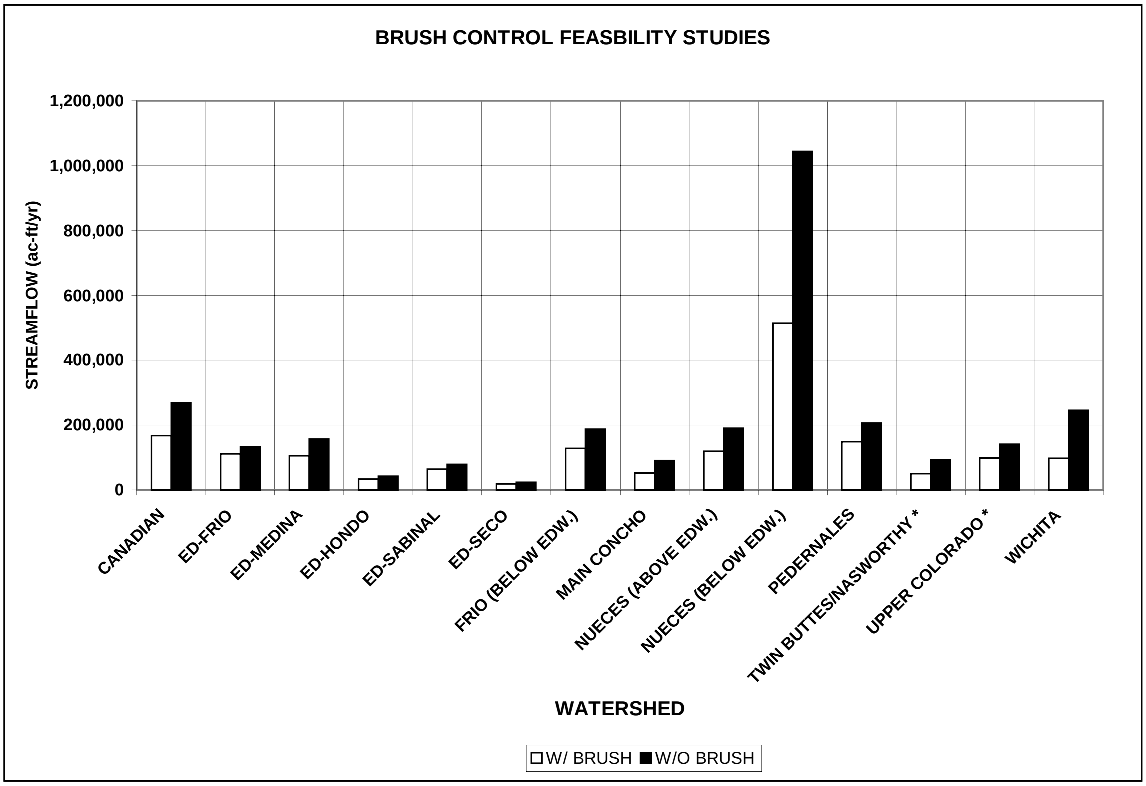

Figure 7. Average annual stream flow at watershed outlet, 1960 through 1998.

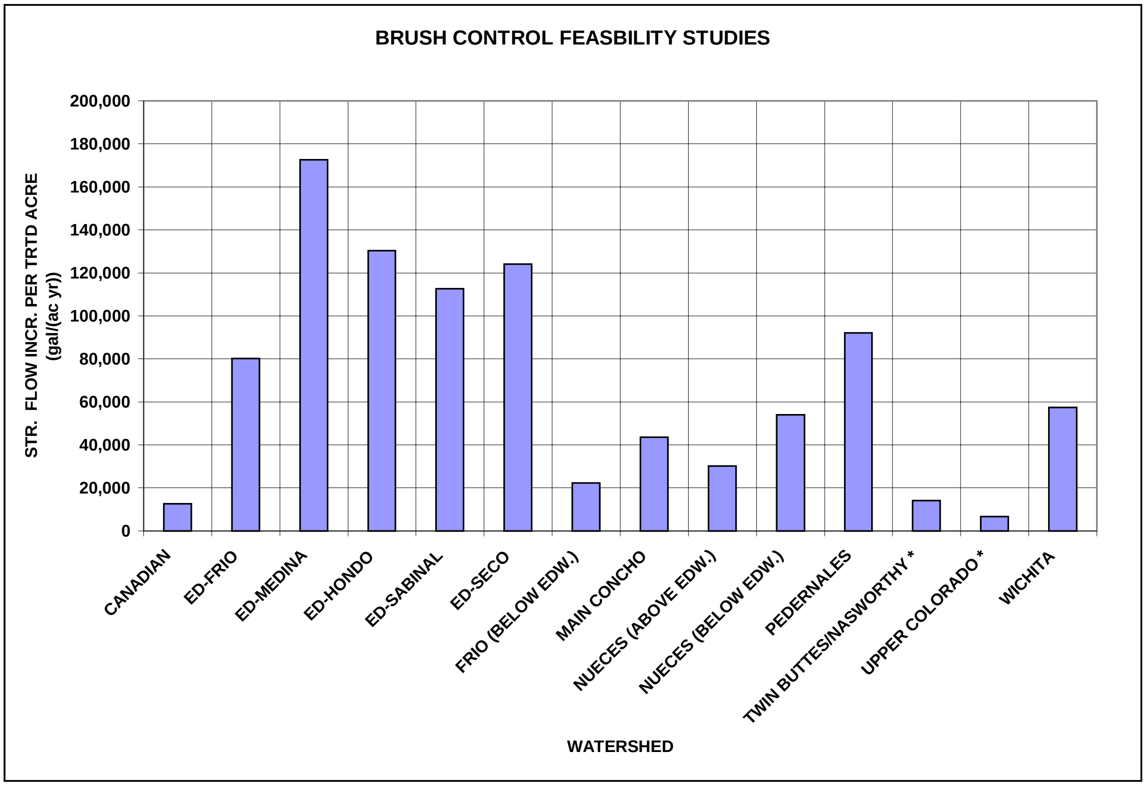

Figure 8
Average annual stream flow increase at watershed outlet, 1960 through 1998.

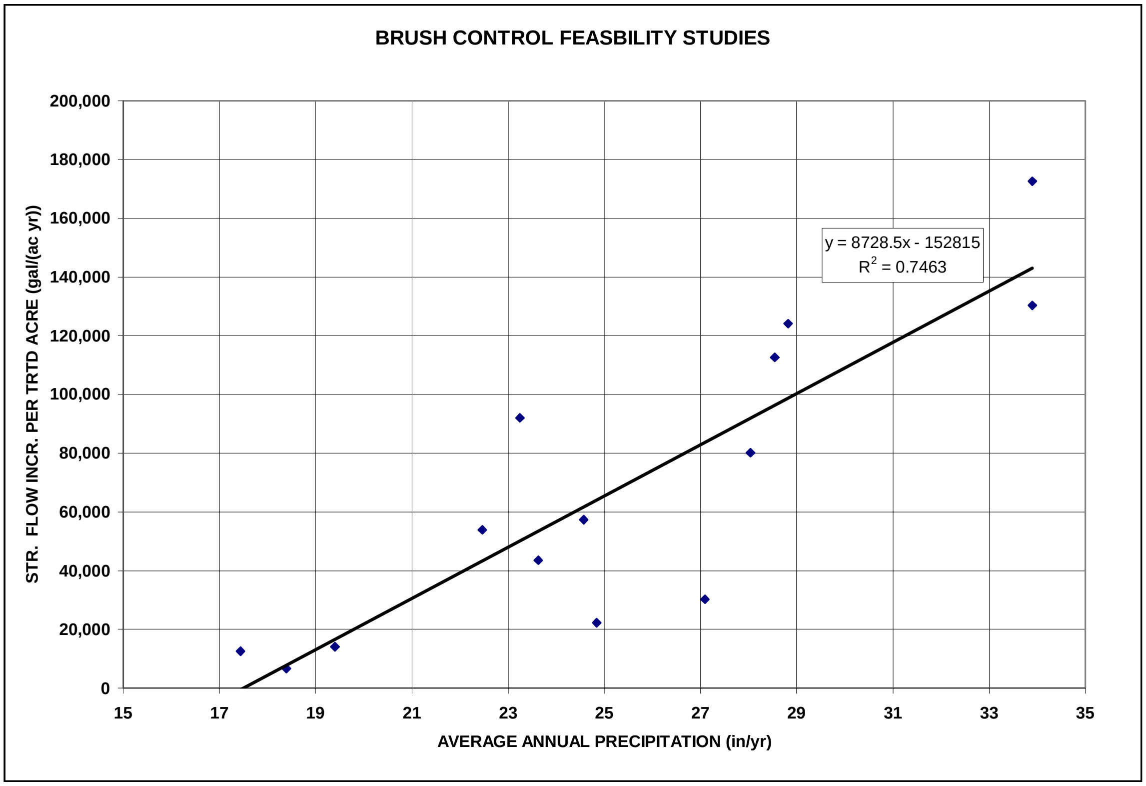

Figure 9.
Average annual stream flow increase versus average annual precipitation, 1960 through 1998. Each point represents one watershed.

CHAPTER 2
ASSESSING THE ECONOMIC FEASIBILITY OF BRUSH CONTROL TO ENHANCE OFF-SITE WATER YIELD

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Abstract: A feasibility study of brush control for off-site water yield was undertaken in 1998 on the North Concho River near San Angelo, Texas. Subsequently, studies were conducted on eight additional Texas watersheds. Economic analysis was based on estimated control costs of the different options compared to the estimated rancher benefits of brush control. Control costs included initial and follow-up treatments required to reduce brush canopy to between 8% and 3% and maintain it at the reduced level for 10 years. The state cost share was estimated by subtracting the present value of rancher benefits from the present value of the total cost of the control program. The total cost of additional water was determined by dividing the total state cost share if all eligible acreage were enrolled by the total added water estimated to result from the brush control program This procedure resulted in present values of total control costs per acre ranging from $33.75 to $159.45. Rancher benefits, based on the present value of the improved net returns to typical cattle, sheep, goat and wildlife enterprises, ranged from $52.12 per acre to $8.95. Present values of the state cost share per acre ranged from $138.85 to $21.70. The cost of added water estimated for the eight watersheds ranged from $16.41 to $204.05 per acre-foot averaged over each watershed.

INTRODUCTION

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

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

The Eight watersheds ranged from the Canadian, located in the northwestern Texas Panhandle to the Nueces which encompasses a large portion of the South

Texas Plains (Chapter 1, Figure 1). In addition to including a wide variety of soils, topography and plant communities, the 8 watersheds included average annual precipitation zones from 15 to 26 inches and growing seasons from 178 to 291days. The studies were conducted primarily between February and September of 2000.

Objectives

This Chapter reports the assumptions and methods for estimating the economic feasibility of a program to encourage rangeland owners to engage in brush control for purposes of enhancing off-site (downstream) water availability. Vegetative cover determination and categorization through use of Landsat imagery and the estimation of increased water yield from control of the different brush type-density categories using the SWAT simulation model for the watersheds are described in Chapter 1. The data created by these efforts (along with primary data gathered from landowners and federal and state agency personnel) were used as the basis for the economic analysis.

This Chapter provides details on how brush control costs and benefits were calculated for the different brush type-densities and illustrates their use in determining cost-share amounts for participating private landowners-ranchers and the State of Texas. SWAT model estimates of additional off-site water yield resulting from the brush control program are used with the cost estimates to obtain estimates of per acre-foot costs of added water gained through the program.

BRUSH CONTROL

It should be noted that public benefit in the form of additional water depends on landowner participation and proper implementation and maintenance of the appropriate brush control practices. It is also important to understand that rancher participation in a brush control program primarily depends on the rancher's expected economic consequences resulting from participation. With this in mind, the analyses described in this report are predicated on the objective of limiting rancher costs associated with participation in the program to no more than the benefits that would be expected to accrue to the rancher as a result of participation.

It is explicitly assumed that the difference between the total cost of the brush control practices and the value of the practice to the participating landowner would have to be contributed by the state in order to encourage landowner participation. Thus, the state (public) must determine whether the benefits, in the form of additional water for public use, are equal to or greater than the state’s share of the costs of the brush control program. Administrative costs (state costs) which would be incurred in implementing, administering and monitoring a brush control project or program are not included in this analysis.

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

Brush control practices include initial and follow-up treatments required to reduce the current canopies of all categories of brush types and densities to 3-8 percent and maintain it at the reduced level for at least 10 years. These practices, or brush control treatments, differed among watersheds due to differences in terrain, soils, amount and distribution of cropland in close proximity to the rangeland, etc. An example of the alternative control practices, the time (year) of application and costs for the Wichita Watershed are outlined in Table 1. Year 0 in Table 1 is the year that the initial practice is applied while years 1 - 9 refer to follow-up treatments in specific years following the initial practice.

The appropriate brush control practices, or treatments, for each brush type-density category and their estimated costs were obtained from focus groups of landowners and NRCS and Extension personnel in each watershed. In the larger watersheds two focus groups were used where it was deemed necessary because of significant climatic and/or terrestrial differences.

Control Costs
Yearly costs for the brush control treatments and the present value of those costs (assuming an 8% discount rate as opportunity cost for rancher investment capital) are also displayed in Table 1. Present values of control programs are used for comparison since some of the treatments will be required in the first year to initiate the program while others will not be needed until later years. Present values of total per acre control costs

range from $33.75 for moderate mesquite that can be initially controlled with herbicide treatments to $159.45 for heavy mesquite that cannot be controlled with herbicide but must be initially controlled with mechanical tree bulldozing or root plowing.

Landowner Benefits From Brush Control
As was mentioned earlier, one objective of the analysis is to equate rancher benefits with rancher costs. Therefore, the task of discovering the rancher cost (and thus, the rancher cost share) for brush control was reduced to estimating the 10 year stream of region-specific benefits that would be expected to accrue to any rancher participating in the program. These benefits are based on the present value of increased net returns made available to the ranching operation through increases or expansions of the typical livestock (cattle, sheep, or goats)

and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program.

Rancher benefits were calculated for changes in existing wildlife operations. Most of these operations were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. For control of heavy mesquite, mixed brush and cedar, wildlife revenues are expected to increase from $0.50 to $1.50 per acre due principally to the resulting improvement in quail habitat and hunter access to quail. Increased wildlife revenues were included only for the heavy brush categories because no changes in wildlife revenues were expected with control for the moderate brush type-density categories.

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

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

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

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

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

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

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

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

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

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

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

For the livestock enterprises, increased net returns would result from increased amounts of usable forage (grazing capacity) produced by removal of the brush and thus eliminating much of the competition for light, water and nutrients within the plant communities on which the enterprise is based. For the wildlife enterprises, improvements in net returns are based on an increased ability to access wildlife for use by paying sportsmen.

As with the brush control methods and costs, estimates of vegetation (forage production/grazing capacity) responses used in the studies were obtained from landowner focus groups, Experiment Station and Extension Service scientists and USDA-NRCS Range Specialists with brush control experience in the respective watersheds. Because of differences in soils and climate, livestock grazing capacities differ by location; in some cases significant differences were noted between sub-basins of a watershed. Grazing capacity estimates were collected for both pre- and post-control states of the brush type-density categories. The carrying capacities range from 70 acres per animal unit year (Ac/AUY) for land infested with heavy cedar to about 15 Ac/AUY for land on which mesquite is controlled to levels of brush less than 8% canopy cover (Table 2.).

Livestock production practices, revenues, and costs representative of the watersheds, or portions thereof, were also obtained from focus groups of local landowners. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into production-based investment analysis budgets.

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

	Brush Type-density Category & Brush Control State											
	Heavy Cedar		Heavy Mesquite		Heavy Mixed Brush		Moderate Cedar		Moderate Mesquite		Moderate Mixed Brush	
Watershed	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
Canadian	-	-	30	20	37	23	-	-	25	20	30	23
Edwards Aquifer	60	30	35	20	45	25	45	30	25	20	35	25
Frio – North	50	30	36	24	36	24	40	30	32	24	32	24
Frio – South	-	-	38	23	35	23	-	-	30	23	30	23
Mid Concho	70	35	38	25	50	30	52	35	32	25	40	30
Nueces – North	50	30	39	27	39	27	40	30	35	27	35	27
Nueces – South	-	-	41	26	38	26	-	-	33	26	33	26
Pedernales	45	28	28	15	40	22	38	28	24	15	34	22
Upper Colorado – East	56	24	32	18	48	21	44	24	28	18	36	21
Upper Colorado – West	70	35	38	25	50	30	52	30	32	25	40	30
Wichita	50	25	32.5	20	38.5	20	40	25	25	20	32.5	20

For ranchers to benefit from the improved forage production resulting from brush control, livestock numbers must be changed as grazing capacity changes. In this study, it was assumed that ranchers would adjust livestock numbers to match grazing capacity changes on an annual basis. Annual benefits that result from brush control were measured as the net differences in annual revenue (added annual revenues minus added annualized costs) that would be expected with brush control as compared to without brush control. It is notable that many ranches preferred to maintain current levels of livestock, therefore realizing benefit in the form of reduced feeding and production risk. No change in perception of value was noted for either type of projected benefit.

The analysis of rancher benefits was done assuming a hypothetical 1,000 acre management unit for facilitating calculations. The investment analysis budget information, carrying capacity information, and brush control methods and costs comprised the data sets that were entered into the investment analysis model ECON (Conner). The ECON model yields net present values for rancher benefits accruing to the management unit over the 10 year life of the projects being considered in the feasibility studies. An example of this process is shown in Table 3 for the control of moderate cedar in the Upper Colorado – West watershed.

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

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

Since a 1,000 acre management unit was used, benefits needed to be converted to a per acre basis. To get per acre benefits, the accumulated net present value of $11,895 shown in Table 3 must be divided by 1,000, which results in $11.90 as the estimated present value of the per acre net benefit to a rancher. The resulting net benefit estimates for all of the type-density categories for all watersheds are shown in Table 4. Present values of landowner benefits differ by location within and across watersheds. They range from a low of $8.95 per acre for control of moderate mesquite in the Canadian Watershed to $52.12 per acre for control of heavy mesquite in the Edwards Aquifer Watershed.

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

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

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

State Cost Share

If ranchers are not to benefit from the state's portion of the control cost, they must invest in the implementation of the brush control program an amount equal to their total net benefits. The total benefits that are expected to accrue to the rancher from implementation of a brush control program are equal to the maximum amount that a profit maximizing rancher could be expected to spend on a brush control program (for a specific brush density category).

Using this logic, the state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher participation. Present values of the state cost share per acre of brush controlled are also shown in Table 4. The State's cost share ranges from a low of $21.70 for control of moderate mesquite in the Wichita Watershed to $138.85 for control of heavy cedar in the Edwards Aquifer Watershed.

The costs to the state include only the cost for the state's cost share for brush control. Costs that are not accounted for, but which must be incurred, include costs for administering the program. Under current law, this task will be the responsibility of the Texas State Soil and Water Conservation Board.

COSTS OF ADDED WATER

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program. The brush control program water yields and the estimated acreage by brush type-density category by sub-basin were supplied by the Blackland Research Center, Texas Agricultural Experiment Station in Temple, Texas (see Chapter 1). The total state cost share for each sub-basin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the sub-basin. The cost of added water resulting from the control of the eligible brush in each sub-basin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the 10-year period using a 6% discount rate). Table 5 provides a detailed example for the Wichita Watershed. The cost of added water from brush control for the Wichita is estimated to average $36.59 per acre-foot for the entire watershed. Sub-basin cost per added acre-foot within the Wichita range from $17.56 to $91.76.

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

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

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

ADDITIONAL CONSIDERATIONS

Total state costs and total possible added water discussed above are based on the assumption that 100% of the eligible acres in each type-density category would enroll in the program. There are several reasons why this will not likely occur. Foremost, there are wildlife considerations. Most wildlife managers recommend maintaining more than 10% brush canopy cover for wildlife habitat, especially white tailed deer. Since deer hunting is an important enterprise on almost all ranches in these eight watersheds it is expected that ranchers will want to leave varying, but significant amounts of brush in strategic locations to provide escape cover and travel lanes for wildlife. The program has consistently encouraged landowners to work with technical specialists from the NRCS and Texas Parks and Wildlife Department to determine how the program can be used with brush sculpting methods to create a balance of benefits.

Another reason that less than 100% of the brush will be enrolled is that many of the tracts where a particular type-density category are located will be so small that it will be infeasible to enroll them in the control program. An additional consideration is found in research work by Thurow, et. al. (2001) that indicated that only about 66% of ranchers surveyed were willing to enroll their land in a similarly characterized program. Also, some landowners will not be financially able to incur the costs expected of them in the beginning of the program due to current debt load.

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

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CHAPTER 9

MAIN CONCHO RIVER WATERSHED – HYDROLOGIC SIMULATION

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WATERSHED DATA

Topography

The outlet or "catchment" for the Main Concho River simulated in this study is the O. H. Ivie Reservoir, which is located in sub-basin number 37. The sub-basin delineation, numbers, and roads (obtained from the Census Bureau) are shown in Figure CO-1.

Weather Stations

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

Soils

The dominant soil series in the Main Concho River watershed are Angelo, Tarrant, Cho, Talpa, Mereta, and Kimbrough. These six soil series represent about 83 percent of the watershed area. A short description of each follows:

> Angelo: The Angelo series consists of deep or very deep, well drained, moderately slowly permeable soils formed in calcareous loamy and clayey alluvium. The deep phase is underlain by limestone. These nearly level to gently sloping upland soils have slopes ranging from 0 to 3 percent.
> Tarrant: The Tarrant series consists of very shallow and shallow, well drained, moderately slowly permeable soils on uplands. They formed in residuum from limestone, and includes interbedded marls, chalks, and marly materials.
> Cho: The Cho series consists of very shallow and shallow to a petrocalcic horizon, well drained, moderately permeable soils that formed in loamy calcareous gravelly alluvium. These soils are on nearly level to moderately sloping stream terraces and alluvial fans. Slopes are from 0 to 8 percent.
> Talpa: The Talpa series consists of very shallow and shallow, well drained, moderately permeable soils that formed in dolomitic limestone of Permian age. These soils are on gently sloping to steep uplands of the Central Rolling Red Plains (MLRA-78B,78C) and Rolling Limestone Prairies (MLRA-78D). Slopes are from 1 to 30 percent.
> Mereta: The Mereta series consists of soils that are shallow to a petrocalcic horizon. They are well drained, moderately slowly permeable soils that formed in loamy, calcareous, alluvium and colluvium. These nearly level to gently sloping soils are on stream terraces and alluvial fans. Slopes range from 0 to 5 percent.

Kimbrough. The Kimbrough series consists of soils that are very shallow to shallow to a petrocalcic horizon. They are well drained, calcareous, gravelly soils that formed in moderately fine textured eolian sediments of the Blackwater Draw Formation of Pleistocene age. These soils are typically on gently sloping plains, narrow ridges, and side slopes along draws. Slope ranges from 0 to 3 percent.

Land Use/Land Cover

Figure CO-3 shows the areas of heavy and moderate brush (oak not included) in the Main Concho River Watershed. This is the area of brush removed or treated in the no-brush simulation.

Ponds and Reservoirs

Surface area, storage, and drainage area were obtained from the Texas Natural Resource Conservation Commission (TNRCC) for existing inventory-sized ponds and reservoirs in the watershed (Figure CO-4), and input to the SWAT model. The stream network and O. H. Ivie Reservoir are also shown in this figure.

Model Input Variables

Significant input variables for the SWAT model for the Main Concho River Watershed are shown in Table CO-1. Input variables were adjusted as needed by sub-basin in order to calibrate flow at the USGS stream gauge. The calibration simulation represents the current "with brush" condition.

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

RESULTS

Calibration

SWAT was calibrated for flow at stream gauge 08136500 (Main Concho River at Paint Rock) (Figure CO-2). Measured flow was input to SWAT for the area above gauge 08136000 (Main Concho River at San Angelo). The results of calibration are shown for the gauge on Figure CO-5. Measured and predicted total monthly flows compare reasonably well with a R^2 value of 0.67 for this gauge. The measured monthly mean is 3,923 acre-feet, and the predicted monthly mean is 3,688 acre-feet.

The predicted total flow was less than measured. This deviation is probably attributed to not accurately predicting base flow in the channel, as well as spatial variability in the precipitation data.

Brush Removal Simulation

The average annual rainfall for the Main Concho River Watershed varies from 22.2 inches in the western portion of the watershed to 25.5 inches in the eastern portion. The composite average for the entire watershed is 23.6 inches. Average annual evapotranspiration (ET) is 22.04 inches for the brush condition (calibration) and 20.89 inches for the no-brush condition. This represents 93% and 89% of precipitation for the brush and no-brush conditions, respectively.

Figure CO-6 shows the cumulative monthly total flow to O. H. Ivie Reservoir for the brush and no-brush conditions from 1960 through 1998. The increase in water yield by sub-basin for the Main Concho River Watershed is shown in Figure CO-7. The amount of annual increase varies among the sub-basins and ranges from 22,527 gallons per acre of brush removed per year in sub-basin number 6, to 89,889 gallons per acre in sub-basin number 8. 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. Table CO-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 entire simulated watershed, the average annual water yield at the sub-basin level increased by 81 % or approximately 48,523 acre-feet. The average annual flow to O. H. Ivie Reservoir increased by 37,636 acre-feet. The increase in volume of flow to O. H. Ivie Reservoir is less because of stream channel transmission losses that occur after water leaves each sub-basin.

TABLE CO-1

SWAT INPUT VARIABLES FOR MAIN CONCHO RIVER WATERSHED		
VARIABLE	**BRUSH CONDITION (CALIBRATION)**	**NO BRUSH CONDITION**
Runoff Curve Number Adjustment	-6	-6
Soil Available Water Capacity Adjustment (inches H^2O/in. soil)	N/A	N/A
Soil Evaporation Compensation Factor	0.10	0.10
Min. Shallow Aqu. Storage for GW flow (inches)	0.00	0.00
Ground Water Delay (days)	35	35
Shallow Aqu. Re-Evaporation (Revap) Coefficient	0.40	0.10
Min. Shallow Aqu. Storage for Revap (inches)	0.00	0.00
Potential Heat Units (^oC)		
Heavy Juniper	4150	N/A
Heavy Mesquite	3610	N/A
Heavy Mixed Brush	3860	N/A
Moderate Juniper	3610	N/A
Moderate Mesquite	3195	N/A
Moderate Mixed Brush	3405	N/A
Heavy Oak	3610	3611
Moderate Oak	3195	3195
Light Brush & Open Range/Pasture	2820	2820
Precipitation Interception (Inches)		
Heavy Juniper	0.79	N/A
Heavy Mesquite	0.00	N/A
Heavy Mixed Brush	0.59	N/A
Moderate Juniper	0.59	N/A
Moderate Mesquite	0.00	N/A
Moderate Mixed Brush	0.39	N/A
Heavy Oak	0.00	0.00
Moderate Oak	0.00	0.00
Light Brush & Open Range/Pasture	0.00	0.00
Plant Rooting Depth (feet)		
Heavy and Moderate Brush	6.5	N/A
Light Brush & Open Range/Pasture	3.3	3.3
Maximum Leaf Area Index		
Heavy Juniper	6	N/A
Heavy Mesquite	4	N/A
Heavy Mixed Brush	4	N/A
Moderate Juniper	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)	0.04	0.04
Subbasin Transmission Loss (inches/hour)	0.015	0.015
Fraction Trans. Loss Returned as Base Flow	0.00	0.00

TABLE CO-2

SUBBASIN DATA - MAIN CONCHO RIVER WATERSHED					
Subbasin	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
1	37,007	17,982	0.49	48,988	880,878,840
2	28,687	16,685	0.58	49,101	819,245,753
3	14,122	7,271	0.51	32,281	234,728,938
4	11,152	985	0.09	63,780	62,807,736
5	35,343	7,658	0.22	33,842	259,168,043
6	77,049	27,782	0.36	22,527	625,846,410
7	36,508	19,446	0.53	34,062	662,374,898
8	106,389	52,700	0.50	89,889	4,737,169,485
9	35,153	14,142	0.40	37,152	525,399,570
10	24,824	3,319	0.13	34,858	115,694,472
11	10,415	3,102	0.30	33,613	104,262,699
12	30,090	7,911	0.26	54,106	428,015,948
13	11,164	1,167	0.10	36,814	42,953,426
14	39,933	10,000	0.25	61,711	617,126,183
15	14,001	4,500	0.32	80,907	364,074,534
16	18,274	2,842	0.16	81,130	230,565,739
17	7,243	462	0.06	87,007	40,201,148
18	23,912	3,625	0.15	80,975	293,572,191
19	2,216	1,090	0.49	80,239	87,464,376
20	1,053	388	0.37	80,044	31,057,341
21	5,864	1,248	0.21	81,234	101,415,917
22	14,752	3,582	0.24	63,588	227,760,179
23	23,072	9,730	0.42	69,689	678,042,343
24	14,172	5,797	0.41	69,855	404,960,135
25	15,719	5,703	0.36	62,293	355,282,605
26	2,836	1,022	0.36	63,270	64,670,788
27	11,405	5,843	0.51	56,724	331,458,858
28	5,190	1,274	0.25	70,936	90,401,488
29	22,360	4,193	0.19	69,138	289,867,262
30	7,122	2,967	0.42	52,865	156,836,363
31	21,661	9,267	0.43	36,407	337,372,326
32	18,813	6,835	0.36	55,358	378,385,001
33	35,479	15,231	0.43	45,337	690,537,575
34	4,384	1,387	0.32	46,593	64,610,709
35	1,357	294	0.22	79,545	23,365,274
36	121	18	0.15	77,984	1,435,896
37	18,011	6,769	0.38	66,822	452,294,623
	786,854 Watershed Total	**284,217 Watershed Total**	**0.36 Watershed Average**	**55,631 Watershed Average**	**15,811,305,073 (48,523 Ac-Ft/yr.) Watershed Total**

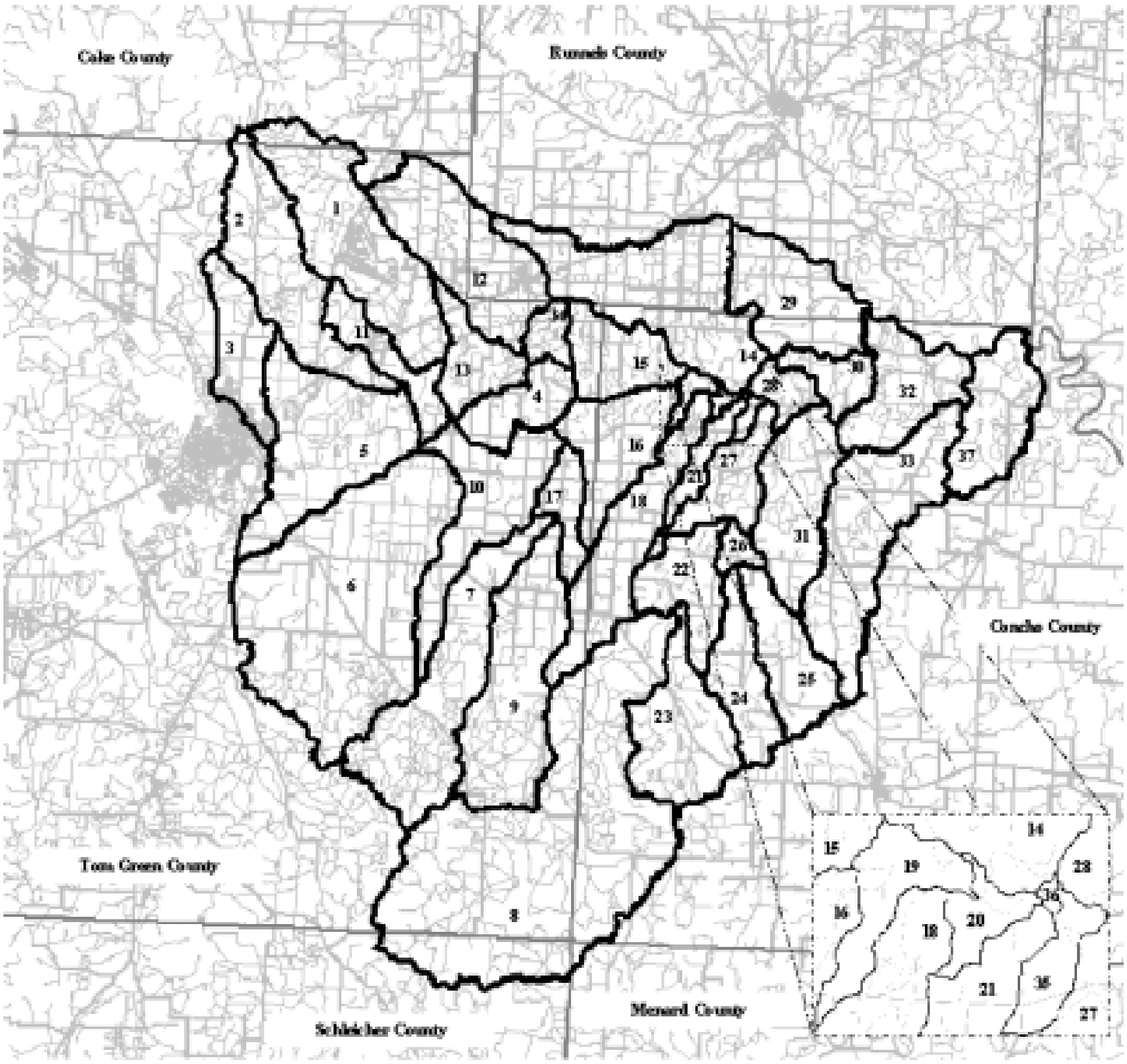

Figure CO-1: Main Concho River Watershed Sub-Basin Map.

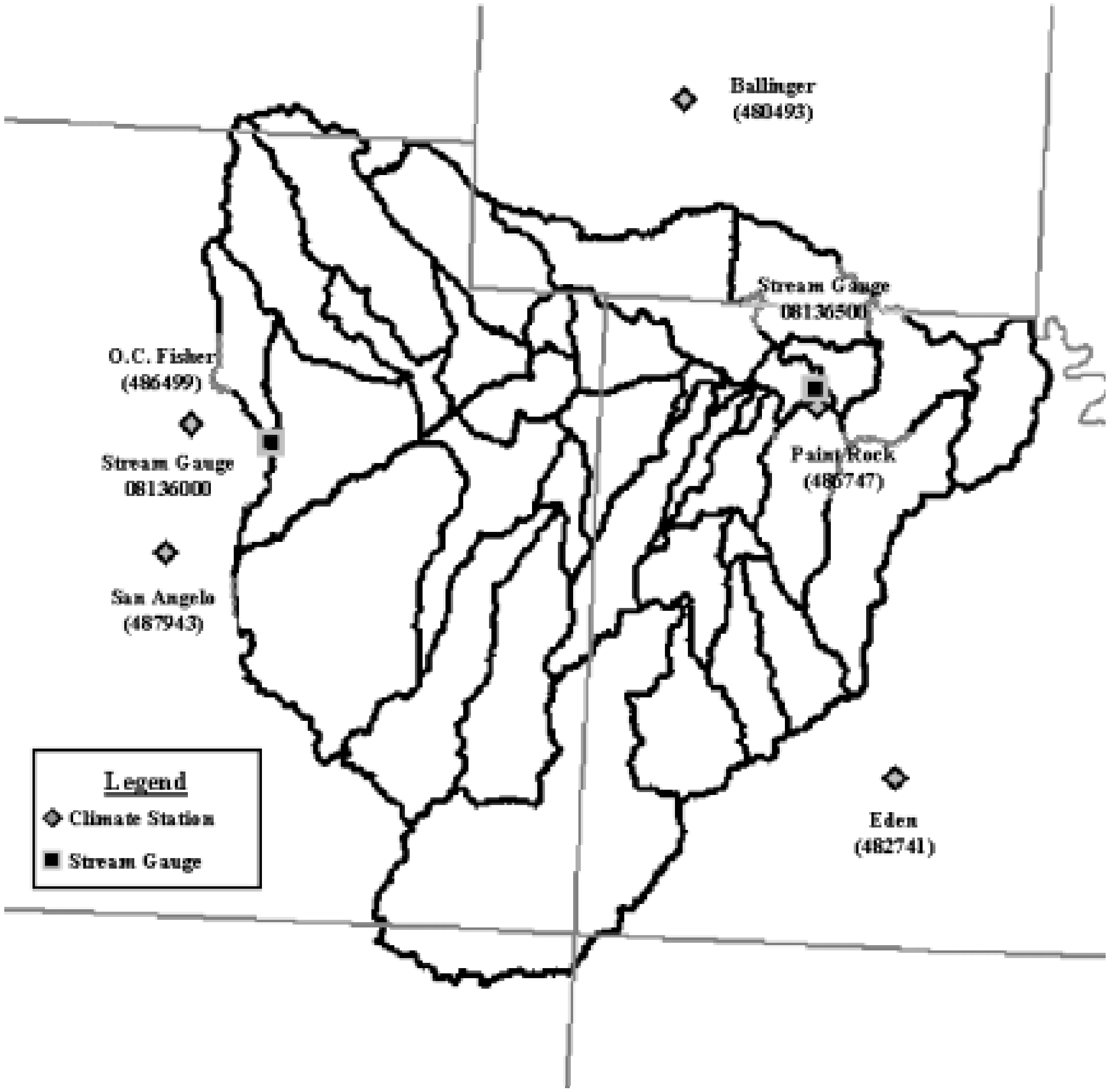

Figure CO-2
Climate and Stream Gauge stations in the Main Concho River Watershed.

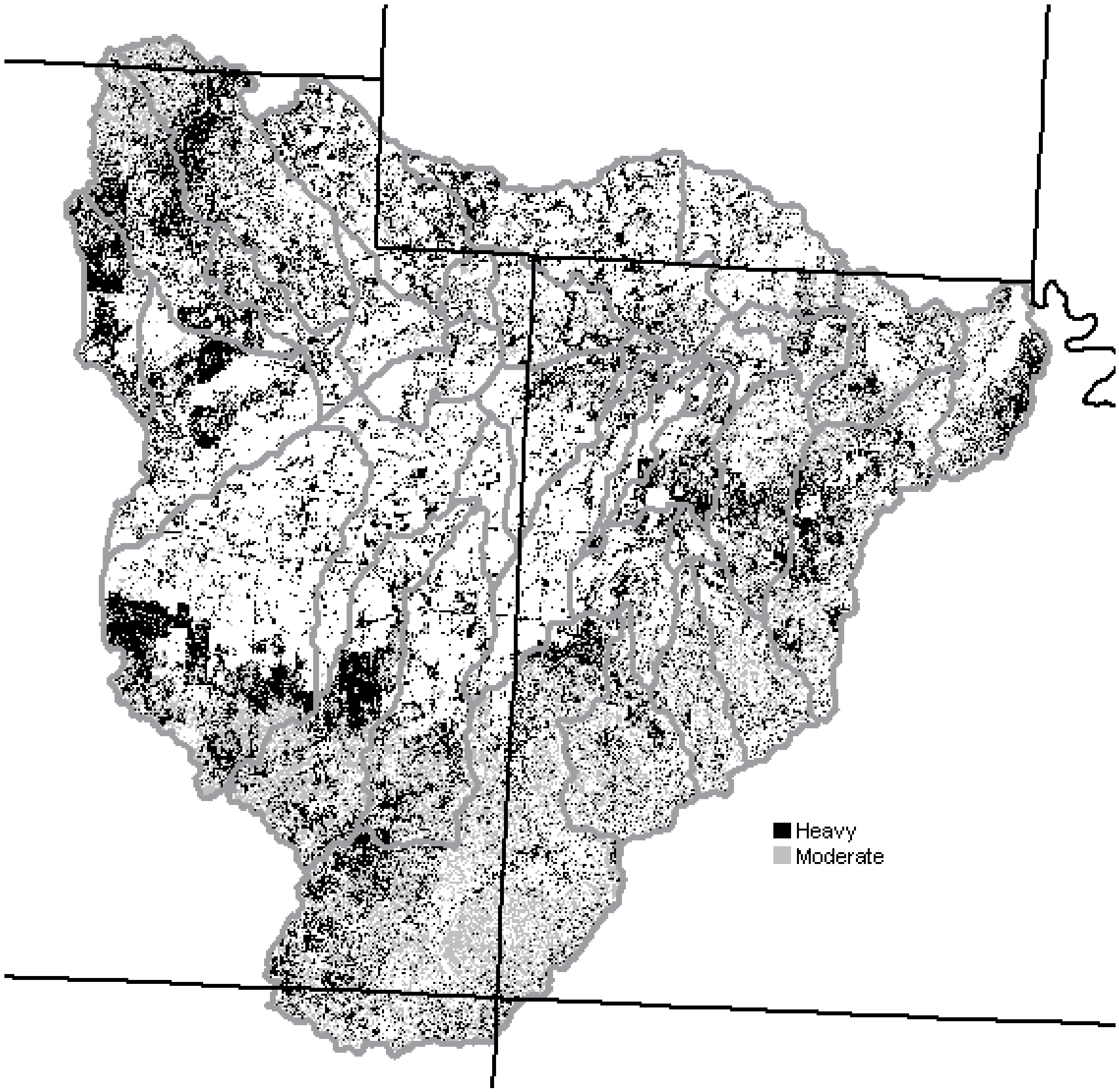

Figure CO-3.
Areas of heavy and moderate brush (oak not included) in the Main Concho River Watershed.

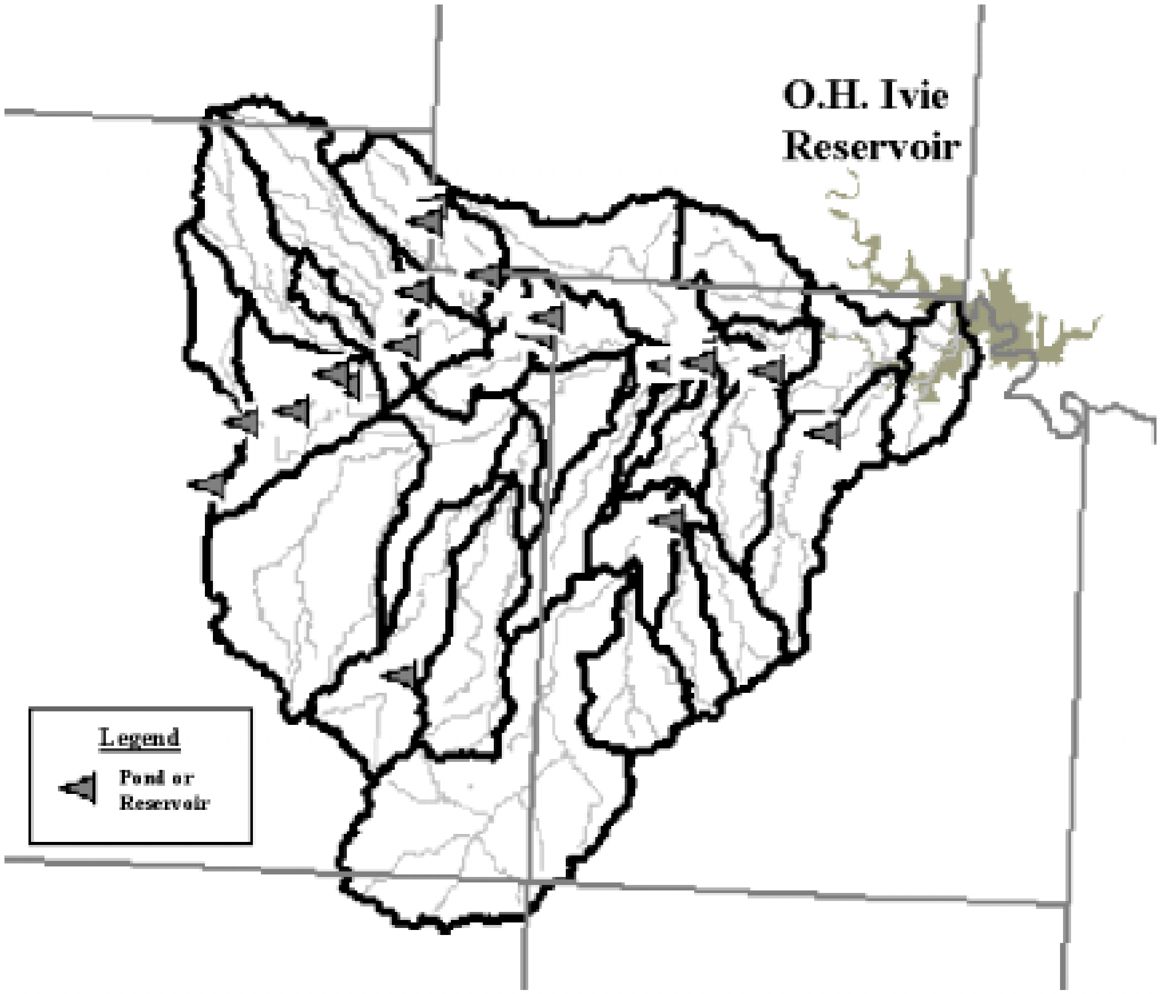

Figure CO-4.
Stream network and significant ponds and reservoirs
in the Main Concho River Watershed
(from Texas Natural Resource Conservation Commission inventory of dams).

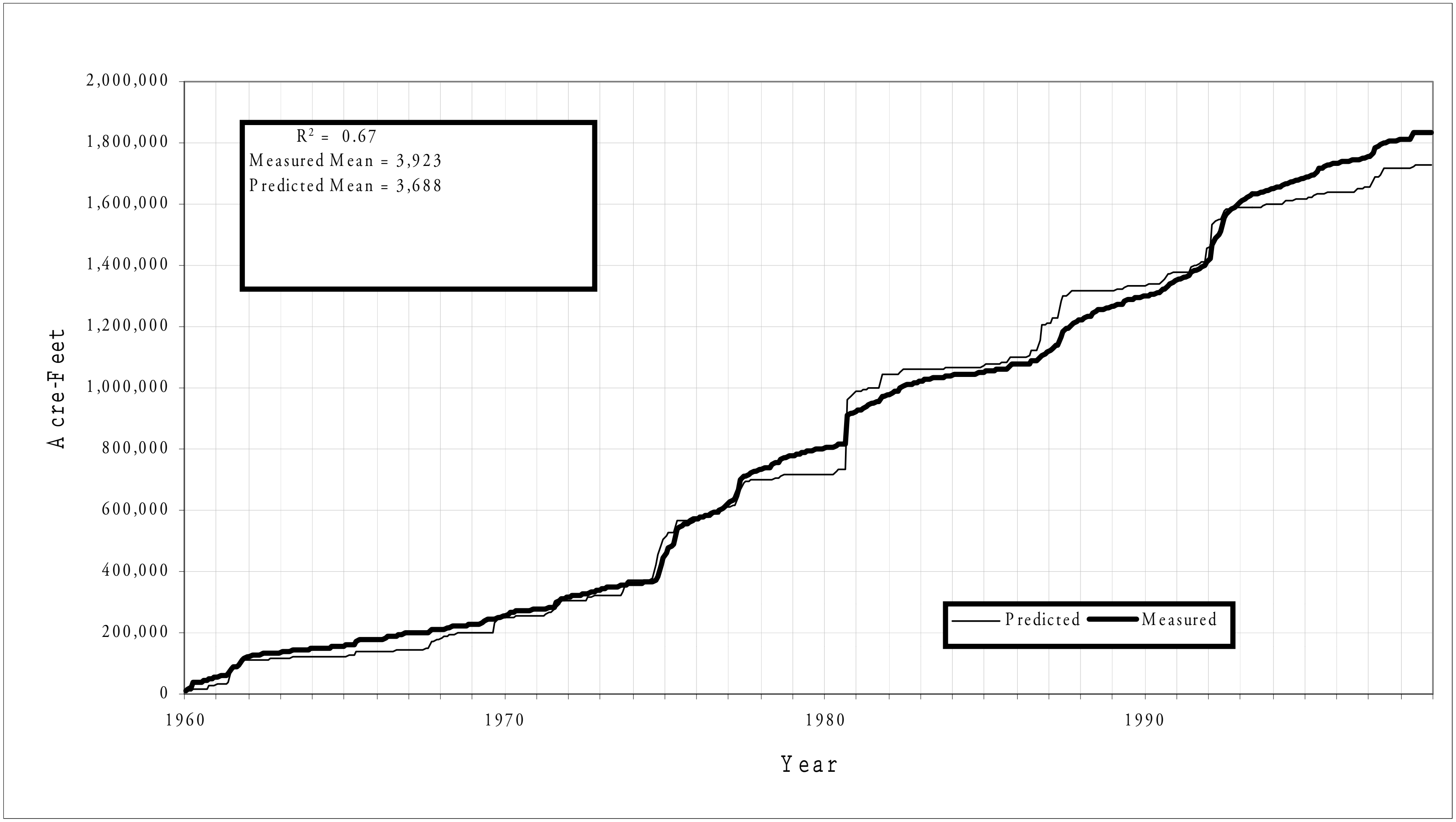

Figure CO-5.
Cumulative monthly total measured and predicted stream flow at gauge 08136500 (at Paint Rock), Main Concho River Watershed, 1960 through 1998. Monthly statistics are shown in box.

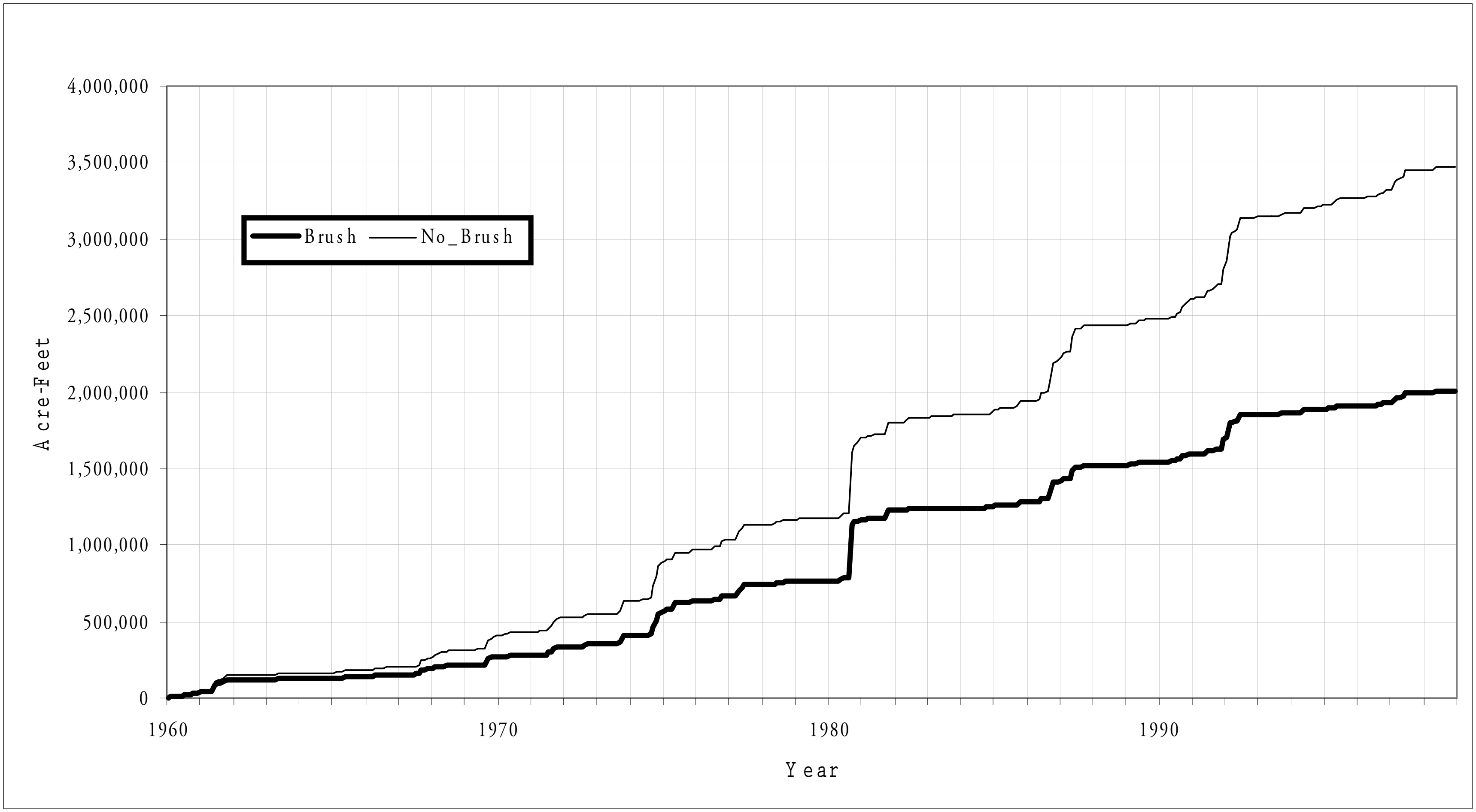

Figure CO-6:
Cumulative monthly total predicted flow to O. H. Ivie Reservoir with and without brush, Main Concho River Watershed, 1960 through 1998.

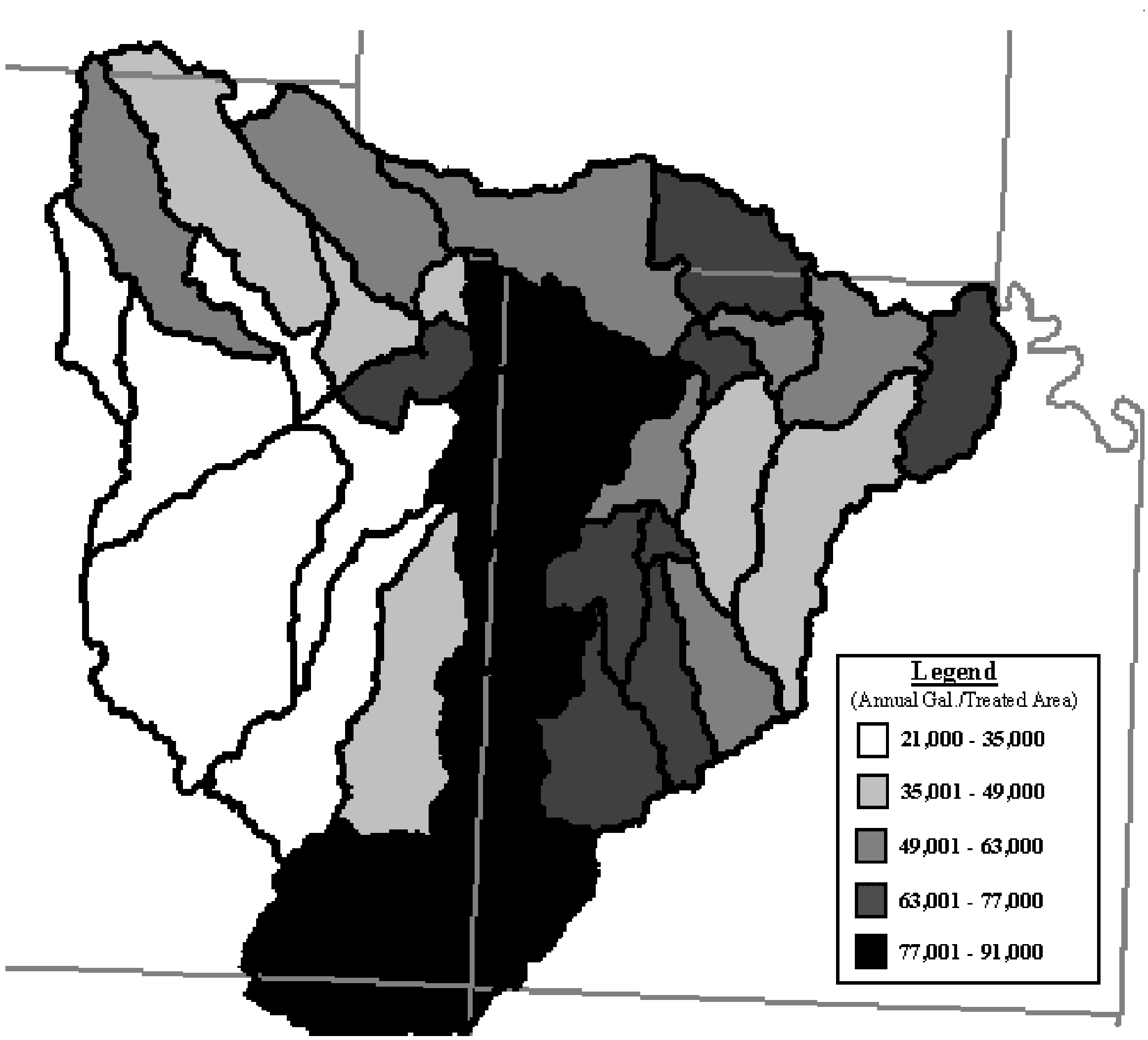

Figure CO-7
Annual increase in water yield per treated acre due to brush removal, Main Concho River Watershed, 1960 through 1998.

CHAPTER 10

MAIN CONCHO RIVER WATERSHED - ECONOMIC ANALYSIS

Joel P. Bach, Research Assistant, Department of Rangeland Ecology and Management and J. Richard Conner, Professor, Department of Agricultural Economics, Texas A&M University

INTRODUCTION

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

BRUSH CONTROL COSTS

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

Obviously, the costs of control will vary among brush type-density categories. Present values (using an 8% discount rate) of control programs are used for comparison since some of the treatments will be required in the first and second years of the program while others will not be needed until year 6 or 7. Present values of total control costs in the project area (per acre) range from $108.75 for mechanical control heavy mesquite to $39.61 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 Table 1.

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

Heavy Cedar - Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	75.00	75.00
5	IPT or Burn	15.00	9.89
		Total	84.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Heavy Mesquite – Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	90.00	90.00
5	IPT or Burn	15.00	9.89
		Total	99.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Heavy Mesquite – Rootplow

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mechanical Rootplow	100.00	100.00
7	IPT or Burn	15.00	8.75
		Total	108.75

Heavy Mesquite -Herbicide

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Aerial Herbicide	26.00	26.00
5	Aerial Herbicide	26.00	17.70
8	IPT or Burn	15.00	7.65
		Total	51.35

Heavy Mixed – Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	90.00	90.00
5	IPT or Burn	15.00	9.89
		Total	99.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Moderate Cedar – Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	60.00	60.00
5	IPT or Burn	15.00	9.89
		Total	69.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.

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

Moderate Mesquite – Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	60.00	60.00
5	IPT or Burn	15.00	9.89
		Total	69.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Moderate Mesquite – Chemical

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Aerial Herbicide	26.00	26.00
5	IPT or Burn	20.00	13.61
		Total	39.61

Moderate Mixed – Mechanical Choice[1]

Treatment Year	Treatment Description	Treatment Cost ($/Acre)	Present Value ($/Acre)
0	Mech. Choice	60.00	60.00
5	IPT or Burn	15.00	9.89
		Total	69.89

[1] Choice of tree dozing with rake and burn, tree shearing with stump spray and later burn, or excavation and later burn.
* Main Concho River Watershed

LANDOWNER AND STATE COST SHARES

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

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

Brush Type-Density Classification	Brush Control (Or) No Control	Program Year									
		0	1	2	3	4	5	6	7	8	9
Heavy Cedar	Brush Control	56.0	45.3	34.7	24.0	24.0	24.0	24.0	24.0	24.0	24.0
	No Control	56.0	56.1	56.1	56.2	56.2	56.3	56.4	56.4	56.5	56.6
Heavy Mesquite	Brush Control	32.0	27.3	22.7	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	No Control	32.0	32.0	32.1	32.1	32.1	32.2	32.2	32.2	32.3	32.3
Heavy Mix	Brush Control	48.0	39.0	30.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
	No Control	48.0	48.1	48.1	48.2	48.2	48.3	48.3	48.4	48.4	48.5
Moderate Cedar	Brush Control	44.0	37.3	30.7	24.0	24.0	24.0	24.0	24.0	24.0	24.0
	No Control	44.0	44.2	44.5	44.7	45.0	45.2	45.5	45.7	46.0	46.2
Moderate Mesquite	Brush Control	28.0	24.7	21.3	18.0	18.0	18.0	18.0	18.0	18.0	18.0
	No Control	28.0	28.2	28.3	28.5	28.6	28.8	28.9	29.1	29.2	29.4
Moderate Mix	Brush Control	36.0	31.0	26.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
	No Control	36.0	36.2	36.4	36.6	36.8	37.0	37.2	37.4	37.6	37.8

* Main Concho River Watershed

As with the brush control practices, the grazing capacity estimates represent a consensus of expert opinion obtained through discussions with landowners, Texas Agricultural Experiment Station and Extension Service Scientists and USDA-NRCS Range Specialists with brush control experience in the area.

Livestock grazing capacities range from about 18 acres per AUY for land on which mesquite is controlled to 56 acres per animal unit year (AUY) for land infested with heavy cedar.

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

Rancher benefits were also calculated for the financial changes in existing wildlife operations. Most of these operations in this region were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. Therefore, wildlife costs and revenues were entered into the model as simple entries in the project period. For control of heavy brush categories, wildlife revenues are expected to increase by about $0.50 per acre (from $8.00 per acre to $8.50 per acre) due principally to the resulting improvement in quail habitat. Wildlife revenues would not be expected to change with implementation of brush control for the moderate brush type-density categories.

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

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Calves	382.5	Pound	.80	306.00
Cows	111.1	Pound	.40	0
Bulls	250.0	Pound	.50	0
			Total	306.00

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	480.0	Pound	0.10	48.00
Salt & Minerals	27.0	Pound	0.20	5.40
Marketing	1.0	Head	6.32	6.32
Veterinary Medicine	1.0	Head	15.00	15.00
Miscellaneous	1.0	Head	12.00	12.00
Net Replacement Cows[3]	1.0	Head	35.28	35.28
Net Replacement Bulls[4]	1.0	Head	3.09	6.09
			Total	128.09

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

*Main Concho River Watersheds

Table 3b. Investment Analysis Budget, Sheep Production*

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Lambs	350.0	Pound	0.85	297.50
Ewes	0.833	Head	30.00	0
Rams	0.037	Head	50.00	0
Wool	8.0	Pound	1.00	8.00
			Total	305.50

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	480.0	Pound	0.10	35.20
Salt & Minerals	27.0	Pound	0.20	18.00
Marketing	1.0	Head	1.00	5.00
Veterinary Medicine	1.0	Head	3.00	15.00
Shearing	1.2	Head	2.00	12.00
Miscellaneous	1.0	Head	1.00	6.00
Net Replacement Ewes[3]	1.0	Head	34.80	34.80
Net Replacement Rams[4]	1.0	Head	7.08	7.80
			Total	133.80

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

*Main Concho River Watershed

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

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Kids	0.85	Head	50.00	255.00
Nannies	0.167	Head	25.00	0
Bucks	0.0076	Head	50.00	0
			Total	$255.00

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	384.0	Pound	0.10	38.40
Salt & Minerals	73.5	Pound	0.20	14.70
Marketing	1.0	Head	1.00	6.00
Veterinary Medicine	1.0	Head	2.50	15.00
Miscellaneous	1.0	Head	1.17	7.00
Net Replacement Nannies[3]	1.0	Head	36.48	36.48
Net Replacement Bucks[4]	1.0	Head	4.74	4.74
			Total	$122.32

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

*Main Concho River Watershed

With the above information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $10.92 per acre for control of moderate mixed brush to $17.22 per acre for the control of heavy mesquite (Table 4).

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state per acre cost share of brush control in the project area range from $27.54 for control of moderate mesquite with chemical treatments to $91.53 for control of heavy mesquite 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 Table 4.

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

Brush Category by Type & Density	PV Total Cost ($/Acre)	Landowner Share ($/Acre)	Landowner (Percent)	State Share ($/Acre)	State (Percent)
Heavy Cedar	84.89	14.90	17.6	69.99	82.4
Heavy Mesquite (Mechanical One)	99.89	17.22	17.2	82.67	82.8
Heavy Mesquite (Mechanical Two)	108.75	17.22	15.8	91.53	84.2
Heavy Mesquite (Chemical)	51.35	17.22	33.5	34.13	66.5
Heavy Mixed Brush	99.89	16.35	16.4	83.54	83.6
Moderate Cedar	69.89	11.32	16.2	58.57	83.8
Moderate Mesquite (Mechanical)	69.89	12.07	17.3	57.82	82.7
Moderate Mesquite (Chemical)	39.61	12.07	30.5	27.54	69.5
Moderate Mixed Brush	69.89	10.92	15.6	58.97	84.4
Average[1]	76.19	13.80	20.0	62.39	80.0

[1] Average is based on Heavy Mesquite Mechanical One and Two comprising 25% each and Heavy Mesquite Chemical comprising 50% of the cost for Heavy Mesquite control and Mechanical and Chemical comprising 50% each of cost for Moderate Mesquite control. Actual average may change depending on relative amounts of each Type- Density Category of brush.
*Main Concho River Watershed

COST OF ADDITIONAL WATER

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program. The brush control program water yields and the estimated acreage by brush type-density category by sub-basin were supplied by the Blackland Research Center, Texas Agricultural Experiment Station in Temple, Texas (see previous Chapter). The total state cost share for each sub-basin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the sub-basin. The cost of added water resulting from the control of the eligible brush in each sub-basin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the 10-year period using a 6% discount rate). The cost of added water was determined to average $42.32 per acre-foot for the entire Main Concho Watershed (Table 5). Sub-basins range from costs per added acre-foot of $24.37 to $87.79.

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	1,047,353.70	2,703.32	21,091.29	49.66
2	1,028,869.30	2,514.17	19,615.58	52.45
3	448,642.90	720.36	5,620.22	79.83
4	59,710.70	192.75	1,503.83	39.71
5	464,227.90	795.36	6,205.38	74.81
6	1,315,453.30	1,920.65	14,984.93	87.79
7	1,116,846.60	2,032.75	15,859.55	70.42
8	2,764,145.30	14,537.84	11,3424.20	24.37
9	799,961.90	1,612.39	12,579.88	63.59
10	213,940.90	355.05	2,770.13	77.23
11	210,617.40	319.97	2,496.41	84.37
12	503,224.00	1,313.53	10,248.18	49.10
13	70,743.54	131.82	1,028.45	68.79
14	639,950.70	1,893.89	14,776.14	43.31
15	277,886.30	1,117.30	8,717.20	31.88
16	172,282.00	707.58	5,520.54	31.21
17	28,006.44	123.37	962.55	29.10
18	232,453.20	900.94	7,029.13	33.07
19	66,974.94	268.42	2,094.20	31.98
20	22,065.41	95.31	743.62	29.67
21	79,795.30	311.23	2,428.25	32.86
22	215,347.00	698.97	5,453.37	39.49
23	516,527.40	2,080.84	16,234.68	31.82
24	311,794.10	1,242.78	9,696.15	32.16
25	299,018.90	1,090.32	8,506.69	35.15
26	61,344.79	198.47	1,548.44	39.62
27	345,814.80	1,017.21	7,936.27	43.57
28	76,262.28	277.43	2,164.52	35.23
29	250,709.00	889.57	6,940.43	36.12
30	161,185.60	481.31	3,755.21	42.92
31	518,303.70	1,035.36	8,077.86	64.16
32	375,339.20	1,161.22	9,059.85	41.43
33	841,688.20	2,119.18	16,533.86	50.91
34	81,932.49	198.28	1,547.00	52.96
35	17,822.28	71.71	559.45	31.86
36	0.00	4.41	34.38	0.00
37	385,728.70	1,388.04	10,829.50	35.62
Totals	$16,021,971.40	----------	378,577.30	Average: $42.32

*Main Concho River Watershed

CHAPTER 15

TWIN BUTTES/NASWORTHY WATERSHED – HYDROLOGIC SIMULATION

Timothy J. Dybala, Civil Engineer, USDA-Natural Resources Conservation Service Blackland Research Center

WATERSHED DATA

Location

The Twin Buttes/Nasworthy watershed was divided into four different drainages for ease of modeling. These sub-watersheds are the Middle Concho River, Spring & Dove Creeks, South Concho River and Pecan Creek. These delineations are shown in Figure TBN–1.

Topography

The outlet or "catchment" for the Middle Concho River simulated in this study is the north pool of Twin Buttes Reservoir, which is located in sub-basin number 28. This modeling subdivision is shown in Figure TBN-2. The outlet for Spring and Dove Creeks (Figure TBN-3) is also the north pool of Twin Buttes Reservoir located in sub-basin number 23. The catchment for the South Concho River (Figure TBN-4) is the south pool of Twin Buttes Reservoir, which is located in sub-basin number 18. The outlet or "catchment" for Pecan Creek (Figure TBN-5) in this study is Lake Nasworthy located in sub-basin number 13.

Figures TBN-2 through TBN-5 show the sub-basin delineation, numbers, and roads (obtained from the Census Bureau) for each modeling subdivision.

Weather Stations

Climate stations for each modeling subdivision (Middle Concho, Spring & Dove Creeks, South Concho, and Pecan Creek) are shown in Figures TBN-6 through TBN-9. For each sub-basin, precipitation and temperature data were retrieved by the SWAT input interface for the climate station nearest the centroid of the sub-basin. USGS stream gauge stations are also shown in these figures.

Soils

The soils in the Twin Buttes/Nasworthy Watershed are represented largely by STATSGO soil associations. The dominant soil series of these associations are Ector, Reagan, Angelo, Tarrant, Rioconcho, and Tobosa. These six soil series represent about 93 percent of the soils polygons in the watershed area. A short description of each follows:

<u>Ector.</u> The Ector series consists of very shallow or shallow, well drained soils that are moderately permeable above a very slowly permeable limestone bedrock. They formed in loamy residuum. These gently sloping to very steep upland soils have slopes ranging from 1 to 60 percent.

Reagan. The Reagan series consists of very deep, well drained, moderately permeable calcareous soils that formed in calcareous loamy materials. These nearly level to gently sloping upland soils are on broad flats, filled valleys and fans. Slopes range from 0 to 3 percent.

Angelo. The Angelo series consists of deep or very deep, well drained, moderately slowly permeable soils formed in calcareous loamy and clayey alluvium. The deep phase is underlain by limestone. These nearly level to gently sloping upland soils have slopes ranging from 0 to 3 percent.

Tarrant. The Tarrant series consists of very shallow and shallow, well drained, moderately slowly permeable soils on uplands. They formed in residuum from limestone, and includes interbedded marls, chalks, and marly materials.

Rioconcho. The Rioconcho series consists of very deep, moderately well drained, slowly permeable soils that formed in clayey or silty alluvium. These nearly level soils are on flood plains and in narrow valleys. Slopes range from 0 to 2 percent.

Tobosa. The Tobosa series consists of very deep, well drained, very slowly permeable soils formed in calcareous clayey materials. These nearly level to gently sloping soils are on uplands. Slopes range from 0 to 3 percent.

Land Use/Land Cover

Figures TBN-10 through TBN-13 show the areas of heavy and moderate brush (oak not included) in the Twin Buttes/Nasworthy Watershed by modeling subdivision. This is the area of brush removed or treated in the no-brush simulation.

Ponds and Reservoirs

Surface area, storage, and drainage area were obtained from the Texas Natural Resource Conservation Commission (TNRCC) for existing inventory-sized ponds and reservoirs in the watershed (Figures TBN-14 through TBN-17), and input to the SWAT model. The stream networks are also shown in these figures.

Model Input Variables

Significant input variables for the SWAT model for the Twin Buttes/Nasworthy Watershed are shown in Table TBN-1. Input variables were adjusted as needed by sub-basin in order to calibrate flow at the applicable USGS stream gauge. Channel transmission losses were assumed to be 0.98 inches per hour in the Middle Concho River with no return base flow. The channel transmission losses were assumed to be 0.94 inches per hour in Spring Creek above gauge 08129300 (Tankers) and 0.06 inches per hour in Dove Creek above gauge 08130500 (Knickerbocker). Losses in channel transmission were assumed to be 0.79 inches per hour in the South Concho River with 75% of this amount returning as base flow. Channel transmission losses were assumed to be 0.59 inches per hour in Pecan Creek with 60% of this amount returning as base flow. The calibration simulation represents the current “with brush” condition.

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

RESULTS

Calibration

SWAT was calibrated for flow at stream gauges 08128400 (Middle Concho River above Tankersley) (Figure TBN-6), 08129300 (Spring Creek at Tankersley) & 08130500 (Dove Creek at Knickerbocker) (Figure TBN-7), 08128000 (South Concho River at Christoval) (Figure TBN-8) and 08131400 (Pecan Creek near San Angelo) (Figure TBN-9). The results of calibrations are shown for these gauges on Figures TBN-18 through TBN-22.

Measured and predicted total monthly flows for the Middle Concho compare well with a R^2 value of 0.82 for gauge 08128400 (Figure TBN-18). The measured monthly mean is 1,023 acre-feet, and the predicted monthly mean is 917 acre-feet. The predicted total flow was just slightly less than measured. Most of this deviation occurred at the end of the simulation (in 1992) and may have resulted from the spatial distribution of one large rainfall event.

Figures TBN-19 and TBN-20 show measured and predicted total monthly flows of Spring and Dove Creeks comparing reasonably well with R^2 values of 0.85 for gauge 08129300 and 0.46 for gauge 08130500. At gauge 08129300 the measured monthly mean is 810 acre-feet, and predicted monthly mean is 789 acre-feet. Gauge 08130500 has a measured mean of 981 acre-feet, and a predicted mean of 1,002 acre-feet. At gauge 08129300 total predicted flow for the simulation period is slightly lower than measured (Figure TBN-19). The lines of cumulative measured and predicted flow diverge somewhat near the beginning of the simulation, but converge toward the end. This may have been due to climate variability that is not reflected in measured data. At gauge 08130500 predicted total flow was more than measured (Figure TBN-20). In 1977, SWAT under-estimated flow by a large amount, causing the cumulative lines of measured and predicted flow to diverge significantly. It is possible that large amounts of rainfall occurred during this time that was not measured accurately at any of the climate stations. The measured and predicted lines for the remainder of the simulated period are generally parallel, with the predicted line approaching and nearly catching up to the measured line near the end of the simulation.

Gauge 08128000 on the South Concho measured and predicted total monthly flows do not compare as well as the other modeling subdivisions in the Twin Buttes/Nasworthy watershed with a R^2 value of 0.26 (Figure TBN-21). Average base flow for this modeling subdivision is 63 % of total flow, which is reasonably close to measured base flow of approximately 70 %. The measured monthly mean is 1,578 acre-feet, and the predicted monthly mean is 1,727 acre-feet. The predicted total flow was more than measured. Most of this deviation is probably attributed to not accurately predicting the large amount of base flow in the channel.

The results of calibration with gauge 08131400 (Pecan Creek) are shown on Figure TBN-22. Measured and predicted total monthly flows do not compare as well as some of the other modeling subdivisions in the Twin Buttes/Nasworthy watershed with a R^2 value of 0.30 for this gauge. The measured monthly mean is 128 acre-feet, and the predicted monthly mean is 171 acre-feet. The predicted total flow was more than measured. Most of this deviation is probably attributed to the fact that only one climatic station was used for rainfall and this station did not accurately represent conditions in the watershed because it is located near the outlet.

Brush Removal Simulation

The average annual rainfall for the Middle Concho River varies from 14.7 inches in the western portion of the watershed to 20.0 inches in the eastern portion. The composite average for the entire subdivision is 18.3 inches. Average annual evapotranspiration (ET) is 17.45 inches for the brush condition (calibration) and 17.09 inches for the no-brush condition. This represents 95% and 93% of precipitation for the brush and no-brush conditions, respectively.

The average annual rainfall for Spring and Dove Creeks varies from 18.5 inches in the western portion of the watershed to 21.6 inches in the eastern portion. The composite average for the entire subdivision is 20.4 inches. Average annual evapotranspiration (ET) is 17.78 inches for the brush condition (calibration) and 16.67 inches for the no-brush condition. This represents 87% and 82% of precipitation for the brush and no-brush conditions, respectively.

The average annual rainfall for the South Concho River varies from 20.3 inches in the western portion of the watershed to 21.6 inches in the eastern portion. The composite average for the entire subdivision is 21.2 inches. Average annual evapotranspiration (ET) is 19.75 inches for the brush condition (calibration) and 18.62 inches for the no-brush condition. This represents 93% and 88% of precipitation for the brush and no-brush conditions, respectively.

The average annual rainfall for Pecan Creek is 20.3 inches. Average annual evapotranspiration (ET) is 18.44 inches for the brush condition (calibration) and 17.11 inches for the no-brush condition. This represents 91% and 85% of precipitation for the brush and no-brush conditions, respectively.

Figure TBN-23 shows the predicted cumulative monthly total flow to Twin Buttes Reservoir for the brush and no-brush conditions from 1960 through 1998. Figure TBN-24 shows the predicted cumulative monthly total flow to Lake Nasworthy for the brush and no-brush conditions from 1960 through 1998. The increase in water yield by sub-basin for the Twin Buttes/Nasworthy Watershed is shown in Figure TBN-25. The amount of annual increase varies among the sub-basins and ranges from 5,467 gallons per acre of brush removed per year in sub-basin number 7 (Middle Concho), to 61,184 gallons per acre in sub-basin number 4 (Spring & Dove Creeks). 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. Table TBN-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 entire simulated watershed, the average annual water yield at the sub-basin level increased by 74 % or approximately 77,990 acre-feet. The average annual flow to Twin Buttes Reservoir and Lake Nasworthy increased by 41,325 acre-feet and 2,264 acre-feet respectively, for a total watershed increase of 43,589 acre-feet. The increase in volume of flow to Twin Buttes Reservoir and Lake Nasworthy is less than the water yield because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occur after water leaves each sub-basin.

TABLE TBN-1

SWAT INPUT VARIABLES FOR TWIN BUTTES/NASWORTHY WATERSHED								
VARIABLE	BRUSH CONDITION (CALIBRATION)				NO BRUSH CONDITION			
	Middle Concho	Spring & Dove	South Concho	Pecan Creek	Middle Concho	Spring & Dove	South Concho	Pecan Creek
Runoff Curve Number Adjustment	-8	-8	-8	-8	-8	-8	-8	-8
Soil Avail. Water Capacity Adjust. (in. H^2O/in. soil)	+0.05	N/A	+0.05	N/A	+0.05	N/A	+0.05	N/A
Soil Evaporation Compensation Factor	0.1	0.1	0.1	0.10	0.10	0.10	0.10	0.10
Min. Shallow Aqu. Storage for GW flow (inches)	0	0	0	0.00	0.00	0.00	0.00	0.00
Ground Water Delay (days)	265	35	35	35	265	35	35	35
Shallow Aqu. Re-Evaporation (Revap) Coefficient	0.4	0.4	0.4	0.40	0.10	0.10	0.10	0.10
Min. Shallow Aqu. Storage for Revap (inches)	0	0	0.04	0.00	0.00	0.00	0.04	0.00
Potential Heat Units (^oC)								
Heavy Juniper	4150	4150	4150	4150	N/A	N/A	N/A	N/A
Heavy Mesquite	3610	3610	3610	3611	N/A	N/A	N/A	N/A
Heavy Mixed Brush	3860	3860	3860	3860	N/A	N/A	N/A	N/A
Moderate Juniper	3610	3610	3610	3611	N/A	N/A	N/A	N/A
Moderate Mesquite	3195	3195	3195	3196	N/A	N/A	N/A	N/A
Moderate Mixed Brush	3405	3405	3405	N/A	N/A	N/A	N/A	N/A
Heavy Oak	3610	3610	3610	3611	3610	3610	3610	3611
Moderate Oak	3195	3195	3195	N/A	3195	3195	3195	N/A
Light Brush & Open Range/Pasture	2820	2820	2820	2781	2820	2820	2820	2781
Precipitation Interception (Inches)								
Heavy Juniper	0.79	0.79	0.79	0.79	N/A	N/A	N/A	N/A
Heavy Mesquite	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A
Heavy Mixed Brush	0.59	0.59	0.59	0.59	N/A	N/A	N/A	N/A
Moderate Juniper	0.59	0.59	0.59	0.59	N/A	N/A	N/A	N/A
Moderate Mesquite	0.00	0.00	0.00	0.00	N/A	N/A	N/A	N/A
Moderate Mixed Brush	0.39	0.39	0.39	0.39	N/A	N/A	N/A	N/A
Heavy Oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moderate Oak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Light Brush & Open Range/Pasture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plant Rooting Depth (feet)								
Heavy and Moderate Brush	6.5	6.5	6.5	6.5	N/A	N/A	N/A	N/A
Light Brush & Open Range/Pasture	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Maximum Leaf Area Index								
Heavy Juniper	6	6	6	6	N/A	N/A	N/A	N/A
Heavy Mesquite	4	4	4	4	N/A	N/A	N/A	N/A
Heavy Mixed Brush	4	4	4	4	N/A	N/A	N/A	N/A
Moderate Juniper	5	5	5	5	N/A	N/A	N/A	N/A
Moderate Mesquite	2	2	2	2	N/A	N/A	N/A	N/A
Moderate Mixed Brush	3	3	3	3	N/A	N/A	N/A	N/A
Heavy Oak	4	4	4	4	4	4	4	4
Moderate Oak	3	3	3	3	3	3	3	3
Light Brush	2	2	2	2	2	2	2	2
Open Range/Pasture	1	1	1	1	1	1	1	1
Channel Transmission Loss (inches/hour)	0.98	0.94 & 0.06	0.79	0.59	0.98	0.94 & 0.06	0.79	0.59
Subbasin Transmission Loss (inches/hour)	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Fraction Trans. Loss Returned as Base Flow	0.00	0	0.75	0.60	0.00	0.00	0.75	0.60

TABLE TBN-2

SUBBASIN DATA - TWIN BUTTES/NASWORTHY WATERSHED					
Subbasin	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
**# MC1	211,304	0	0.00	0	0
MC2	7,332	4,379	0.60	5,473	23,967,709
**#MC3	176,942	0	0.00	0	0
**#MC4	73,600	0	0.00	0	0
MC5	14,159	3,533	0.25	8,198	28,961,239
** MC6	68,281	0	0.00	0	0
MC7	52,662	14,673	0.28	5,467	80,219,580
MC8	6,857	1,061	0.15	8,860	9,403,568
MC9	74,712	9,248	0.12	10,310	95,354,657
MC10	3,996	437	0.11	6,690	2,921,367
**#MC11	125,727	0	0.00	0	0
MC12	39,428	20,798	0.53	8,303	172,689,922
MC13	26,630	19,504	0.73	10,918	212,938,097
MC14	13,950	9,230	0.66	11,229	103,650,307
MC15	16,415	5,479	0.33	9,474	51,912,762
MC16	108,522	40,498	0.37	9,234	373,960,351
MC17	36,146	24,760	0.69	13,029	322,602,068
MC18	56,713	34,833	0.61	10,503	365,844,550
MC19	15,512	9,539	0.61	9,810	93,584,365
MC20	1,752	1,115	0.64	9,045	10,085,112
MC21	53,743	30,200	0.56	9,160	276,620,604
MC22	31,175	19,523	0.63	10,994	214,634,970
MC23	85,184	62,653	0.74	14,777	925,853,301
MC24	43,765	34,045	0.78	15,082	513,448,349
MC25	54,769	40,059	0.73	13,997	560,713,394
MC26	73,256	51,616	0.70	10,618	548,050,093
MC27	78,179	57,271	0.73	10,047	575,423,771
MC28	50,151	27,310	0.54	7,966	217,552,581
SD1	57,402	31,897	0.56	30,137	961,288,661
SD2	42,467	19,547	0.46	48,346	945,015,702
SD3	63,664	26,024	0.41	54,400	1,415,720,275
SD4	11,201	9,336	0.83	61,184	571,234,993
SD5	326	164	0.50	26,780	4,402,416
SD6	13,329	10,857	0.81	41,189	447,206,055
SD7	17,567	13,422	0.76	39,540	530,712,082
SD8	8,300	4,957	0.60	30,599	151,684,470
SD9	18,570	9,849	0.53	34,186	336,687,178
SD10	14,253	10,320	0.72	34,221	353,162,102
SD11	24,063	17,983	0.75	40,785	733,442,938
SD12	24,908	19,009	0.76	42,505	807,955,606
SD13	12,340	9,644	0.78	47,654	459,589,309

TABLE TBN-2 (continued)

Subbasin	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
SD14	20,589	15,527	0.75	40,981	636,308,516
SD15	20,285	14,816	0.73	34,593	512,534,487
SD16	15,538	12,671	0.82	36,271	459,572,044
SD17	13,072	10,158	0.78	33,994	345,312,501
SD18	11,656	8,834	0.76	26,465	233,800,919
SD19	2,367	1,576	0.67	8,775	13,832,035
SD20	25,674	15,031	0.59	21,164	318,128,906
SD21	17,473	12,300	0.70	34,199	420,650,953
SD22	3,949	1,243	0.31	9,196	11,427,179
SD23	10,658	5,649	0.53	27,772	156,871,387
SC1	42,406	0	0.00	0	0
SC2	12,852	2,543	0.20	59,410	151,090,053
SC3	24,476	12,192	0.00	50,043	610,107,105
SC4	15,563	8,351	0.00	43,884	366,458,887
SC5	13,052	7,977	0.61	47,893	382,050,413
SC6	1,900	1,401	0.00	33,718	47,242,081
SC7	15,486	5,904	0.38	49,485	292,180,472
SC8	11,434	5,287	0.46	49,545	261,958,329
SC9	8,718	6,755	0.77	37,161	251,003,374
SC10	10,660	8,392	0.79	35,020	293,876,898
SC11	37,330	26,004	0.00	51,328	1,334,706,343
SC12	12,802	9,034	0.71	43,521	393,175,577
SC13	36,712	27,184	0.74	36,569	994,076,780
SC14	1,109	666	0.60	39,826	26,535,836
SC15	21,100	14,255	0.68	46,832	667,605,094
SC16	21,889	17,340	0.79	41,654	722,288,072
SC17	18,194	13,108	0.72	39,749	521,019,605
SC18	7,260	3,346	0.46	5,945	19,890,993
PE1	7,257	3,853	0.53	53,424	205,850,701
PE2	3,388	2,442	0.72	46,275	113,017,068
PE3	4,463	3,633	0.81	31,541	114,599,104
PE4	4,478	3,142	0.70	33,351	104,780,481
PE5	13,853	11,243	0.81	37,947	426,626,535
PE6	2,664	2,094	0.79	49,633	103,924,649
PE7	6,595	4,757	0.72	35,325	168,040,884
PE8	3,141	2,486	0.79	46,278	115,044,144
PE9	3,462	2,555	0.74	22,266	56,891,695
PE10	1,473	813	0.55	16,525	13,430,196
PE11	1,255	969	0.77	15,335	14,863,737
PE12	3,104	1,957	0.63	8,027	15,705,989
PE13	5,268	3,143	0.60	5,809	18,258,260

TABLE TBN-2 (continued)

TWIN BUTTES/NASWORTHY WATERSHED					
	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
	2,423,854 *(1,768,001 ac. treated subs)*	1,015,407	0.57 *(based on treated subs)*	25,028	25,413,232,785 (77,990 Ac-Ft/yr.)

Notes:

1 - *Numbers prefaced by MC denote subbasins in the Middle Concho River*

2 - *Numbers prefaced by SD denote subbasins in Spring and Dove Creeks*

3 - *Numbers prefaced by SC denote subbasins in the South Concho River*

4 - *Numbers prefaced by PE denote subbasins in Pecan Creek*

5 - *** No brush control modeled in these subbasins*

6 - *# Subbasins 1, 3, 4, & 11 in Middle Concho modeled as NOT contributing to stream gage.*

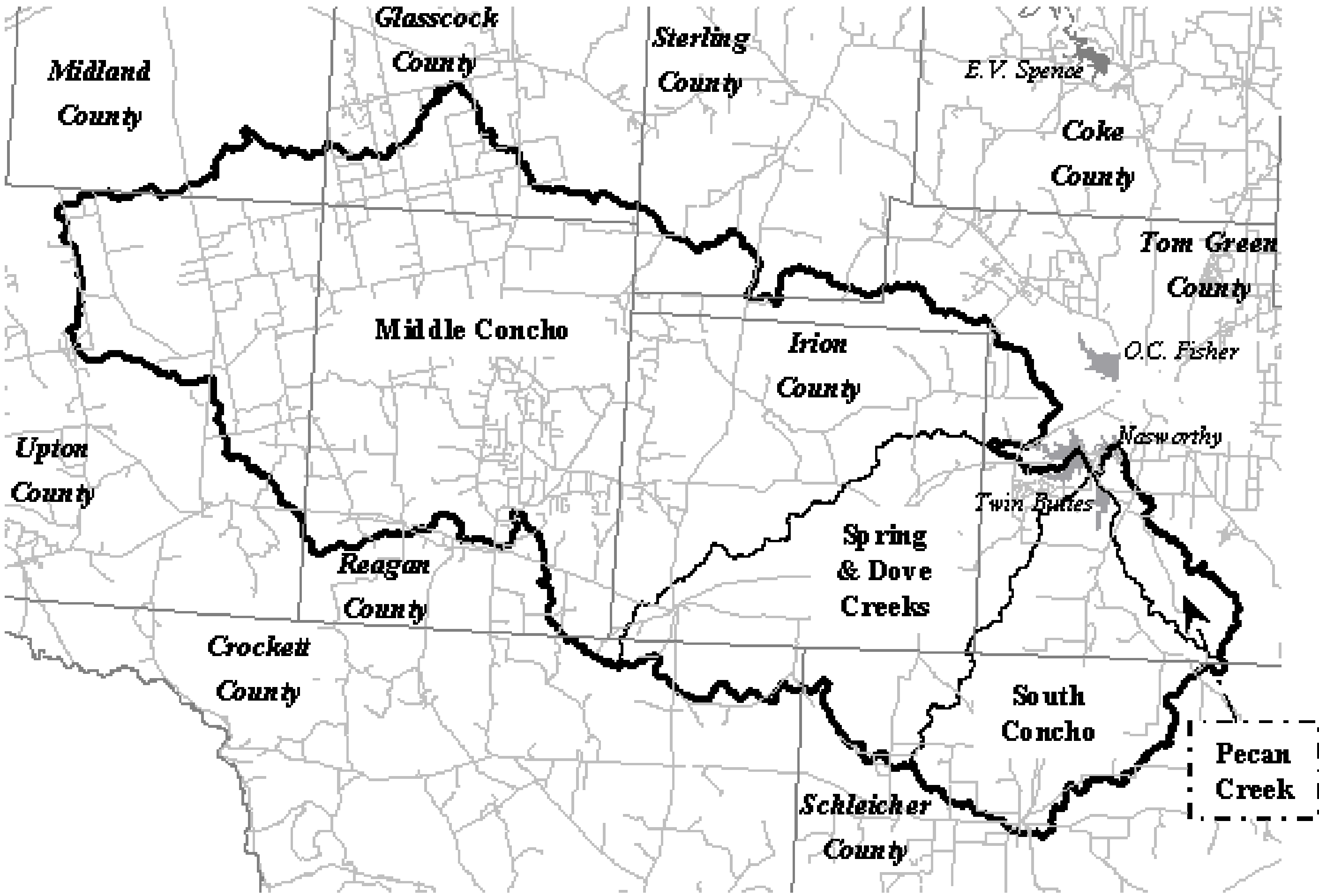

Figure TBN-1 Location Map - Major subdivisions of the Twin Buttes/Nasworthy Watershed

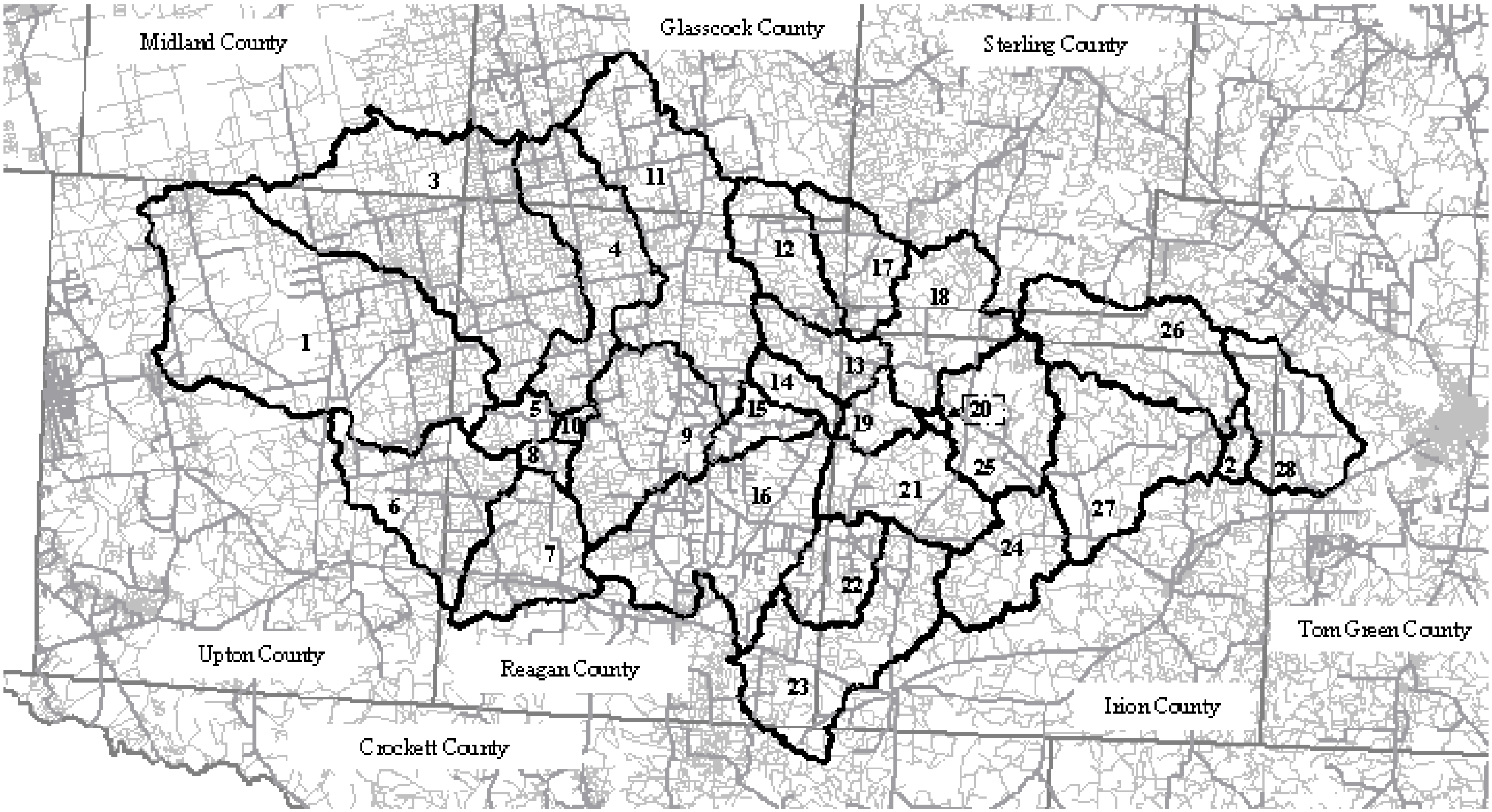

Figure TBN-2. Middle Concho River Sub-Basin Map

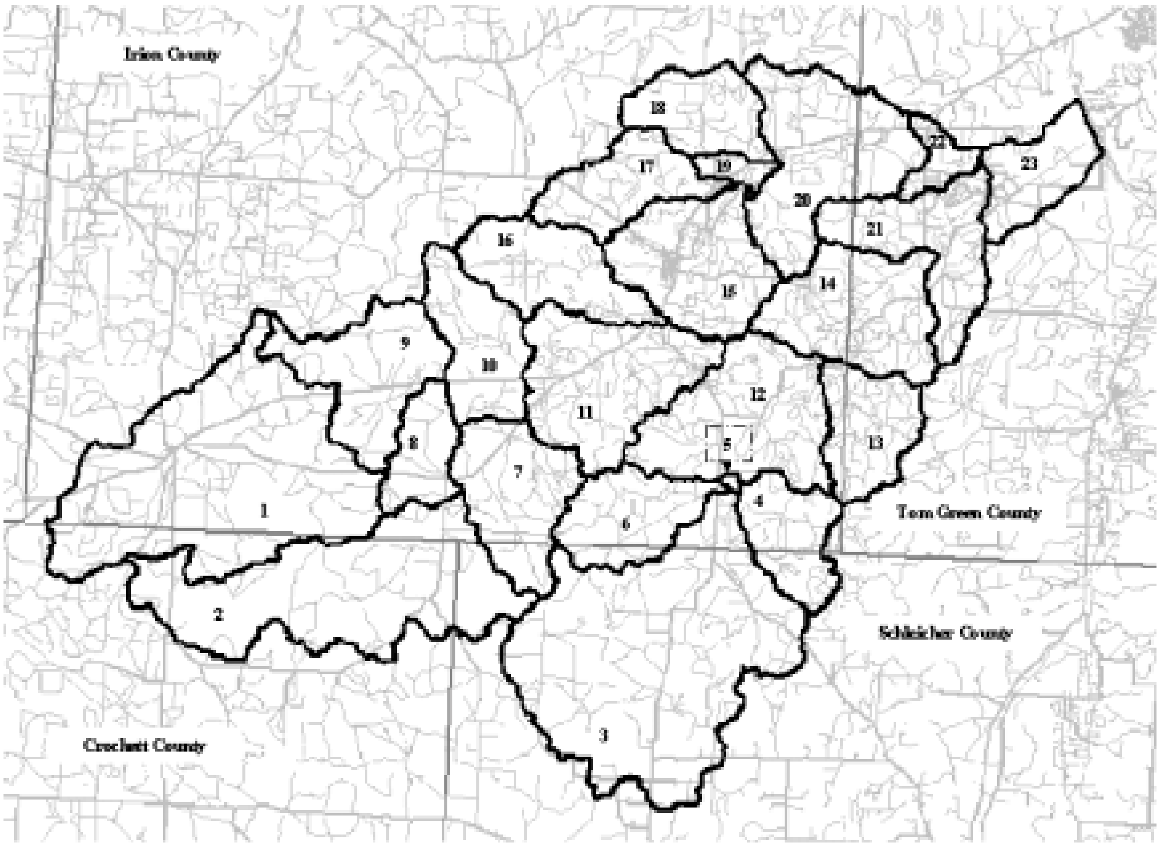

Figure TBN-3. Spring and Dove Creek Sub-Basin Maps

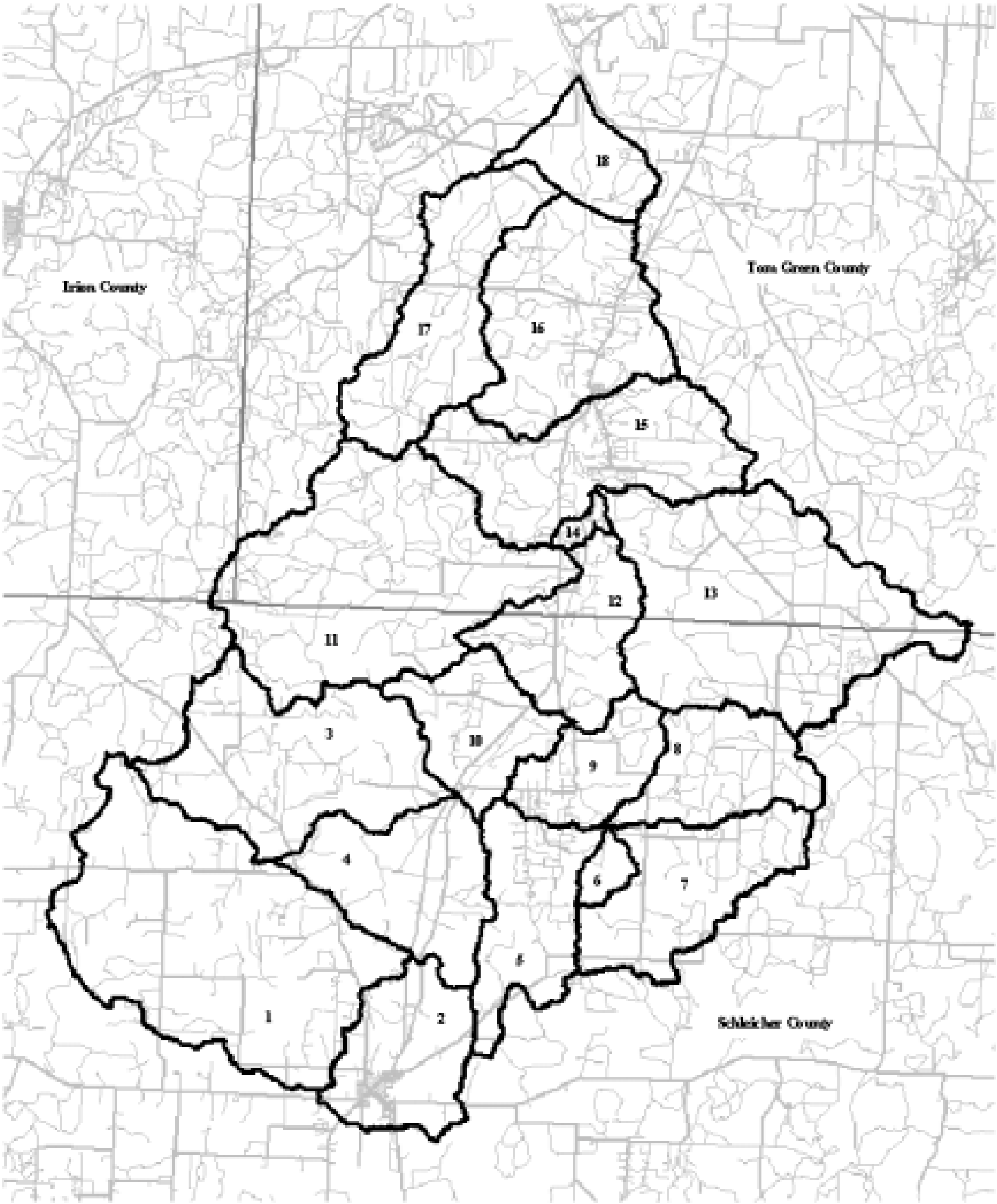

Figure TBN-4. South Concho River Sub-Basin Map.

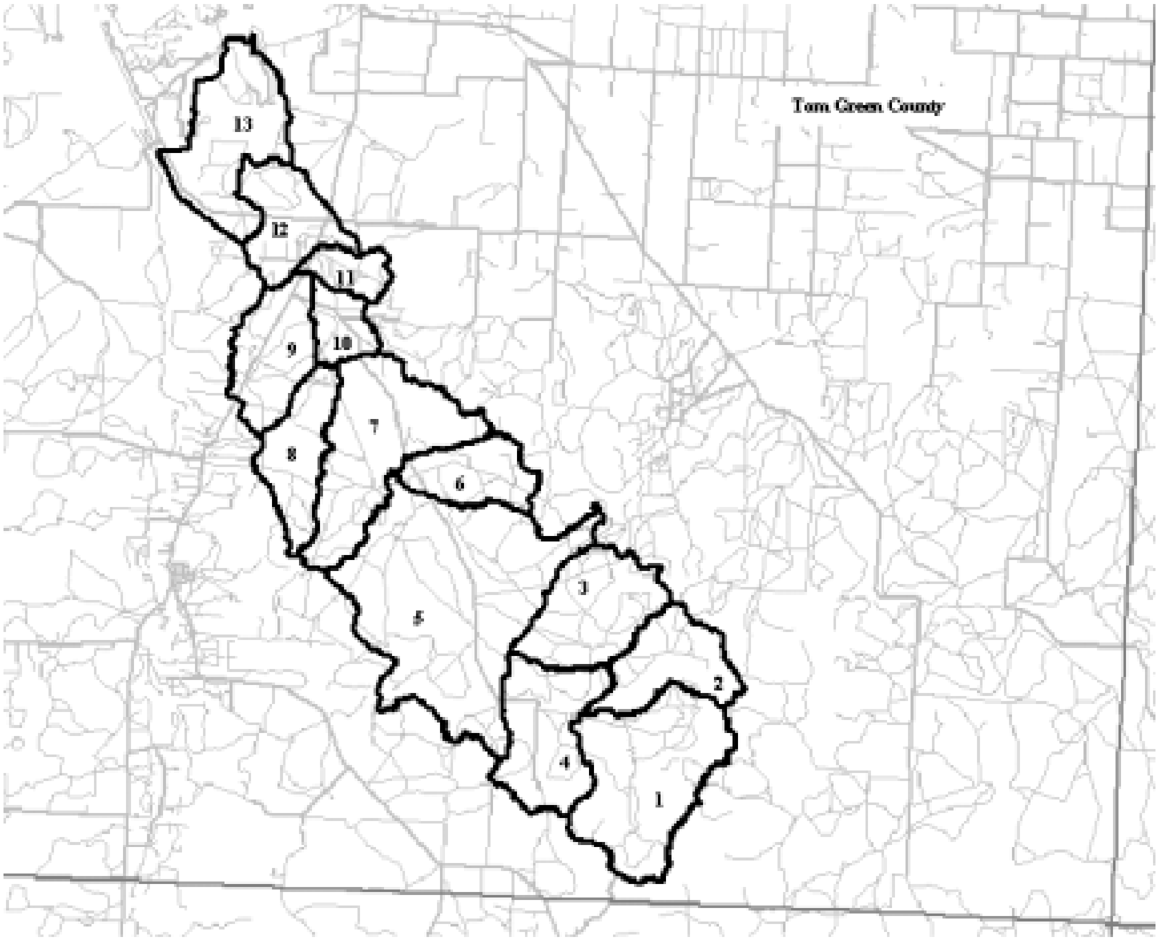

Figure TBN-5. Pecan Creek Sub-Basin Map.

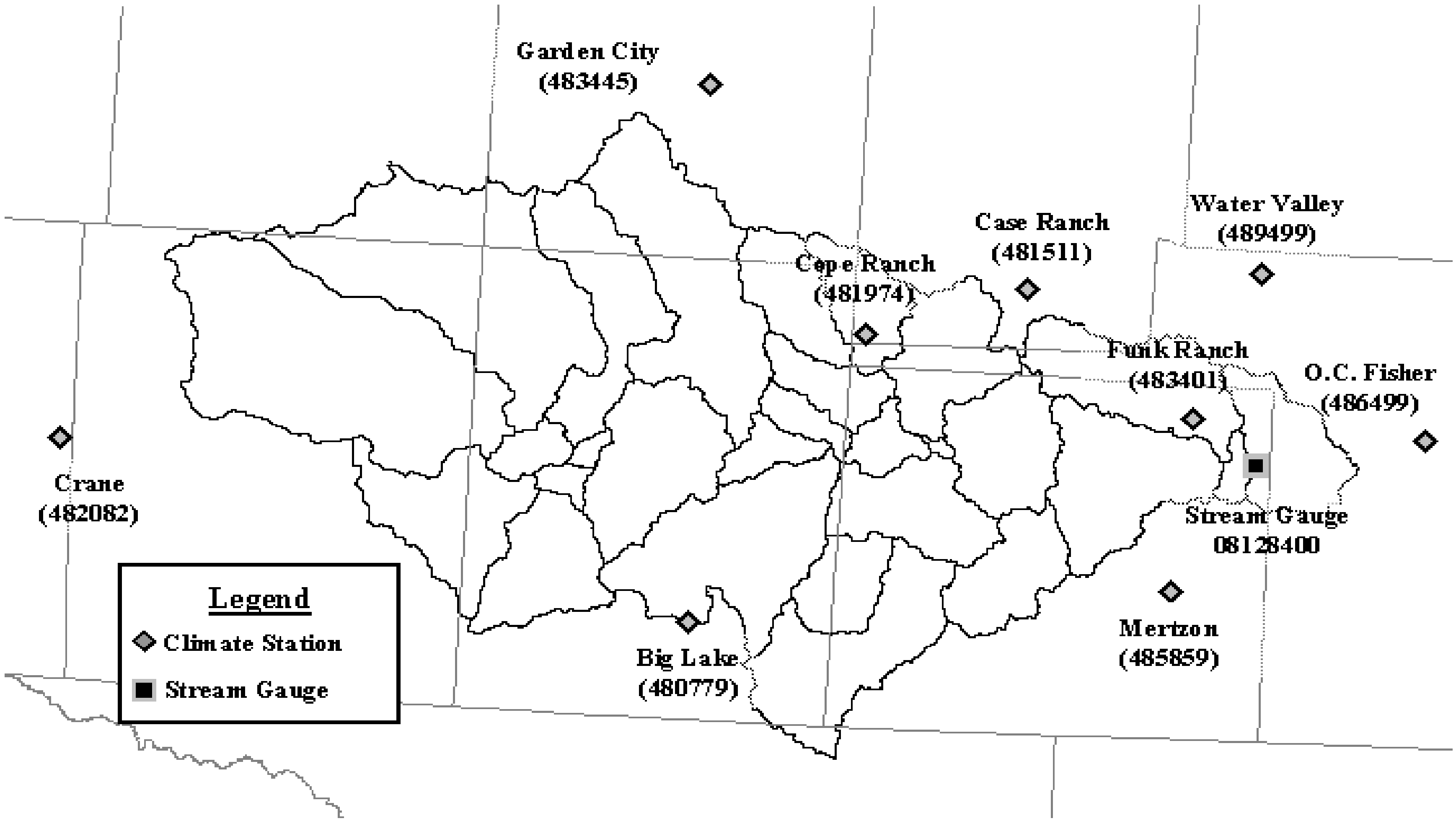

Figure TBN-6. Climate and Stream Gauge Stations in the Middle Concho River.

Figure TBN-7. Climate and Stream Gauge stations in Spring and Dove Creeks.

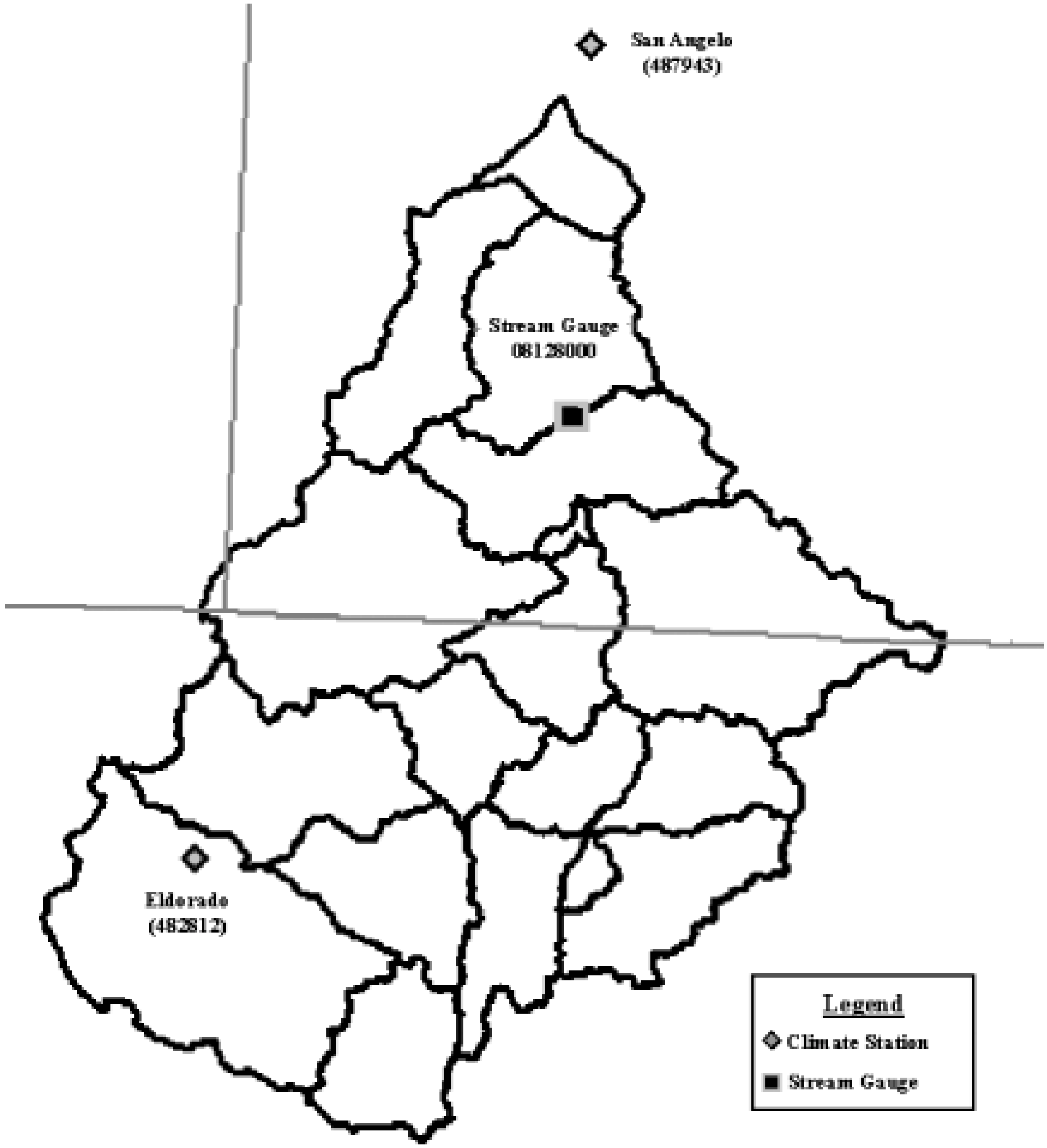

Figure TBN-8. Climate and Stream Gauge Stations in the South Concho River.

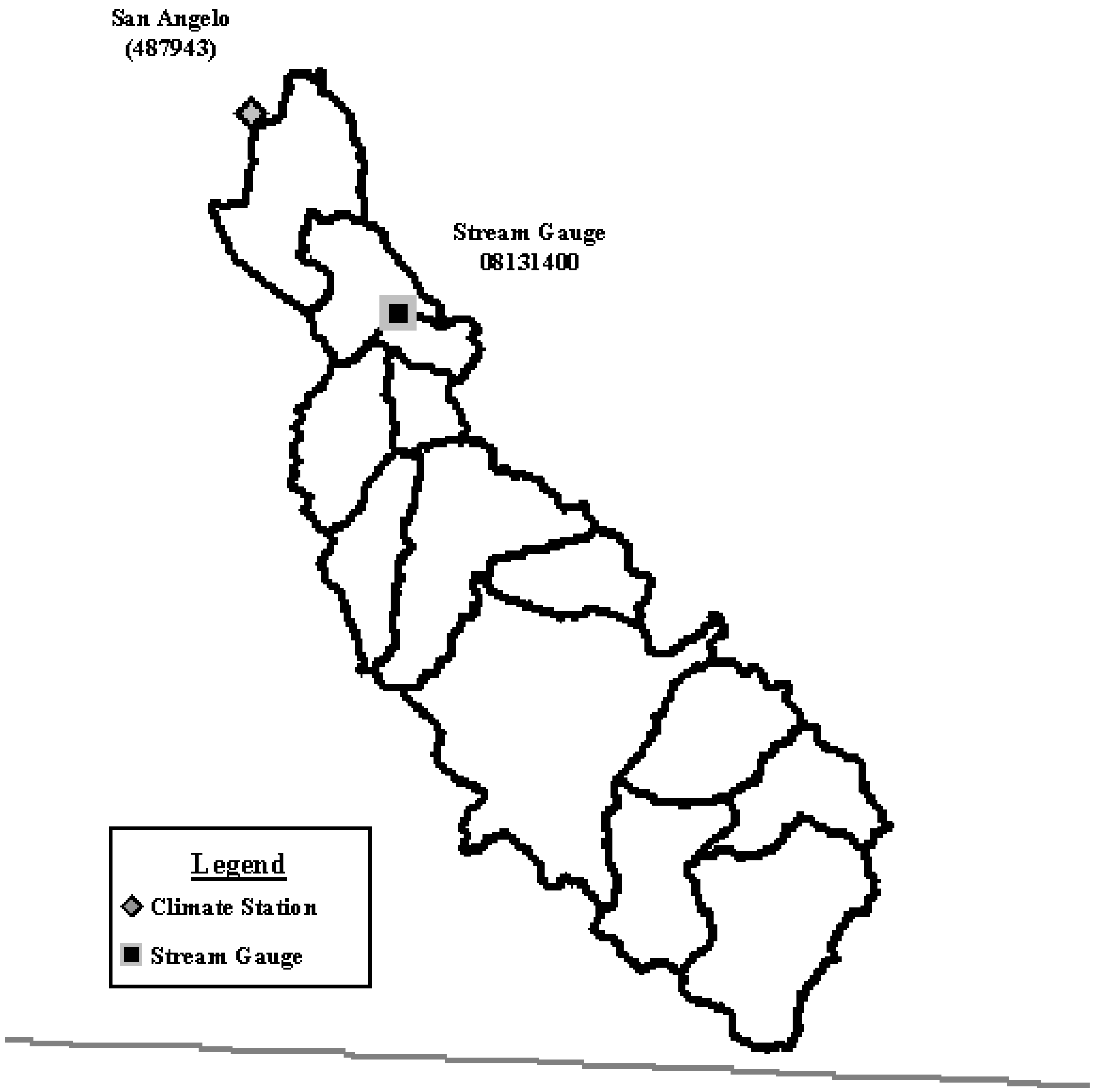

Figure TBN-9. Climate and Stream Gauge Stations in Pecan Creek.

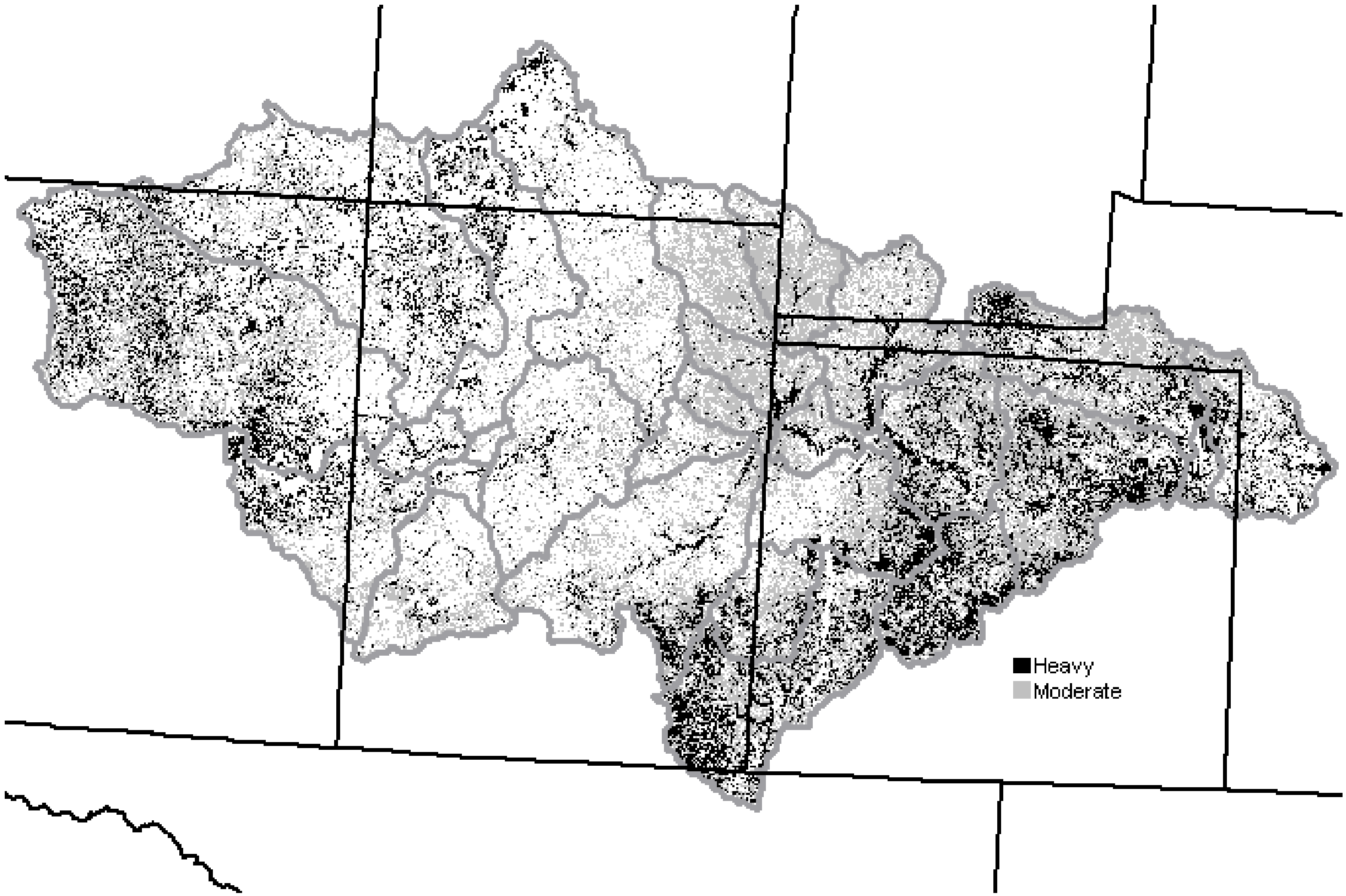

Figure TBN-10. Areas of Heavy and Moderate Brush (oak not included) in the Middle Concho River.

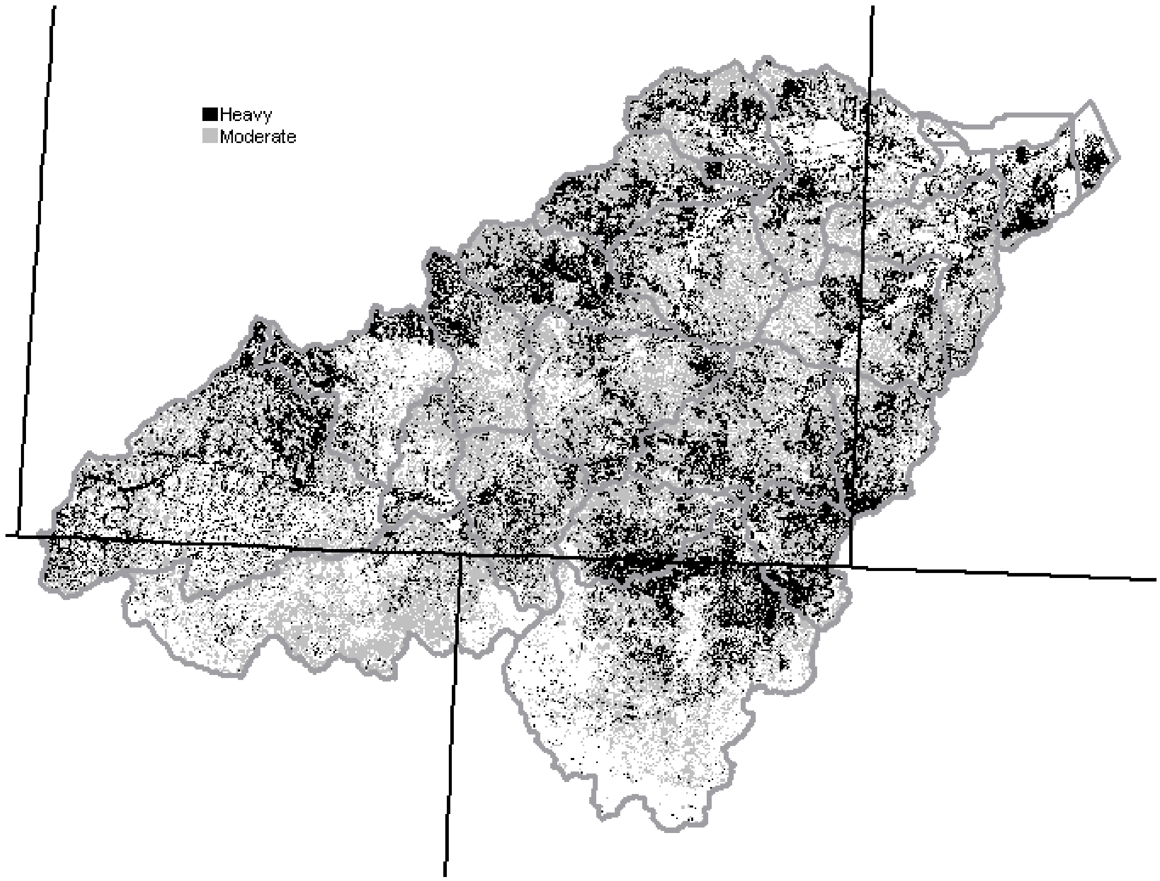

Figure TBN-11.
Areas of heavy and moderate brush (oak not included)
in Spring and Dove Creeks.

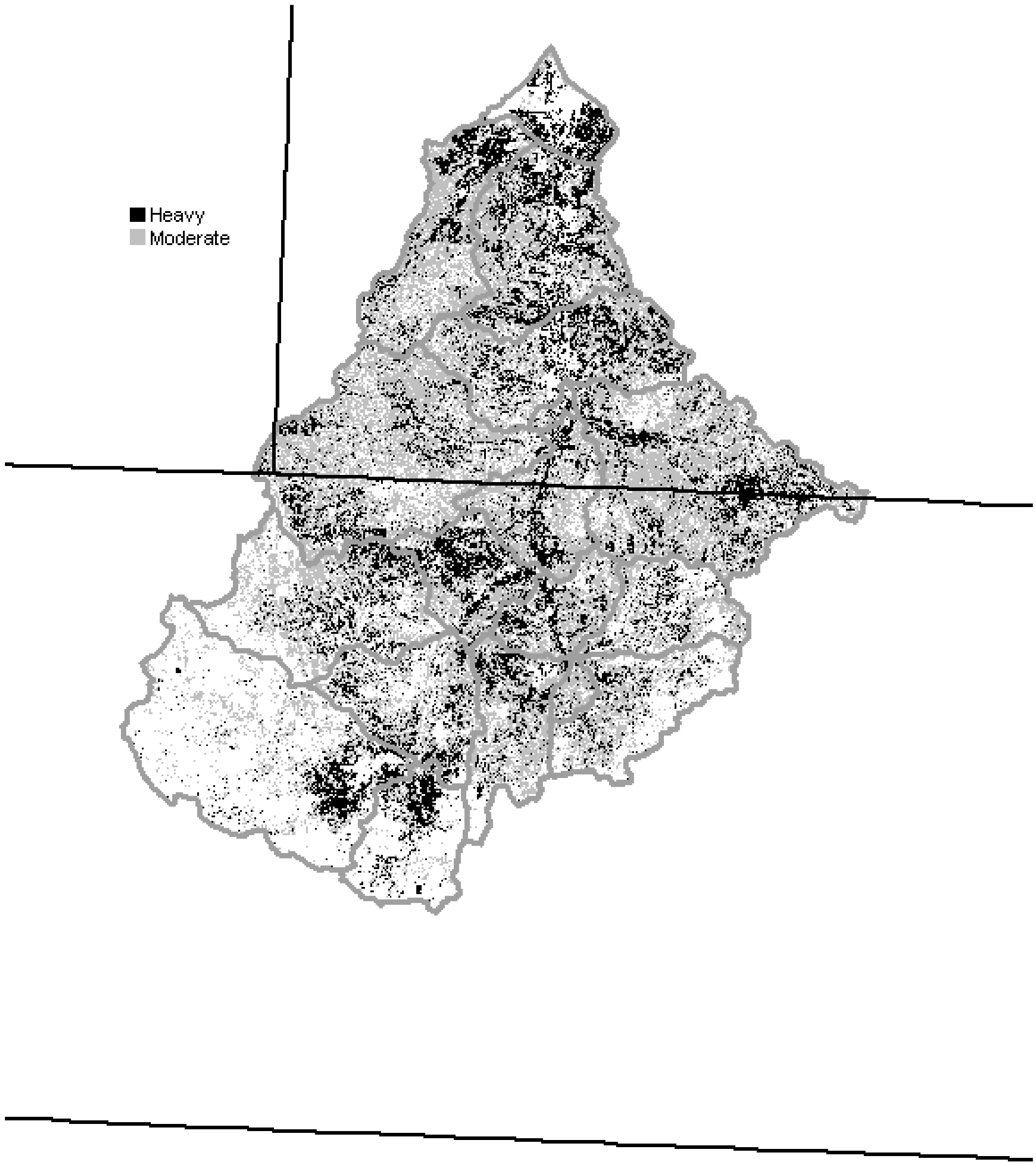

Figure TBN-12.
Areas of Heavy and Moderate Brush (oak not included)
in the South Concho River.

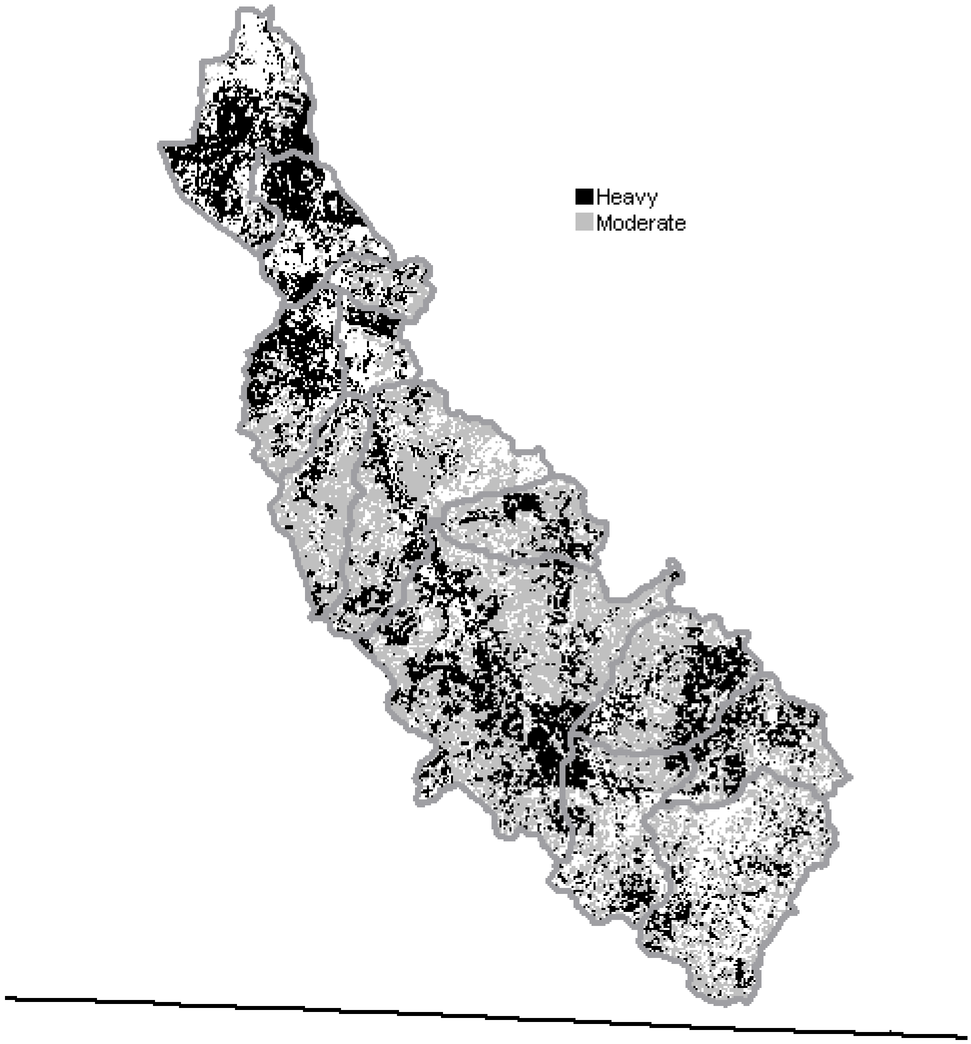

Figure TBN-13.
Areas of heavy and moderate brush (oak not included) in Pecan Creek.

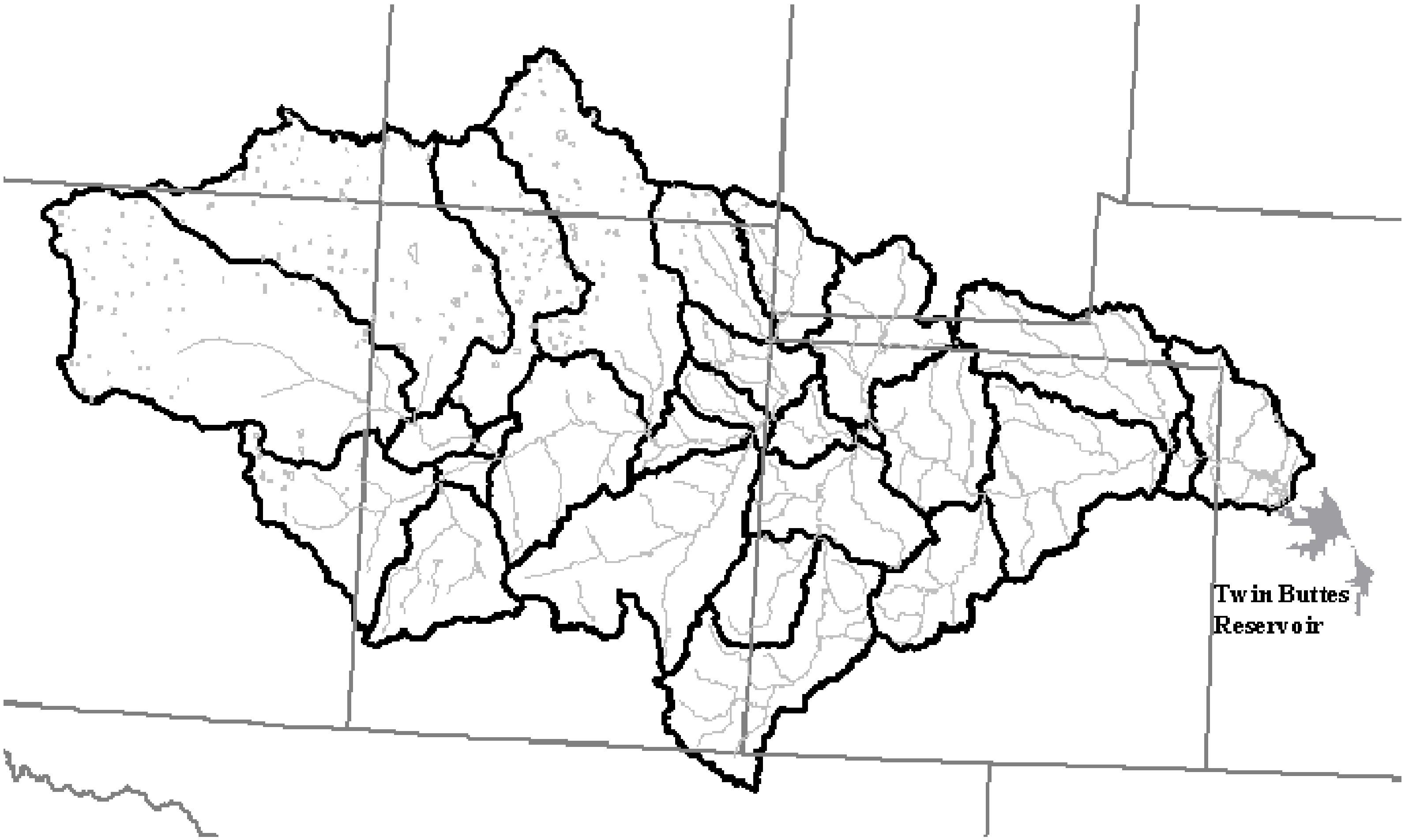

Figure TBN-14. Stream network and Twin Buttes Reservoir in the Middle Concho River.

Figure TBN-15.
Stream network and significant ponds and reservoirs in Spring and Dove Creeks
(from Texas Natural Resource Conservation Commission inventory of dams).

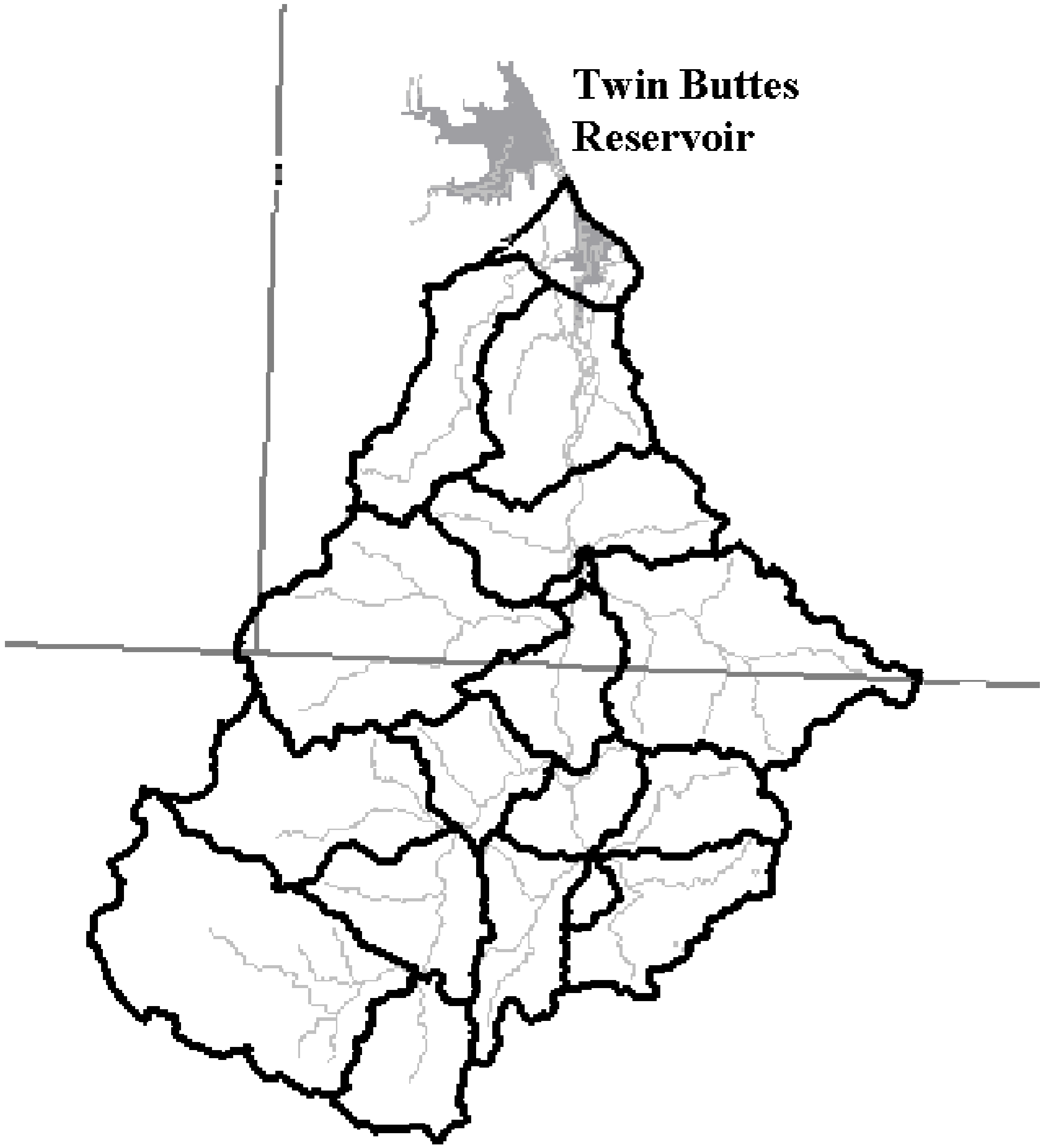

Figure TBN-16.
Stream network and Twin Buttes Reservoir in the South Concho River.

Figure TBN-17. Stream network and Lake Nasworthy in Pecan Creek.

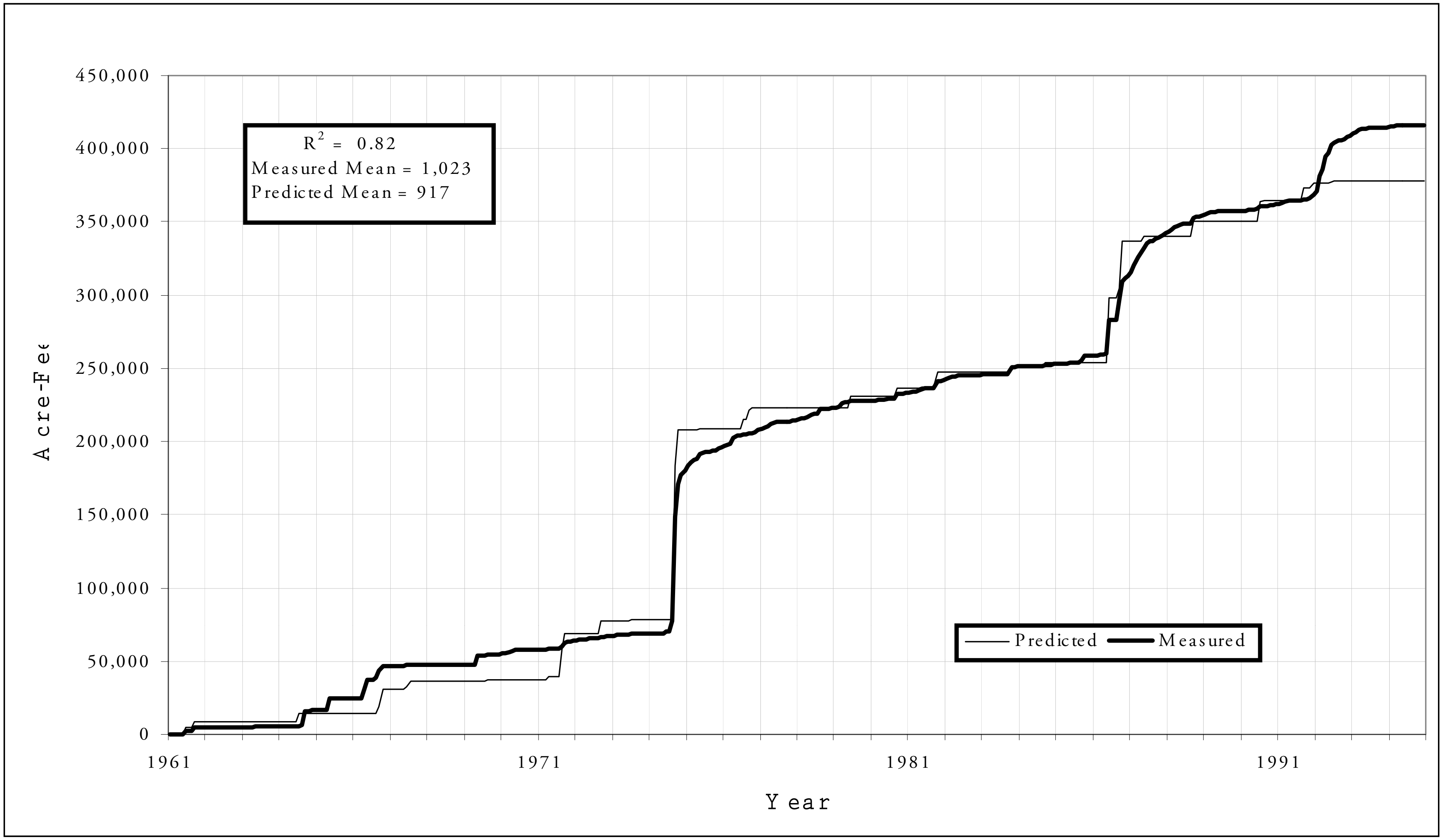

Figure TBN-18.
Cumulative monthly total measured and predicted stream flow at gauge 08128400 (near Tankersley), Middle Concho River, 1961 through 1994. Monthly statistics are shown in box.

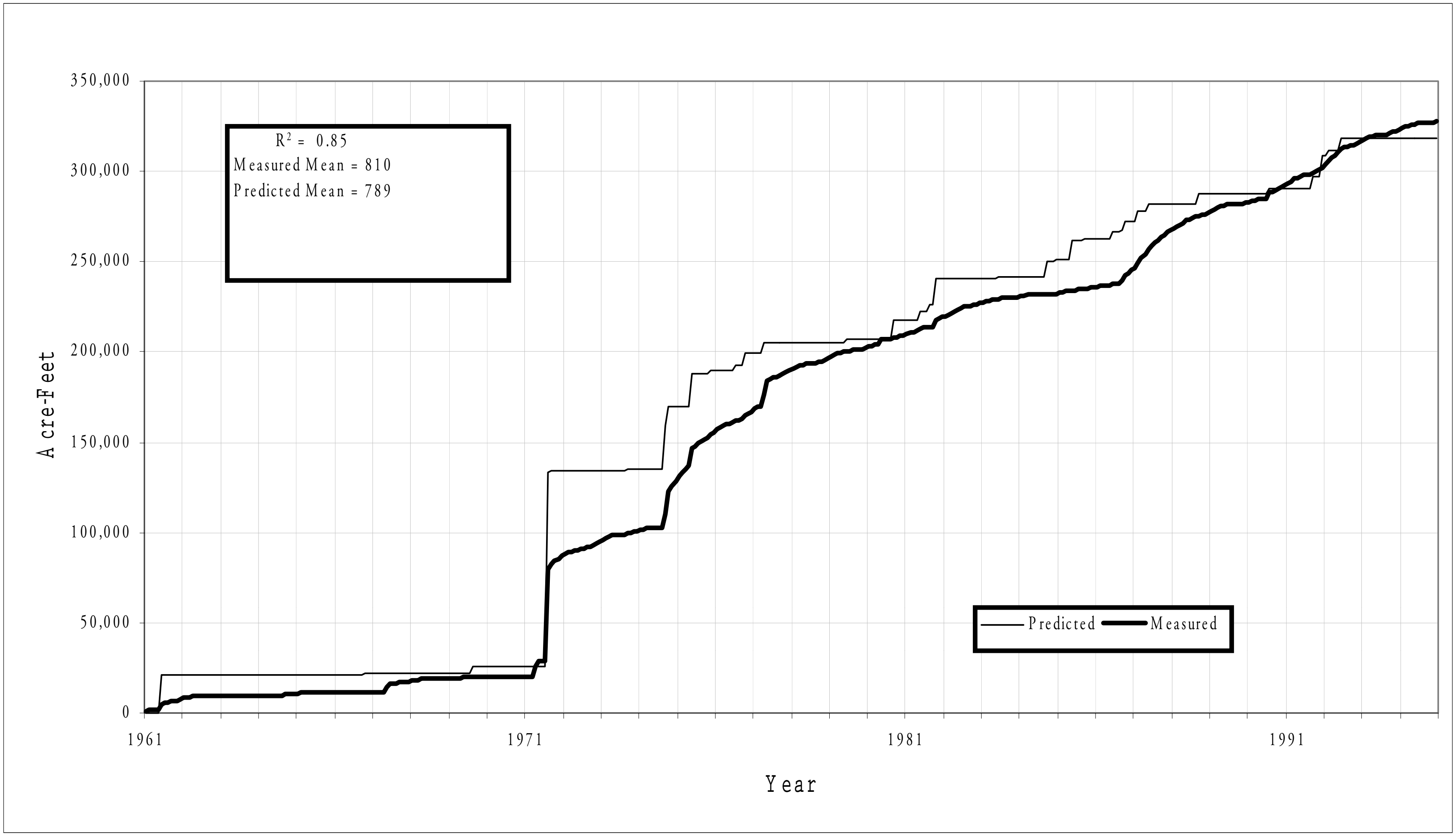

Figure TBN-19. Cumulative monthly total measured and predicted stream flow at gauge 08129300 (above Tankersley), Spring Creek, 1961 through 1994. Monthly statistics are shown in box.

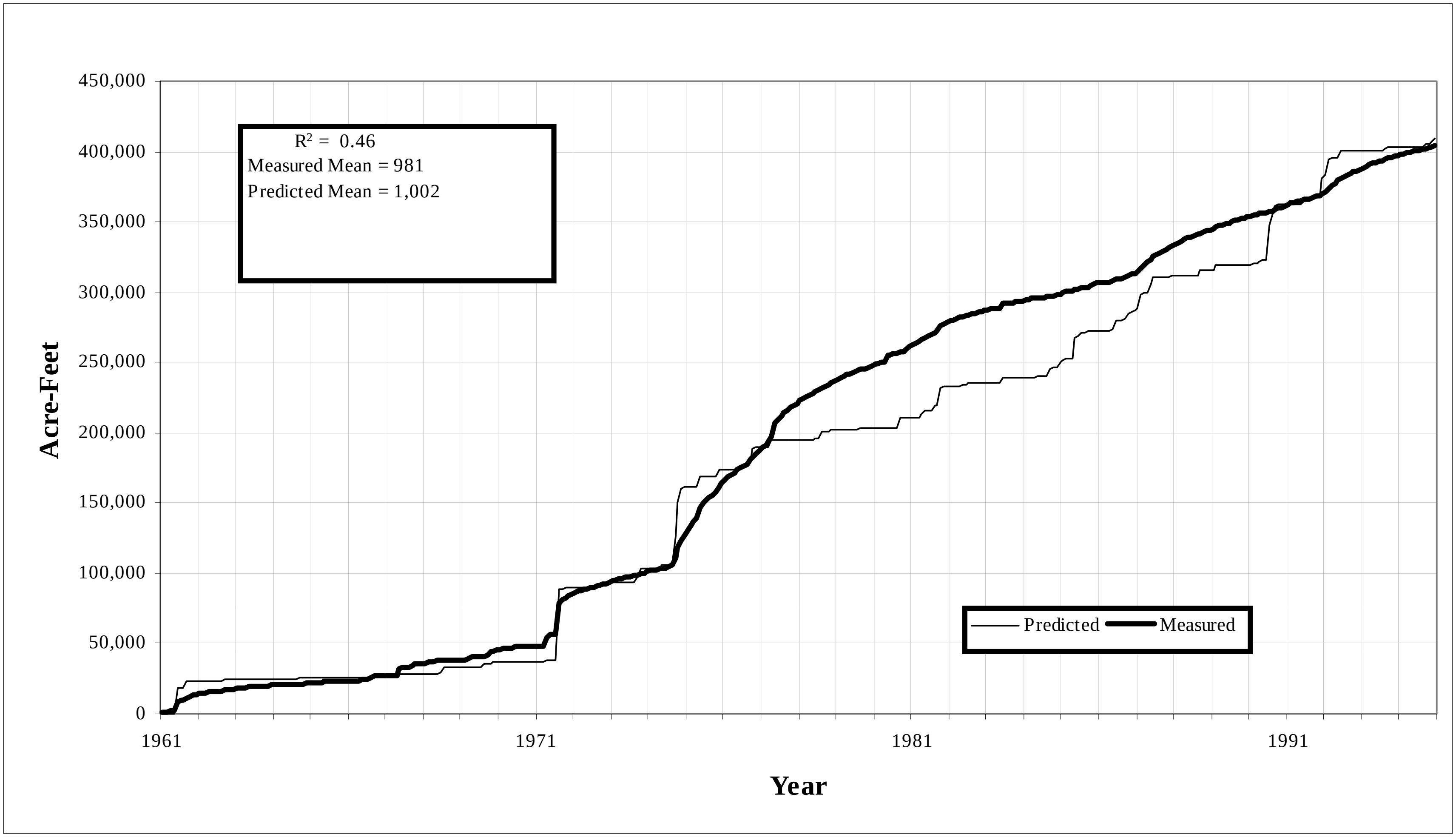

Figure TBN-20. Cumulative monthly total measured and predicted stream flow at gauge 08130500 (at Knickerbocker), Dove Creek, 1961 through 1994. Monthly statistics are shown in box.

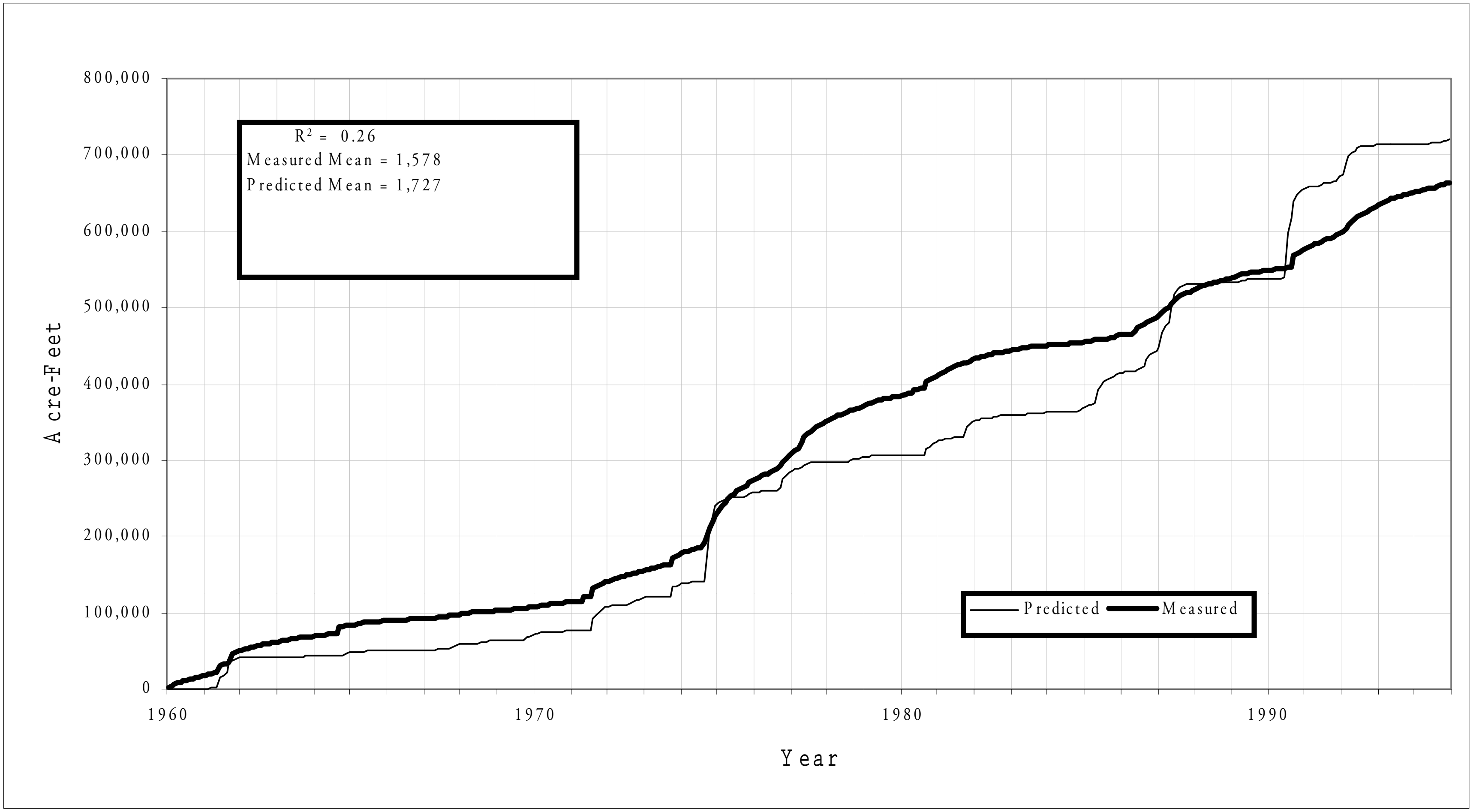

Figure TBN-21. Cumulative monthly total measured and predicted stream flow at gauge 08128000 (at Christoval), South Concho River, 1960 through 1994. Monthly statistics are shown in box.

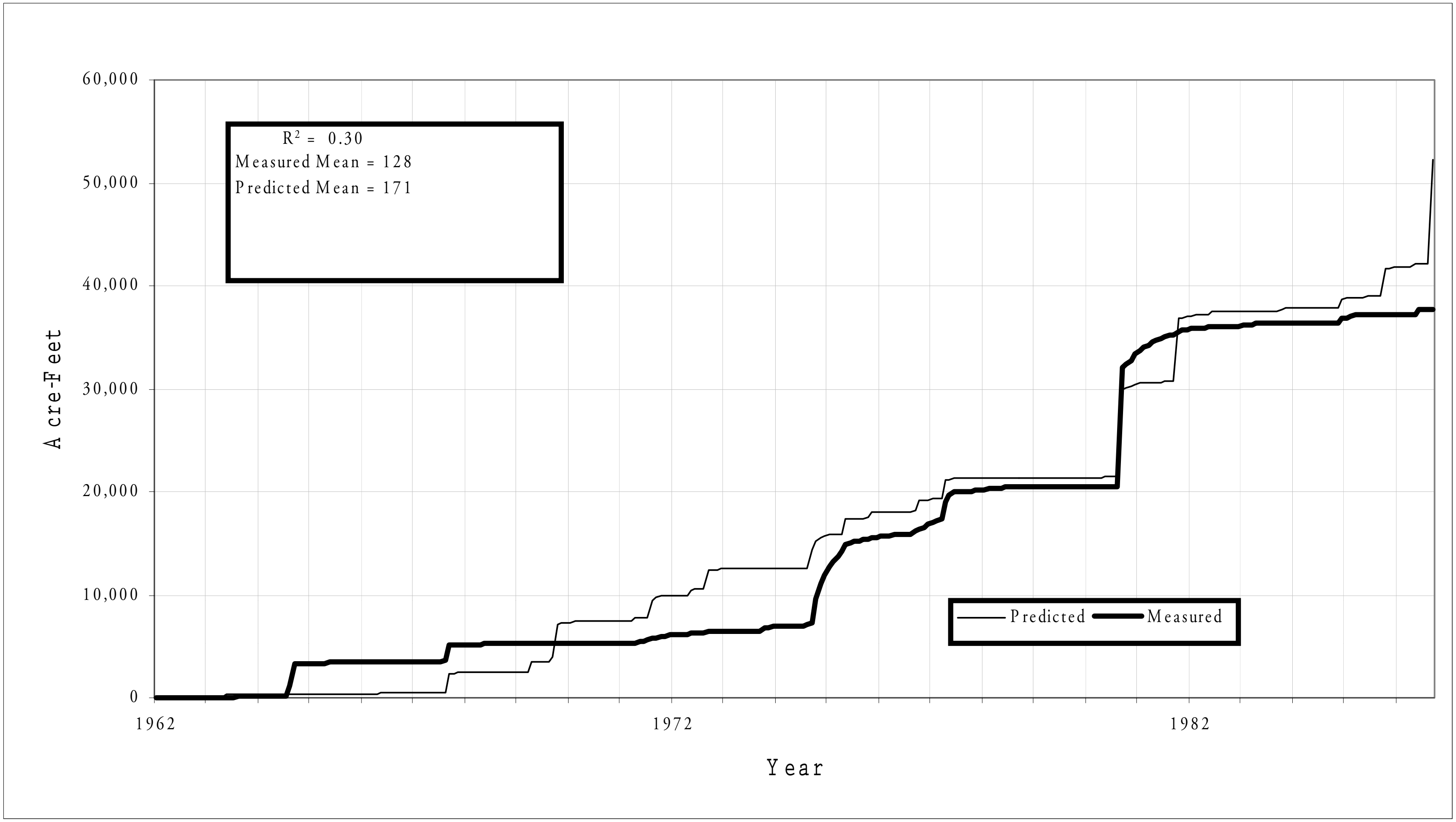

Figure TBN-22. Cumulative monthly total measured and predicted stream flow at gauge 08131400 (near San Angelo), Pecan Creek, 1962 through 1986. Monthly statistics are shown in box.

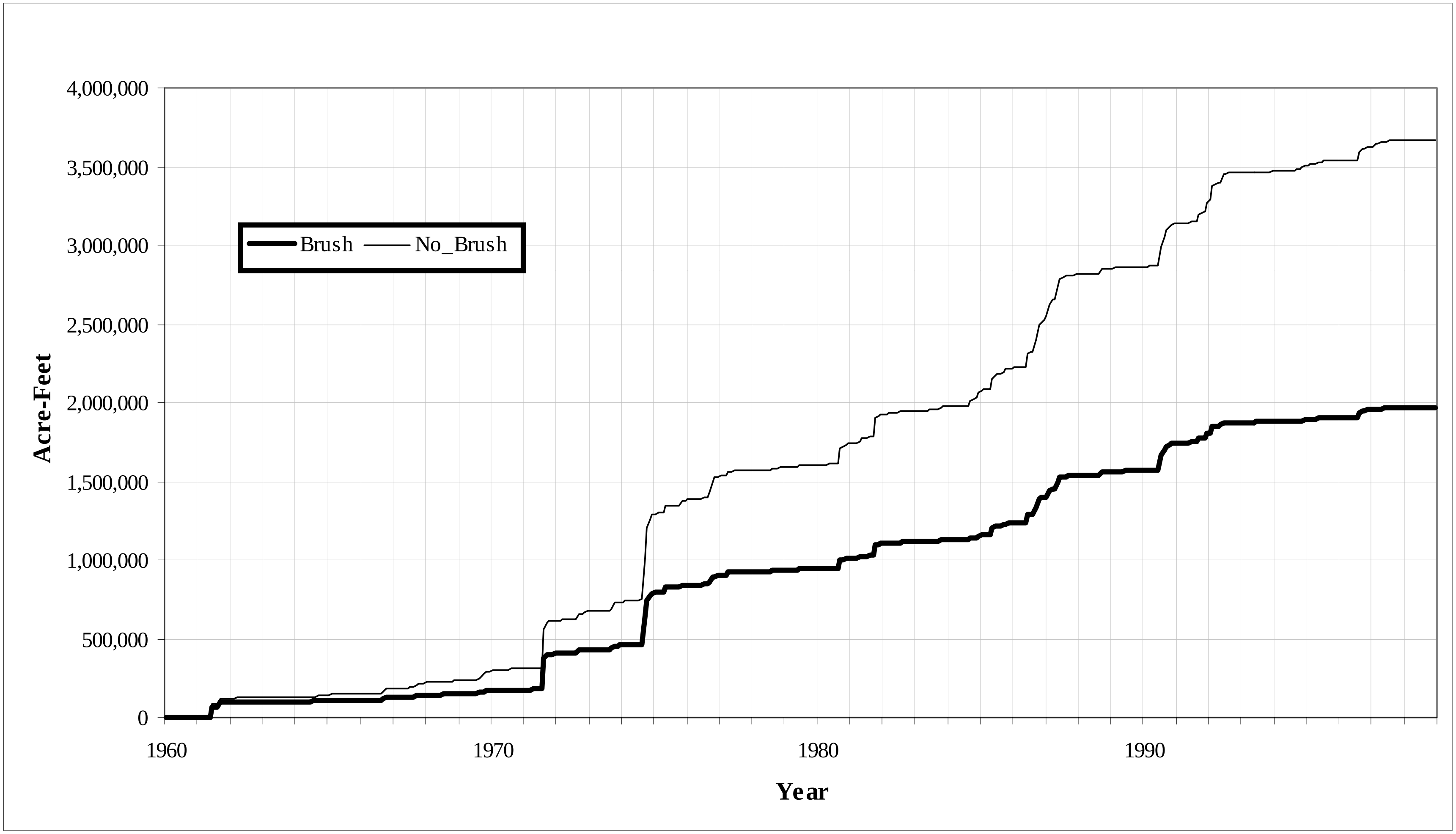

Figure TBN-23.
Cumulative monthly total predicted flow to Twin Buttes Reservoir with and without brush, 1960 through 1998.

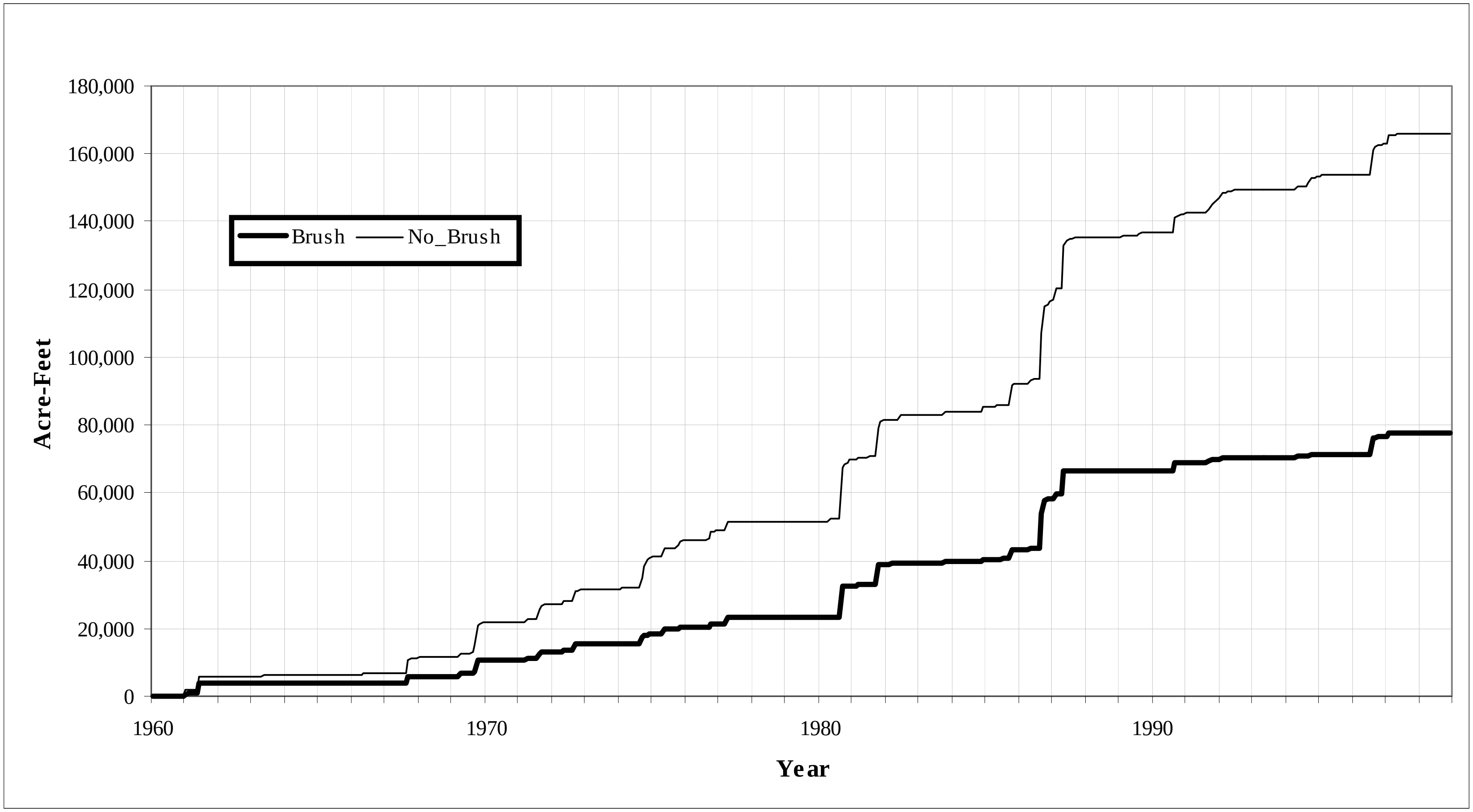

Figure TBN-24. Cumulative monthly total predicted flow to Lake Nasworthy with and without brush, 1960 through 1998.

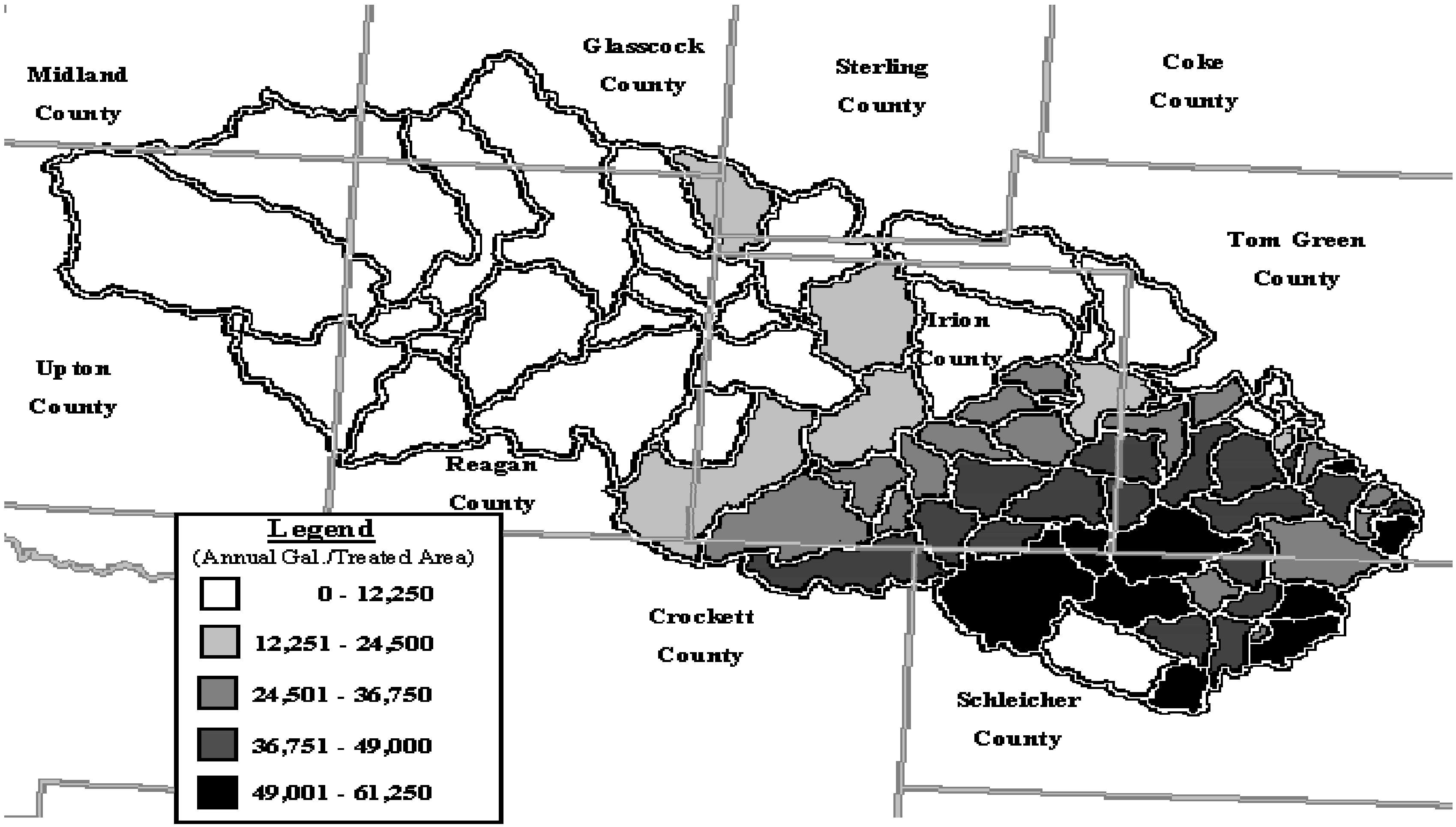

Figure TBN-25.
Annual increase in water yield per treated acre due to brush removal,
Twin Buttes/Nasworthy Watershed, 1960 through 1998.

CHAPTER 16
TWIN BUTTES/NASWORTHY WATERSHED
ECONOMIC ANALYSIS

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INTRODUCTION

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

BRUSH CONTROL COSTS

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

Obviously, the costs of control will vary among brush type-density categories. Present values (using an 8% discount rate) of control programs are used for comparison since some of the treatments will be required in the first and second years of the program while others will not be needed until year 6 or 7. Present values of total control costs in the project area (per acre) range from $39.61 for moderate mesquite that can be initially controlled with herbicide treatments to $94.89 for mechanical control of heavy cedar, mesquite and mixed brush. The costs of treatments, year those treatments are needed and treatment life for each brush type density category are detailed in Table 1.

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

Heavy Cedar – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	85.00	85.00
5	IPT or Burn	15.00	9.89
		Total	94.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Heavy Mesquite – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	85.00	85.00
5	IPT or Burn	15.00	9.89
		Total	94.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Heavy Mesquite – Chemical

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Aerial Herbicide	26.00	26.00
5	Aerial Herbicide	26.00	17.70
8	IPT or Burn	15.00	7.65
		Total	51.35

Heavy Mixed – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	85.00	85.00
5	IPT or Burn	15.00	9.89
		Total	94.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Moderate Cedar – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	55.00	55.00
5	IPT or Burn	15.00	9.89
		Total	64.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Moderate Mesquite – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	55.00	55.00
5	IPT or Burn	15.00	9.89
		Total	64.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

Moderate Mesquite - Chemical

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Aerial Herbicide	26.00	26.00
5	IPT or Burn	20.00	13.61
		Total	39.61

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

Moderate Mixed – Mechanical Choice[1]

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	55.00	55.00
5	IPT or Burn	15.00	9.89
		Total	64.89

[1]Choice of tree dozing with rake, stack and burn, tree shearing with stump spray and later burn, or excavation and later burn.

* Middle and South Concho River Watersheds

LANDOWNER AND STATE COST SHARES

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

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

Brush Type-Density Classification	Brush Control (Or) No Control	Program Year									
		0	1	2	3	4	5	6	7	8	9
Heavy Cedar	Brush Control	70.0	55.0	45.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	No Control	70.0	70.0	70.1	70.2	70.3	70.4	70.5	70.6	70.7	70.8
Heavy Mesquite	Brush Control	38.0	33.0	28.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	No Control	38.0	38.0	38.1	38.1	38.2	38.2	38.3	38.3	38.4	38.4
Heavy Mix	Brush Control	50.0	43.0	36.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	No Control	50.0	50.0	50.1	50.2	50.3	50.4	50.5	50.5	50.6	50.6
Moderate Cedar	Brush Control	52.0	43.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
	No Control	52.0	52.3	52.7	53.0	53.4	53.8	54.1	54.4	54.7	54.9
Moderate Mesquite	Brush Control	32.0	28.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	No Control	32.0	32.2	32.4	32.6	32.8	33.0	33.2	33.4	33.6	33.7
Moderate Mix	Brush Control	40.0	35.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	No Control	40.0	40.2	40.5	40.8	41.0	41.3	41.6	41.8	42.0	42.2

* Middle and South Concho River Watersheds

As with the brush control practices, the grazing capacity estimates represent a consensus of expert opinion obtained through discussions with landowners, Texas Agricultural Experiment Station and Extension Service Scientists and USDA-NRCS Range Specialists with brush control experience in the area. Livestock grazing capacities range from about 25 acres per AUY for land on which mesquite is controlled to 70 acres per animal unit year (AUY) for land infested with heavy cedar.

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

Rancher benefits were also calculated for the financial changes in existing wildlife operations. Most of these operations in this region were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. Therefore, wildlife costs and revenues were entered into the model as simple entries in the project period. For control of heavy brush categories, wildlife revenues are expected to increase by about $0.50 per acre (from $8.00 per acre to $8.50 per acre) due principally to the resulting improvement in quail habitat. Wildlife revenues would not be expected to change with implementation of brush control for the moderate brush type-density categories.

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

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Calves	472.50	Pound	0.77	363.83
Cows	111.1	Pound	.40	0
Bulls	10.0	Pound	.50	0
			Total	363.83

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	500.0	Pound	0.10	50.00
Salt & Minerals	27.0	Pound	0.20	5.40
Marketing	1.0	Head	6.32	6.32
Veterinary Medicine	1.0	Head	15.00	15.00
Miscellaneous	1.0	Head	12.00	12.00
Net Replacement Cows[3]	1.0	Head	35.28	35.28
Net Replacement Bulls[4]	1.0	Head	6.09	6.09
			Total	130.09

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

* Middle and South Concho River Watersheds

Table 3b. Investment Analysis Budget, Sheep Production*

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Lambs	315.0	Pound	0.85	267.75
Ewes	0.83	Head	30.00	0
Rams	0.037	Head	50.00	0
Wool	8.0	Pound	1.00	8.00
			Total	275.75

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	400.0	Pound	0.10	40.00
Salt & Minerals	90.0	Pound	0.20	18.00
Marketing	1.0	Head	1.00	5.00
Veterinary Medicine	1.0	Head	3.00	15.00
Shearing	1.2	Head	2.00	12.00
Miscellaneous	1.2	Head	1.00	6.00
Net Replacement Ewes[3]	1.0	Head	34.80	34.80
Net Replacement Rams[4]	1.0	Head	7.80	7.80
			Total	138.60

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

* Middle and South Concho River Watersheds

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

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Kids	0.80	Head	50.00	240.00
Nannies	0.167	Head	25.00	0
Bucks	0.0076	Head	50.00	0
			Total	$240.00

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	400.0	Pound	0.10	40.00
Salt & Minerals	73.5	Pound	0.20	14.70
Marketing	1.0	Head	1.00	6.00
Veterinary Medicine	1.0	Head	2.50	15.00
Miscellaneous	1.0	Head	1.17	7.00
Net Replacement Nannies[3]	1.0	Head	36.48	36.48
Net Replacement Bucks[4]	1.0	Head	9.36	9.36
			Total	$128.54

WARNING – This Information Does Not Contain All Revenues Nor All Costs Associated With The Described Production Enterprise.

* Middle and South Concho River Watersheds

With the above information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $9.91 per acre for control of moderate mixed brush to $16.59 per acre for the control of heavy cedar (Table 4).

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state per acre cost share of brush control in the project area range from $29.12 for control of moderate mesquite with chemical treatments to $79.23 for control of heavy mesquite 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 Table 4.

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

Brush Category by Type & Density	PV Total Cost ($/Acre)	Landowner Share ($/Acre)	Landowner (Percent)	State Share ($/Acre)	State (Percent)
Heavy Cedar	94.89	16.59	17.5	78.30	82.5
Heavy Mesquite (Mechanical One)	94.89	15.66	16.5	79.23	83.5
Heavy Mesquite (Chemical)	51.35	15.66	30.5	35.69	69.5
Heavy Mixed Brush	94.89	16.35	17.2	78.54	82.8
Moderate Cedar	64.89	11.79	18.2	53.10	81.8
Moderate Mesquite (Mechanical)	64.89	10.49	16.2	54.40	83.8
Moderate Mesquite (Chemical)	39.61	10.49	26.5	29.12	73.5
Moderate Mixed Brush	64.89	9.91	15.3	54.98	84.7
Average[1]	71.29	13.37	19.74	57.92	80.26

* Twin Buttes and Nasworthy Watersheds

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

COST OF ADDITIONAL WATER

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

The Twin Buttes/Nasworthy watershed is a complex of individual watersheds including the Middle Concho River, Spring and Dove Creeks, the South Concho River, and Pecan Creek, all of which drain into the Twin Buttes Reservoir and Lake (Nasworthy before becoming the Main Concho River. Costs of added water resulting from the removal of brush was determined for each component of the complex.

The cost of added water was determined to average $204.05 per acre-foot for the Middle Concho Watershed (Table 5a). For the Dove and Spring Creek Watersheds, the cost of added water from brush control averages $60.14 per acre-foot (Table 5b). Average cost per acre-foot for added water in the South

Concho watershed is $50.92 (Table 5c). For the Pecan Creek watershed, the cost of added water from brush control averages $70.80 per acre-foot (Table 5d). The average cost of water gained from brush control is $90.79 per acre-foot for the entire Twin Buttes/Nasworthy watershed.

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	0.00	0.00	0.00	0.00
2	263,044.78	73.55	573.87	458.37
3	0.00	-------	-------	0.00
4	0.00	-------	-------	0.00
5	196,104.30	88.88	693.43	282.80
6	0.00			0.00
7	738,932.40	246.18	1,920.73	384.71
8	58,794.56	28.86	225.15	261.13
9	491,068.80	292.63	2,283.12	215.09
10	23,204.70	8.97	69.95	331.74
11	0.00	-------	-------	0.00
12	991,240.84	529.97	4,134.79	239.73
13	951,419.52	653.48	5,098.47	186.61
14	448,585.92	318.09	2,481.75	180.75
15	266,848.74	159.31	1,242.97	214.69
16	2100,789.60	1,147.64	8,953.90	234.62
17	1137,920.00	990.03	7,724.21	147.32
18	1743,997.00	1,122.74	8,759.58	199.10
19	490,770.52	287.20	2,240.73	219.02
20	57,670.86	30.95	241.47	238.83
21	1668,651.50	848.92	6,623.25	251.94
22	1097,959.40	658.69	5,139.10	213.65
23	3511,937.00	2,841.34	22,168.13	158.42
24	2119,024.20	1,575.72	12,293.73	172.37
25	2338,374.70	1,720.77	13,425.42	174.18
26	2725,217.00	1,681.90	13,122.21	207.68
27	3382,707.30	1,765.91	13,777.64	245.52
28	1436,962.30	667.64	5,208.96	275.86
Totals:	28,241,226.00	----------	138,402.60	Average: $204.05

* Middle Concho River Watershed

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	1,696,697.98	2,950.09	23,016.58	73.72
2	935,717.30	2,900.15	22,626.94	41.35
3	1,329,157.42	4,344.69	33,897.24	39.21
4	532,079.44	1,753.06	13,677.34	38.9
5	9,210.58	13.51	105.41	87.38
6	604,906.52	1,372.42	10,707.66	56.49
7	728,537.52	1,628.70	12,707.08	57.33
8	259,313.22	465.5	3,631.85	71.4
9	584,263.92	1,033.26	8,061.46	72.48
10	596,360.72	1,083.81	8,455.92	70.53
11	994,549.26	2,250.85	17,561.16	56.63
12	1,073,602.04	2,479.52	19,345.25	55.5
13	566,362.68	1,410.43	11,004.16	51.47
14	873,983.02	1,952.76	15,235.43	57.37
15	846,784.56	1,572.91	12,271.85	69
16	783,846.14	1,410.37	11,003.74	71.23
17	606,748.36	1,059.73	8,267.98	73.39
18	516,411.00	717.51	5,598.00	92.25
19	94,034.04	42.45	331.19	283.93
20	872,345.14	976.3	7,617.11	114.52
21	682,862.88	1,290.93	10,071.84	67.8
22	68,301.02	35.07	273.61	249.63
23	333,447.24	481.42	3,756.04	88.78
Totals:	15,589,522.00	----------	259,224.83	Average: $60.14

* Spring and Dove Creek Watersheds

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	0.00	0.00	0.00	0.00
2	141,602.83	463.68	3,617.62	39.14
3	611,666.89	1,872.35	14,608.07	41.87
4	420,561.43	1,124.62	8,774.29	47.93
5	419,905.69	1,172.47	9,147.61	45.90
6	71,133.39	144.98	1,131.14	62.89
7	292,600.67	896.67	6,995.81	41.83
8	257,138.27	803.92	6,272.19	41.00
9	361,328.87	770.30	6,009.89	60.12
10	461,294.92	901.88	7,036.43	65.56
11	1,302,785.48	4,096.06	31,957.49	40.77
12	463,386.63	1,206.61	9,413.98	49.22
13	1,448,543.59	3,050.71	23,801.64	60.86
14	34,600.85	81.44	635.36	54.46
15	793,152.09	2,048.80	15,984.78	49.62
16	959,060.47	2,216.62	17,294.07	55.46
17	676,635.19	1,598.95	12,475.01	54.24
18	209,888.66	61.04	476.26	440.70
Totals:	8,925,285.94	-----------	175,631.64	Average: $50.82

* South Concho River Watershed

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

Sub-basin No.	Total State Cost (Dollars)	Avg. Annual Water Increase (Acre-Feet)	10 Year Added Water (Acre-Feet)	State Cost for Added Water (Dollars Per Acre Foot)
1	203,244.20	631.73	4,928.78	41.24
2	144,765.20	346.84	2,706.02	53.50
3	216,383.10	351.69	2,743.90	78.86
4	181,265.50	321.56	2,508.81	72.25
5	664,743.10	1,309.27	10,214.91	65.08
6	122,015.10	318.93	2,488.32	49.04
7	261,917.40	515.70	4,023.48	65.10
8	132,148.50	353.06	2,754.56	47.97
9	147,649.20	174.59	1,362.18	108.39
10	48,561.62	41.22	321.57	151.02
11	56,165.89	45.62	355.89	157.82
12	118,131.50	48.20	376.06	314.13
13	196,544.80	56.03	437.17	449.59
Totals:	$2,493,535.00	----------	35,221.63	Average: $70.80

*Pecan Creek Watershed

CHAPTER 17
UPPER COLORADO RIVER WATERSHED – HYDROLOGIC SIMULATION

Steven T. Bednarz, Civil Engineer, USDA-Natural Resources Conservation Service Blackland Research and Extension Center

WATERSHED DATA

Location
The Upper Colorado River Watershed is located in west and central Texas (Figures 1 and UC-1). The upper portion of the watershed is in the High Plains Major Land Resource Area (MLRA), and the lower portion is in the Edwards and Rolling Plains MLRA'0s.

Topography
The outlet or "catchment" for the portion of the Upper Colorado River simulated in this study is Lake O.H. Ivie, which is located in sub-basin number 70. The sub-basin delineation and numbers are shown in Figure UC-2. Roads (obtained from the Census Bureau) are shown in Figure UC-3.

Weather Data
The average annual rainfall for the Upper Colorado River Watershed varied from 14.3 inches in the western portion of the watershed to 24.7 inches in the eastern portion. The composite average for the entire watershed was 18.4 inches. Weather stations used for modeling are shown in Figure UC-4. For each sub-basin, precipitation and temperature data were retrieved by the SWAT input interface for the climate station nearest the centroid of the sub-basin.

Soils
The dominant soil series in the portion of the Upper Colorado River watershed where brush treatment was simulated were Amarillo, Brownfield, Ector, Miles, Nuvalde, Olton, Portales, Potter, Rowena, and Vernon. These ten soil series represented about 53 percent of the area. A short description of each follows:

Amarillo. The Amarillo series consists of very deep, well drained, moderately permeable soils. These soils formed in calcareous, loamy eolian sediments in the Blackwater Draw Formation of Pleistocene age. These soils are on nearly level to gently sloping plains. Slope ranges from 0 to 5 percent. Mean annual precipitation is 19 inches and the mean annual temperature is 60 degrees F.

Brownfield. The Brownfield series consists of very deep, well drained, moderately permeable soils that formed in moderately sandy, eolian sediments in the Blackwater Draw Formation of Pleistocene age. Brownfield soils are on nearly level to gently sloping plains. Slope ranges from 0 to 5 percent. The mean annual precipitation is 19 inches and the mean annual temperature is 61 degrees F.

Ector. The Ector series consists of very shallow or shallow, well drained soils that are moderately permeable above a very slowly permeable limestone bedrock. They formed in loamy residuum. These gently sloping to very steep upland soils have slopes ranging from 1 to 60 percent.

Miles. The Miles series consists of very deep, well drained, moderately permeable soils that formed in loamy alluvial materials. These soils are on nearly level to moderately sloping terrace pediments on uplands in the Central Rolling Red Plains (MLRA 78B, 78C). Slopes range from 0 to 8 percent.

Nuvalde. The Nuvalde series consists of very deep, well drained, moderately permeable soils that formed in limey alluvium. These soils are on nearly level to gently sloping stream terraces and alluvial fans. Slopes range from 0 to 5 percent.

Olton. The Olton series consists of very deep, well drained, moderately slowly permeable soils that formed in loamy, calcareous eolian sediments in the Blackwater Draw Formation of Pleistocene age. These soils are on nearly level to gently sloping plains and upper side slopes of playas and draws. Slope ranges from 0 to 5 percent. Mean annual precipitation is 20 inches, and mean annual temperature is 62 degrees F.

Portales. The Portales series consists of very deep, well drained, moderately permeable soils. These soils formed in medium to moderately fine textured, calcareous, lacustrine sediments of Pleistocene age. These soils are on nearly level to very gently sloping concave plains associated with playa lake basins. Slope ranges from 0 to 1 percent. The mean annual precipitation is about 18 inches and the mean annual temperature is about 61 degrees F.

Potter. The Potter series consists of soils that are shallow to a fractured and weathered caliche layer. They are well drained, moderately permeable soils that formed in moderately to strongly cemented caliche of Miocene-Pliocene age. These soils are on very gently sloping to steep sloping convex hills, ridges, and upper side slopes, around the margin of larger playa lakes, ancient drainage ways, and along the Caprock Escarpment. Slopes range from 1 to 30 percent. The mean annual precipitation is 19 inches and the mean annual temperature is 61 degrees F.

Rowena. The Rowena series consists of very deep, well drained, moderately slowly permeable soils on upland plains. They formed in calcareous loamy and clayey sediments. Slopes range from 0 to 3 percent.

Vernon. The Vernon series consists of moderately deep, well drained, very slowly permeable soils that formed in residuum weathered from claystone. These soils are on gently sloping to steep uplands of the Central Rolling Red Plains (MLRA-78B, 78C), Central Limestone Prairies (MLRA 78D) and North Central Prairie (MLRA 80B). Slopes range from 1 to 45 percent.

Land Use/Land Cover
Figure UC-5 shows the areas of heavy and moderate brush (oak not included) in the Upper Colorado River Watershed. This was the area of brush removed or treated in the no-brush simulation. Brush treatment was not simulated in sub-basins west of the 18 inch isohyet.

Ponds, Reservoirs, Withdrawals
Surface area, storage, and drainage area were obtained from the Texas Natural Resource Conservation Commission (TNRCC) for existing inventory-sized ponds and reservoirs in the watershed (Figure UC-6), and input to the SWAT model. Withdrawals from reservoirs for municipal and other uses were estimated from data obtained from Texas Water Development Board (TWDB). Since data for low flow withdrawals (brine control) from the Colorado River was not available, an estimated withdrawal of 7 cubic feet per second (14 acre-feet per day) was used for sub-basin 53.

Model Input Variables
Significant input variables for the SWAT model for the Upper Colorado River Watershed are shown in Table UC-1. The input variables for the no-brush condition, with one exception, were the same as the calibration variables, with the change in land use being the only difference between the two simulations. The exception is that we assumed the shallow aquifer re-evaporation coefficient would be higher for brush than for other types of cover because brush is deeper rooted, and opportunity for re-evaporation from the shallow aquifer is higher. The re-evaporation coefficient for all brush hydrologic response units (HRU – combinations of soil and land use/cover) is 0.4, and for non-brush HRU's is 0.1.

UPPER COLORADO RIVER WATERSHED RESULTS

Calibration
SWAT was calibrated for flow at 13 USGS stream gauges shown in Figure UC-7. The results of calibration are shown for gauges 08117995, 08123800, 08121000 and 08126380 in Figures UC-8 through UC-11. The simulation period for gauge 08117995 was 1988 through 1998. The simulation period for the other 3 gauges was 1960 through 1998. Measured and predicted total monthly flows compare reasonably well with R^2 values of 0.49 for gauge 08123800, 0.50 for gauge 08121000, 0.44 for gauge 08126380, and 0.24 for gauge 08117995. The low value of R^2 at gauge 08117995 was probably due to the spatial variability of rainfall which was not reflected in measured weather data.

The measured and predicted monthly means were reasonably close for all four gauges. However, SWAT over-predicted flow at gauge 08123800 and under-predicted by a small amount at the other three gauges. At all four stream gauge stations, SWAT under-predicted flows in some portions of the simulation period and over-predicted in others. Again, this was most likely due to spatial variability of rainfall which was not reflected in measured weather data.

Brush Removal Simulation

Average annual evapotranspiration (ET) was 17.59 inches for the brush condition (calibration) and 17.34 inches for the no-brush condition, or 96% and 94% of precipitation for the brush and no-brush conditions, respectively.

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 are shown in Table UC-2. The amount of annual increase varied among the sub-basins and ranged from 0 gallons per acre of brush removed per year in sub-basin number 46, to 55,354 gallons per acre in sub-basin number 67. Variations in the amount of increased water yield were expected and were 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 were most likely due to greater rainfall volumes as well as increased density and canopy of brush.

A gray-scale graph of the sub-basins in the Upper Colorado River watershed, with water yield increases represented by varying color intensities is shown in Figure UC-12. Darker shading represents higher water yield increases. Sub-basin lines are not shown for the area west of the 18-inch isohyet, because brush treatment was not modeled in this area.

Figure UC-13 shows the average annual flow to Lakes Thomas, Colorado City, Champion Creek, Oak Creek, Spence, Ballinger, Elm Creek, and Ivie for the brush and no-brush conditions from 1960 through 1998. The average annual increase in flow to these lakes is shown in Table UC-3. The increase in volume of flow to the reservoirs was less than the water yield in some cases because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occurred between each sub-basin and the watershed outlet.

For the entire simulated watershed, the average annual water yield increased by about 49% or 142,667 acre-feet, and flow at the watershed outlet (Lake O.H. Ivie) increased by 41,995 acre-feet.

Table UC-1. SWAT Input Variables

VARIABLE	BRUSH CONDITION (CALIBRATION)	NO BRUSH CONDITION
Runoff Curve Number Adjustment	- 6 to + 4	- 6 to + 4
Soil Available Water Cap. Adj.(inches H^2O/in.soil)	0 & -0.03	0 & -0.03
Soil Evaporation Compensation Factor	0.1	0.1
Min. Shallow Aqu. Storage for GW flow (inches)	0.04 to 3.94	0.04 to 3.94
Shallow Aqu.Re-Evaporation (Revap) Coefficient	0.4	0.1
Min. Shallow Aqu. Storage for Revap (inches)	0	0
Potential Heat Units (^oC)		
Heavy Cedar	3900	N/A
Heavy Mesquite	3393	N/A
Heavy Mixed Brush	3627	N/A
Moderate Cedar	3393	N/A
Moderate Mesquite	3003	N/A
Moderate Mixed Brush	3198	N/A
Heavy Oak	3393	3393
Moderate Oak	3003	3003
Light Brush & Open Range/Pasture	2613	2613
Precipitation Interception (inches)		
Heavy Cedar	0.79	N/A
Heavy Mesquite	0	N/A
Heavy Mixed Brush	0.59	N/A
Moderate Cedar	0.59	N/A
Moderate Mesquite	0	N/A
Moderate Mixed Brush	0.39	N/A
Heavy Oak	0	0
Moderate Oak	0	0
Light Brush & Open Range/Pasture	0	0
Plant Rooting Depth (feet)		
Heavy and Moderate Brush	6.5	N/A
Light Brush & Open Range/Pasture	3.3	3.3
Maximum Leaf Area Index		
Heavy Cedar	6	N/A
Heavy Mesquite	4	N/A
Heavy Mixed Brush	4	N/A
Moderate Cedar	5	N/A
Moderate Mesquite	2	N/A
Moderate Mixed Brush	3	N/A
Heavy Oak	4	4
Moderate Oak	3	3
Light Brush	2	2
Open Range & Pasture	1	1
Channel Transmission Loss (inches/hour)	0.04 to 3.94	0.04 to 3.94
Subbasin Transmission Loss (inches/hour)	0.015 to 3.94	0.015 to 3.94
Fraction Trans. Loss Returned as Base Flow	0.5	0.5

Table UC-2. Subbasin Data and Water Yield
(Subbasins west of 18 inch isohyet not shown)

Subbasin No.	Total Area (acres)	Brush Area (Treated) (acres)	Brush Fraction (Treated)	Increase in Water Yield (gal/acre/year)	Increase in Water Yield (gallons/year)
12	219,688	67,370	0.31	8,304	559,439,440
13	114,447	38,974	0.34	8,752	341,114,277
16	41,400	2,905	0.07	7,740	22,483,504
17	332,809	80,307	0.24	3,221	258,662,343
18	115,928	8,008	0.07	7,940	63,578,516
45	192,855	70,409	0.37	13,303	936,651,614
48	86,673	33,792	0.39	19,737	666,957,730
LakeThomas Sub-Total	1,103,799	301,765	---	---	2,848,887,423
14	410,310	85,244	0.21	283	24,125,643
34	214,246	111,558	0.52	9,958	1,110,858,823
35	12,402	6,358	0.51	7,453	47,384,781
39	55,689	27,724	0.50	1,752	48,580,691
40	251,022	65,750	0.26	1,384	90,973,764
41	115,948	48,184	0.42	4,160	200,435,985
42	35,165	17,519	0.50	7,421	130,000,262
43	312,065	193,394	0.62	26,671	5,158,068,825
44	166,797	71,372	0.43	12,340	880,704,493
46	101,104	0	0.00	0	0
47	286,802	153,260	0.53	13,650	2,091,998,799
49	112,026	34,266	0.31	23,106	791,750,571
50	129,158	51,670	0.40	26,237	1,355,656,892
51	37,252	14,785	0.40	15,451	228,437,699
52	6,044	1,900	0.31	21,404	40,658,577
53	34,026	8,453	0.25	19,775	167,150,103
54	46,604	19,347	0.42	10,368	200,585,259
55	12,614	5,700	0.45	18,376	104,738,881
56	69,810	32,679	0.47	10,501	343,156,838
57	42,491	14,283	0.34	17,874	255,292,573
58	46,588	10,170	0.22	25,548	259,833,678
59	50,020	14,575	0.29	11,143	162,403,864
60	115,737	40,347	0.35	31,535	1,272,324,292
61	209,281	118,333	0.57	26,205	3,100,969,477
63	207,677	145,343	0.70	46,389	6,742,303,822
71	49,384	32,119	0.65	37,078	1,190,934,522
Lake Spence Sub-Total	3,130,263	1,324,333	---	---	25,999,329,115
23	275	68	0.25	30,304	2,056,702
62	151,532	96,616	0.64	47,225	4,562,662,619
64	191,842	103,836	0.54	30,568	3,174,002,519
65	113,345	44,505	0.39	25,291	1,125,582,148
66	64,080	18,768	0.29	43,104	808,987,807
67	148,849	54,485	0.37	55,354	3,015,979,797
68	297,452	76,466	0.26	37,586	2,874,039,243
69	34,341	7,319	0.21	20,590	150,706,327
70	146,571	47,122	0.32	40,874	1,926,086,710
Lake Ivie Sub-Total	1,148,288	449,185	---	---	17,640,103,873
GRAND TOTAL	**5,382,350**	**2,075,282**	**---**	**---**	**46,488,320,411**
Watershed Average	**---**	**---**	**0.39**	**22,401**	**---**

Table UC-3. Inflow to Reservoirs

RESERVOIR	INFLOW TO RESERVOIRS (AC-FT/YR) BRUSH	NO BRUSH	INCREASE
J.B. THOMAS	12,188	16,734	4,546
COLORADO CITY	5,807	8,369	2,562
CHAMPION CREEK	9,101	11,880	2,779
OAK CREEK	18,307	30,974	12,666
E.V. SPENCE	72,293	124,162	51,870
LAKE BALLINGER	18,339	27,595	9,256
ELM CREEK	22,885	31,706	8,821
O.H. IVIE	97,598	139,593	41,995

Note: The flow to Lake O.H. Ivie shown in Table UC-3 does not include flow from the Main Concho. Main Concho flow to Ivie is given in the "Main Concho" chapter of this report.

Figure UC-1. Location of the Upper Colorado River Watershed.

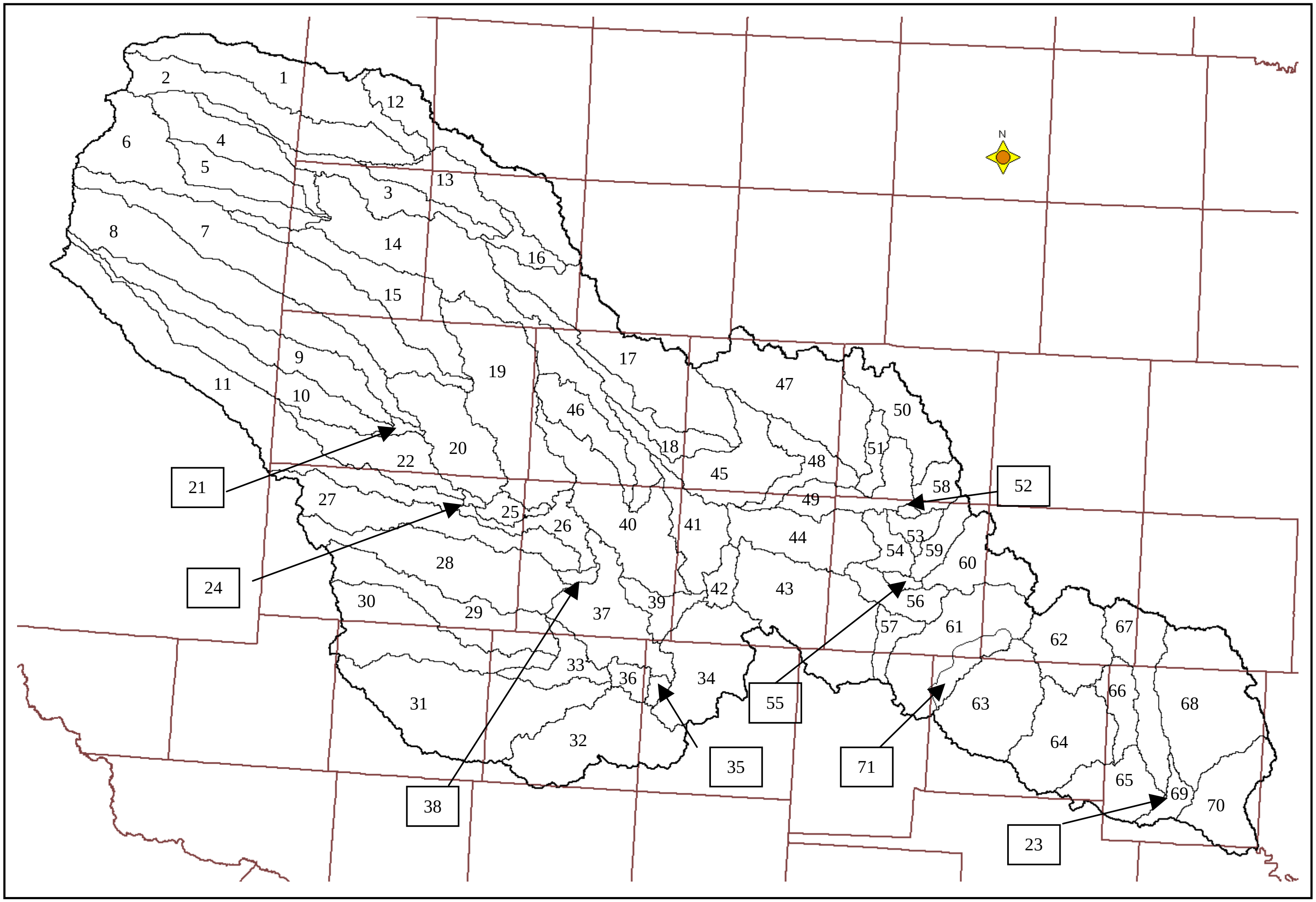

Figure UC-2. Upper Colorado River Watershed sub-basin map.

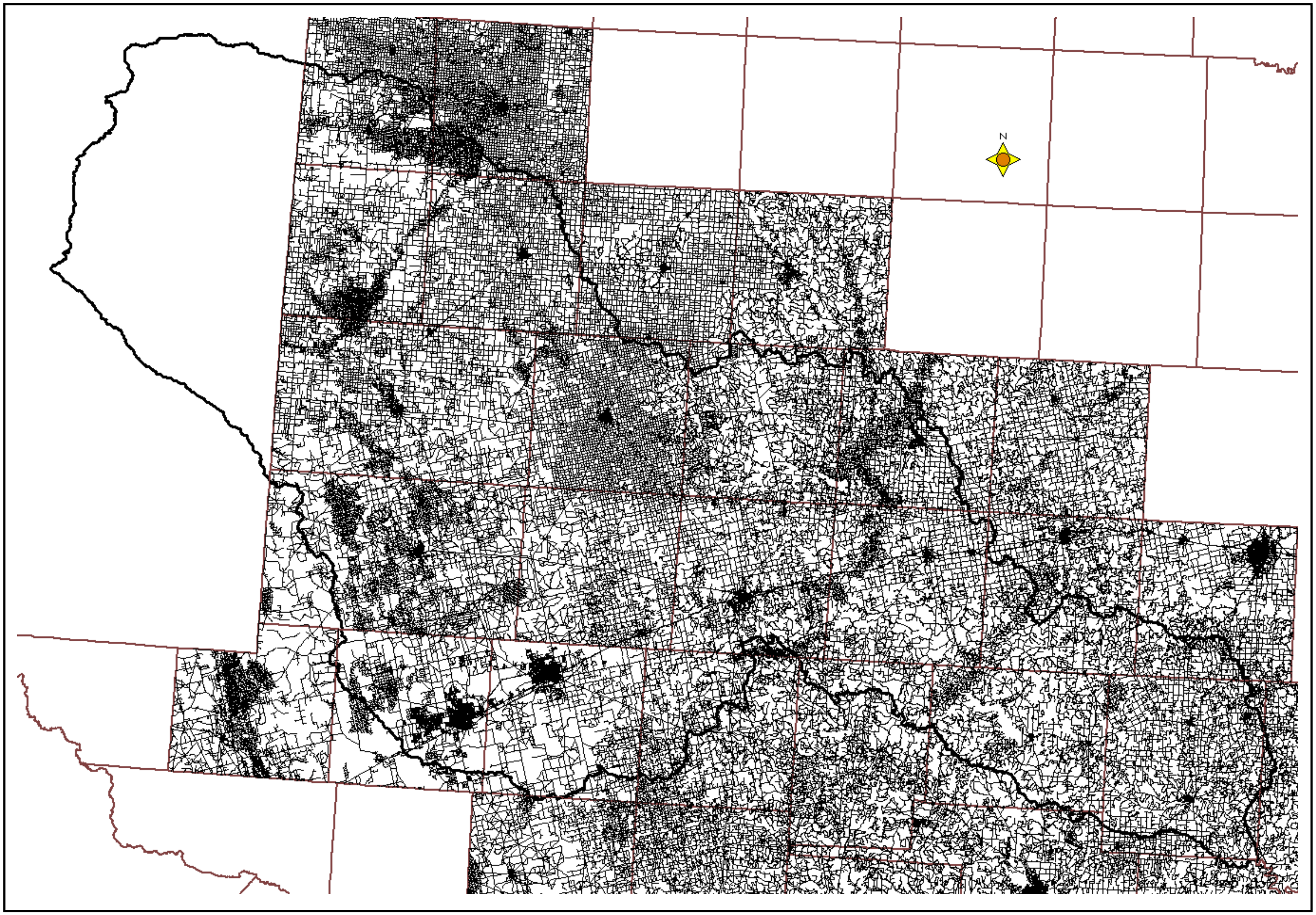

Figure UC-3. Upper Colorado River Watershed roads map.

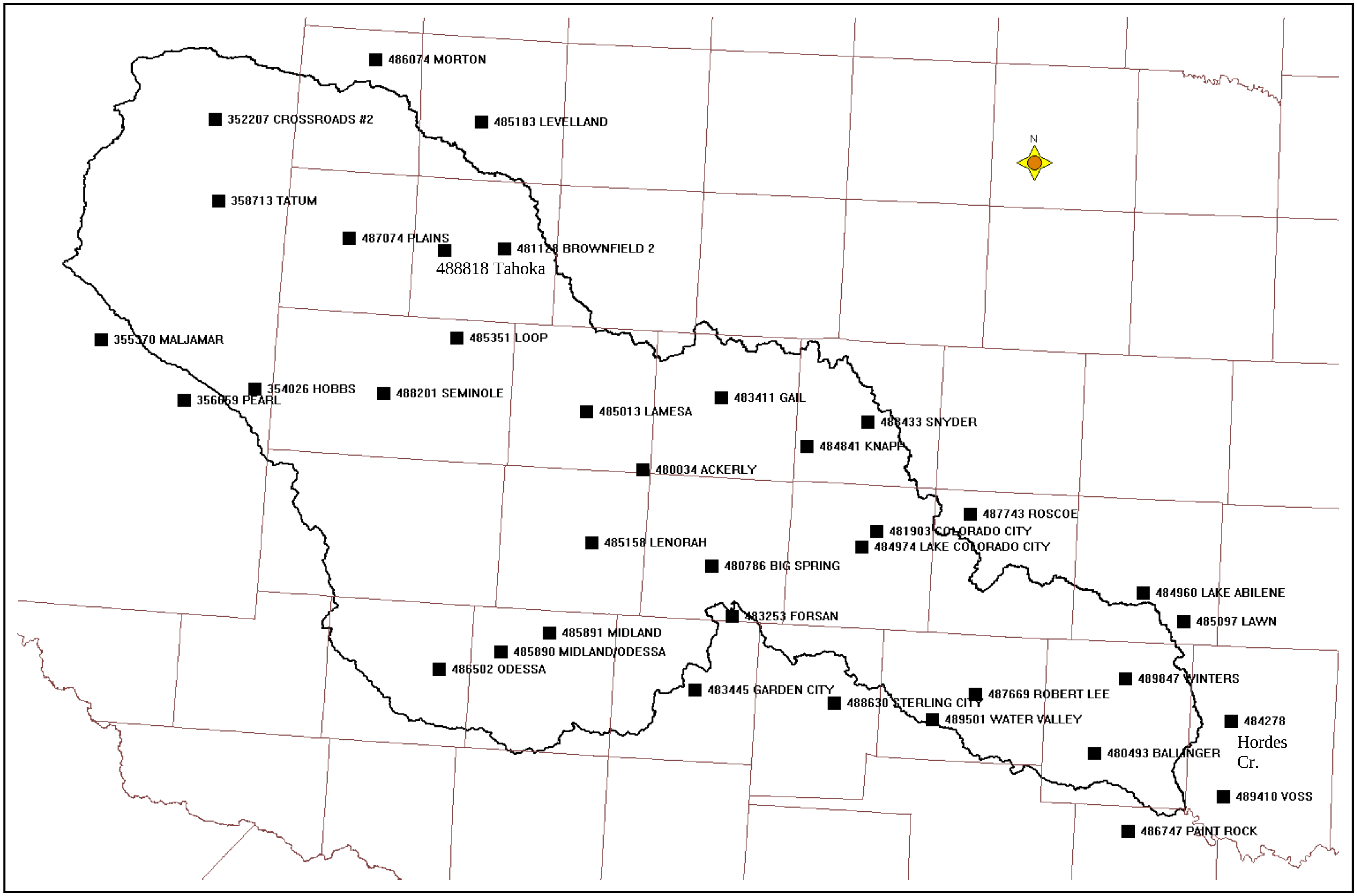

Figure UC-4. Weather stations in the Upper Colorado River Watershed.

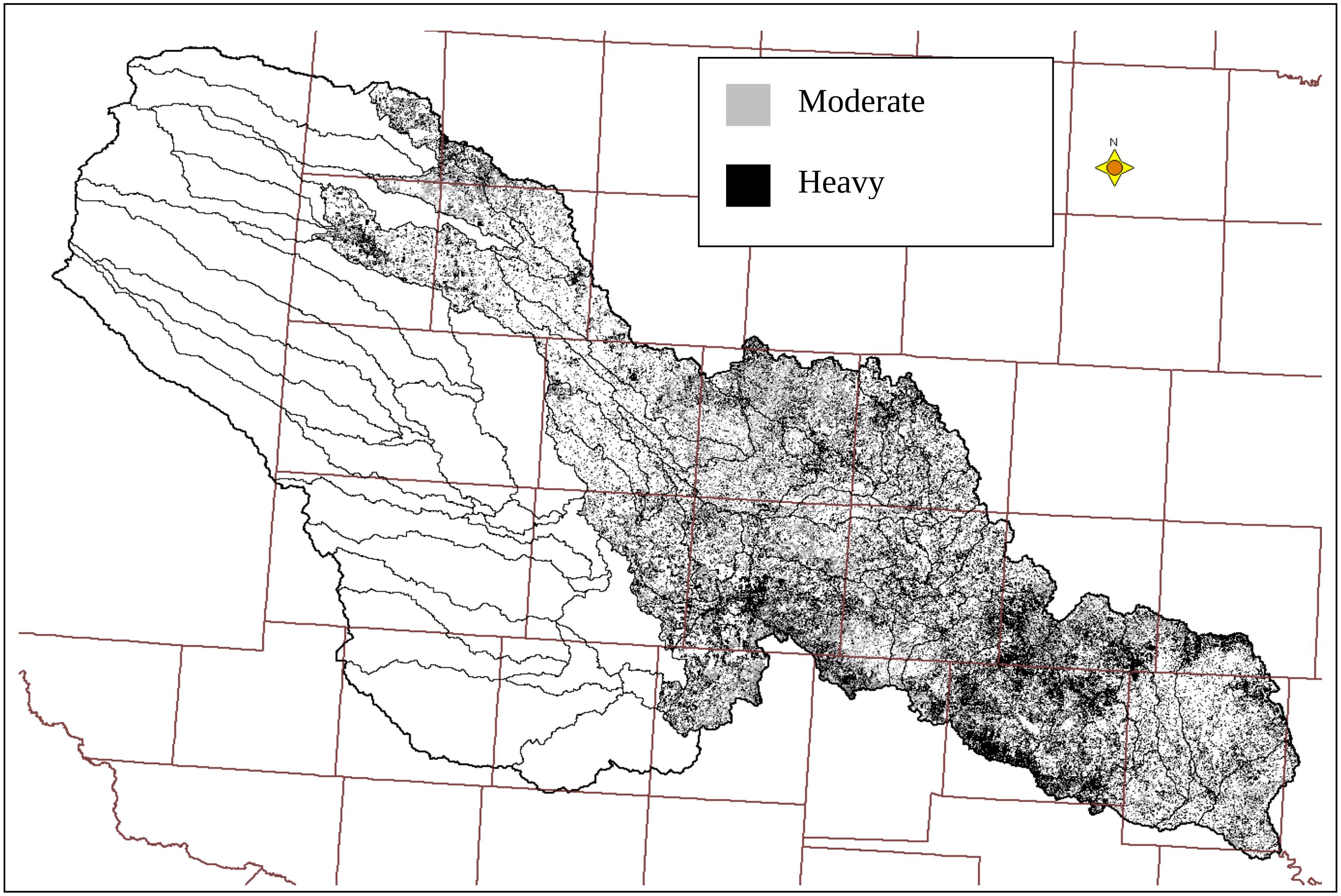

Figure UC-5.
Areas of heavy and moderate brush planned for treatment (oak not included) in the Upper Colorado River Watershed (brush treatment not planned in sub-basins west of 18 inch isohyet).

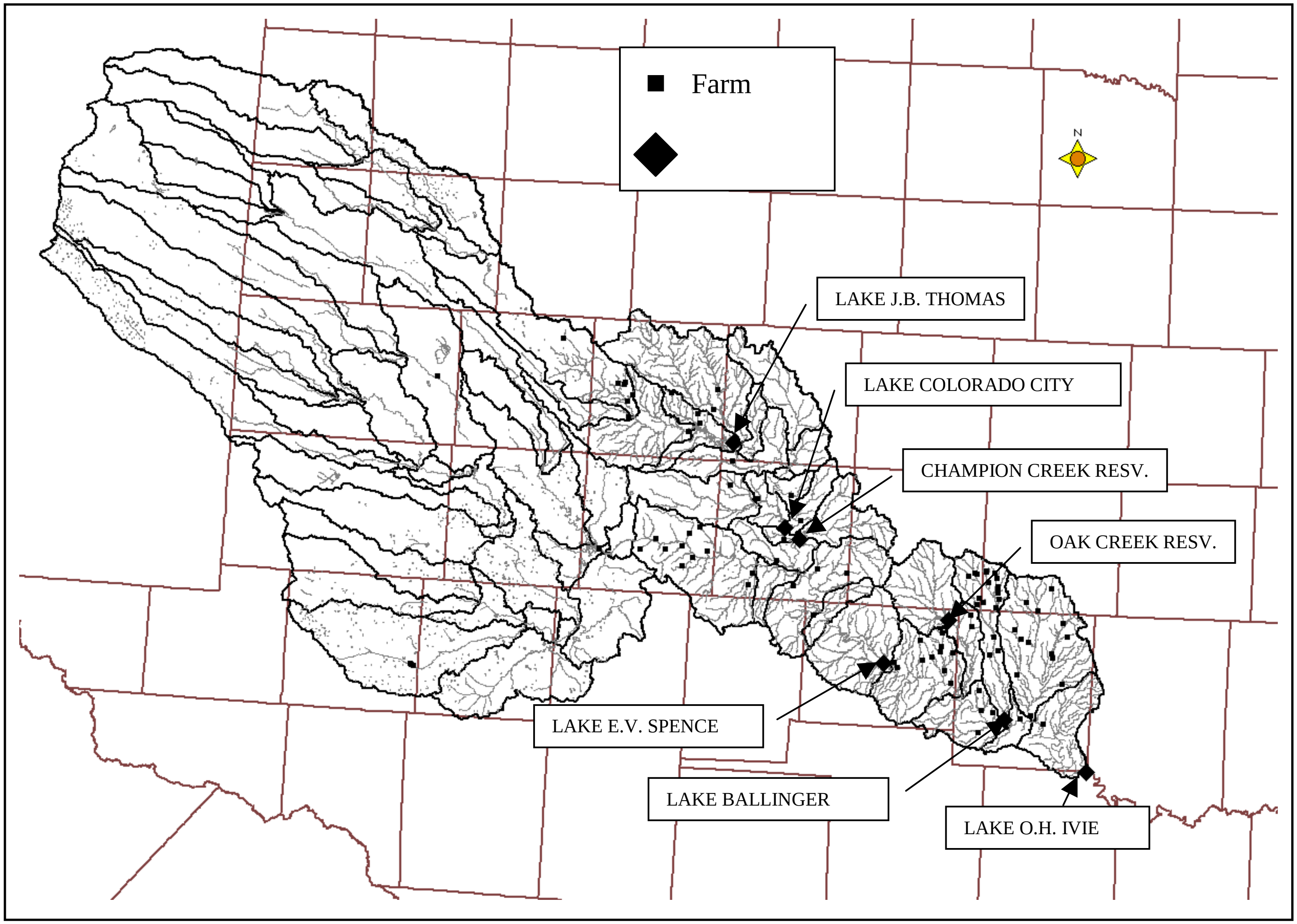

Figure UC-6.
Significant ponds and reservoirs in the Upper Colorado River Watershed (from Texas Natural Resource Conservation Commission inventory of dams).

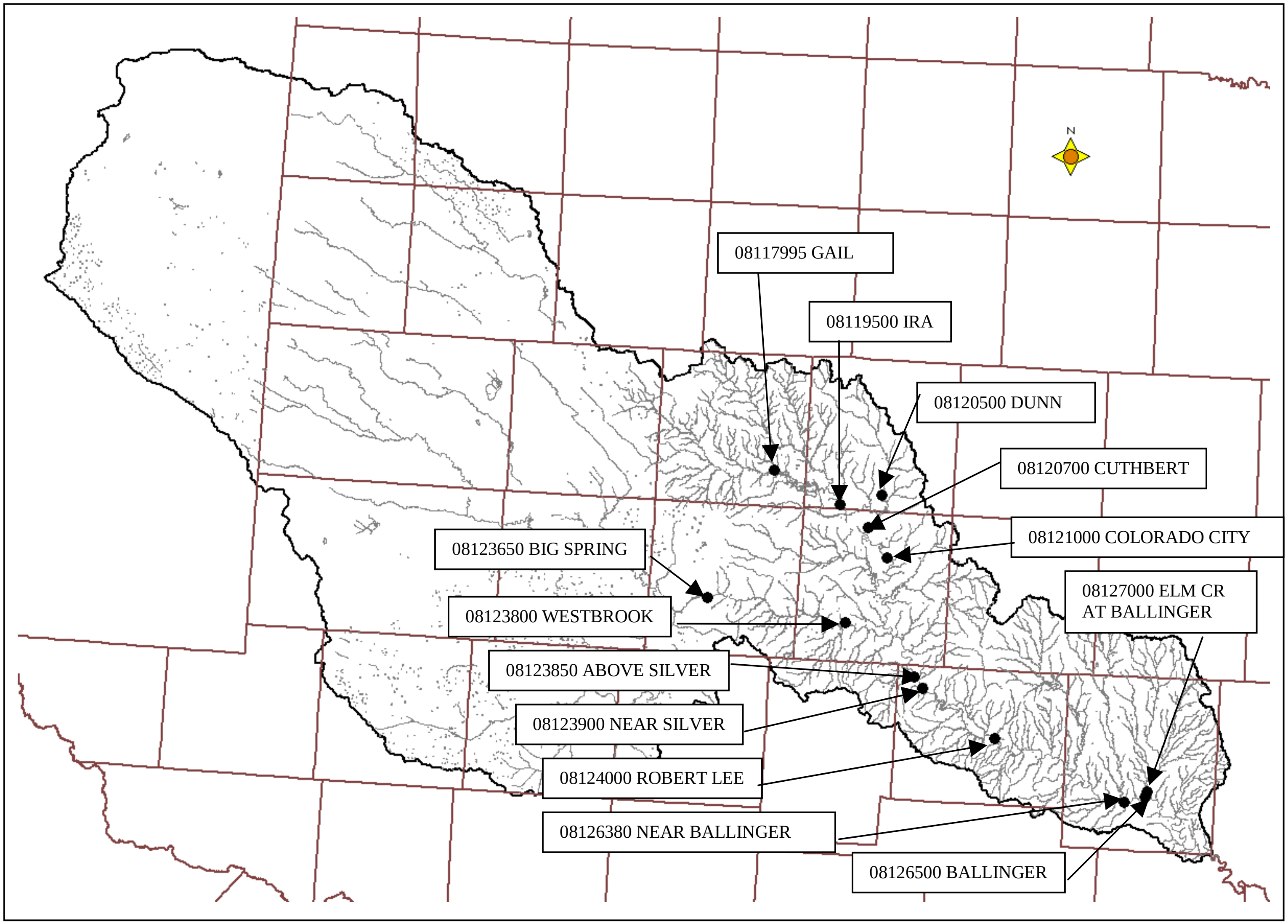

Figure UC-7. Stream gauges used for calibration of the Upper Colorado River Watershed.

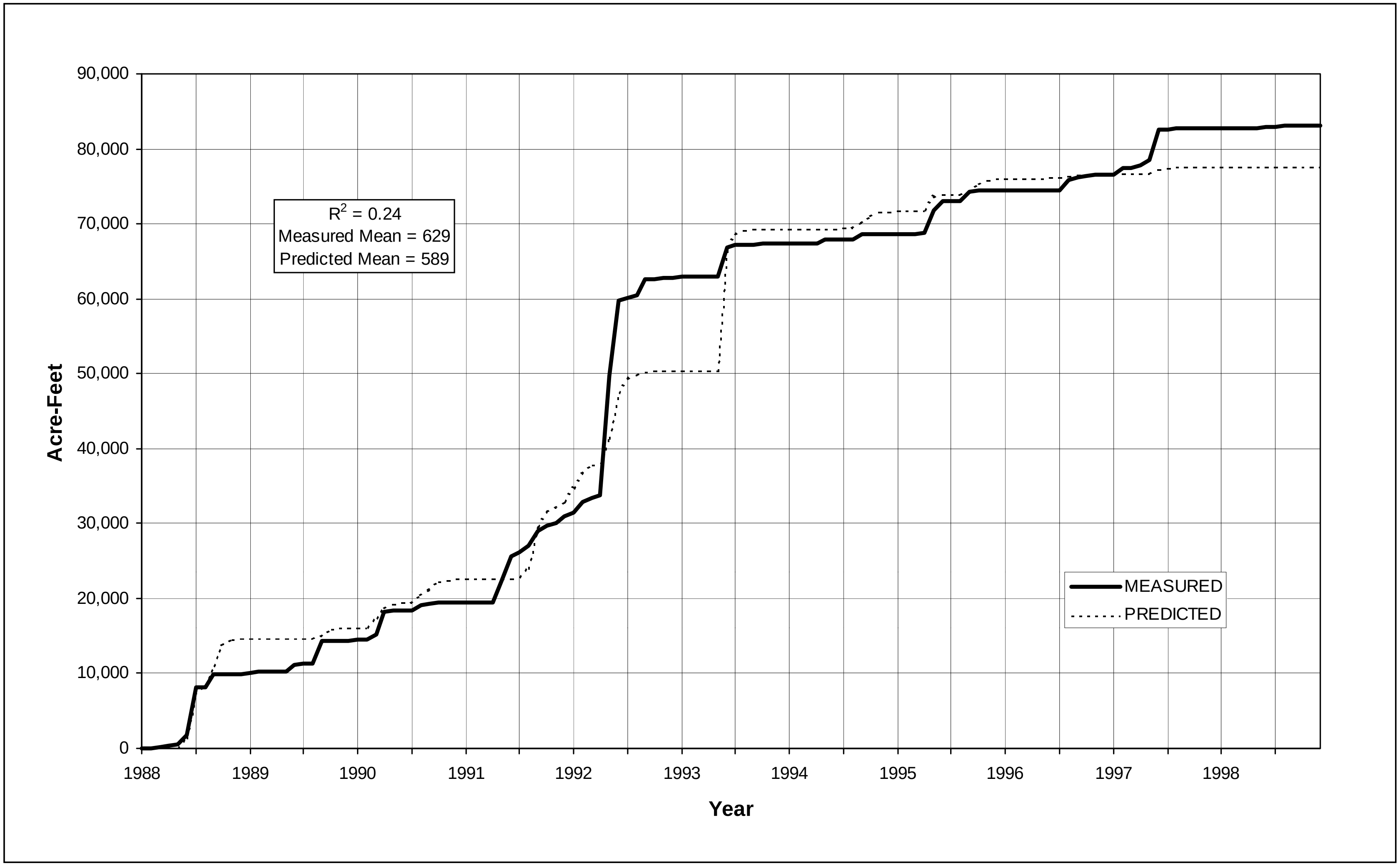

Figure UC-8. Cumulative monthly measured and predicted stream flow at gauge 08117995 (Gail), Upper Colorado River Watershed, 1988 through 1998. Monthly statistics are shown in box.

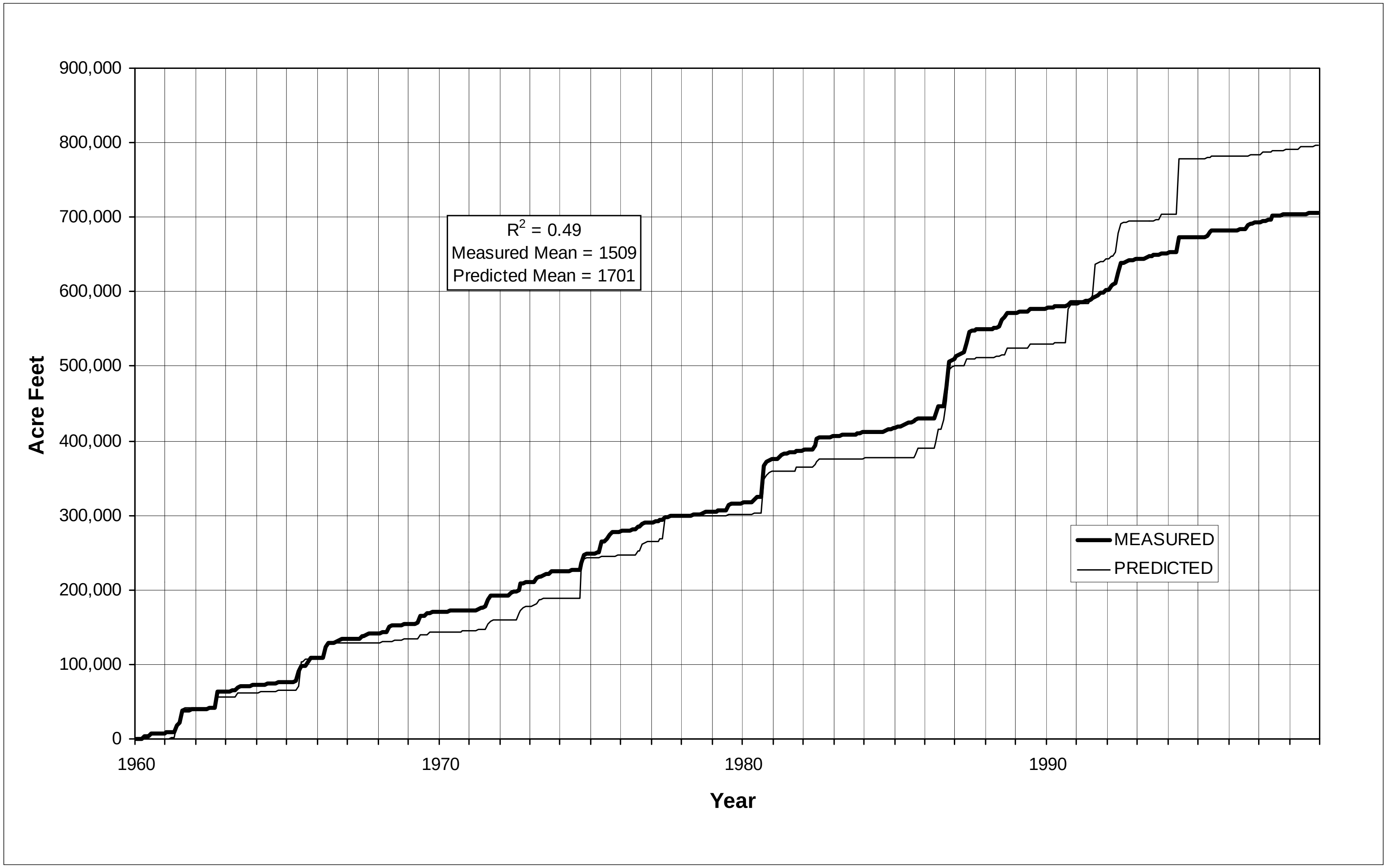

Figure UC-9. Cumulative monthly measured and predicted stream flow at gauge 08123800 (Westbrook), Upper Colorado River Watershed, 1960 through 1998. Monthly statistics are shown in box.

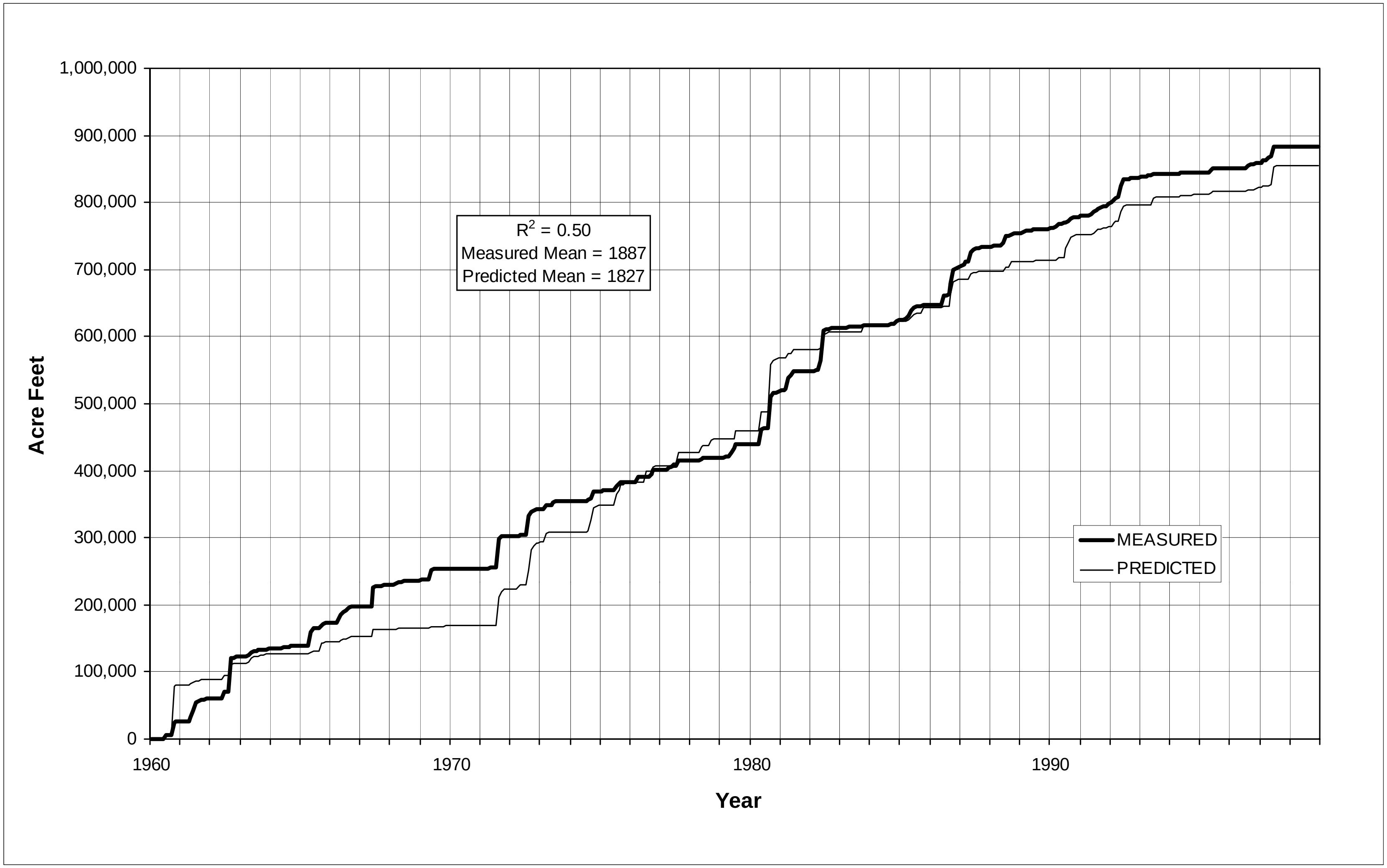

Figure UC-10. Cumulative monthly measured and predicted stream flow at gauge 08121000 (Colorado City), Upper Colorado River Watershed, 1960 through 1998. Monthly statistics are shown in box.

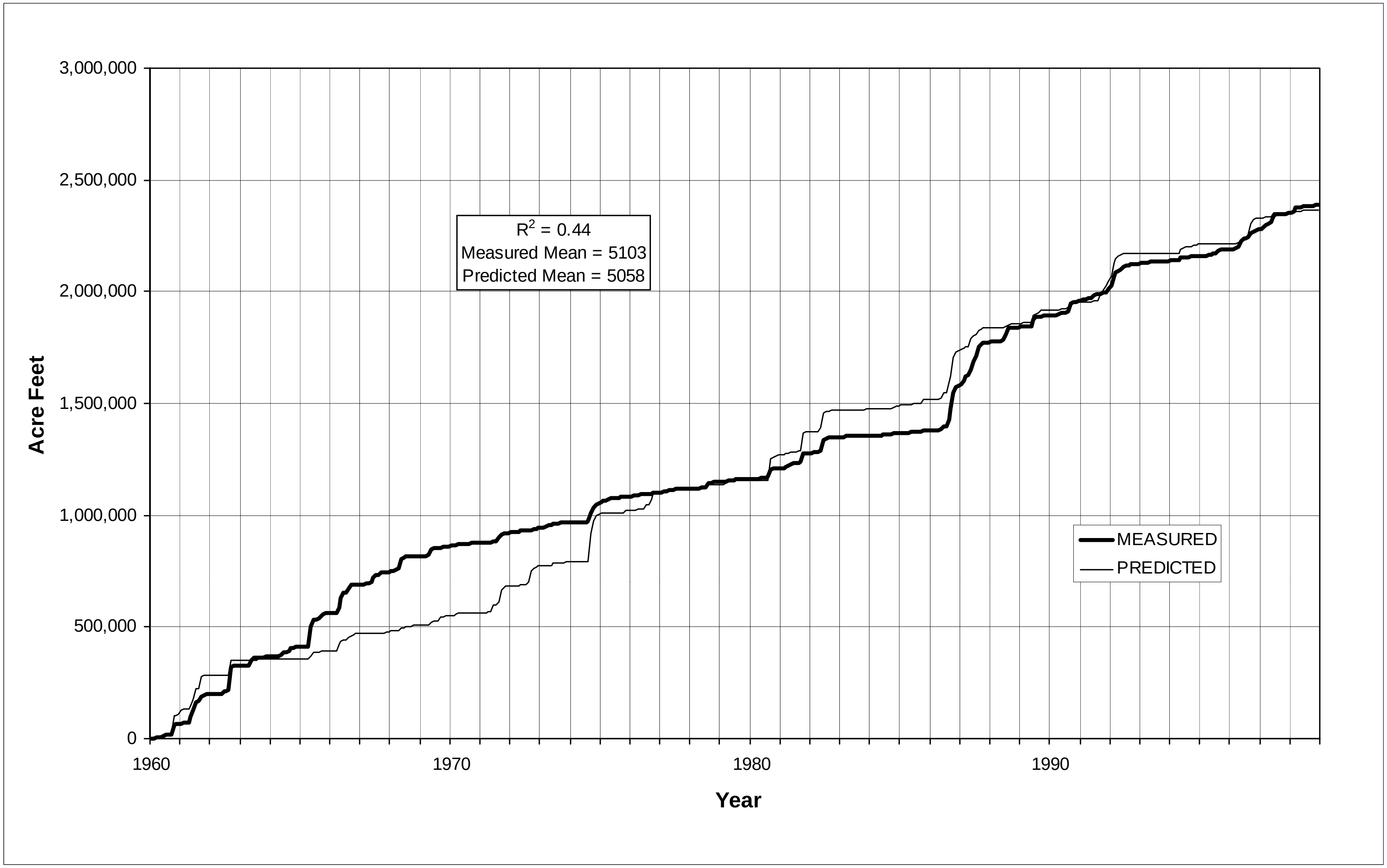

Figure UC-11. Cumulative monthly measured and predicted stream flow at gauge 08126380 (Near Ballinger), Upper Colorado River Watershed, 1960 through 1998. Monthly statistics are shown in box.

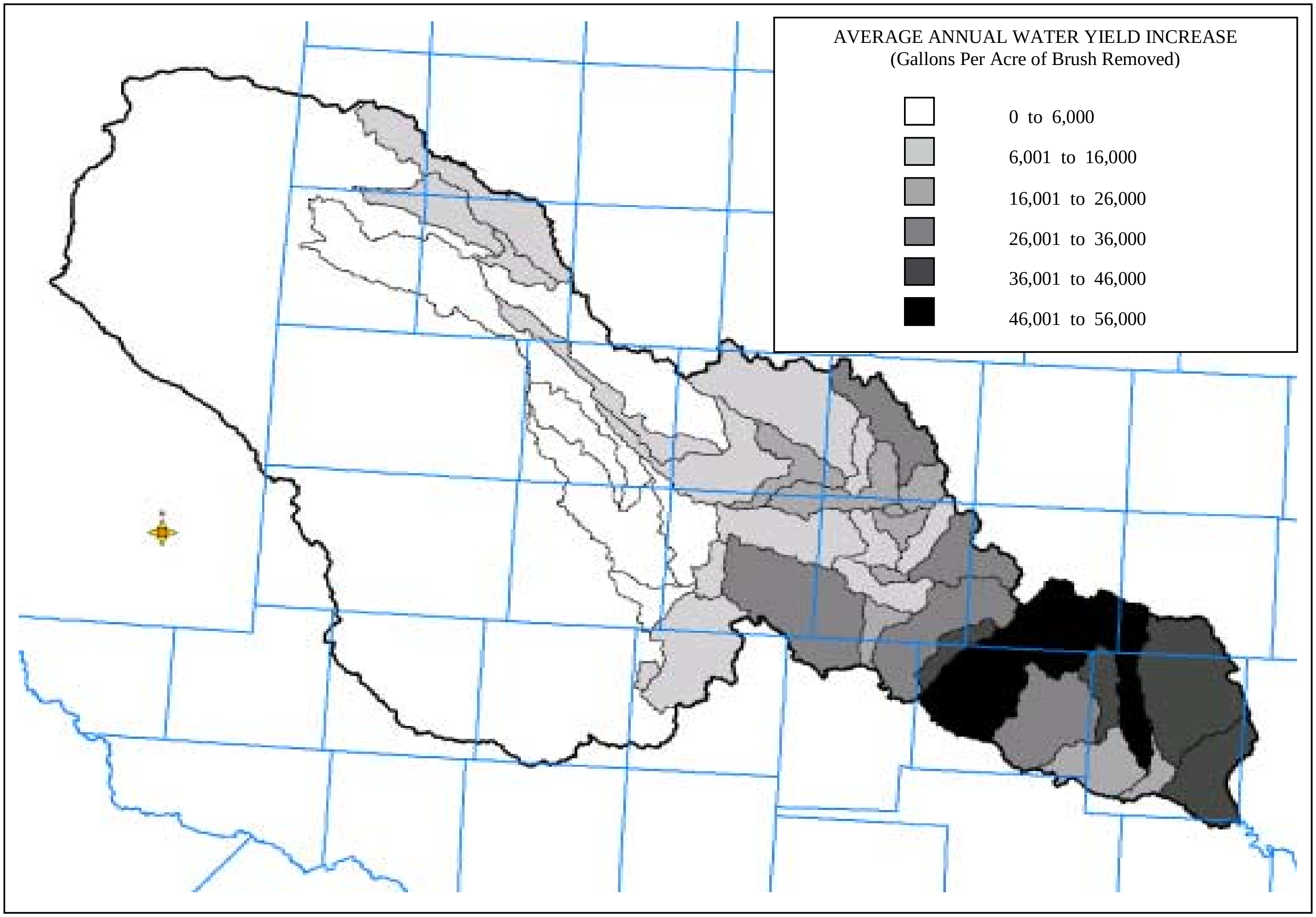

Figure UC-12.
Increase in water yield per unit area of brush treated, Upper Colorado River Watershed, 1960 through 1998. Sub-basin boundaries and water yields are shown only for areas where brush treatment was planned and simulated.

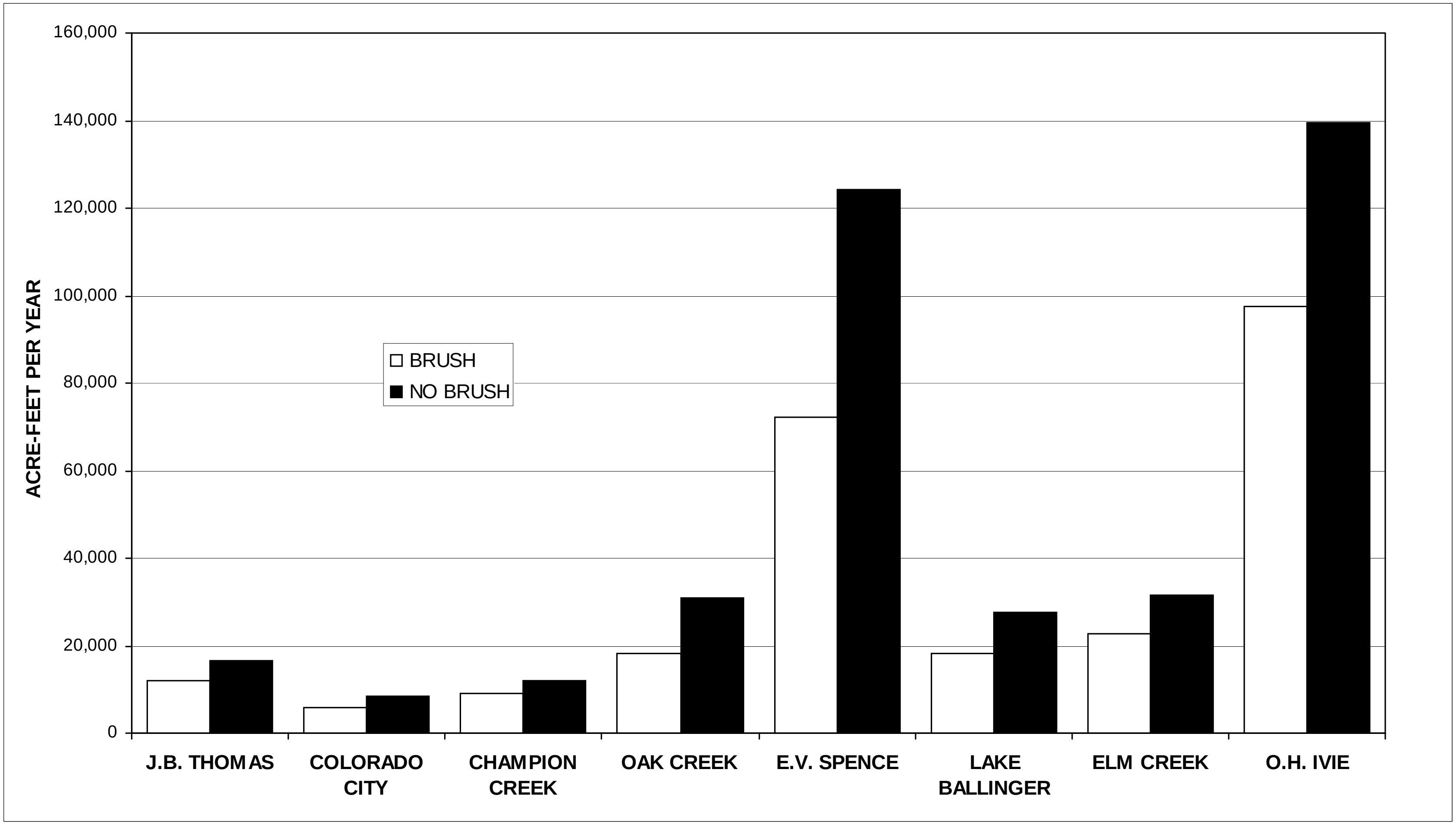

Figure UC-13. Average annual inflow to reservoirs for brush and no-brush conditions, Upper Colorado River Watershed, 1960 through 1998. Flow to O.H. Ivie does not include flow from the Main Concho. Flow to Ivie from the Main Concho is given in the "Main Concho" chapter of this report.

CHAPTER 18
UPPER COLORADO WATERSHED - ECONOMIC ANALYSIS
Joel P. Bach, Research Assistant, Department of Rangeland Ecology and Management and J. Richard Conner, Professor, Department of Agricultural Economics Texas A&M University

CONTROL COSTS

Control costs include initial and follow-up treatments required to reduce brush canopy to 5% or less and maintain it at the reduced level for at least 10 years. 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. Present values of total control costs per acre range from $94.89 for mechanical control of heavy mesquite to $35.89 for moderate mesquite that can be initially controlled with herbicide treatments. Costs of treatments, year those treatments are needed for each brush type density category are detailed in Table 1. Although labeled as Upper Colorado, these practices and costs apply to only the sub-basins which drain to reservoirs up stream of Lake Ivey. Brush control practices and costs discussed in the Main Concho watershed report (Chapter 10) apply to Upper Colorado sub-basins # 23, 62, 64, 65, 66, 67, 68, 69, and 70.

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

Heavy Cedar Mech. (tree doze, rake & burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Tree doze, rake, burn	70.00	70.00
5	IPT or Burn	15.00	9.89
		Total	79.89

Heavy Cedar Mech. (two way chain & burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Two way chain , burn	28.00	28.00
5	IPT or Burn	15.00	9.89
		Total	37.89

Heavy Mesquite (Mech. Choice - tree doze, rake & burn - shears, spray, burn - extricate, burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	85.00	85.00
5	IPT or Burn	15.00	9.89
		Total	94.89

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

Heavy Mesquite (Herbicide)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Aerial Herbicide	26.00	26.00
5	Aerial Herbicide	26.00	17.70
8	IPT or Burn	15.00	7.65
		Total	51.35

Heavy Mixed (Mech. Or Herbicide/ Mech. Choice - spray/ tree doze, rake & burn - shears, spray, burn - extricate, burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech./Herb. Choice	70.00	70.00
5	IPT or Burn	15.00	9.89
		Total	79.89

Moderate Cedar (Mech. Choice - tree doze, rake & burn - shears, spray, burn - extricate, burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	35.00	35.00
5	IPT or Burn	15.00	9.89
		Total	44.89

Moderate Mesquite (Herbicide)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Aerial Herbicide	26.00	26.00
5	IPT or Burn	15.00	9.89
		Total	35.89

Moderate Mesquite (Mech. Choice - tree doze, rake & burn - shears, spray, burn - extricate, burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	35.00	35.00
5	IPT or Burn	15.00	9.89
		Total	44.89

Moderate Mixed (Mech. Choice - tree doze, rake & burn - shears, spray, burn - extricate, burn)

Year	Treatment	Treatment Cost($)/Acre	Present Value($)/Acre
0	Mech. Choice	35.00	35.00
5	IPT or Burn	15.00	9.89
		Total	44.89

*Upper Colorado River watershed

RANCHER BENEFITS AND STATE'S COST SHARE

Rancher benefits are the total benefits that will accrue to the rancher as a result of the brush control program. In order for the rancher to have no net benefit from the state's portion of the control cost, he is expected to invest or incur costs for an amount equal to his total net benefits. Therefore, his total benefits 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). 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 are shown in Table 2.

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

YEAR	0	1	2	3	4	5	6	7	8	9
Heavy Cedar										
Controlled	70	55	45	35	35	35	35	35	35	35
No Control	70	70	70.1	70.2	70.3	70.4	70.5	70.6	70.7	70.8
Heavy Mesquite										
Controlled	38	33	28	25	25	25	25	25	25	25
No Control	38	38	38.1	38.1	38.2	38.2	38.3	38.3	38.4	38.4
Heavy Mixed										
Controlled	50	43	36	30	30	30	30	30	30	30
No Control	50	50	50.1	50.2	50.3	50.4	50.5	50.5	50.6	50.6
Moderate Cedar										
Controlled	52	43	35	35	35	35	35	35	35	35
No Control	52	52.3	52.7	53	53.4	53.8	54.1	54.4	54.7	54.9
Moderate Mesquite										
Controlled	32	28	25	25	25	25	25	25	25	25
No Control	32	32.2	32.4	32.6	32.8	33	33.2	33.4	33.6	33.7
Moderate Mixed										
Controlled	40	35	30	30	30	30	30	30	30	30
No Control	40	40.2	40.5	40.8	41	41.3	41.6	41.8	42	42.2

*Upper Colorado River Watershed

As with the brush control practices, the grazing capacity estimates represent a consensus of expert opinion obtained through discussions with Texas Agricultural Experiment Station and Extension Service Scientists and USDA-NRCS Range Specialists with brush control experience in the area. Livestock grazing capacities range from about 70 acres per animal unit year (AUY) for land infested with heavy cedar to about 25 acres per AUY for land on which mesquite is controlled.

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 production investment analysis budgets. This information for the livestock enterprise (cattle) in the area is in Table 3. The data are reported per animal unit for the livestock enterprises. From these budgets, data was entered into the investment analysis model (see Chapter 2).

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

Partial Revenues[1]

Revenue Item Description	Quantity	Unit	$ / Unit	Cost
Calves	382.5	Pound	.80	306.00
Cows	111.1	Pound	.40	0
Bulls	250.0	Pound	.50	0
			Total	306.00

Partial Variable Costs[2]

Variable Cost Item Description	Quantity	Unit	$ / Unit	Cost
Supplemental Feed	480.0	Pound	0.10	48.00
Salt & Minerals	27.0	Pound	0.20	5.40
Marketing	1.0	Head	6.32	6.32
Veterinary Medicine	1.0	Head	15.00	15.00
Miscellaneous	1.0	Head	12.00	12.00
Net Replacement Cows[3]	1.0	Head	35.28	35.28
Net Replacement Bulls[4]	1.0	Head	3.09	6.09
			Total	128.09

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 Main Concho and Upper Colorado River Basins, Lake Ivey Watershed. 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.

* Upper Colorado River Watershed

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

With this information, present values of the benefits to landowners were estimated for each of the brush type-density categories using the procedure described in Chapter 2. They range from $16.76 per acre for the control of heavy cedar to $10.25 per acre for control of moderate mixed brush (Table 4).

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

Brush type/density	PV of Total Cost ($/Acre)	Rancher Share ($/Acre)	Rancher %	State Share ($/Acre)	State %
Hv. Cedar - TD	79.89	16.76	21.0	63.13	79.0
Hv. Cedar Chn	37.89	16.76	44.2	21.13	55.8
Hv. Mes. Mec.	94.89	15.89	16.7	79.00	83.3
Hv. Mes. Hrb.	51.35	15.89	37.8	35.46	69.1
Hv. Mx.	79.89	15.07	18.9	64.82	81.1
Mod. Cedar	44.89	11.90	26.5	32.99	73.5
Mod. Mes. Mec	44.89	10.55	23.5	34.34	76.5
Mod. Mes. Hrb.	35.89	10.55	29.4	25.34	70.6
Mod. Mx.	44.89	10.25	22.8	34.64	77.2
	Average		26.8**		73.2

* Upper Colorado River Watershed

** Based on Heavy Cedar being controlled with 50% chaining-50% tree dozing and all Mesquite controlled with 50% mechanical-50% herbicide.

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 cost share per acre of brush control range from $79.001 for control of heavy mesquite to $21.13 for control of heavy cedar with chaining. Present values for total treatment cost, rancher benefits and state cost share for all brush type - density categories are shown in Table 4.

COST OF ADDITIONAL WATER

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program. The brush control program water yields and the estimated acreage by brush type-density category by sub-basin were supplied by the Blackland Research Center, Texas Agricultural Experiment Station in Temple, Texas (see previous Chapter). The total state cost share for each sub-basin is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category for the sub-basin. The cost of added water resulting from the control of the eligible brush in each sub-basin is then determined by dividing the total state cost share by the added water yield (adjusted for the delay in time of availability over the 10-year period using a 6% discount rate). The cost of added water thus determined averages $96.76per acre foot for the entire Upper Colorado watershed (Table 5). Sub-basins range from costs per added acre foot of $44.11 to $7,672.72.

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

Sub-basin	Total State Cost ($)	Avg. Annual Gallon Increase	Avg. Annual Ac.Ft. Increase	Added Ac.Ft 10Yr. Disctd	St. Cost per Ac.Ft. Added Water ($)
1	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00
12	2962397.01	559439439.82	1716.86	13394.92	221.16
13	1469706.17	341114276.75	1046.84	8167.46	179.95
14	4432154.69	24125643.20	74.04	577.65	7672.72
15	0.00	0.00	0.00	0.00	0.00
16	166245.14	22483503.71	69.00	538.33	308.81
17	3438849.36	258662342.75	793.81	6193.27	555.26
18	264176.01	63578516.39	195.12	1522.29	173.54
19	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
23	3969.12	2056701.64	6.31	49.24	80.60
24	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00
29	0.00	0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.00	0.00
31	0.00	0.00	0.00	0.00	0.00
32	0.00	0.00	0.00	0.00	0.00
33	0.00	0.00	0.00	0.00	0.00
34	4804346.83	1110858822.57	3409.10	26597.80	180.63
35	305199.37	47384781.14	145.42	1134.56	269.00
36	0.00	0.00	0.00	0.00	0.00
37	0.00	0.00	0.00	0.00	0.00
38	0.00	0.00	0.00	0.00	0.00
39	5109546.20	48580690.87	149.09	1163.19	4392.70
40	5414745.57	90973763.56	279.19	2178.23	2485.85
41	2029570.94	200435984.87	615.12	4799.13	422.90
42	902016.22	130000262.03	398.96	3112.66	289.79
43	8594379.96	5158068825.25	15829.53	123502.01	69.59
44	2812453.79	880704492.53	2702.78	21087.11	133.37
45	2865851.29	936651613.87	2874.48	22426.68	127.79
46	0.00	1405132.30	4.31	33.64	0.00

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

Sub-basin	Total State Cost ($)	Average Annual Gal. Increase	Avg. Annual Ac.Ft. Incr.	Added Ac.Ft 10Yr. Disctd	St. Cost per Ac.Ft. Added Water ($)
47	6534598.50	2091998798.91	6420.11	50089.69	130.46
48	1443277.16	666957730.15	2046.82	15969.27	90.38
49	1475584.03	791750571.44	2429.79	18957.25	77.84
50	2542729.81	1355656892.25	4160.36	32459.11	78.34
51	623534.41	228437699.33	701.05	5469.59	114.00
52	97885.70	40658577.40	124.78	973.51	100.55
53	470543.15	167150103.04	512.96	4002.15	117.57
54	909316.20	200585258.76	615.57	4802.70	189.33
55	298472.83	104738881.26	321.43	2507.81	119.02
56	1570582.10	343156837.85	1053.11	8216.36	191.15
57	541136.21	255292573.20	783.46	6112.59	88.53
58	615236.09	259833678.17	797.40	6221.32	98.89
59	784132.84	162403863.53	498.40	3888.51	201.65
60	2076647.32	1272324291.72	3904.62	30463.84	68.17
61	5660618.85	3100969477.45	9516.53	74247.93	76.24
62	6008825.07	4562662618.69	14002.30	109245.92	55.00
63	7273478.12	6742303822.35	20691.37	161434.07	45.06
64	6711608.80	3174002519.43	9740.66	75996.60	88.31
65	2669410.19	1125582148.22	3454.28	26950.33	99.05
66	1107822.48	808987807.10	2482.69	19369.97	57.19
67	3185660.82	3015979797.49	9255.70	72212.99	44.11
68	4847857.35	2874039242.71	8820.10	68814.44	70.45
69	469023.51	150706327.03	462.50	3608.43	129.98
70	2542332.41	1926086710.43	5910.94	46117.18	55.13
71	1665068.91	1190934522.12	3654.84	28515.09	58.39
TOTAL	107700990.51			1113124.83	
Average					$96.76

*Upper Colorado River watershed.