CANADIAN RIVER WATERSHED

BRUSH CONTROL PLANNING, ASSESSMENT AND FEASIBILITY STUDY

DECEMBER, 2000

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PREPARED FOR

TEXAS STATE SOIL & WATER CONSERVATION BOARD

PREPARED BY

CANADIAN RIVER MUNICIPALWATER AUTHORITY

BLACKLAND RESEARCH & EXTENSION CENTER

TEXAS AGRICULTURAL EXPERIMENT STATION

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U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

DECEMBER, 2000

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1. INTRODUCTION

Prepared for Canadian River Municipal Water Authority
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Lake Meredith, located on the Canadian River north of Amarillo, is the major surface supply reservoir in the Texas High Plains. Completed in 1964, the reservoir is used to supply water to 11 Texas cities via a pumping and distribution system that is owned and operated by the Canadian River Municipal Water Authority (CRMWA). The combined population served by Lake Meredith is about 500,000.

At the time it was designed, and reflecting historically observed runoff, the firm yield of the lake was estimated at 103,000 acre-feet per year (AFY). The actual firm yield has proven to be about 76,000 AFY, or 74% of what was predicted. This value is effectively the reliable long-term inflow, minus lake evaporation and seepage losses. The cost of Lake Meredith water, as delivered to the member cities (but before treatment and local distribution) is approximately $100 per acre-foot. The Authority has recently invested more than this amount to acquire and develop ground water resources in Roberts County, Texas.

Much of the drainage area above Lake Meredith is located in New Mexico, and in that area much of the flow is retained by Conchas and Ute Reservoirs. Consequently, a substantial portion of the actual firm yield of the lake is derived from runoff originating in tributary drainages that join the river in Texas. The total inflow measured at the Amarillo gage since Ute Reservoir began operation in 1963 has averaged just over 126,000 AFY (based on gaging records through 1998). Of this, a bit less than 30,000 AFY represents releases from Ute Reservoir. The incremental inflow from watersheds that join the river below Ute is nearly 97,000 AFY.

A potentially major factor accounting for a firm yield below expectations is rainfall interception and evapotranspiration by brush vegetation. Other factors may include: evapotranspiration from phreatophytic vegetation (this is especially important between the Amarillo gage and the lake); irrigation pumping from the Ogallala aquifer; retention of runoff by stock ponds and contour tillage; and the storage and other effects in New Mexico.

A recent study of the hydrologic impacts of brush infestation and control in the North Concho River watershed (near San Angelo, Texas) indicated that removal of brush vegetation could result in large increases in surface water flow, at a reasonable cost. Consequently, the Texas State Legislature has tasked the Texas State Soil and Water Conservation Board to assess brush control alternatives in several other drainage basins, including the Texas portion of the Canadian River watershed above Lake Meredith.

This report summarizes the Canadian River study. The study has considered the hydrologic benefits of various levels of brush eradication and removal within the watershed, and the dollar costs to the State of Texas from such control. The study was accomplished through a partnership involving CRMWA, which drafted the overall report and assembled background information, and staff at the Texas Agricultural Extension Service at the Blacklands Research Center in Temple, which performed the quantitative hydrologic and economic analyses. J. R. Bell of the U.S. Natural Resources Conservation Service drafted Section 3.2.1 of the report. The large number of other professionals who provided information of value to the study is too large to allow a listing of individual names; the contribution from each is hereby acknowledged with appreciation.

2. EXECUTIVE SUMMARY

Prepared for Canadian River Municipal Water Authority
By Lee Wilson and Victoria O'Brien
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The rapid depletion of water resources in Texas due to urban growth, agriculture, industrial and other increased uses requires and demands that state government take immediate and decisive steps toward developing, saving, enhancement and utilization of existing known water resources that are now being robbed from the people of Texas by non- productive and noxious brush.

Studies in the North Concho River watershed identified a need for and the value of efforts to salvage water through control of brush vegetation, and led to similar studies in other Texas watersheds. This report summarizes the study of the Canadian River watershed. The substance of the study is presented in **five chapters**, which are summarized below. The paramount conclusion flowing through the report is that with successful brush control on the watershed, stream flow in the Canadian River can be substantially increased over the current amount, at a cost that is competitive with what a West Texas city or individual pays for water.

Chapter 3. A review of general conditions in the Canadian River watershed of Texas (area of 3,943 square miles) indicates that most of the runoff is from rolling hills known as the "Canadian Breaks", where the vegetation cover reflects semi-arid conditions, and the land use is predominantly for grazing. Lake Meredith, the major water supply reservoir in the Texas High Plains, gets most of its supply from this drainage. The reservoir yield has been adversely affected by upstream reservoirs in New Mexico. Since construction of Ute Reservoir, NM, average and median river flows at a gage above the reservoir are 267 cfs and 139 cfs, respectively. Of the total annual flow of about 126,000 AFY, about 97,000 AFY originates downstream of the New Mexico reservoirs. One advantage expected from increased streamflow by brush control should be an improvement in the water quality of Lake Meridith along with the increased yield.

A survey of the historic literature suggests that the dense stands of mesquite and other brush plants now found in much of the basin were not common prior to European settlement. Surveys done as part of this survey also identified nearly 2,000 acres of salt cedar in the upper reaches of Lake Meredith, along the Canadian River channel, and in lower parts of some tributaries.

Chapter 4. The Soil and Water Assessment Tool (SWAT) model was used to simulate the effects of brush removal on water yield in 8 watersheds in Texas for 1960 through 1998. Landsat7 satellite imagery was used to classify land use, and the 1:24,000 scale digital elevation model (DEM) was used to delineate the watershed boundaries and subbasins. After calibration of SWAT to existing stream gauges, brush removal was simulated by converting all heavy and moderate categories of brush (except oak) to open range (native grass). Treatment or removal of light brush was not simulated. Results of brush treatment in all watersheds are presented. Water yield (surface runoff and base flow) varied by subbasin, but all subbasins showed an increase in water yield as a result of removing brush. Economic and wildlife habitat considerations will impact actual amounts of brush removed.

Chapter 5. The SWAT model was applied to 312 sub-basins in watersheds that join the mainstem Canadian River in Texas, above Lake Meredith. Model inputs included weather records, soils, land use and cover, and specifications for Lake Meredith, and various parameters used by the model to calculate runoff and the water balance. Of the latter, the only variable that was adjusted to calibrate the model was the runoff curve for heavy and moderate brush densities. Various model inputs that reflect vegetation conditions (runoff curve, soil evaporation, shallow aquifer recharge, canopy interception, rooting depth and maximum leaf area) were adjusted to reflect the effects of brush control.

The SWAT model calibration was based on matching predicted and observed flow at a gage near Lake Meredith on the Canadian mainstem, for 37 years, 1960-1996. The predicted values matched observed flows with a r^2 value of 0.95. The effect of brush control, averaged over 37 years, are nearly 98,000 acre-feet/year. There are several reasons for the increased stream flows from brush control: a) there is about 10% less direct evaporation to the atmosphere from reduced canopy interception and shallower rooting systems of grasses, b) there is more surface runoff from grassed surfaces, and c) less shallow aquifer water re-evaporation from grasslands.

Chapter 6. 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.

Chapter 7. The economic methods described in Chapter 6 were used with the predicted water savings from Chapter 5 to estimate the per acre-foot costs of a brush control program for water yield for the Lake Meredith watershed. 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. Specific treatments and cost factors were obtained from meetings with landowners and local range experts. Landowners were assumed to cost-share up the amount the treatments would benefit livestock forage; these amounts range from $9.59 per acre for control of moderate mixed brush to $11.37 per acre for the control of heavy mesquite. Remaining funding would come from the State at rates estimated (in present value terms) to range from $26.10 for control of moderate mesquite with chemical treatments to $62.84 for control of heavy mixed brush.

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 $26.10 for control of moderate mesquite with chemical treatments to $62.84 for control of heavy mixed brush. 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 7-4.

The cost of added water was determined to average $111.37 per acre-foot for the entire watershed, with cost for individual sub-basins being as low as $26.16 per acre foot. The results indicate that for an investment of about $6 million (in the 15 sub-basins with the lowest cost per acre-foot), a 10 year water savings of nearly 164,000 acre-feet could be accomplished, for an average cost of less than $37 per acre-foot. Similarly, if controls were implemented in the 50 most cost-effective sub-basins, the total investment of $18.9 million would secure about 364,000 acre-feet of saved water, at a cost averaging less than $52 per acre-foot.

3. HYDROLOGIC EVALUATION

Prepared for Canadian River Municipal Water Authority
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Section 3.2.1 prepared by J. R. Bell, U.S. Natural Resources Conservation Service

3.1 Description Of The Watershed

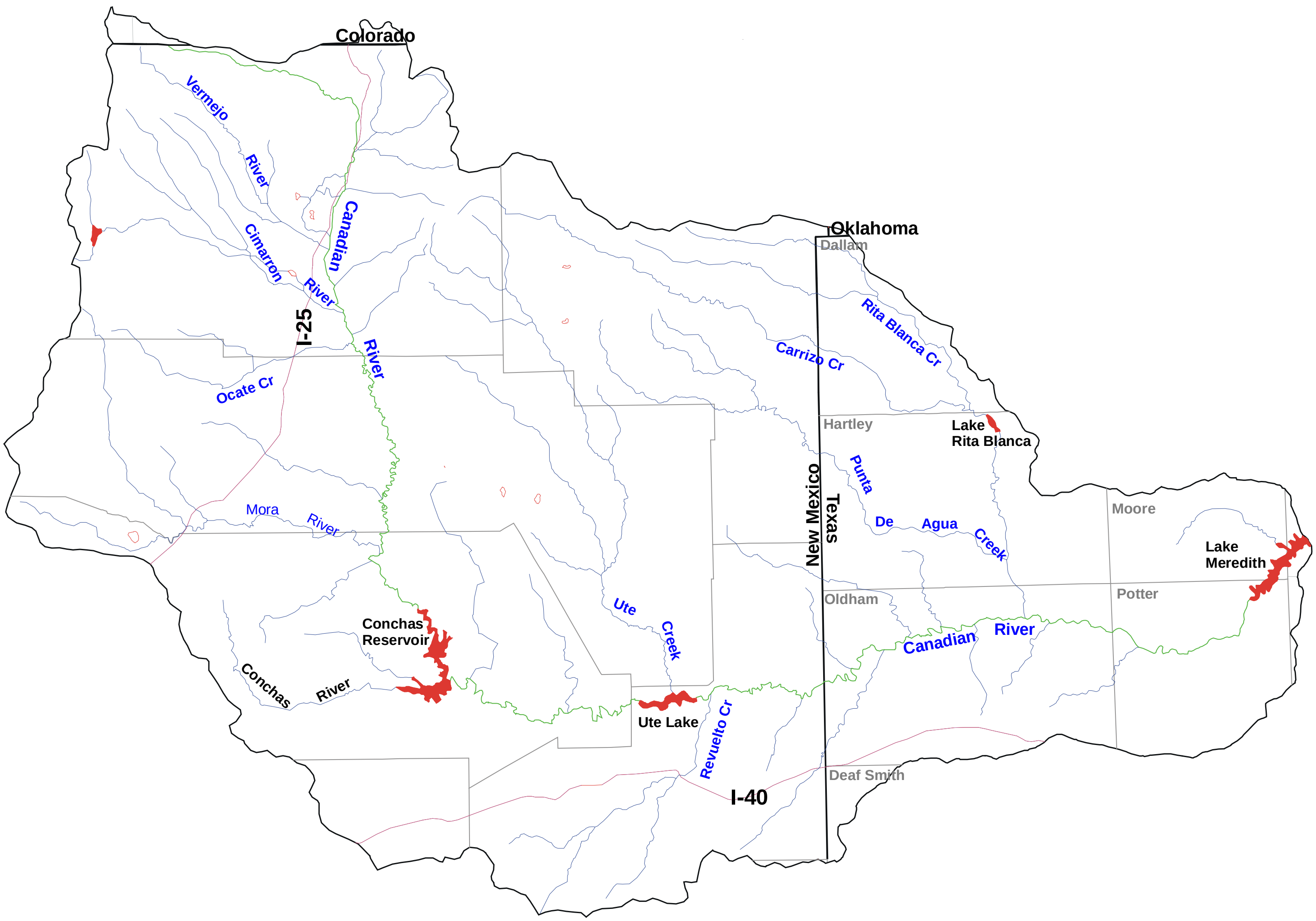
Location. The Canadian River originates on the east slopes of the southern Rocky Mountains of New Mexico. Major tributaries in New Mexico are the Conchas River, which joins the Canadian at Conchas Reservoir, and Ute Creek, which joins at Ute Reservoir. Below Ute Dam, the river flows east to the Texas State line, through the Texas Panhandle into Oklahoma, and merges with the Arkansas River in eastern Oklahoma.

This report is concerned primarily with the Canadian River watershed in Texas, which includes about 115.8 river miles from the New Mexico state line to the confluence of Camp Creek at the headwaters of Lake Meredith (TWC, 1991; see Figure 3-1). The watershed includes all or part of Dallam, Deaf Smith, Hartley, Moore, Oldham, and Potter Counties, Texas.

Drainage features. Total basin drainage area in Texas above Lake Meredith is 3,943 square miles. An additional 15,666 square miles of drainage in New Mexico contributes to the Canadian River in Texas.

Elevations along the river in Texas range from about 3510 ft at the New Mexico state line to about 2936 ft at the normal pool elevation of Lake Meredith. Topographically, the watershed consists of rolling and steep hills near the river (known as the "Canadian Breaks"), and more level uplands of the High Plains. Downstream of Ute Reservoir, river geometry is fairly consistent all the way down to Lake Meredith. The river bottom varies from 150 to 400 feet wide, and typically contains a meandering, shallow body of flowing water that is approximately one-fifth the size of the bank to bank width. Water depths are shallow, in the 0.3-1.6 feet range.

Figure 3-1. Canadian River Basin in New Mexico and Texas



Tributaries to the Canadian River in New Mexico, between Ute Lake and the State Line include Revuelto Creek, Tuscocoillo Canyon, Rana Canyon, Trujillo Creek, and Nara Visa Arroyo. Major streams joining the Canadian River in Texas are Punta de Agua Creek, Carrizo Creek, Rita Blanca Creek, East and West Amarillo Creeks. Big Blue and other streams drain directly to the reservoir. Most of the tributary creeks to the Canadian River do not have perennial flow, except locally near the main channel. The main exception is the Punta de Agua Creek tributary that cuts deeply into the Ogallala formation and thereby receives significant inflow from ground water.

Climate. The climate of the Canadian River watershed in the Texas High Plains is semi-arid. Summers are hot and dry and winters are mild. A high percentage of sunshine and a rather low humidity prevail over the region.

The area is subject to rapid and large temperature changes, especially during the winter. In the spring, moving low-pressure systems produce high winds, with March and April having the strongest. Wind speeds average over 13 mi/hr with south and southwesterly directions prevailing.

The normal daily minimum and maximum temperatures in January are –6°C (22°F) and 9°C (49°F). In July, the normal daily minimum and maximum temperatures are 19°C (66°F) and 33°C (91°F) (TWC, 1991).

About 75% of the total annual precipitation of 19 inches occurs from thunderstorm activity in April through September. Figure 3-2 presents the average yearly precipitation measured from 1960 to 1998 at the Amarillo airport, and from a combination of stations throughout the Canadian River Basin area used in the watershed model that is described in Chapters 4 and 5. The Amarillo average tends to be higher than the basin-wide average because the basin covers a very large area, and rainfall generally increases from the west to the east.

Figure 3-3 shows the Canadian River flow at the Amarillo gage and the average yearly precipitation measured at the airport. There is some suggestion that streamflow may have declined, relative to the long-term trend of reasonably steady precipitation. There is no basis to suggest that climate is a major factor accounting for the low firm yield of Lake Meredith.

Figure 3-2. Average yearly precipitation at 18 stations in and near the Basin from SWAT input files and at Amarillo airport stations only.

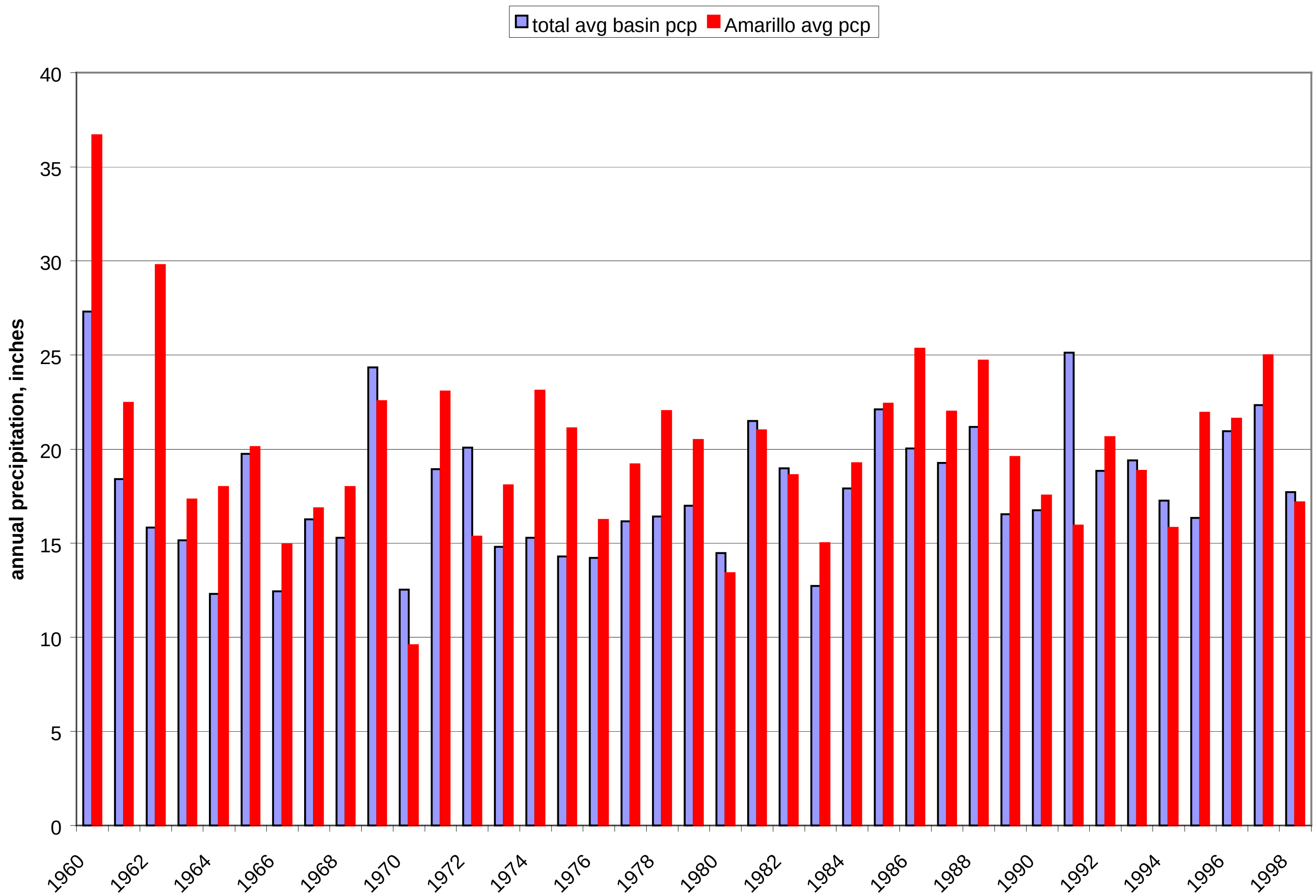
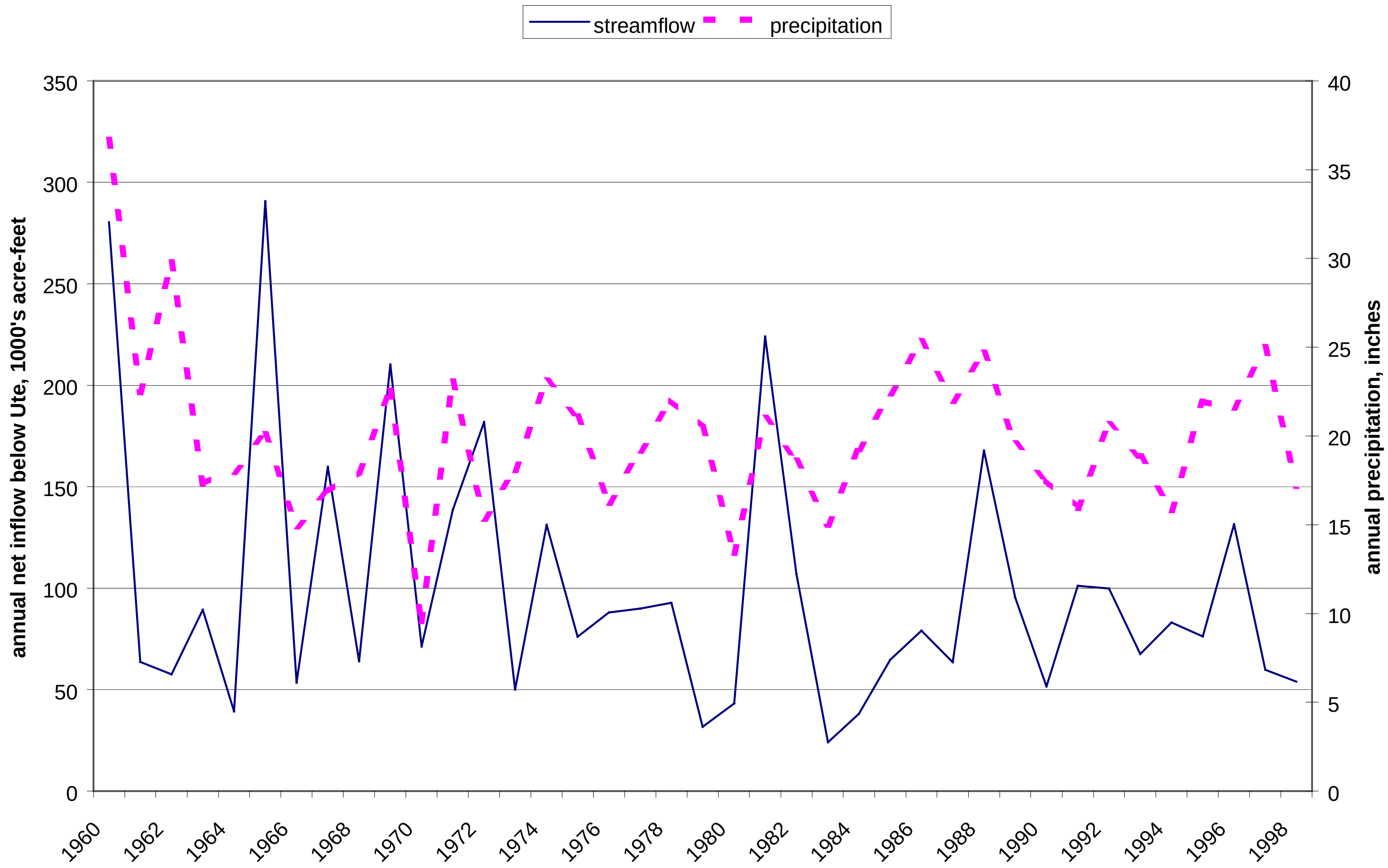


Figure 3-3. Average net inflow to Canadian River below Ute Reservoir, as measured at Amarillo gage, compared to average annual precipitation at Amarillo airport.



Evaporation rates are high in the Texas Panhandle. The Class A pan 60-year average evaporation rate in the Amarillo area is 66.49 inches during the 6-month growing season from April 1, to September 30. In this year 2000, every month of the growing season had above average evaporation rates, except June; and August and September set new maximum evaporation rates for the past 60 years (Byron Neal, USDA, Amarillo, personal communication). Since the evaporation rates are so much higher than precipitation amounts, stormwater contributions directly to the river, and indirectly by aquifer recharge and increased spring flows, occur primarily in response to large precipitation events.

Land use and vegetation. Within the watershed boundaries considered in this study, land use is almost exclusively for livestock grazing with few areas suitable for cultivation. Population centers in the basin include Amarillo, Dumas and Dalhart. Elsewhere, human population is sparse consisting of widely scattered ranching complexes in private ownership.

A good characterization of the vegetation conditions in the watershed is given in the range site descriptions prepared by the U.S. Natural Resources Conservation Service. These descriptions are summarized in Table 3-1.

There are few trees growing within the Canadian River watershed of Texas; the exceptions are fringes of cottonwood, willow and hackberry along the stream beds. Saltcedar (*Tamarix ramosissima*), an invading deleterious woody plant has become established along many bottomlands. Woody shrubs such as mesquite, sagebrush, skunkbush and yucca cover much of the remaining area, along with various grasses and forbs. Wildlife, including deer, antelope, coyotes and wild turkeys, is abundant along with small animals and reptiles.

As part of this study, an aerial reconnaissance to identify salt cedar infestations was conducted in early November, 2000. The work was performed by Ms. Vicky O'Brian of Lee Wilson and Associates and Mr. Lynn Wauer of the U.S. Natural Resources Conservation Service, Vega, TX. The flight used a Cessna 210 cruising at about 500 feet elevation at 110 miles per hour. The timing of the flight allowed viewing of salt cedar in their fall color, thus facilitating identification.

Table 3-1. Plant communities found in the Texas drainage of the Canadian River Basin. These descriptions reflect natural historical conditions in the tributary streams that drain through the Canadian River Breaks.

Range Site Name	Description
Mixedland Slopes	A mid and tall grass site with a good variety of forbs and a smaller woody plant component. Major grass species are little bluestem, sideoats grama, sand bluestem and blue grama. This site differs from sandy loam site in that the limey topsoil promotes an increased growth of sideoats grama and little bluestem. Sand sagebrush is the major woody species along with yucca and skunkbush.
Sand Hills	A tall grass and shrub climax community with lesser amounts of midgrasses. Sand bluestem, little bluestem, giant sandreed, and switchgrass are the dominant tall grass species. Sand paspalum, sideoats grama, hairy grama, and perennial threeawn are the main mid/short grass species. From 20-30% of the composition is made up of shrubs such as sand sagebrush and skunkbush. This is a fragile site and is subject to wind erosion if not protected by a good cover of deep-rooted perennial plants.
Sandy	This site is dominated by tall grasses, mainly sand bluestem and little bluestem with lesser amounts of switchgrass, indiangrass, and the taller dropseeds. A significant midgrass component exists comprised of sideoats grama, sand paspalum, sand dropseed, fall witchgrass, and perennial threeawn. Forbs make up from 5 to 8 % of total vegetation with shrubs making up from 8 to 15%. The shrub component consists of a combination of sand sagebrush, skunkbush and sand shinoak. Some sandy sites tend to not have shinoak present while others have significant amounts present. Occasional motts of sand plum are scattered throughout the site.
Draw	The natural plant community is dominantly midgrasses with lesser amounts of both tall and shortgrass species. A few forbs occur along with a few woody plants. These sites catch runoff from surrounding shortgrass sites. The dominant species are western wheatgrasses, vine mesquite, sideoats grama and where slightly saline influences exist alkali sacaton may be a significant component. Blue grama/buffalograss always make up most of the shortgrass compliment. In general, midgrasses make up 50% of the total herbage with shortgrasses making up 15 to 25% in instances where soil and moisture conditions are more favorable. Tall grasses such as switchgrass and indiangrass will be found. These are usually less than 15% of the total site composition. There are a few forbs present but they tend to be obscured by thick grass growth. Shrubs and trees are relatively few and occur intermittently.
Clay loam	The natural plant community for this site is short grass dominant with a few midgrasses and a few forbs. There are few shrubs present and no trees. It is a short grass site. The dominant is blue grama, which makes up from 50 to 60% of the total composition. Sideoats grama, vine mesquite, and western wheatgrass will make up 10 to 15% in climax. Other grasses that make up less than 15% together are sand dropseed, gummy lovegrass, tumble windmillgrass, sand muhly, silver bluestem, galleta, and bottlebrush squirreltail. Forbs are moisture dependent and are less than 5% of the total composition. This is a preferred site by livestock. It is not diverse vegetatively. The main factors limiting plant growth are heavy textured subsoils and the high tension with which water is held in the soil.
Very shallow	The natural plant community is made up of a mixture of short and mid grasses with some occasional tall grass species and a significant forb and shrub component. Vegetation in general is sparse. The major grasses are sideoats grama and little bluestem. Other commonly found grasses are perennial threeawn, hairy grama, sand muhly, slim tridens, and occasional plants of sand bluestem and indiangrass in cracks and crevices where moisture can accumulate. Several perennial forbs and shrubs occur adding to the diversity. The site is not extensively used by livestock due to low palatability of the species present, which is largely due to the limey soil. Browsing wildlife species frequently utilize the site.

Table 3-1. Continued.

Sandy loam	The natural plant community is basically a mixture of midgrasses and tall grasses. Little bluestem is usually the dominant tall grass and sideoats grama is the dominant midgrass. There are "tight" spots occurring within the site that may be dominated by shorter grasses such as blue grama. Forbs make up from 5 to 8% of total production with shrubs such as sand sagebrush and yucca making up as much as 10% of total. This is a productive site when well managed and is preferred by livestock.
Gravelly	The natural plant community is a mixture of short, mid and tall grasses with considerable forbs and a few shrubs. The most significant grasses are sideoats grama, little bluestem, hairy grama, and sand dropseed. Other species include black grama, fall witchgrass, slim tridens, and tall grasses such as indiangrass and sand bluestem in the most favorable exposures. Dominant forbs are oenothera species, halfshrub sundrop, ratany, buckwheats, dotted gayfeather, aster species, penstemons, and annuals. Broom snakeweed is the main half shrub present. The shrubs include feather dalea, skunkbush, and yucca. Occasionally juniper will be scattered over the site.
Hardland slopes	This is a transitional site dominated by shortgrasses with a significant midgrass component. Blue grama is the dominant grass making up 50% or more of the total production. Buffalograss and sideoats grama are next in importance. Other midgrasses are vine mesquite and western wheatgrass that occur in micro lows where moisture collects. This site is very productive if runoff can be minimized. When heavily grazed, cover is not sufficient to retard runoff and the slopes carry it away rapidly. Yucca is the principal woody plant with relatively few forbs being present. This site is subject to gully erosion when cover is poor.
Sandy bottomland	The natural plant community is tall and mid grasses, few forbs, scattered shrubs and a few trees. Generally plant density is less than on a loamy bottomland site. The main tall grasses are switchgrass, indiangrass, sand bluestem, and little bluestem. Midgrasses such as sand lovegrass, sand dropseed, needle and thread, canada wildrye, western wheatgrass, and meadow dropseed are also present. Shrubs such as baccharis, sand sagebrush, skunkbush and sand plum are dispersed throughout the site. Cottonwoods, western soapberry and occasional willows comprise the tree component. Production varies from moderate to very good depending on the degree of development of soil. Since this soil is still very young developmentally, it is difficult to describe a climax community that covers all sites.
Loamy bottomland	The natural plant community is mid and tall grasses with a good forb population and a few woody plants. The site catches extra runoff from surrounding areas and is also subject to overflow from time to time. The major tall grass species are switchgrass, indiangrass, and sand bluestem. Midgrasses include sideoats grama, western wheatgrass, meadow dropseed, vine mesquite, and silver bluestem. Several climax forbs are present along with occasional cottonwoods, willows, hackberry, and a few shrubs. A few short grasses will be present but should not make up more than 5 to 10% of the total vegetation.
Wet bottomland	The natural plant community is a combination of tall grasses, sedges and rushes, forbs and shrubs with scattered trees. Major species are switchgrass, eastern gramagrass, prairie cordgrass, tall dropseed. Indiangrass, alkali sacaton, inland saltgrass and sand bluestem. In the wetter areas there will be significant amounts of spike sedges and rushes with occasional cattails and common reedgrass. Major forbs are maximilian sunflower, goldenrod, bluebell, tall gayfeather, cardinal flower, primroses, and annuals. The major shrubby species include baccharis, indigobush amorpha, and button willow. Trees present include cottonwood, willow, and occasionally persimmon, hackberry, elm and roughleaf dogwood.

Areas with salt cedar were marked on U.S. Geological Survey topographic maps and on high-quality NRCS air photos taken in 1996. Salt cedars were abundant close to the shore of Lake Meredith, lined the river banks upstream with a typical width of 30 feet on each side, and in the lower reaches of the Punta del Agua drainage and some other tributaries. Approximately 1,773 acres of salt cedar were mapped from Lake Meredith to the New Mexico State Line. This estimate primarily represents moderate to heavy stands of older trees, at least 6 feet or taller, that were easily identifiable from the air. It does not include all the stands of smaller trees, nor salt cedars seen growing as understory to larger cottonwood trees. In addition, there may have been some undercount of acreage because some plants were still green; and some had lost all their leaves.

Analysis of water use by, and control of, salt cedar was outside the scope of this study. In general, salt cedar has the potential to use large quantities of water -- several acre-feet per acre -- due to the fact that their roots typically tap directly into a shallow water table. Thus the salt cedars observed during the aerial reconnaissance could account for several thousand acre-feet of water consumption. On the other hand, replacement vegetation (e.g. cottonwoods, willows) also are phreatophytes so the net water savings is therefore moderated (though habitat values are much improved).

There has been some salt cedar cutting and burning done by the National Park Service in the Lake Meredith headwaters; costs for this program were not available. Salt cedar control in New Mexico using a combination of herbicides, burning and mechanical control cost $300 to $600 per acre (Taylor and McDaniel, 1998). Considering the time value of money, there probably are substantial areas where salt cedar clearing would salvage water at a cost that could be less than $50 per acre-foot.

3.2 Historical Considerations

3.2.1 Ecological History

No previously published summary of the ecological history of the Canadian watershed of Texas was identified during this study. Therefore, a new historical summary was needed. By all accounts, the person most knowledgeable on this subject is Mr. J. R. Bell, Rangeland Management Specialist for the USDA Natural Resources Conservation Service in Amarillo, Texas. Mr. Bell kindly prepared a summary, which appears as Section 3.2.1 below. Portions of the narrative are the opinions of the author based on experience and personal observation. Mr. Bell's contribution to this report is greatly appreciated.

The Canadian River corridor was known in centuries past to many and varied travelers. Native Americans used the area extensively for eons prior to any European presence. Then came Spaniards, French, Mexican, and Anglos. Some were adventurers, some explorers, some surveyors, and some military commanders. From the 1540's to pre-settlement times of the mid-1800's they came through the region. Some did not tarry long, but some called the area home for long periods of time. Not many recorded much in writing about the area, but some certainly did. Some of these written records are helpful to us today in understanding the area as it must have been in those days. Has the landscape changed from then until now? What about the plant life and the wildlife of those days? We get glimpses of the period by examining the few written records left to us by these travelers of times long gone.

Don Juan Onate visited the region in 1601. While traveling from west to east down the river he "took delight in the broad river valley" and noted that the vegetation was more verdant than that of the "plains above." He described the "outlying formations" (mesas) and the rocky escarpments that characterize the western portion of the Canadian River Breaks. He recorded that "the Indians of the nation called Apachi offered them tasty plums that were found in the valley groves." Onate stated that his group could easily travel the broad valley and that the rate of progress was very good. This seems to suggest that there were few obstacles to travel for persons on foot, riding horses, and oxen pulling carts. Perhaps many of the eroded gullies and washes that are found today did not exist then. We can only assume that it may have been so. These are certainly barriers to that mode of travel. He spoke of "springs of good water and groves of trees" which occurred fairly frequently. Water and wood was rather easy to come by and forage for their animals could easily be found. We can see that the water resources might have been a bit different because there are not many springs to be found close to the river in these present times. Wild game was plentiful as they saw many cibolas (cows), meaning bison. He described elk as “deer as large as horses.” Onate did not record much in the way of hardships encountered in his journey.

The French traders Paul and Pierre Mallet visited the region in the spring of 1740. They traveled on the south side of the river “beneath the bluffs of the Llano.” Somewhere in present Oldham County they visited a Comanche village of some considerable size. This indicates that the Comanche had begun to dominate the region and had by this time acquired horses for themselves. The Indians were friendly and offered no trouble. The Mallets found the traveling easy with forage and water sufficient for their party. They did note that the riverine corridor was much preferable to the “barren plains of the Llano above.”

During the 1700’s the Comanches began to do some trading with the Mexican peoples of the upper Pecos region and the Canadian River became somewhat of a trade route. There were many good camping places along the river. One such place recorded was Tecovas springs in northwest Potter County. It is recorded as having excellent water and many large cottonwood trees so as to make it a good spot to linger and trade. From what we can gather, the bison did venture out onto the Llano Estacado when there was water available in the playa lakes, otherwise they tended to skirt the edge of the Llano where there was adequate waterings. There are still in existence some old buffalo trails worn into the sandstone in the western Texas Panhandle. Mexican ciboleros (buffalo hunters) began to regularly visit the region usually in the fall of the year, to secure a supply of meat for the winter. They used long lances and speedy horses to dispatch the great animals. The meat was dried and hauled back to the upper Pecos in carts.

Major Stephen H. Long led a survey party along the Canadian in 1820. In his party was Edwin James, a renowned botanist. Near the New Mexico line they encountered hard going due to sandy stretches along the river, and “dunes” which were difficult to negotiate with their wagons. Here water was in short supply and game was scarce. In just a few days, however, they found themselves in an area of “many grapevines, plums and fine groves of trees.” James describes the Canadian River at one of their camps as being “about 60 yards wide, with about 20 yards being sandbars, and the rest water about 10 inches deep. The current is moderate and the color intensely red." James commented further that although the region did have extensive areas that appeared to be fertile, the general scarcity of water and wood made it uninhabitable.

In 1839 Josiah Gregg, who made numerous trips down the Santa Fe Trail, investigated the Canadian corridor as a possible trade route. He stated that the Canadian valley was "one of the most magnificent sights that I have ever beheld." Gregg's statement is of some significance as he was already an experienced plains traveler and had seen a lot of the plains region. He and his group was "not want to venture onto the Llano" for fear of becoming lost. Gregg thought that the plains would always be uninhabitable for the most part. The riverine corridor was much more appealing to Gregg. He spoke of sandy soils, tall grass and spring water being readily available.

In 1845 Col. John J. Abert made a reconnaissance survey for the Corps of Topographical Engineers. His journal records an abundance of plant and animal communities along the river. He records seeing numerous species of tall grass including a "type of tall cane" (probably *Phragmites communis* – common reedgrass). Also recorded were hackberry, cottonwood, wild chinaberry, buttonbush, and groves of mesquite. Grapevines, plum bushes and numerous yellow blossomed herbs were also mentioned. Abert even mentioned the "annoying sandburs" and various "spinescent cacti ." He describes the valley as "fertile to the eye in spite of some sandy and duney areas." In contrast, he describes the high plains tableland as being " altogether desertlike." The party collected samples from the "agate bluffs" of the Alibates area. The season was autumn and Abert said he was greatly impressed with the natural beauty of the landscape. The picture Abert paints is one of a diverse plant community, one that includes grasses, shrubs, herbs and trees; and a beautiful landscape. He does mention that mesquite was found in several places in the region but does not indicate that it was widespread in nature as is the case today. Abert had to make numerous detours in the sandhills of northern Potter County to go around the head of draws and ravines. Abert's description of the river suggests that it was pretty similar to what it is today except for the amount of fresh water entering from various tributaries.

Capt. Randolph Marcy in 1852 recorded the presence of good spring flow near the mouth of Sierrita de la Cruz creek in northwest Potter County. He also records that they found "mesquite timber and wild fruits" in the ravines at that location. Marcy describes the Llano Estacado near present day Adrian, TX. As "a vast, illimitable expanse of desert prairie with not a tree, shrub or any other object, either animate or inanimate, to relieve the dreary monotony of the prospect." Marcy's description was a bit overstated, but his view was shared by many of his contemporaries. Marcy, being a military man paid a lot of attention to the type of forage found for his animals and the comforts of his men. When in the region of the Canadian valley he generally found things favorable.

Lt. A.W. Whipple conducted a survey for a possible transcontinental railroad Route along the Canadian River in 1853. He also had a botanist in his company, Dr. John Milton Bigelow. There was an artist named Mollhausen in the group who made etchings from some of the sketches he took on the journey. In general, his sketches reaffirm the open landscape with cottonwood trees scattered along the river. There was juniper present in some of the canyons, but there is no indication that there were many shrubs present at all. Dr. Bigelow found that the plant communities were quite diverse in the valley, but declared the plant community of the Llano to contain "nothing of floral interest." In general, Whipple found the Canadian River corridor fairly hospitable.

In 1864, Kit Carson led a military expedition into the Panhandle to engage the hostile Comanches and Kiowas. He found a sizable camp of Indians in the broad floodplain near present day Borger. He declared that the grass was so tall in one place that an Indian on horseback could disappear into it. So we again see that the Indians used the river corridor to a great extent because it provided all their requirements.

As we try to sum up what has been written about historic ecology of the region, we do not find that many specifics, but quite a lot of general information. It would be difficult to draw scientifically based conclusions on exactly how the landscape has changed in the last 150 to 200 years but we do have some insights we can draw from. All the writers in the previous paragraphs stated that the landscape was one of open grassland with scattered groves of trees, probably cottonwoods, western soapberry, and hackberry. Shrubs such as sand plum and sumac along with grapevines were common along the streambank in many places. Tall grasses were dominant in the river floodplain and in the subirrigated areas. It is very likely that more live water flowed into the river from creeks and streams that were spring fed. Grazing pressure from domestic livestock has reduced the amount of tall grass vegetation in many areas and weeds and short grasses have taken their place. Overall condition of the range, and individual plant vigor has declined since the 1870's. Spring water flow has declined over the years according to interviews with individuals that have been in the area since the 1920's. Erosion on the watershed has increased due to less vegetative cover. The early writers did not mention the thick infestations of brushy plants such as mesquite although some mesquite was present. Junipers were confined to the canyons and rough areas as they are today. The mesquite has increased dramatically during the past 75 years. This can be substantiated by looking at old photos of the area and by interviews with ranching families knowledgeable about the condition of the range since the early 1900's. Many other individuals have stated that the amount of mesquite has doubled since 1950. No doubt that drouths of the 1930's and 1950's saw an increase in the recruitment of mesquite. Mesquite has been spread by beans passing through cattle, which has been shown to be a major factor in rate of increase of the species. Increased pressure on the palatable grasses and forbs has allowed competitive brush to gain a foothold more easily. The cessation of prairie fires most certainly allowed species like yucca to increase more rapidly, and probably played a part in keeping many other brushy species suppressed. None of the early writers mentioned the saltcedar (*Tamarix*) and it is believed that this species was not introduced into the southwest until the 1820's. The saltcedar when considered as a single species, is the greatest water user on a per plant basis. In the riparian zone it may have negatively affected shallow water tables and probably competes vigorously with species like cottonwood. There is no doubt that considerable water is being used by woody vegetation in the watershed. In addition, ground water pumping may have negatively affected spring flow higher up in the watershed.

In contemplating watershed treatment programs, it is advisable to adopt a thoughtful, holistic approach that includes all the best management practices. If this is done, then it is probable that water quality and quantity can be positively affected. In addition, productivity can be improved, plant communities stabilized and natural beauty preserved.

3.2.2 Hydrological History

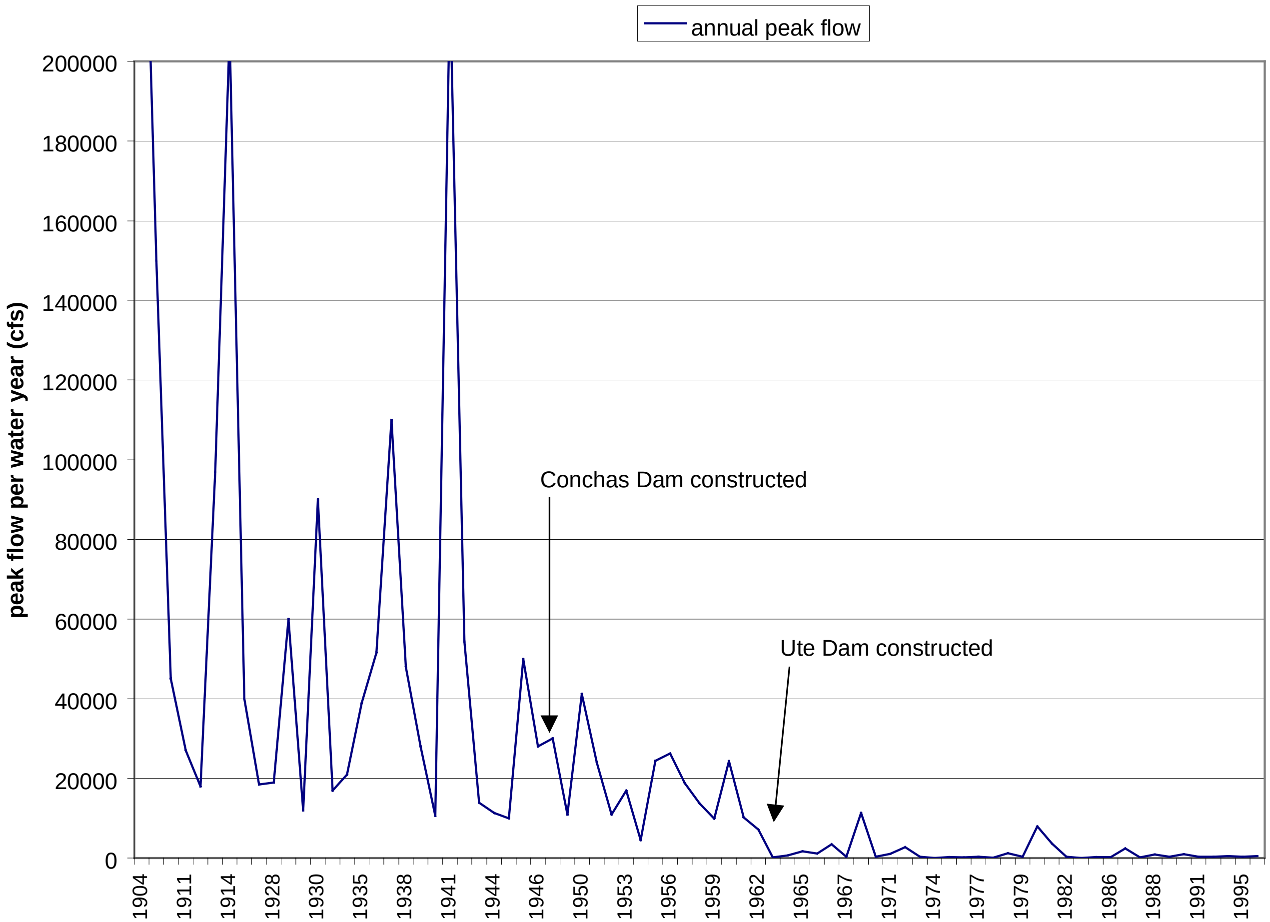
With reservoir construction during the 20th century, the Canadian River drainage basin above Lake Meredith has been divided into two segments: the area above Ute Reservoir, near Logan, NM and the area below Ute Reservoir. Most of the basin drainage area is above Ute Reservoir. Runoff in the upper basin has been controlled by Conchas Reservoir since 1938 and Ute Reservoir since 1963. There is use of Conchas water for irrigation, but otherwise the primary depletion in New Mexico is for reservoir evaporation. Ute Reservoir accounts for a small seepage discharge to the Canadian River (2 cfs or less); substantial releases to Texas have occurred only during periods of abundant storm water runoff, or as required under terms of the Canadian River Compact.

In Texas, Rita Blanca Lake was constructed by the U.S. Soil Conservation Service and has controlled flows to Punta de Agua Creek, a major tributary to the Canadian River upstream of Lake Meredith since 1941 (Figure 3-1).

Historical mean daily discharge data for the Canadian Basin are available from the USGS for the Canadian River at Logan, NM from 1909 to the present, although prior to 1930 there are some data gaps and “unreliable” records. The USGS Canadian River gage near Amarillo has a continuous record since April 1938 and the Revuelto Creek tributary to the Canadian near Logan since August 1959. There are also short periods of flow records from discontinued stations at Tramperos Creek near Stead, NM (1966-1973), Punta de Agua Creek near Channing, TX (1967-1973), and the Canadian River at Tascosa, TX (from 1968-1977). Also daily reservoir storage data are available from CRMWA for Lake Meredith since it was built 1964.

The USGS gage data for the Canadian River near Logan, New Mexico is downstream about 1.5 miles from Ute Dam. The USGS recorded annual peak flows at the Logan gage are shown in Figure 3-4. It is evident from the graph that flood flows at Logan decreased substantially after completion of Conchas and Ute Reservoirs. For the period of record from Jan. 1, 1930 through Sept. 30, 1999, the average daily flow was 161 cfs and median daily flow was 3.3 cfs. Before completion of Ute Reservoir, the gage records from 1930-1962 show the average yearly flow was 292 cfs, median yearly flow was 140 cfs. After Ute completion, average and median yearly flows were about 40 and 20 cfs respectively

Figure 3-4. Canadian River gage near Logan, NM annual peak flows measured by USGS from 1904 to 1996.



Revuelto Creek contributes irrigation return flows and stormwater flows to the Canadian River on an irregular basis.. The USGS recorded annual peak flows at the Revuelto Creek gage are shown in Figure 3-5. The average historical daily discharge from Aug. 1, 1959 to Sept. 30, 1999 was 46 cfs and the median daily discharge was 5.4 cfs. There may be a slightly downward trend in peak flows at this site.

The USGS gage data for the Canadian River near Amarillo, Texas is located 17 miles upstream of Lake Meredith at the US 87-287 crossing. The USGS recorded annual peak flows at the Amarillo gage also decreased after completion of Ute Reservoir (Figure 3-6). For the period April 1, 1938 through Sept. 30, 1999, the average daily flow was 289 cfs and the median daily flow was 27 cfs. Before completion of Ute Reservoir, the gage records from 1938-1962 show the average yearly flow was 461 cfs, and median yearly flow was 179 cfs. After Ute completion, average and median yearly flows were about 267 and 139 cfs respectively. A plot of the total acre-feet per year through each of the Logan and Amarillo gages is shown in Figure 3-7. The Amarillo flow is consistently higher, representing net inflow from watersheds that join the Canadian River in easternmost New Mexico and in Texas.

Figure 3-8 shows the quantity of this net inflow, i.e. the difference between the gaging records at Amarillo and Logan. The total flow at Amarillo is just over 126,000 AFY, and the average flow at Ute has been just under 30,000 AFY. Consequently, about 97,000 AFY of net inflow has reached the Canadian River from the watersheds that are below Ute. Based on Figure 3-8, there appears to be an overall downward trend in the net inflow value. However, given the variability in the data, this trend is not statistically significant.

In the Firm Yield Analysis for Lake Meredith prepared for the CRMWA in 1993, a review of the historic water balance showed that not all the runoff which passes through the Amarillo gage reaches Lake Meredith (LWA, 1993). Bank storage, backwater and/or floodplain effects, and evapotranspiration from salt cedar above Lake Meredith account for this water loss.

There are no significant direct diversions of surface water from the Canadian River between Ute Reservoir and Lake Meredith. The City of Amarillo is permitted to discharge 1 MGD of treated effluent to East Amarillo Creek, but since 1978 a local industry has been reusing the wastewater and discharges to the creek have not been made on a regular basis. The River Road WWTP is

Figure 3-5. Revuelto Creek gage downstream of Logan, NM annual peak flows measured by USGS from 1959 to 1997.

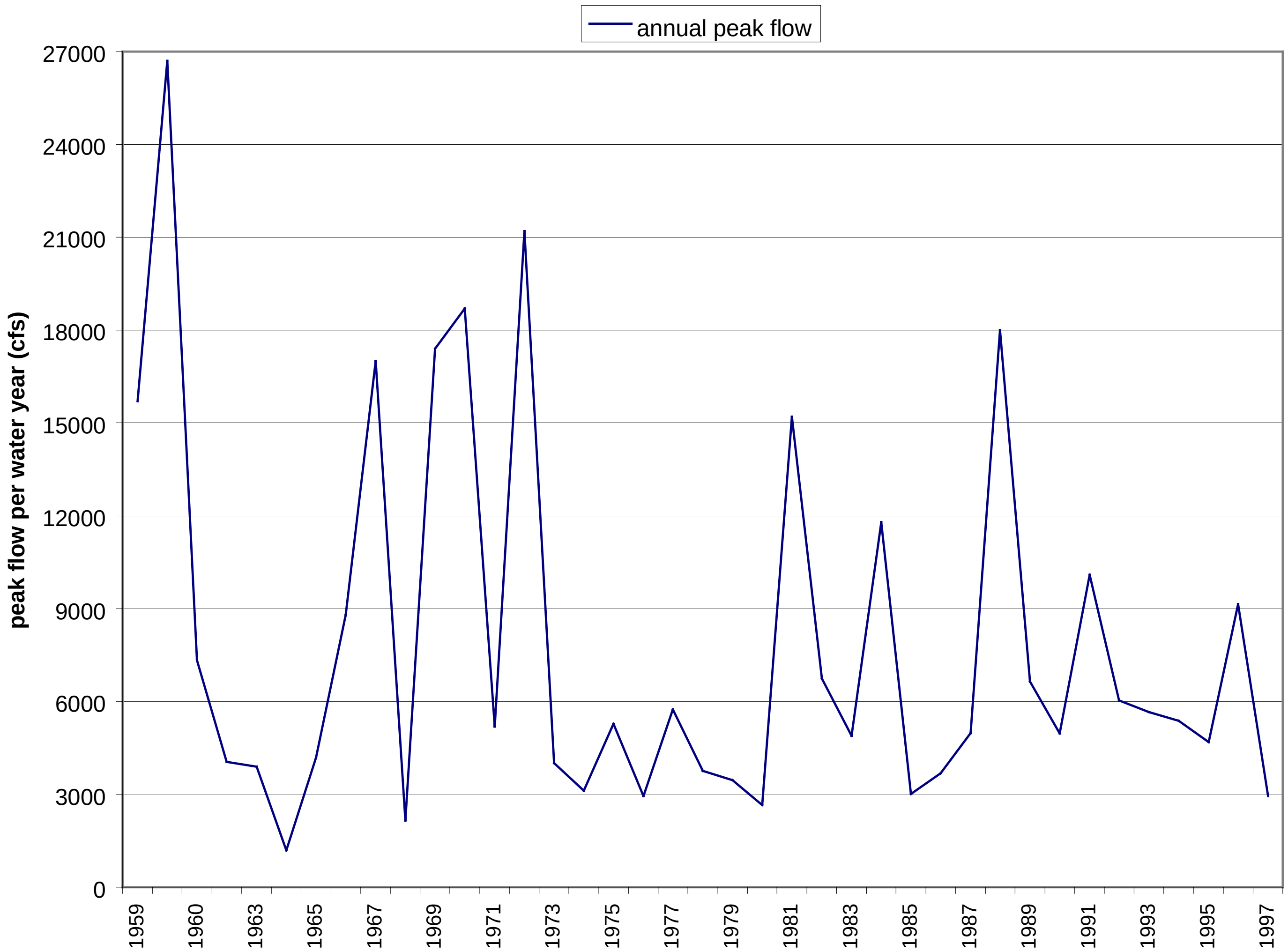


Figure 3-6. Canadian River gage near Amarillo, TX annual peak flows measured by USGS from 1938 to 1999.

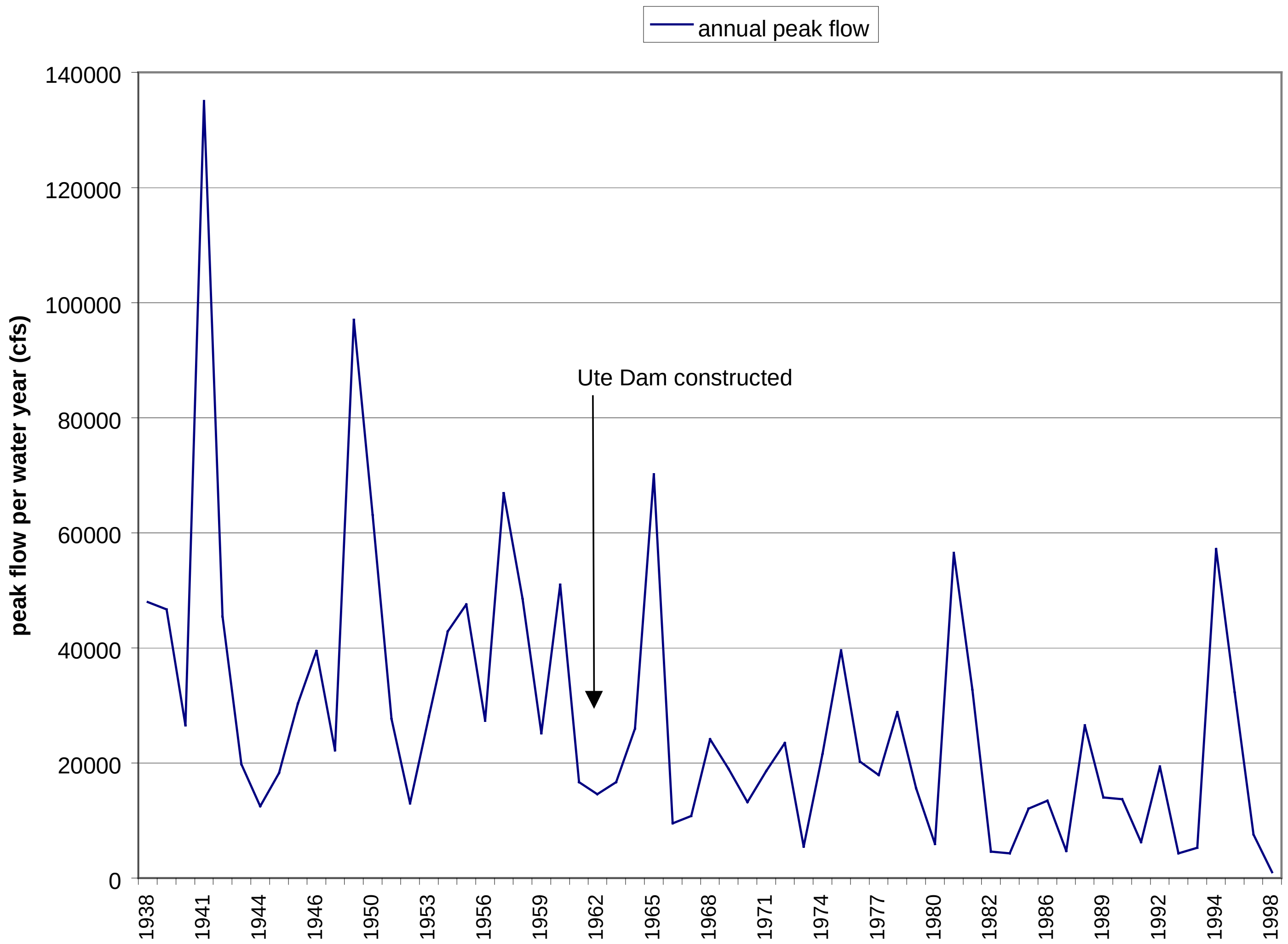


Figure 3-7. Total acre-feet per year of stream flow at Amarillo and Logan gages.

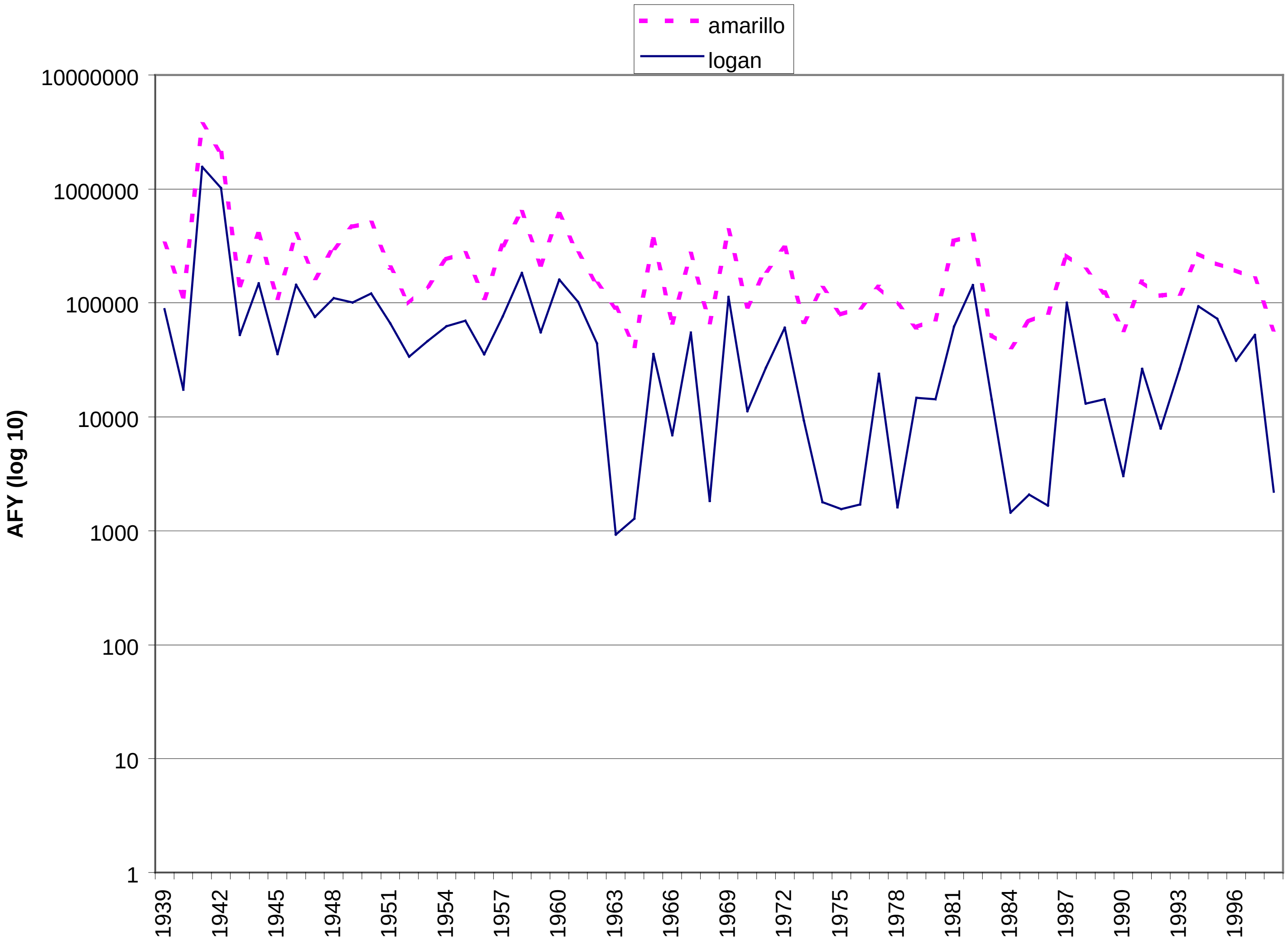
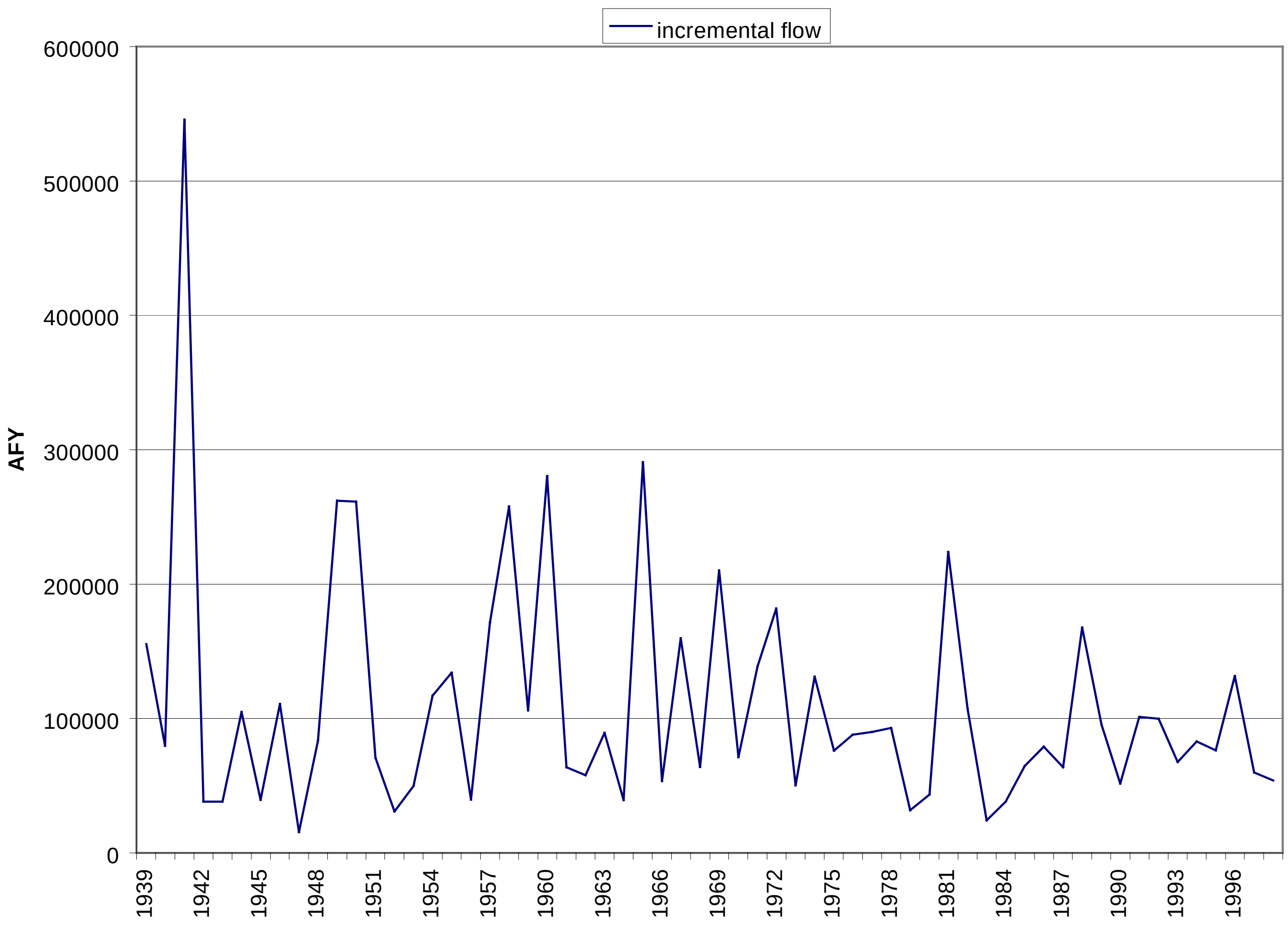


Figure 3-8. Incremental flow at Amarillo, acre-feet per year.



the only significant point source of wastewater to the Canadian River upstream of Lake Meredith (TWC, 1991).

The gage on the Canadian River just above the Texas state line was monitored from 1969-1984, only. The average daily flow was 81 cfs; the median was 13 cfs. Another discontinued monitoring station on the Canadian River at Tascosa had average daily flow of 168 cfs and median flow was 30 cfs from 1968 to 1977 records.

The development of ground water is an important component of the hydrological history of the watershed. The High Plains aquifer system is dominated by the Ogallala formation, a unit with a very large quantity of stored water but a low rate of natural recharge. With the development of large-scale irrigation operations on the High Plains following World War II, pumpage from the aquifer far outpaced recharge. As a result, the water table dropped consistently in the 1950’s - 70’s and it appeared that the aquifer would eventually be depleted. Water levels have somewhat stabilized since then, as conservation practices have substantially reduced pumping.

A survey of springs by Gunnar Brune (1981) identified approximately 170 sites in the Texas Panhandle where seeps and springs once existed. Abandoned structures, weather-beaten by time and neglect, and dying cottonwood trees still mark many of these sites where early plains pioneers attempted to establish a homestead. Archeological artifacts found near many of the former spring sites also attest to the importance these “watering holes” once had to the early natives of this land. Longtime residents of the High Plains recall that some springs dried up early in the 20th century, while other springs ceased to flow by the 1950s and 1960s when irrigation pumpage had its greatest effect on water levels (discussion of Brune from TWDB, 1993). Hydrologic changes associated with brush expansion may have contributed to the change as well.

Brune also identified approximately 225 actively flowing seeps and springs, the majority of which occur along the eastern escarpment and in the Canadian River breaks. Most of these springs have relatively low flows, with only 25 having a measured flow exceeding three cubic feet per second.

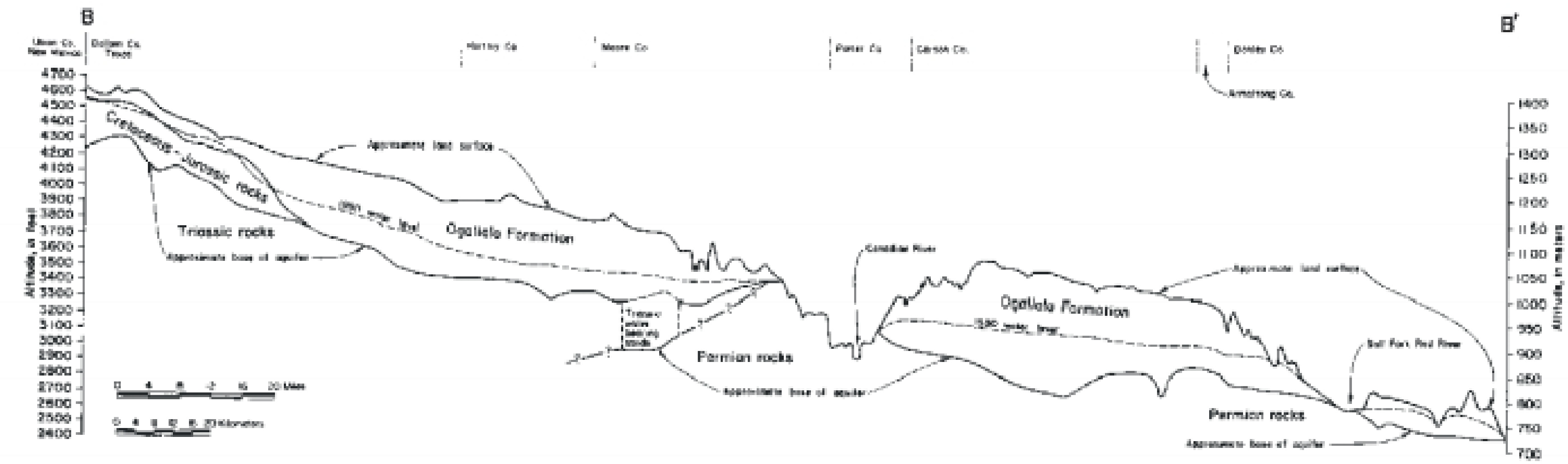
3.3 Geological Considerations

The plains of the Canadian River Basin in Texas are part of the North Plains and southern High Plains topographic features that have been dissected by the Canadian and North Canadian Rivers and their tributaries. The transition zone of about 20-25 miles is known as the Canadian River "breaks". There is little well-defined drainage except in the valleys cut by streams through the relatively flat plains. The slope of the land surface is generally eastward. The land surface elevation within the Texas portion of the basin ranges from 4,735 feet in northwest Dallam County to 2,167 feet in the valley of the Canadian River in eastern Hemphill County.

The Canadian River bed lies at an elevation of about 650 feet below that of the surrounding plains. From the New Mexico/Texas state line, the river has cut through fluvial sediments, and detrital and sedimentary rocks. The youngest, most recent areally extensive rock units are sands, gravel, silts and clays of the Tertiary Ogalalla formation. Below are shale, sandstone, and siltstone of the Triassic Dockum group; and finally shale, sandstone, siltstone, dolomite, gypsum, anhydrite and salt of the Permian Quartermaster formation and Whitehorse group. The broad outer valley, along the north and south margins of the "breaks", is cut through the Ogalalla. The inner valley between the river and the "breaks" is cut in the Triassic and Permian rocks. Beneath the river channel, Triassic rocks predominantly of shale and sandstone and Permian rocks extend to depths totaling 1,500 feet to at least 4,000 feet and rest on igneous basement rocks. River alluvium is found along the major channels; and there are eolian sands and playa lake deposits atop some areas of the Ogallalla.

Figure 3-9 shows a generalized geologic cross section from northwest Dallam County to southeast Donley County in the Texas panhandle. The section crosses the Canadian River at Lake Meredith in Potter county (from TDWR, 1984).

Figure 3-9. Geologic cross section from the northwest corner of Dallum County, TX to the southeast corner of Donley County, TX (modified from TDWR Report 288, 1984).



3.4 Existing Surface Water Hydrology

Gaged surface water flows on the river and several tributary streams are discussed in section 3.2.2, related to hydrologic history.

The three major reservoirs on the Canadian River are Conchas and Ute in New Mexico, and Lake Meredith in Texas. These reservoirs are operated under the conditions of the Canadian River Compact, which sets reservoir storage limitations for the three states involved (New Mexico, Texas and Oklahoma).

The Canadian River Municipal Water Authority (CRMWA) operates Lake Meredith for the Federal Bureau of Reclamation and provides water to eleven cities in the Texas panhandle. Capacity of Lake Meredith is 896,458 ac-ft. During periods of abundant runoff, releases and spills from Ute Reservoir contribute water to Lake Meredith, but most of the inflow originates below Ute. River flow below Ute primarily comes from streams such as Revuelto Creek in New Mexico, and Punta de Agua and smaller tributaries in Texas during rainfall events. Other water sources below Ute Reservoir are a minor part of the Lake's water supply, such as ground water discharge, seepage through Ute Dam, wastewater discharges to the river and precipitation directly on the reservoir surface.

Rita Blanca Lake, on the Rita Blanca Creek in the Punta de Agua subbasin, is operated by Dallam and Hartley counties for recreational purposes. The City of Dalhart discharges treated domestic wastewater directly to the reservoir, which has become very biologically productive and experiences algal blooms and elevated pH levels (TWDB, 1997).

East Amarillo Creek originates within the city of Amarillo and flows northward to the Canadian River approximately 7.5 miles upstream of Lake Meredith. It has little or no surface flow much of the year and it is not gaged, but runoff is included in flows recorded downstream at the USGS Amarillo station. Flow down this creek is comprised of stormwater runoff from the City of Amarillo, and flow in the lower reaches of the creek is occasionally supplemented by discharges from the City's Wastewater Treatment Plant.

In "An Assessment of the Biological Integrity of the Western Canadian River Basin in Texas", a rapid bioassessment was done by the Red River Authority of Texas during the summer of 1997.

The Amarillo Creek station (at US 287) scored in the highest of the eight stations studied for biological integrity, even though it was the only area studied that was greatly affected by anthropogenic activity. The reason for the high biological integrity was attributed to good physical habitat and the additional flows, which aids during the hot, dry summers in the region (RRA, 1998).

Also in the RRA assessment, the Punta de Agua @ Highway 767 station is described as having “abundant fish cover, high-quality clear water, mud substrate, and lacks (well-defined) stream banks”. This habitat should support biological communities, however the yearly recurrence of “no flow” conditions on the creek likely negatively impact the biological communities. The Big Blue Creek @ FM 1913 station is described as “characterized by shallow clear water running over a sandy substrate.” Coetas Creek on Alibates Ranch, Chicken Creek on LX Ranch and Bonita Creek on LX Ranch are identified as three small aquifer-fed creeks in close proximity to one another. Coetas Creek and Chicken Creek showed similar biological results, as these streams are physically similar, and overall the biological health was excellent for this region. The Bonita Creek station was located near a home and picnic area, and showed more impairment in its biological communities. There were beaver dams along the stream, which pooled up much of the stream. Sedimentation was much greater at the Bonita Creek station, affecting the suitability of the substrate (as compared to the cobble substrate of the Coetas and Chicken Creeks).

3.5 Existing Ground Water Hydrology

The principal aquifer in the Canadian River Basin is the Ogallala formation of Tertiary age, forming a large unconfined ground water reservoir. This unit generally consists of heterogeneous sequences of coarse-grained sand and gravel in the lower part grading upward into fine clay, silt and sand. Outcrop and core studies by Gustavson and Winkler (1987) indicate the Ogallala in Texas and New Mexico consists of "alluvial sediments that partly fill paleovalleys and widespread thick eolian sediments capping paleo-uplands and most fluvial sections." Calcic paleosols and fossil evidence suggest a depositional environment in a mostly semiarid to subhumid climate (Winkler, 1990; Schultz, 1990; and Thomasson, 1990). Saturated thickness of the Ogallala ranges from 20 to about 540 feet (TWDB, 1997). Some of the Quaternary sediments at the surface offer favorable conditions for recharge to underlying beds (TWDB, 1993).

Recharge to the Ogallala formation is from rainfall and snow in Texas and New Mexico. Estimates of annual recharge rates for the aquifer vary considerably, ranging from 0.01 (Stone, 1984) to 0.833 (TWDB) inches per year. Due to the semi-arid climate of the High Plains, with an average annual gross lake evaporation rate of 72 to 81 inches and slow infiltration rates, only a small amount of rainwater percolates to the water table. Heavy precipitation runoff accumulates in the playa lakes. While some studies suggest that the silt and clay bottoms of the playas render them nearly impermeable, others indicate that leakage through the playas is the primary source of recharge to the entire aquifer (Nativ and Riggio, 1990) (cited in TWDB, 1993).

Discharge from the aquifer occurs in springs that typically occur on tributary streams where the surface elevation intercepts the water table; and as a baseflow discharge to the Canadian River, which is a gaining stream throughout its length in Texas. However, the connection between the main Ogallala aquifer and the river is limited in the study area, as the mainstem channel is cut below the Ogallala and into underlying bedrock. The largest amount of discharge occurs through pumping wells. High Plains irrigation represents about 65 percent of the total irrigated acreage in the state, and 83 percent of the acres are irrigated with ground water (TWDB, 1993).

3.6 Description of the Watershed Hydrologic System

The natural hydrologic system of the Canadian River watershed included three primary components: spring runoff from snow melt in the Sangre de Cristo mountains (and to a lesser extent the High Plains); flood inflows during times of significant rainfall; and ground water inflows in the form of tributary baseflow and spring discharges.

With construction of Conchas and Ute Reservoirs, the importance of spring runoff to Lake Meredith has been greatly reduced and is significant only in exceptionally wet years when these reservoirs both spill. Spring discharges appear to have declined. At least within the period of gage records, it is not certain that there has been a decrease in flood inflows from the tributaries to the Canadian that join the river below Ute. If such a decrease has occurred, it would result from factors such as increased brush density and changes in farm practices (including construction of ponds).

Harman et al. (1998) report on application of a model known as APEX, which was used to predict sedimentation of Lake Meredith from a portion of the Canadian River watershed. The 640 square mile study area was estimated to contribute 62 acre-feet per year of water transported sediment each year, and less than 1 acre-foot/year of wind transported sediment. Sediment production was highly correlated with runoff, which suggests that activities that increase runoff may have implications regarding reservoir sedimentation.

Except for Lake Meredith itself, there has been little development of surface water in the basin. Nonetheless, total water use in the region is very large. Water planning is currently being done for the entire State of Texas, including specifically the “Panhandle Water Planning Area” (PWPA) which includes 21 counties, many within the Canadian River Basin. According to the State plan, water use in the PWPA during 1996 totaled over 2 million ac-ft, or approximately 17 percent of the state total. The revised total water demand projections for the 21 county region for 2000 is 1,718,400 ac-ft and steadily increases to 1,812,948 ac-ft for the year 2050. Total regional water demand is projected to surpass the available water resources by 2020, and projections for year 2050 indicate a total regional need for new supplies of 975,400 AFY.

Almost all of the "need" is for irrigation water, and likely will not in fact be met. Projected municipal and industrial demands will be met by development of currently or readily available resources.

3.7 Hydrologic Evaluation Summary and Conclusions

Based on the evaluations presented in prior sections, and information presented in Chapter 4, the following conclusions can be made regarding hydrologic conditions in the Canadian River watershed above Lake Meredith.

1. The firm yield of Lake Meredith is substantially less than expected when the dam and reservoir were constructed.
2. There has been a substantial reduction in streamflow caused by water capture and storage at Conchas and Ute Reservoirs, New Mexico.
3. There is minimal direct use of the Canadian River streamflows in Texas above Lake Meredith.
4. The inflow that occurs below Ute Reservoir represents the dominant source of water supply for Lake Meredith. Most of this inflow originates in Texas.
5. There are no useful gaging station records that allow assessment of major Texas tributaries to the Canadian River above Lake Meredith.
6. The tributaries to the Canadian River are generally not perennial, except locally in reaches very near the mainstem.
7. Water levels have declined in the Ogallala aquifer, due to irrigation pumping. The decline has stabilized in recent years.
8. There is substantial brush vegetation in the watershed, much more than occurred prior to European occupancy. The effects of this vegetation are undoubtedly reflected by the observed runoff patterns.
9. Significant amounts of streamflow are lost in the area just above Lake Meredith, due at least in part to evapotranspiration from phreatophytic vegetation.
10. The information is such that the best approach to assessing the effectiveness of brush control measures is via an appropriate hydrologic model, as presented in Chapter 4.

3.8 References Cited in Chapter 3

Brune, Gunnar. 1981. Springs of Texas, Volume 1. Fort Worth, Branch-Smith.

Gustavson, T.C. and Winkler, D.A. 1987. Depositional environments of the Miocene-Pliocene Ogallala Formation, Texas Panhandle and eastern New Mexico (abs.). Geological Society of America, Abstracts with Programs, v. 19, p. 687.

Harman, Wyatte L., Ranjan Muttiah, Melanie Magre and J. R. Williams. 1998. Sedimentation of Lake Meredith: an investigation of water and wind deposition. Report by Texas Agricultural Experiment Station, Blacklands Research and Extension Center, Temple TX, submitted to the Amarillo National Resources Center for Plutonium.

LWA, 1993. Firm Yield of Lake Meredith, Texas. Prepared for Canadian River Municipal Water Authority by Parkhill, Smith and Cooper, Inc. and Lee Wilson & Associates, Inc.

Nativ, Ronit and Riggio, Robert. 1990. Meteorologic and isotopic characteristics of precipitation events with implications for ground-water recharge, Southern High Plains. In Gustavson, T.C., ed., Geologic framework and regional hydrology, upper Cenozoic Blackwater Draw and Ogallala formations, Great Plains: The University of Texas, Bureau of Economic Geology, p. 152-179.

Neal, Byron. 2000. Telephone conversation with USDA, Amarillo, Texas on evaporation rates. Oct. 2000.

RRA, 1998. An Assessment of the Biological Integrity of the Western Canadian River Basin in Texas. Red River Authority of Texas, Wichita Falls, TX 76301.

Schultz, G.E. 1990. Clarendonian and Hemphillian vertebrate faunas from the Ogallala Formation (late Miocene-early Pliocene) of the Texas panhandle and adjacent Oklahoma. In Gustavson, T.C., ed., Geologic framework and regional hydrology, upper Cenozoic Blackwater Draw and Ogallala formations, Great Plains: The University of Texas, Bureau of Economic Geology, p. 56-97.

Stone, W.J. 1984. Preliminary estimates of Ogallala aquifer recharge using chloride in the unsaturated zone, Curry County, New Mexico. In Whetstone, G.A., ed., Proceedings, Ogallala aquifer symposium II: Lubbock, Texas Tech University Water Resources Center, p. 376-391.

Taylor, John P. and Kirk C. McDaniel. 1998. Restoration of Saltcedar (*Tamarix* sp.)-Infested Floodplains on the Bosque del Apache National Wildlife Refuge. Weed Technology, vol. 12, pp. 345-352.

TDWR, 1984. Evaluating the Ground-Water Resources of the High Plains of Texas. Texas Department of Water Resources, Report 288, Volume 1.

Thomasson, J.R. 1990. Fossil plants from the late Miocene Ogallala Formation of central North America, possible paleoenvironmental and biostratigraphic significance. In Gustavson, T.C., ed., Geologic framework and regional hydrology, upper Cenozoic Blackwater Draw and Ogallala formations, Great Plains: The University of Texas, Bureau of Economic Geology, p. 99-114.

TWC. 1991. Waste Load Evaluation for Dissolved Oxygen in the Canadian River above Lake Meredith in the Canadian river Basin, Segment 0103. Texas Water Commission Draft subject to revision.

TWDB. 1993. The High Plains Aquifer System of Texas, 1980 to 1990 Overview and Projections. Texas Water Development Board, Report 341.

TWDB. 1997. Water for Texas, Vol. II, Technical Planning Appendix. Texas Water Development Board, Austin, TX..

Winkler, D.A. 1990. Sedimentary facies and biochronology of the upper Tertiary Ogallala Group, Blanco and Yellow House Canyons, Texas Panhandle. In Gustavson, T.C., ed., Geologic framework and regional hydrology, upper Cenozoic Blackwater Draw and Ogallala formations, Great Plains: The University of Texas, Bureau of Economic Geology, p. 39-55.

Literature Reviewed by J. R. Bell

Custer, George Armstrong. 1962. My Life on the Plains. University of Oklahoma Press, Norman OK.

Haley, J. Evetts. 1936. Charles Goodnight – Cowman and Plainsman. Houghton Mifflin, Boston MA.

Morris, John Miller. 1997. El Llano Estacado: Exploration and Imagination on The High Plains of Texas and New Mexico 1536-1860. Texas State Historical Association. Austin, Texas.

Rathjen, Frederick W., 1998. The Texas Panhandle Frontier. Rev. ed. Texas Tech University Press, Lubbock, TX.

4. BRUSH / WATER YIELD FEASIBILITY STUDIES

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4.1 Abstract

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

4.2 Background

Recent droughts in Texas have brought attention to the critical need for increasing water supplies in some water-short locations, especially the western portion of the state. Increases in brush area and density may contribute to a decrease in 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.

4.3 Methods

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

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

Geographic Information System (GIS). In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (e.g., soils, land use, and topography) for comprehensive simulation models and spatially display model outputs. Much of the initial research was devoted to linking single-event, grid models with raster-based GIS (Srinivasan and Engel, 1991; Rewerts and Engel, 1991; Srinivasan and Arnold, 1993) using the Graphical Resources Analysis Support System (GRASS) (U.S. Army, 1988). The input interface extracts model input data from map layers and associated relational databases for each subbasin. Soils, land use, weather, management, and topographic data are collected and written to appropriate model input files. The output interface allows the user to display output maps and graph output data by selecting a subbasin from a GIS map. The study was performed using GRASS GIS integrated with the SWAT model, both of which operate in the UNIX operating system. Development of databases and GIS layers was an integral part of the feasibility study. The data was assembled at the highest level of detail possible in order to accurately define the physical characteristics of each watershed.

Topography. The United States Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of a watershed as a topographical database. The DEM available for the project area is the 1:24,000 scale map (U.S. Geological Survey, 1999). The resolution of the DEM is 30 meters, allowing detailed delineation of subbasins within each watershed. Some of the 8 watersheds designated for study were further sub-divided for ease of simulation. The location and boundaries of the watersheds are shown in Figure 4-1.

The number of subbasins delineated in each watershed varied because of size and methods used for delineation, and ranged from 5 to 312 (Table 4-1).

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 4-2.

Figure 4-1. Watersheds included in the study area.

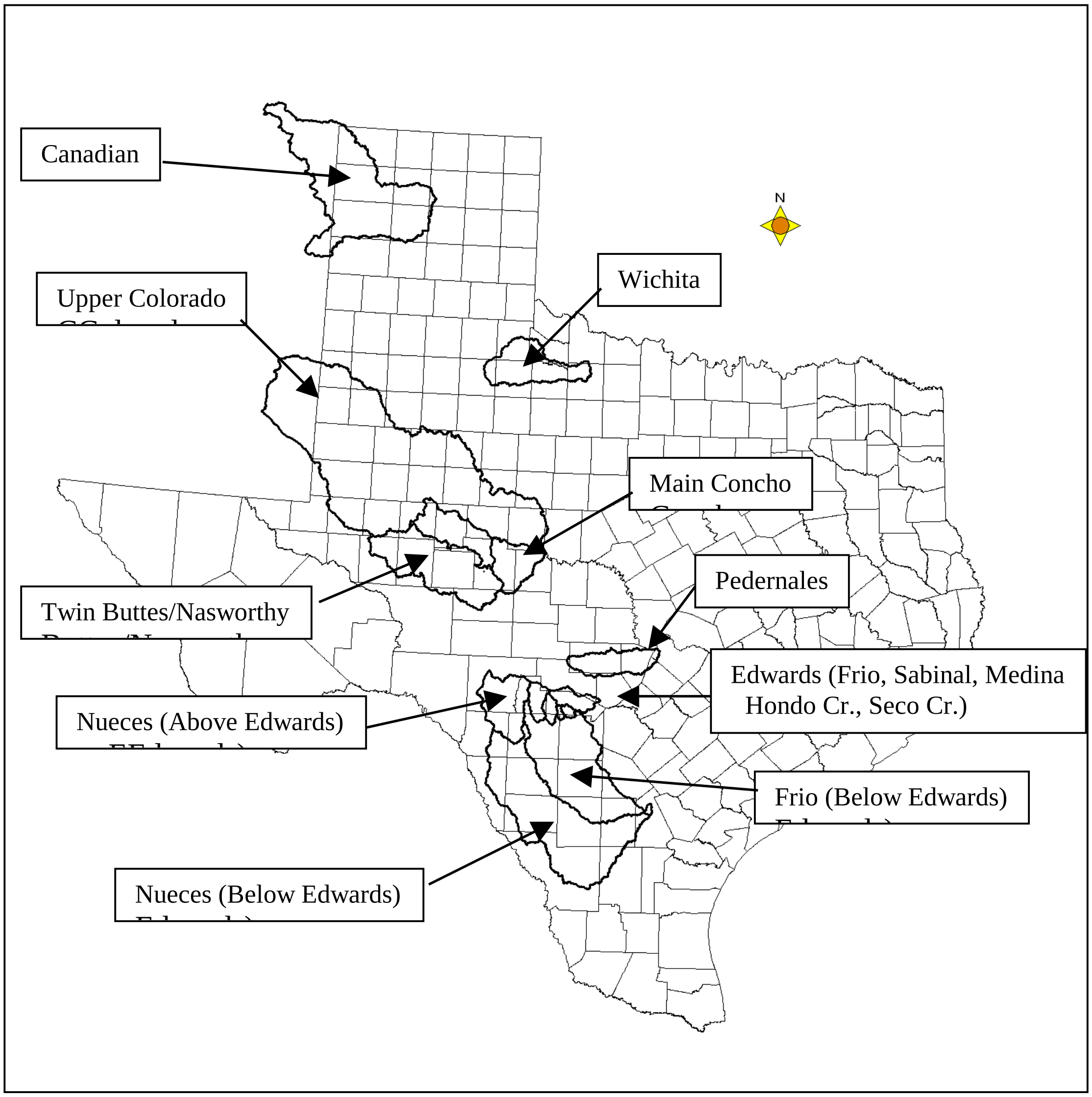

Figure 4-2. Average annual precipitation. Averages are for all climate stations in each watershed.

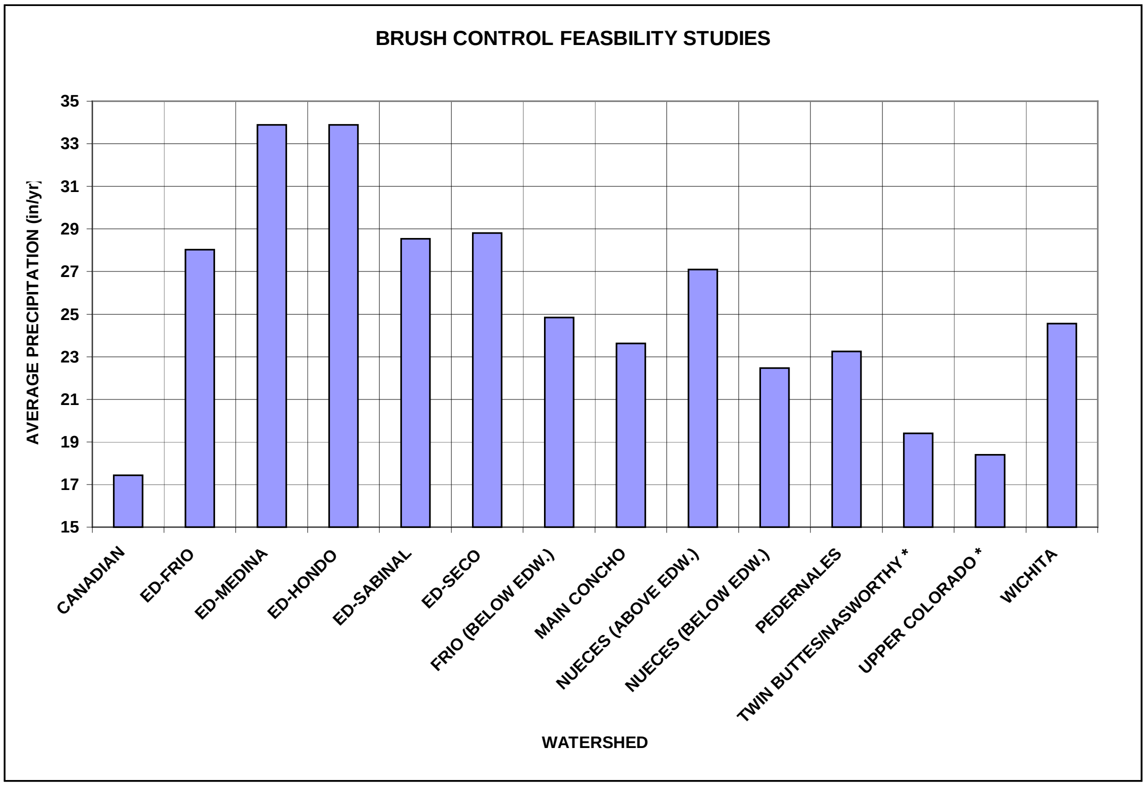

Table 4-1. Subbasin delineation.

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

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

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

1. The majority of the information was a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. This database was known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) soils data. The CBMS database differs from some grid GIS databases in that the attribute of each cell was determined by the soil that occurs under the center point of the cell instead of the soil that makes up the largest percentage of the cell. This method of cell attribute labeling had the advantage of a more accurate measurement of the various soils in an area. The disadvantage was for any given cell the attribute of that cell may not reflect the soil that actually makes up the largest percentage of that cell.
2. The Soil Survey Geographic (SSURGO) was the most detailed soil database available. This 1:24,000-scale soils database was available as printed county soil surveys for over 90% of Texas counties. It was only currently available as a vector or high resolution cell data base at the inception of this project for a few counties in the project area. In the SSURGO database, each soil delineation (mapping unit) was described as a single soil series.

3. The soils data base currently available for all of the counties of Texas is the State Soil Geographic (STATSGO) 1:250,000-scale soils data base. The STATSGO database covers the entire United States and all STATSGO soils were defined in the same way. In the STATSGO database, each soil delineation of a STATSGO soil was a mapping unit made up of more than one soil series. Some STATSGO soils were made up of as many as twenty SSURGO soil series. The dominant SSURGO soil series within an individual STATSGO polygon was selected to represent that area.

The GIS layer representing the soils within the project area was a compilation of CBMS, SSURGO, and STATSGO information. The most detailed information was selected for each individual county and patched together to create the final soils layer. In the project area, approximately 2/3 of the soil data was derived from CBMS and the remainder was largely STATSGO data. Only a very small percentage was represented by SSURGO.

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

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 4-2).

Table 4-2. 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

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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 ArcInfoTM point coverage.

ERDAS's ImagineTM 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 4-3 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.

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Table 4-3. 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
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Model inputs. Required inputs for each subbasin (e.g. soils, land use/land cover, topography, and climate) were extracted and formatted using the SWAT/GRASS input interface. The input interface divided each subbasin into a maximum of 30 virtual subbasins or hydrologic response units (HRU). A single land use and soil were selected for each HRU. The number of HRU's within a subbasin was determined by: (1) creating an HRU for each land use that equaled or exceeded 5 percent of the area of a subbasin; and (2) creating an HRU for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). The total number of

HRU's for each watershed was dependent on the number of subbasins and the variability of the land use and soils within the watershed. The soil properties for each of the selected soils were automatically extracted from the model-supported soils database.

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

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

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

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

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

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

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

Brush removal simulations. T.L. Thurow (Thurow, 1998) suggested that brush control is most likely to increase water yields in areas that receive at least 18 inches of average annual rainfall. Therefore, brush treatment was not planned in areas generally west of the 18 inch rainfall isohyet (Figure 4-3). 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.

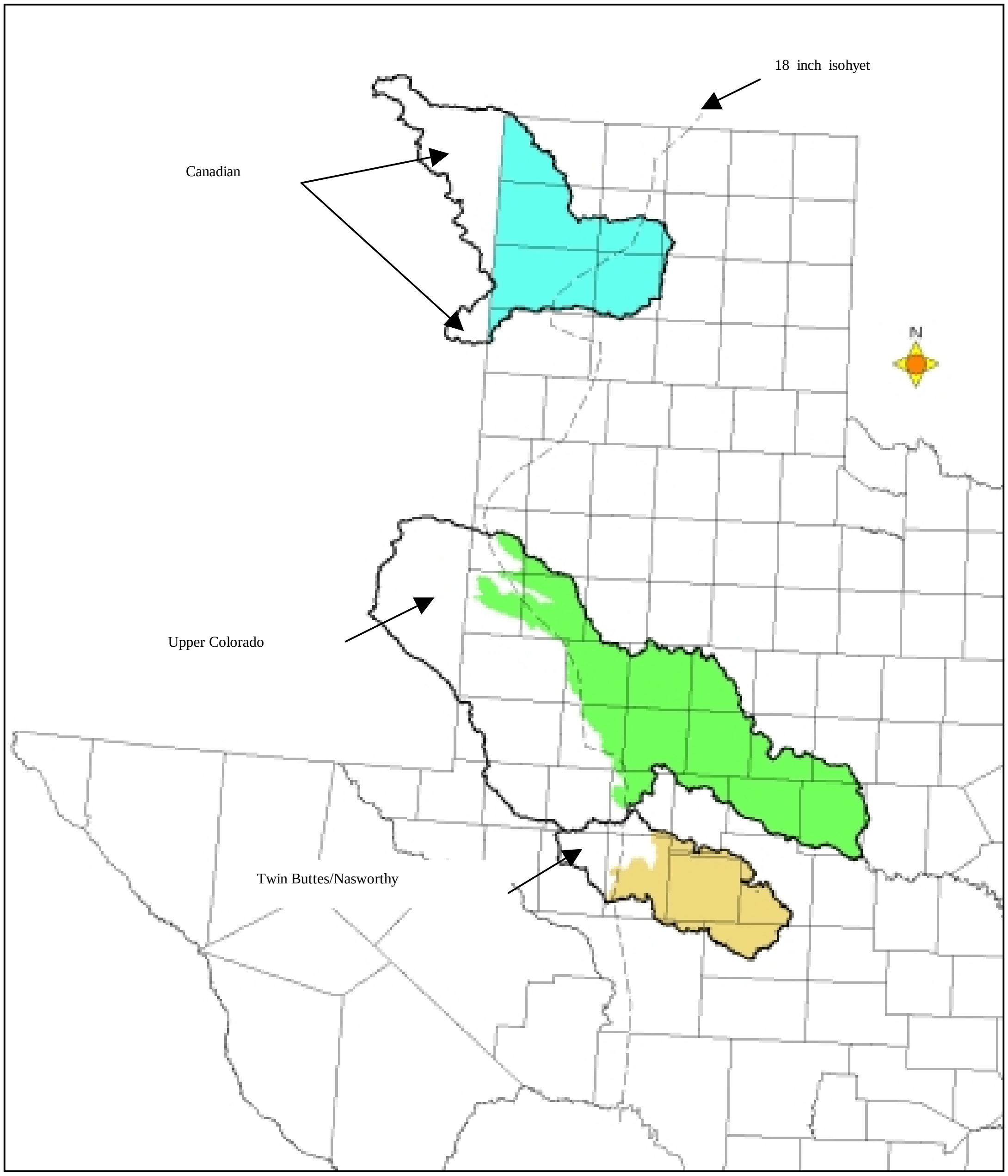
Some areas in the Upper Colorado and Twin Buttes/Nasworthy watersheds do not contribute to stream flow at downstream gauging stations (USGS, 1999). These areas have little or no defined stream channel, and considerable natural surface storage (e.g. playa lakes) that capture surface runoff. We used available 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 4-3).

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.

Figure 4-3. Areas where brush treatment was not planned (non-shaded portions of each watershed).



4.4 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 4-4. 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 4-5. 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 4-6).

The average annual stream flow (acre-feet) for the brush and no-brush conditions is shown for each watershed outlet in Figure 4-7. 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 4-8). In some cases, the increase in stream flow was less than the increase in water yield because of the capture of runoff by upstream reservoirs, as well as stream channel transmission losses that occurred between each subbasin and the watershed outlet.

1

There was a high correlation between stream flow increase and precipitation (Figure 4-9). The amount of stream flow increase was greater in watersheds with higher average annual precipitation.

Figure 4-4. 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.

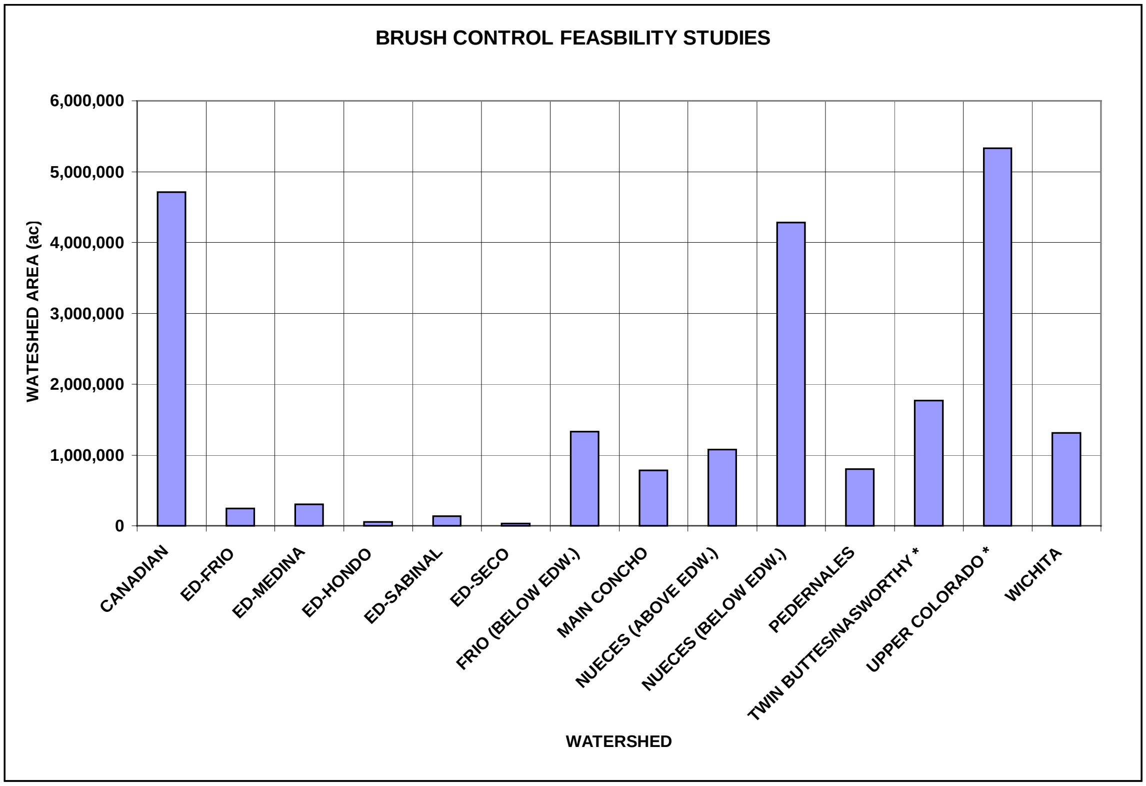


Figure 4-5. Fraction of watershed containing heavy and moderate brush that was treated. For watersheds that lie across the 18 inch isohyet, this is the fraction of the portion of the watershed where brush treatment was planned and simulated

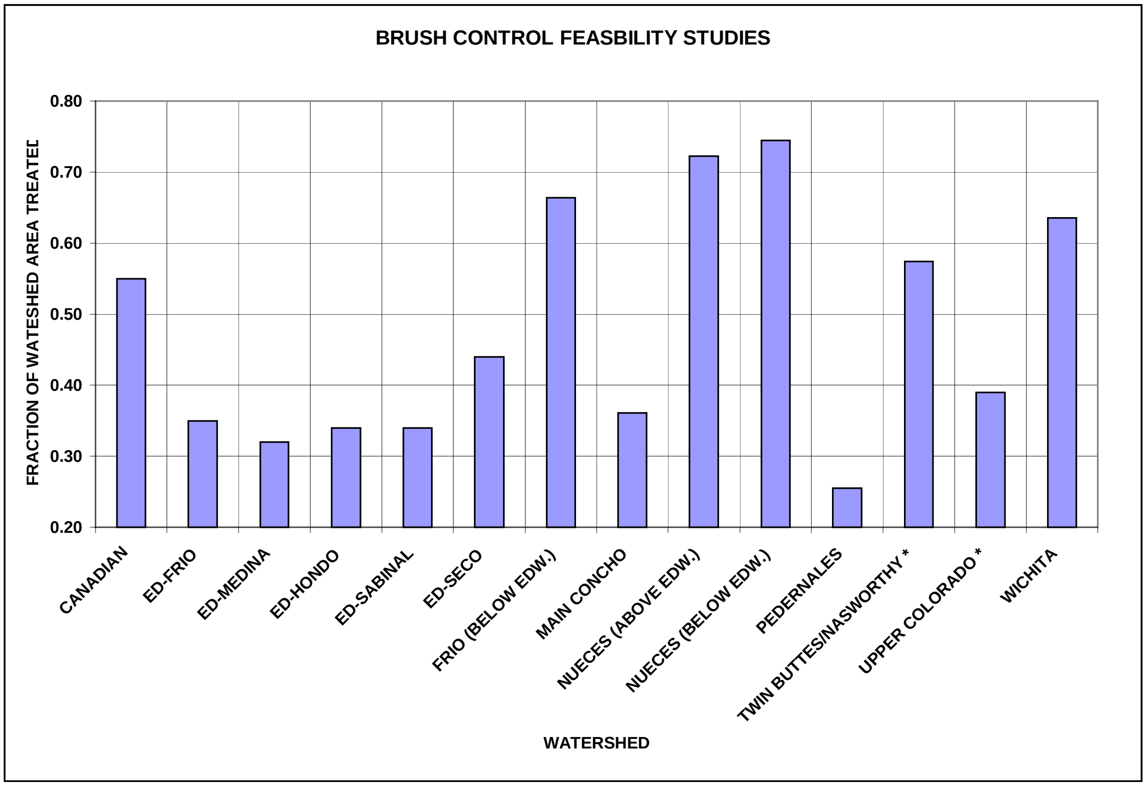


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Figure 4-6. Average annual water yield increase, 1960 through 1998.

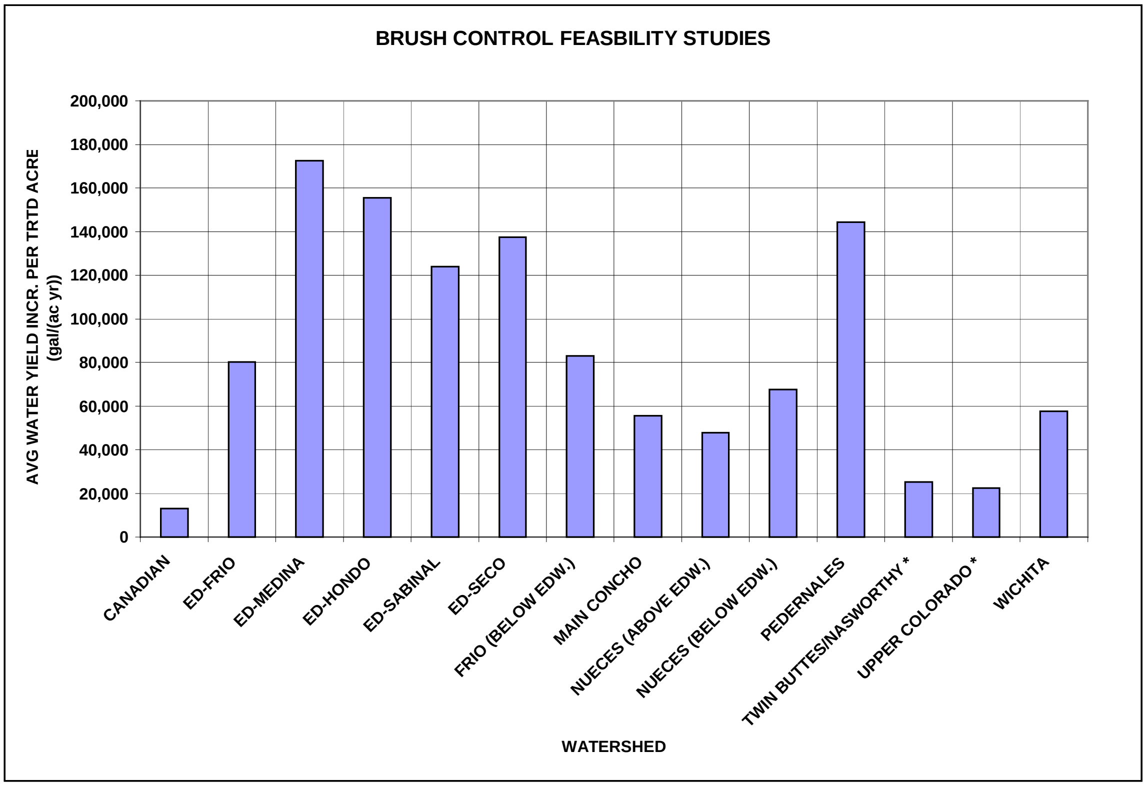


Figure 4-7. Average annual stream flow at watershed outlet, 1960 through 1998.

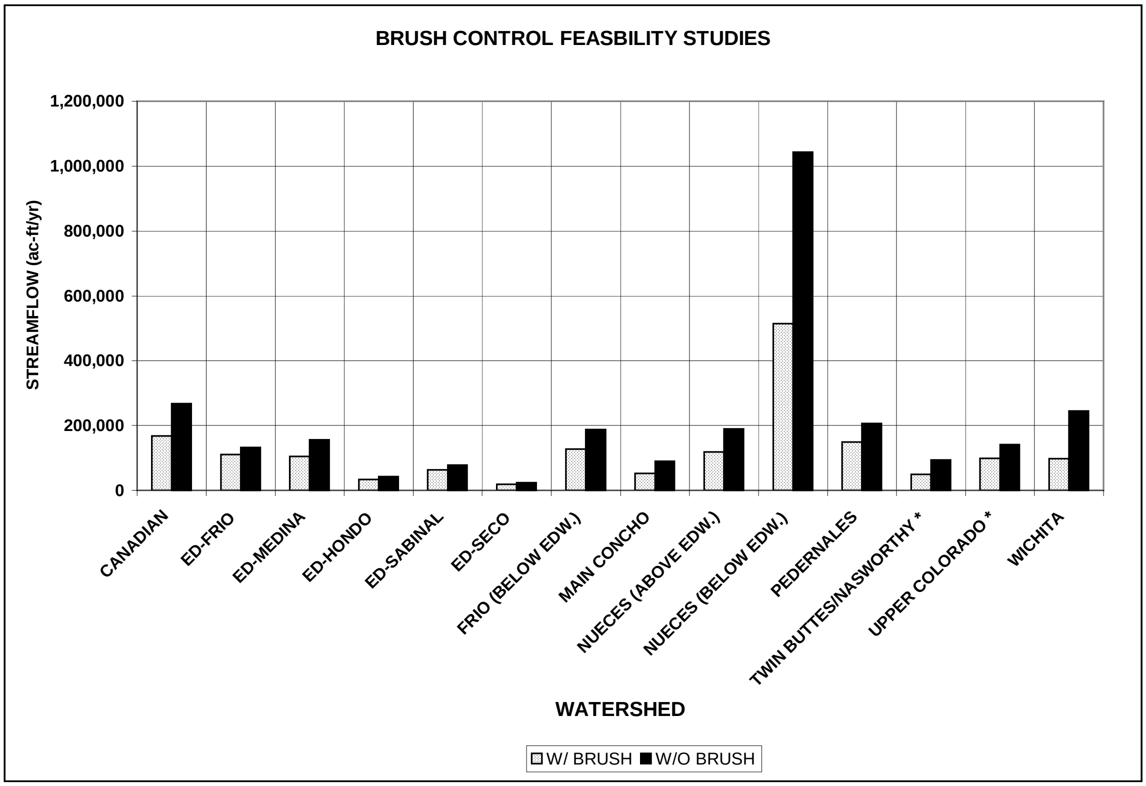


Figure 4-8. Average annual stream flow increase at watershed outlet, 1960 through 1998.

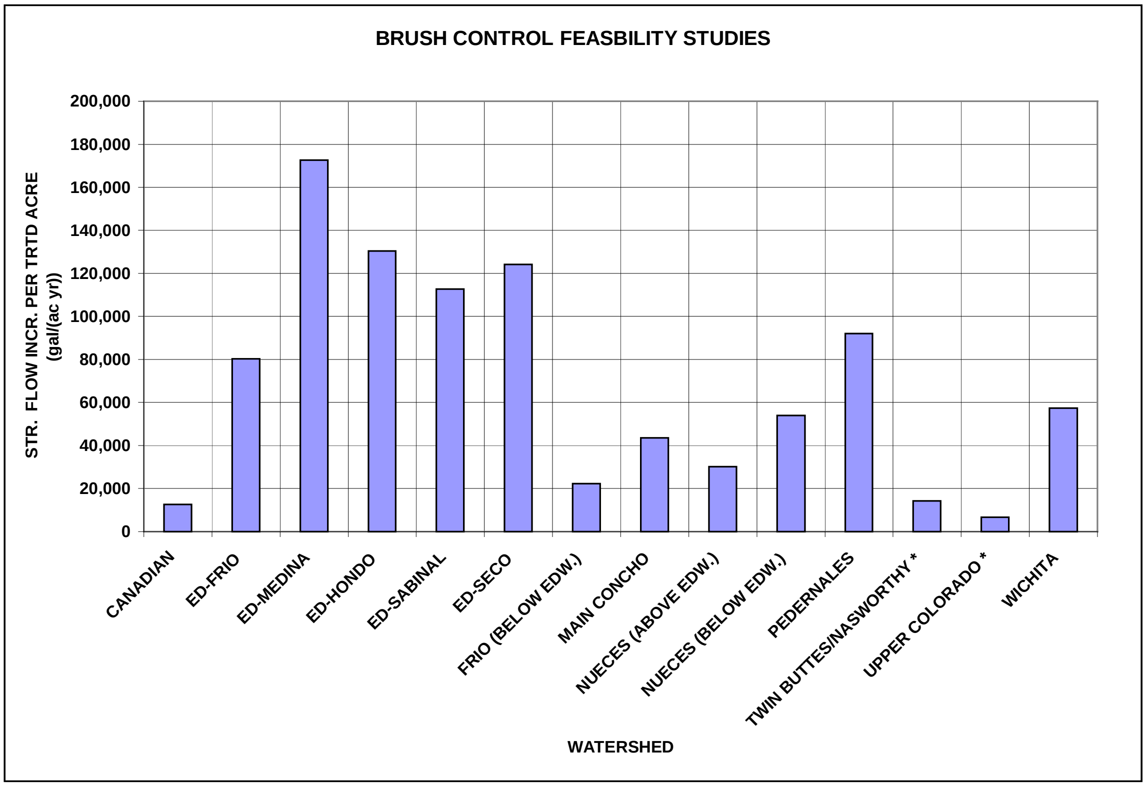
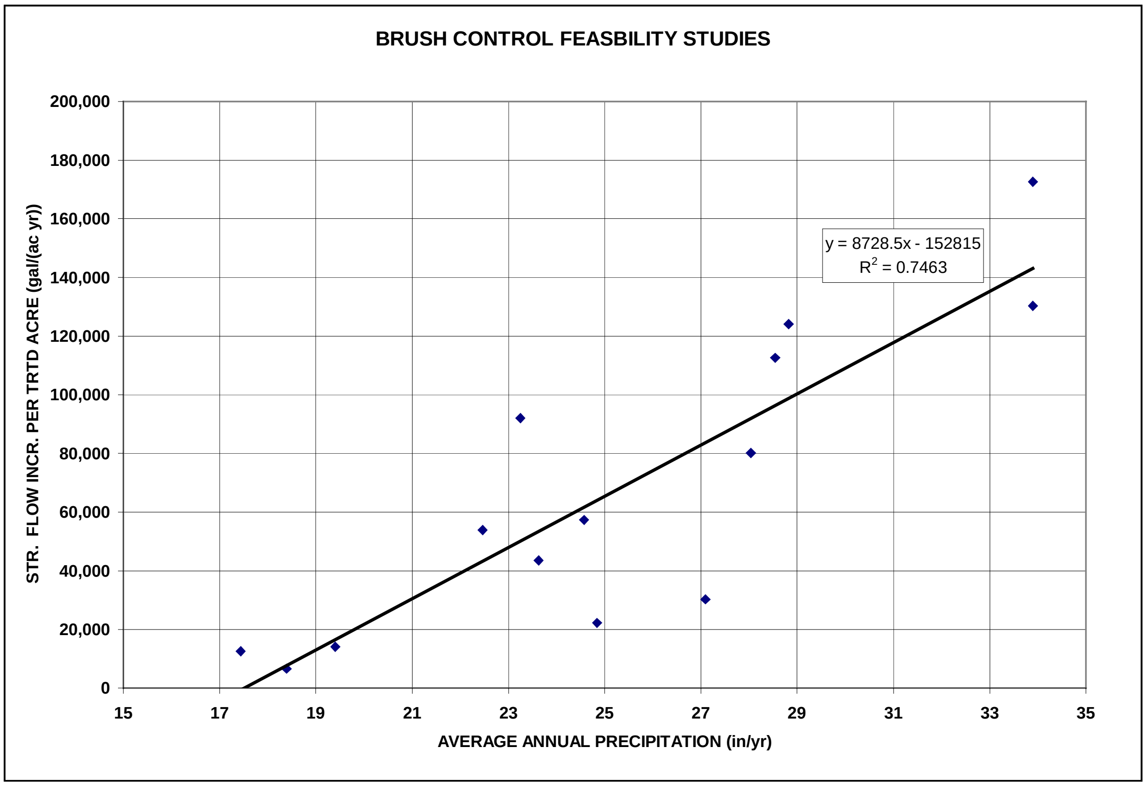


Figure 4-9. Average annual stream flow increase versus average annual precipitation 1960 through 1998. Each point represents one watershed.



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.

4.5 Summary

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

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

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

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

4.6 Literature Cited in Chapter 4

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5. CANADIAN RIVER WATERSHED - HYDROLOGIC SIMULATION

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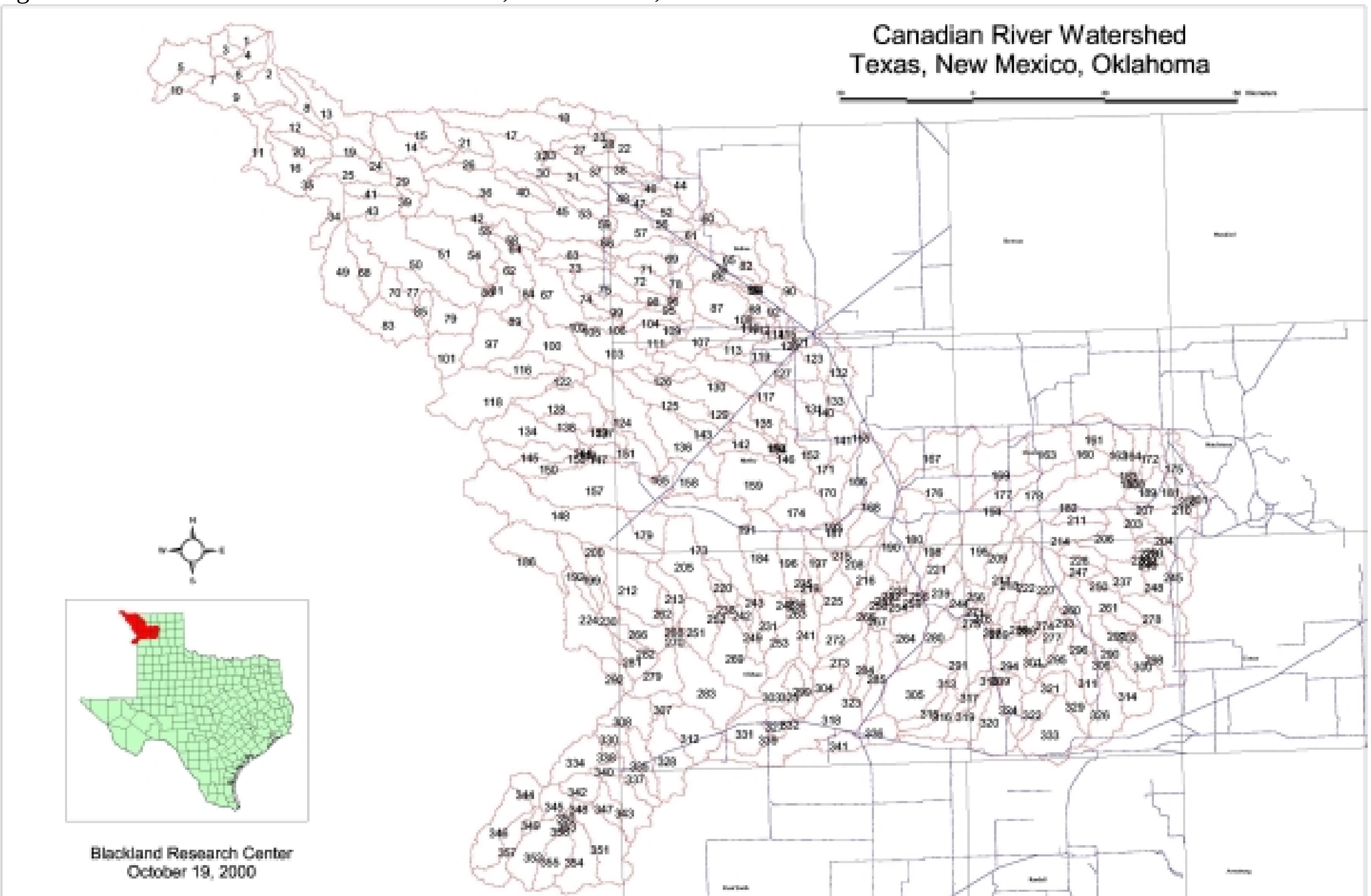
5.1 Watershed Data

Location. The modeled Canadian river basin covers a total drainage area of about 19,000 km^2 (4.7 million acres) ranging from the headwaters at Punta de Agua to final outflow at lake Meredith. The average annual precipitation within the Texas portion of the Canadian basin varies from about 350 mm (14 inches) in the West to about 460 mm (18 inches) in the East. Physiographically the Canadian basin occupies the arid to semi-arid regions of the great plains characterized with breaks on either side of the Canadian river. The geology on the upper reaches of the Canadian within Texas is composed primarily of quaternary period rock, while formations closer to the main river vary from the quaternary to the Jurassic periods. The quaternary period resource type is either made of recharge sand or wind blown (eolian) sand. The Jurassic formation especially in Oldham, and Potter counties is composed of sandstone, mudstone, dissected red beds (mud and sand), or severely eroded lands (Kier et al., 1977). A unique hydrologic feature are the playa lakes with intermittent water holding which dot the landscape. The soils range from fine sandy loam along recharge areas to thin to moderate silt loam in the upper reaches of the Canadian within Texas. The counties within the study area from North to South (clockwise) were: Dallam, Hartley, Moore, Hutchinson, Oldham, Potter, and Carson.

Topography. Figure 5-1 shows the sub-basins, and sub-basin numbers that were used for hydrology modeling. Economic analysis is also reported by sub-basin numbers. Generally, the lower the number, the closer the sub-basin is to the outlet of the watershed. The numbers starting with 1 represent sub-watersheds within the 11090101 USGS Hydrologic Cataloging Unit (HCU) called the Middle Canadian-Trujillo, sub-basins beginning with the number 2 are located within the 11090102 (Punta De Agua) HCU, sub-basins beginning with the number 3 are located within HCU 11090103 (Rita Blanca), sub-basins beginning with number 4 are located within

Figure 5-1. Canadian River Watershed Texas, New Mexico, Oklahoma



HCU 11090104 (Carrizo), and sub-basins beginning with number 5 are located within HCU 11090105 (Lake Meredith). There were a total of 312 sub-basins modeled. Most of the sub-basins ranged in area from 10,000 – 40,000 acres.

Weather stations. Figure 5-2 shows the weather stations used to model the hydrology of the Canadian basin. Weather data was collected from 1960 to 1998 and included daily precipitation, maximum and minimum temperatures, and solar radiation. If data were missing for any weather station, then the closest weather station was used to replace missing data. Each sub-basin was assigned its closest weather station.

Soils. The following soils along with lesser soils were used to model the Canadian:

- Mobeetie (*thermic Aridic Ustochrepts*): Deep, well drained, moderate to rapidly permeable soils formed in calcareous loamy alluvial materials. Slopes generally range from 0-15%. Mobeetie consisted of 10.2% of the study area.
- Dallam (*mesic Aridic Paleustalfs*): Deep, well drained, moderately permeable soils formed in loamy calcareous materials. Soils are on nearly level and gently sloping uplands. Slopes range from 0-5%. Dallam soils consisted of about 15.5 % of the study area.
- Gruver (*mesic Aridic Paleustaffs*): Deep, well drained moderately permeable soils formed in calcareous eolian sediments. The soils are on nearly level and gently rolling uplands. Slope range from 0-3%. Gruver consisted of 6% of the Canadian basin.
- Berda (thermic *Aridic Ustochrepts*): Deep well drained, moderately permeable soils formed in calcareous loam materials. These soils are found on nearly level to steep erosion prone uplands. Slopes can range from 0-50%. The Berda soil series consisted 3% of the Canadian.

Land use/land cover. Figure 5-3 shows areas with heavy and moderate brush cover that were removed and assumed converted to open grasslands (brush control simulation). The land use/cover map was based on classification of 1999 Landsat-7 satellite imagery (see earlier project description for classification details).

Ponds & reservoirs. The major reservoir in the watershed was Lake Meredith. Information on normal pool levels, and emergency spillway height were input into the SWAT model. No detail reservoir operation was modeled. Water was assumed controlled when levels reached principle spillway. Lake Meredith water level data were obtained from the nation wide Dam inventory of the Army Corp of Engineers.

Figure 5-2. Weather stations in the Canadian Watershed.

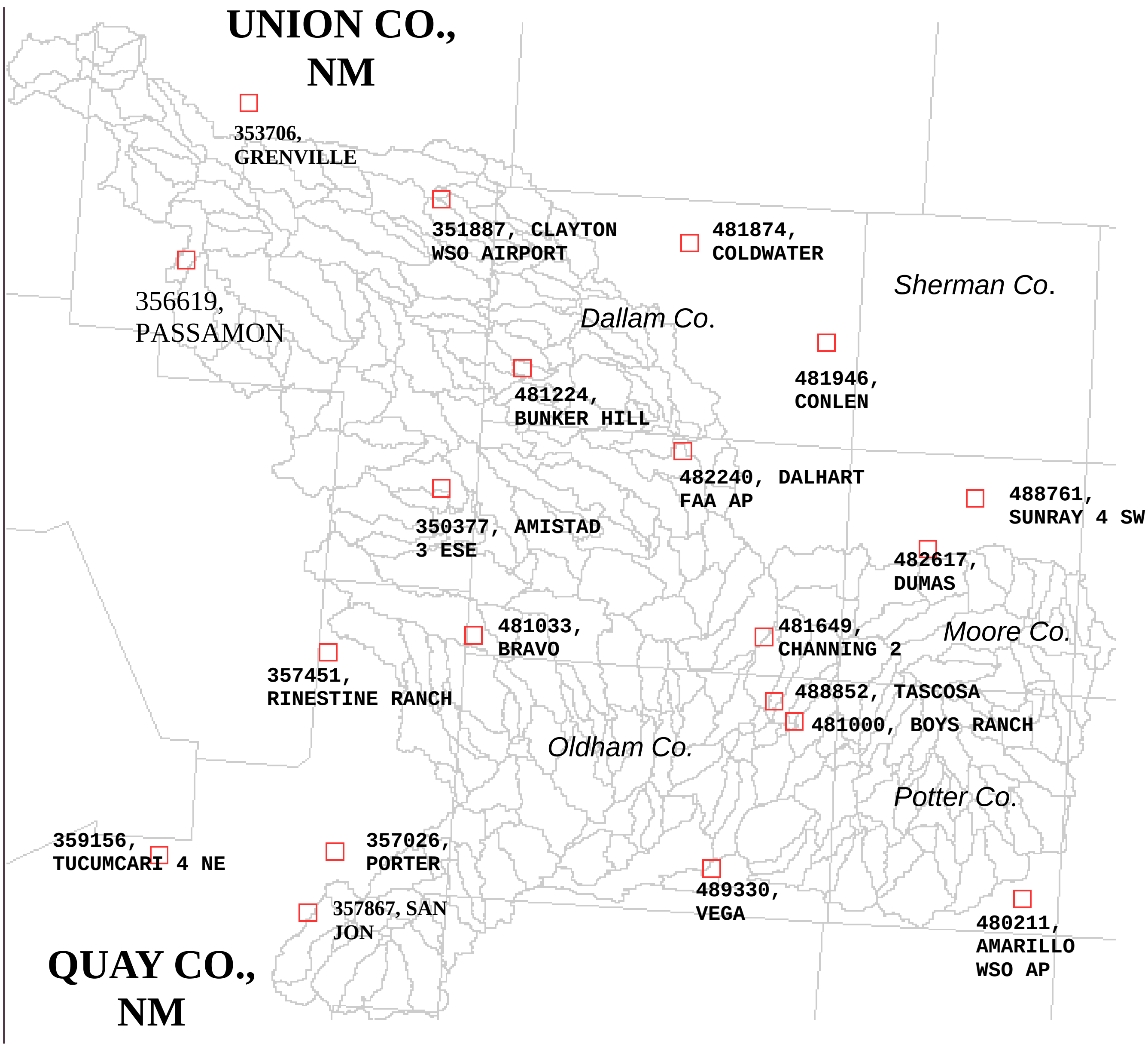
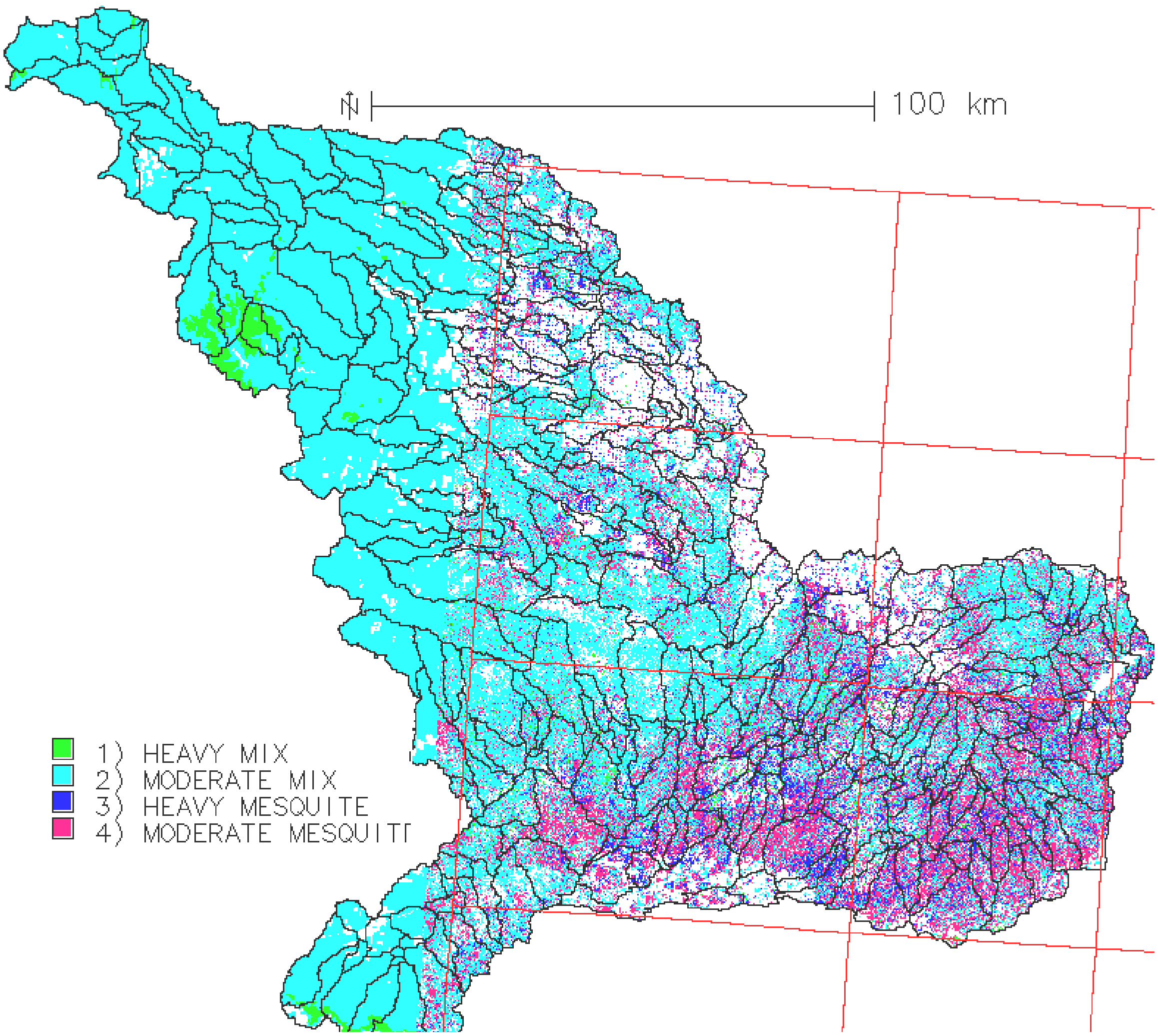


Figure 5-3. Major brush types in the Canadian subject to brush removal.

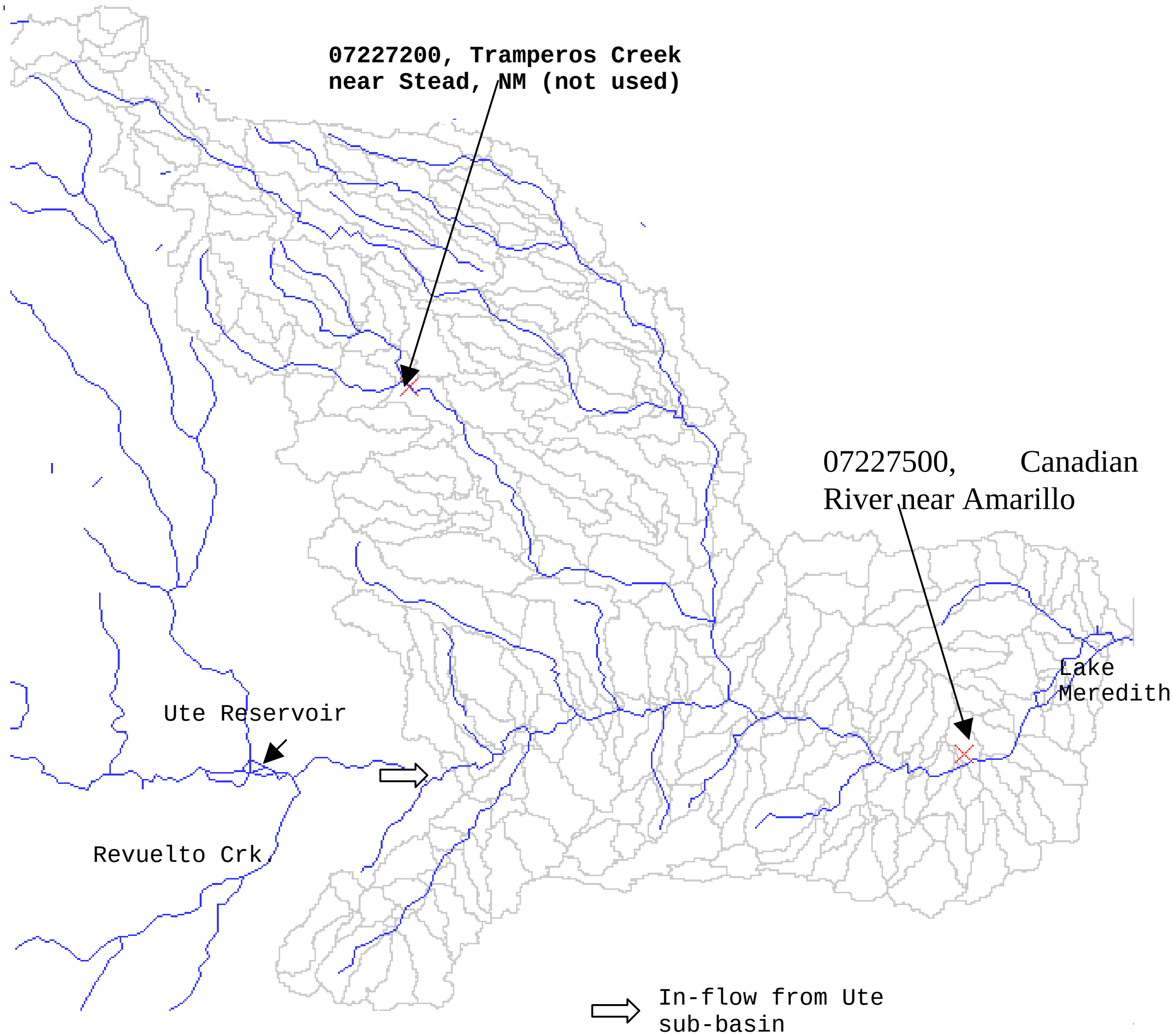


Model input variables. The important inputs and their values before and after calibration of the SWAT model are shown in Table 5-1. The SWAT model calibration was based on matching predicted and observed flow at a gage near Lake Meredith on the Canadian mainstem (see Figure 5-4). The curve number is used in a runoff rating curve developed by the USDA-NRCS to specify fraction of rainfall that runoffs surfaces based on vegetation and surface soil. The higher the curve number, the more the runoff. The curve numbers shown are for the most common soils which had a B type well drained soil. Based on field experience of NRCS range specialists, vegetation was assumed with same curve number before and after brush control in mixed land cover types. The soil evaporation compensation factor (esco) specifies whether the deeper soil layers should be weighted to control soil water evaporation. Generally, the value of esco is near 0.85, but is adjusted in dry climates to reflect more moisture storage in deeper soil layers. The shallow aquifer re-evaporation coefficient (Revap) specifies the fraction of water stored in aquifers lost back to the atmosphere. The soils in SWAT range in depths from 6-8 feet, while the shallow aquifer is assumed down to 150 feet. The shallow aquifer conveys water by base flow back into streams. The potential heat units (PHU) specifies the cumulative temperature above a base temperature at which there will be full canopy. As seen the PHU varies by type of vegetation on the Canadian. The PHUs are a function of latitude: PHUs decrease with increasing latitude. The precipitation intercepted by canopy was based on field experimental work (Thurow and Taylor, 1995) and calibration of SWAT to measured stream flows. Plant rooting depth, and leaf area indices (LAI) were based on observed values, and modeling experience. The LAI specifies the projected vegetation area (in units of m2) per ground surface area (m2).

Table 5-1. SWAT model input values.

	Before Calibration	After Calibration	After brush Control
Curve number			
Heavy Mesquite	77	58	61
Heavy mixed	77	62	62
Moderate mesquite	77	83	86
Moderate mixed	77	82	82
Soil evaporation compensation	0.95	0.95	0.95
Shallow aquifer re-evaporation	0.12	0.12	0.03
Potential Heat Units			
Heavy Mesquite	3000	N/A	
Heavy mixed brush	3000	N/A	
Moderate Mesquite	3000	N/A	
Moderate mixed	3000	N/A	
Open grassland	2600	N/A	
Canopy interception (inches)		N/A	
Heavy Mesquite	0.4	N/A	0
Heavy mixed	0	N/A	0
Moderate mesquite	0.2	N/A	0
Moderate mixed	0	N/A	0
Open grassland	0	N/A	0
Rooting depth (feet)		N/A	
Heavy/Moderate brush	6.5	N/A	3.3
Open grassland	3.3	N/A	3.3
Maximum Leaf Area Index		N/A	
Heavy Mesquite	4	N/A	1
Heavy mixed	4	N/A	1
Moderate mesquite	2	N/A	1
Moderate mixed	3	N/A	1
Open grassland	1	N/A	1

Figure 5-4. Stream gages on the Canadian. Tamperos Creek gage was not used for calibration since very limited data from 1967 to 1973 was available. Measured flows at Revuelto and Ute were input into an independent SWAT run for the Ute watershed. Outflows from Ute watershed were used as external flows into the SWAT Canadian model.



5.2 Results

Calibration. Figure 5-5 shows the SWAT predicted flows plotted against observed flows. The r2 which indicates how well predictions match against observations was estimated at r2 = 0.95. Since USGS measured flows were available for 37 years, the SWAT model predictions were compared over the same time period. If r2 were 1.0, then there would be a perfect match between prediction and observation.

Brush removal simulation. Figure 5-5 also shows the flows into Lake Meredith after brush control. Averaged over the 37 years of SWAT simulation, the expected water savings from brush control is nearly 98,000 acre-feet/year. There are several reasons for the increased stream flows from brush control: a) there is about 10% less direct evaporation to the atmosphere from reduced canopy interception and shallower rooting systems of grasses, b) there is more surface runoff from grassed surfaces, and c) less shallow aquifer water re-evaporation from grasslands.

Table 5-2 shows the water savings from brush control in each sub-basin within the Canadian watershed. The water savings in gallons/treated acre/year represents the amount of water increase (decrease) leaving the sub-basin taking into account cleared area, agriculture, urban and other land uses in the sub-basin.

5.3 References Cited in Chapter 5

Kier R.S., L.E. Garner, and L.F. Brown Jr. 1977. Land Resources of Texas. Bureau of Economic Geology, University of Texas, Austin, Texas.

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

Table 5-2. Water savings by sub-basin number.

SUB	Area, acres	Trt. Acres	% treated	Savings, gal/tr.ac/yr	Savings, Gallons/year
1001	84,289	84,289	100	7,105	598,900,926
1002	57,057	37,772	66.2	6,510	245,911,111
1003	13,231	13,231	100	4,691	62,070,873
1004	31,045	31,045	100	4,242	131,705,370
1005	37,529	37,529	100	4,576	171,712,910
1006	35,707	23,852	66.8	6,418	153,091,455
1007	15,252	15,252	100	5,027	76,679,841
1008	10,899	10,899	100	5,684	61,950,106
1009	17,723	17,723	100	8,215	145,590,026
1010	12,165	12,165	100	5,383	65,484,259
1011	39,566	39,566	100	6,705	265,284,921
1012	32,650	32,650	100	4,976	162,472,328
1013	11,578	11,578	100	6,055	70,100,238
1014	8,475	6,517	76.9	4,411	28,747,646
1015	6,576	6,576	100	7,150	47,021,614
1016	10,883	10,883	100	5,582	60,754,286
1017	3,057	3,057	100	6,169	18,857,143
1018	7,441	7,441	100	3,187	23,716,667
1019	16,781	16,781	100	1,749	29,350,370
1020	6,329	6,329	100	7,747	49,033,228
1021	15,330	15,330	100	7,738	118,631,429
1022	19,652	19,652	100	4,204	82,616,058
1023	4,369	4,369	100	5,286	23,091,349
1024	13,940	13,940	100	5,685	79,250,661
1025	1,961	1,961	100	8,843	17,337,513
1026	865	865	100	3,231	2,794,312
1027	15,329	15,329	100	21,811	334,346,746
1028	2,439	2,439	100	6,660	16,242,460
1029	370	185	50	2,485	459,101
1030	19,930	19,930	100	15,143	301,782,698
1031	7,796	7,796	100	10,929	85,200,688
1032	34,009	34,009	100	13,082	444,899,788
1033	772	772	100	7,860	6,064,233
1034	12,659	12,659	100	10,531	133,301,640
1035	3,597	2,766	76.9	549	1,518,042
1036	19,436	15,044	77.4	505	7,598,280
1037	39,580	39,580	100	2,697	106,742,566
1038	7,055	7,055	100	638	4,503,598
1039	9,000	9,000	100	15,619	140,567,778
1040	14,155	14,155	100	21,350	302,211,032
1041	9,016	9,016	100	22,152	199,716,799
1042	6,824	6,824	100	10,506	71,688,757
1043	17,753	17,753	100	12,917	229,309,074
1044	26,878	26,878	100	6,432	172,867,751
1045	28,992	18,468	63.7	3,800	70,177,196
1046	20,223	13,711	67.8	28,310	388,169,815
1047	7,904	5,185	65.6	29,787	154,451,376

Table 5-2. Continued.

SUB	Area	Trt. Acres	% treated	Gallons/tr.ac/year	Gallons/year
1048	7,086	5,704	80.5	10,539	60,113,677
1049	12,412	7,484	60.3	3,158	23,636,138
1050	20,161	20,161	100	4,651	93,760,794
1051	2,517	1,877	74.6	324	609,206
1052	12,396	8,219	66.3	5,452	44,809,815
1053	5,651	4,588	81.2	3,181	14,597,698
1054	8,645	6,968	80.6	6,489	45,214,259
1055	11,100	11,100	100	230	2,556,005
1056	19,681	15,588	79.2	8,854	138,008,333
1057	26,056	26,056	100	6,335	165,073,836
1058	9,016	7,005	77.7	9,921	69,494,841
1059	10,436	7,649	73.3	871	6,661,481
1060	2,007	1,616	80.5	161	260,106
1061	3,751	3,166	84.4	8,110	25,678,968
1062	16,595	13,226	79.7	11,309	149,571,005
1063	31,091	25,371	81.6	454	11,521,984
1064	1,081	1,081	100	180	194,444
1065	24,700	24,700	100	8,967	221,483,730
1066	803	803	100	196	157,275
1067	22,122	22,122	100	5,708	126,263,439
1068	18,248	18,248	100	12,893	235,272,857
2001	20,022	20,022	100	881	17,649,206
2002	59,929	59,929	100	300	17,972,275
2003	33,175	33,175	100	900	29,847,328
2004	33,700	33,700	100	1,090	36,744,101
2005	18,062	18,062	100	860	15,534,656
2006	16,441	16,441	100	526	8,645,899
2007	7,549	5,986	79.3	1,719	10,292,778
2008	14,712	12,093	82.2	2,309	27,922,116
2009	11,038	11,038	100	56	614,762
2010	15,453	15,453	100	643	9,930,476
2011	8,583	8,583	100	592	5,083,942
2012	5,048	5,048	100	2,033	10,261,772
2013	324	324	100	628	203,571
2014	25,749	25,749	100	1,248	32,129,365
2015	19,328	19,328	100	2,642	51,069,524
2016	6,762	6,762	100	1,215	8,212,196
2017	28,853	28,853	100	3,254	93,883,042
2018	31,153	31,153	100	892	27,794,444
2019	17,337	17,337	100	2,506	43,449,735
2020	33,052	23,169	70.1	4,347	100,713,757
2021	16,179	16,179	100	2,953	47,773,413
2022	56,424	56,424	100	1,924	108,538,307
2023	6,499	5,375	82.7	3,498	18,801,958
2024	37,220	37,220	100	2,717	101,136,376
2025	8,568	8,568	100	4,008	34,339,286
2026	26,074	20,494	78.6	4,370	89,561,005

Table 5-2. Continued.

SUB	Area	Trt. Acres	% Treated	Gallons/tr.ac/year	Gallons/year
2027	27,262	20,583	75.5	2,546	52,412,566
2028	31,427	25,959	82.6	9,011	233,905,556
2029	30,829	30,829	100	3,341	102,987,222
2030	9,772	7,876	80.6	1,021	8,038,175
2031	10,111	10,111	100	2,654	26,836,481
2032	30,397	30,397	100	5,933	180,329,603
2033	10,420	6,544	62.8	10,540	68,970,767
2034	9,077	3,477	38.3	5,162	17,947,222
2035	14,450	14,450	100	3,521	50,870,238
2036	18,972	18,972	100	3,881	73,641,005
2037	14,820	9,974	67.3	12,135	121,031,746
2038	17,136	17,136	100	5,255	90,041,984
2039	1,158	1,158	100	4,750	5,500,344
2040	6,607	6,607	100	2,746	18,144,709
2041	13,277	13,277	100	4,595	61,003,122
2042	1,776	1,014	57.1	15,427	15,642,751
2043	62,182	62,182	100	10,593	658,679,233
2044	41,646	30,443	73.1	4,627	140,863,519
2045	16,719	13,241	79.2	7,334	97,107,540
2046	4,878	4,878	100	12,160	59,317,910
2047	31,076	22,095	71.1	8,358	184,658,862
2048	24,391	24,391	100	6,251	152,461,640
2049	13,616	13,616	100	6,950	94,631,270
2050	14,372	14,372	100	10,693	153,687,540
3001	21,057	21,057	100	72	1,511,032
3002	25,920	25,920	100	1,156	29,954,815
3003	12,442	12,442	100	181	2,252,169
3004	38,378	38,378	100	101	3,863,836
3005	11,254	11,254	100	139	1,566,984
3006	27,094	16,311	60.2	3,051	49,768,598
3008	35,441	35,441	100	3,104	110,006,720
3009	2,656	1,742	65.6	4,611	8,032,698
3010	10,389	10,389	100	4,279	44,454,418
3011	7,796	7,796	100	3,242	25,274,656
3012	13,230	13,230	100	3,422	45,272,646
3014	12,119	9,634	79.5	1,529	14,731,878
3016	34,738	34,738	100	2,727	94,726,032
3017	8,228	5,891	71.6	3,087	18,189,418
3018	18,772	12,634	67.3	231	2,915,344
3019	8,460	8,460	100	4,292	36,305,741
3020	34,333	28,805	83.9	2,824	81,340,159
3021	5,434	1,109	20.4	16	17,460
3022	6,916	6,916	100	3,512	24,288,889
3023	9,726	6,273	64.5	1,832	11,489,894
3024	8,691	6,458	74.3	1,682	10,863,598
3025	7,950	7,950	100	2,125	16,893,386
3026	9,664	4,958	51.3	2,649	13,135,132
3027	5,187	5,187	100	4,727	24,516,667
3028	18,558	8,147	43.9	6,021	49,054,444
3030	4,199	1,747	41.6	2,557	4,465,608
3031	23,944	16,737	69.9	3,910	65,446,640

Table 5-2. Continued.

SUB	Area	Trt. Acres	% Treated	Gallons/tr.ac/year	Gallons/year
3033	19,343	4,526	23.4	3,552	16,076,958
3034	34,241	11,334	33.1	6,177	70,010,291
3035	11,964	3,338	27.9	3,290	10,981,614
3036	12,088	3,095	25.6	3,255	10,072,619
3037	11,378	0	0	0	0
3038	16	16	100	46	714
3040	48,041	32,284	67.2	6,740	217,603,307
3042	2,902	0	0	0	0
3043	2,038	450	22.1	252	113,492
3044	14,079	6,490	46.1	4,753	30,852,381
3045	4,060	2,075	51.1	5,368	11,136,958
3046	12,458	2,915	23.4	4,577	13,343,122
3048	16,534	5,125	31	5,500	28,191,481
3049	9,215	0	0	0	0
3050	14,788	7,512	50.8	4,164	31,281,296
3051	7,626	0	0	0	0
3053	17,149	0	0	0	0
3054	12,536	12,536	100	3,096	38,815,106
3055	24,129	8,155	33.8	4,820	39,307,381
3056	16,843	16,843	100	9,400	158,318,545
3061	170	170	100	9,965	1,690,979
4001	8,120	8,120	100	752	6,105,370
4002	8,089	8,089	100	40	320,582
4003	25,781	25,781	100	70	1,794,788
4004	18,155	18,155	100	41	738,889
4005	9,293	9,293	100	28	258,810
4007	8,552	8,552	100	28	238,148
4008	8,630	8,630	100	108	933,519
4009	22,354	22,354	100	225	5,027,831
4010	11,563	11,563	100	20	235,317
4011	26,306	26,306	100	164	4,310,714
4014	14,804	14,804	100	208	3,076,138
4015	14,959	14,959	100	669	10,013,889
4016	22,833	18,061	79.1	70	1,271,667
4017	12,983	12,983	100	71	917,751
4018	8,815	8,815	100	19	169,921
4020	3,705	3,705	100	443	1,642,751
4021	17,568	17,568	100	160	2,803,545
4022	12,273	12,273	100	771	9,464,206
4023	7,225	7,225	100	385	2,777,963
4024	8,784	8,784	100	227	1,994,471
4025	36,432	36,432	100	1,350	49,166,349
4027	15,175	15,175	100	170	2,584,286
4029	726	726	100	1,675	1,215,635
4030	14,573	10,959	75.2	3,737	40,956,614
4031	35,723	23,577	66	3,492	82,338,492
4032	10,050	2,291	22.8	4,528	10,376,508
4033	8,491	0	0	0	0
4034	13,770	2,837	20.6	3,426	9,719,365
4035	10,914	3,285	30.1	3,903	12,823,862
4036	17,491	0	0	0	0

Table 5-2. Continued.

SUB	Area	Trt. Acres	% Treated	Gallons/tr.ac/year	Gallons/year
4037	6,546	2,062	31.5	3,706	7,641,534
4038	24,962	0	0	0	0
4039	8,165	0	0	0	0
4040	10,405	2,466	23.7	2,481	6,118,175
4041	4,631	0	0	0	0
4042	8,661	6,158	71.1	3,620	22,290,688
4043	386	294	76.2	4,826	1,419,524
4045	8,552	4,823	56.4	3,792	18,291,561
4046	22,848	6,032	26.4	3,590	21,656,958
4047	2,887	1,423	49.3	3,743	5,327,169
4048	12,783	9,715	76	3,729	36,225,714
4050	2,176	988	45.4	1,420	1,403,228
4051	1,976	0	0	0	0
4057	11,331	2,187	19.3	4,556	9,963,651
5001	39,879	0	0	0	42,698
5002	11,378	9,114	80.1	14,259	129,951,296
5003	16,765	16,765	100	13,051	218,794,894
5004	19,899	19,899	100	11,579	230,411,561
5005	12,519	12,519	100	10,495	131,392,143
5006	9,648	6,541	67.8	11,546	75,528,280
5007	29,671	0	0	0	0
5008	8,938	8,938	100	13,457	120,278,704
5009	13,245	13,245	100	20,235	268,015,714
5010	25,521	7,299	28.6	25,675	187,406,376
5011	19,976	19,976	100	14,190	283,468,995
5012	8,182	6,284	76.8	17,651	110,916,164
5013	14,635	5,429	37.1	17,050	92,574,233
5014	39,737	39,737	100	16,903	671,682,751
5015	21,320	21,320	100	9,258	197,382,778
5016	15,345	15,345	100	13,181	202,267,804
5017	803	803	100	8,585	6,889,947
5018	926	926	100	11,227	10,397,037
5019	8,074	8,074	100	20,347	164,268,757
5020	20,316	20,316	100	6,977	141,744,974
5021	24,870	24,870	100	17,266	429,415,741
5022	32,465	22,953	70.7	20,144	462,362,672
5023	8,676	8,676	100	23,046	199,954,418
5024	8,846	8,846	100	18,077	159,903,413
5025	25,842	19,588	75.8	27,221	533,222,487
5026	21,472	21,472	100	17,699	380,035,608
5027	12,244	8,154	66.6	18,755	152,932,619
5028	17,475	17,475	100	3,848	67,248,968
5029	19,698	19,698	100	17,915	352,899,921
5030	10,127	10,127	100	15,905	161,071,429
5031	15,144	15,144	100	16,692	252,782,090
5032	9,602	9,602	100	11,112	106,697,804
5033	5,589	3,795	67.9	30,228	114,709,312
5034	15,917	15,917	100	12,794	203,633,836
5035	8,366	8,366	100	8,095	67,724,074
5037	17,043	17,043	100	17,912	305,279,365
5038	15,376	15,376	100	18,558	285,340,899

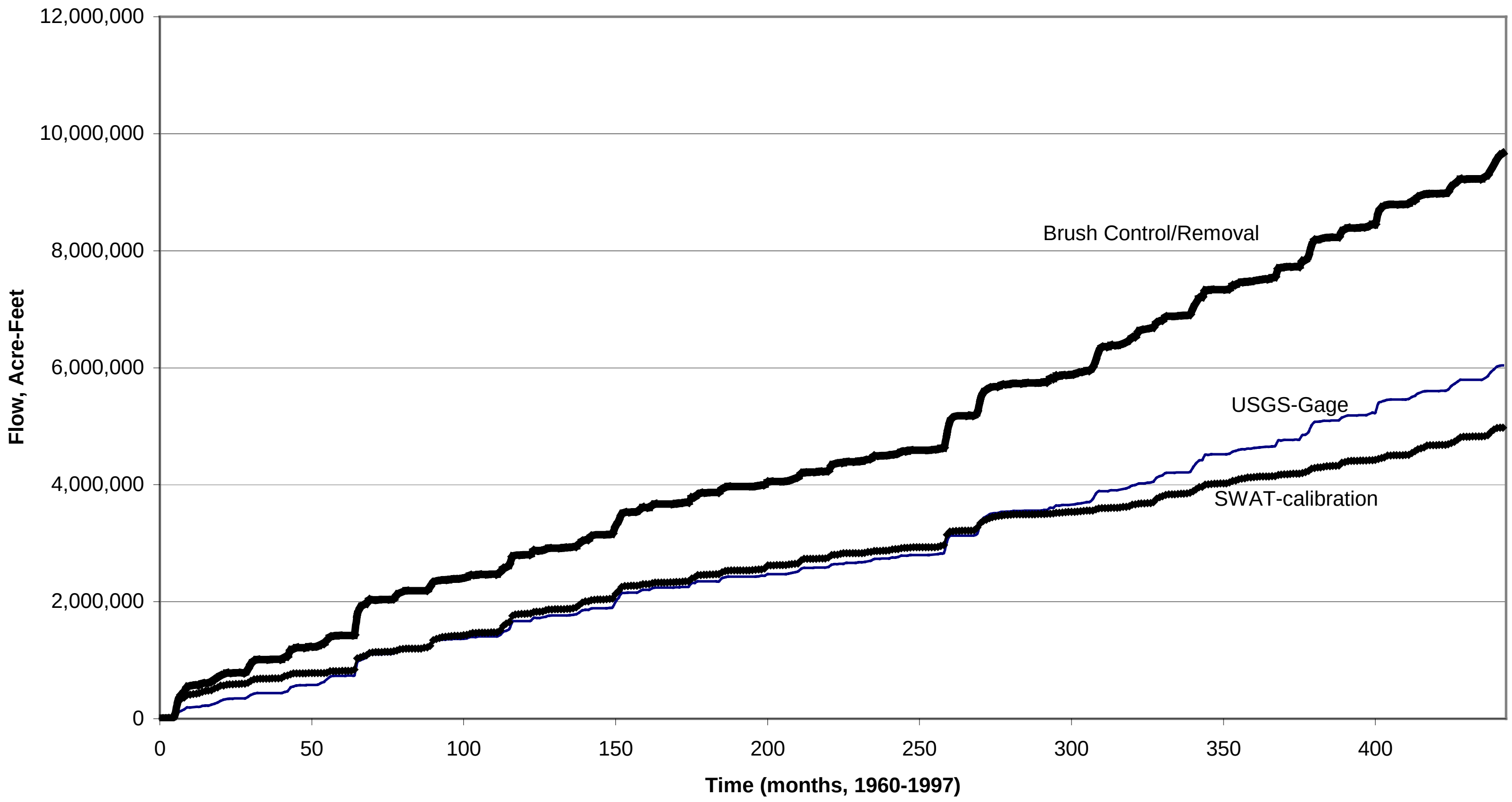
Table 5-2. Continued.

SUB	Area	Trt. Acres	% Treated	Gallons / tr.ac / year	Gallons / year
5039	4,261	4,261	100	22,129	94,290,899
5040	12,967	12,967	100	27,602	357,923,730
5041	10,683	10,683	100	33,393	356,724,153
5042	8,954	8,954	100	11,624	104,079,683
5043	14,404	14,404	100	24,398	351,417,302
5044	2,702	2,702	100	10,607	28,658,439
5045	864	654	75.7	14,711	9,620,450
5046	8,398	6,215	74	14,454	89,823,810
5047	4,369	3,229	73.9	14,287	46,131,799
5048	4,848	4,848	100	8,829	42,798,175
5049	864	864	100	19,570	16,914,603
5050	14,789	14,789	100	13,451	198,937,222
5051	5,342	5,342	100	14,101	75,321,376
5052	1,035	1,035	100	15,891	16,439,577
5053	1,591	1,165	73.2	9,680	11,273,466
5054	17,954	17,954	100	21,509	386,169,418
5055	21,366	21,366	100	4,381	93,593,942
5056	2,686	2,686	100	3,034	8,149,762
5057	5,480	4,455	81.3	3,458	15,406,958
5058	12,458	12,458	100	10,524	131,112,116
5059	14,928	14,928	100	8,200	122,410,926
5060	1,158	864	74.6	20,483	17,692,857
5061	11,547	11,547	100	18,168	209,793,704
5062	18,571	14,764	79.5	3,740	55,216,693
5063	3,103	3,103	100	23,811	73,894,947
5064	5,758	5,758	100	16,797	96,720,132
5065	18,942	18,942	100	22,378	423,868,042
5066	9,186	9,186	100	18,149	166,711,005
5067	3,427	3,427	100	18,703	64,096,614
5068	1,096	846	77.2	19,834	16,784,577
5069	12,228	12,228	100	8,772	107,260,847
5070	18,402	14,078	76.5	21,309	299,978,915
5071	31,184	23,450	75.2	13,791	323,407,090
5072	571	571	100	15,210	8,687,831
5073	972	972	100	15,518	15,086,958
5074	8,352	8,352	100	15,112	126,212,090
5075	13,616	13,616	100	11,776	160,343,730
5076	13,029	13,029	100	31,682	412,781,905
5077	7,209	7,209	100	13,916	100,317,646
5078	16,025	16,025	100	10,558	169,197,698
5079	8,969	8,969	100	22,593	202,636,323
5080	24,762	24,762	100	22,889	566,789,418
5081	13,354	13,354	100	23,314	311,325,688
5082	54,911	32,727	59.6	35,994	1,177,964,815
5083	9,433	9,433	100	13,058	123,174,683
5084	35,769	35,769	100	15,297	547,147,989
5085	5,079	5,079	100	12,691	64,457,937
5086	9,201	9,201	100	14,737	135,595,291
5087	2,424	2,424	100	7,219	17,497,249

Table 5-2. Continued.

SUB	Area		% Treated	Gallons / tr.ac / year	Gallons / year
5088	1,513	1,513	100	4,378	6,622,434
5089	1,606	1,606	100	14,301	22,968,677
5090	8,304	5,024	60.5	15,455	77,648,519
5091	12,874	12,874	100	14,502	186,697,963
5092	11,685	11,685	100	21,969	256,720,159
5093	16,025	16,025	100	39,753	637,020,582
5094	5,775	5,775	100	28,495	164,549,841
5095	22,338	22,338	100	27,721	619,237,063
5096	13,338	10,350	77.6	14,233	147,311,561
5097	21,612	21,612	100	16,003	345,848,598
5098	14,266	14,266	100	11,201	159,791,614
5099	8,723	6,062	69.5	18,411	111,612,804
5100	13,230	13,230	100	15,060	199,249,577
5101	33,330	33,330	100	46,896	1,563,020,238
5102	12,196	0	0	0	0
5103	9,416	2,505	26.6	39,033	97,765,794
Totals	4,712,811	3,949,960			33,504,018,598
Weighted					
Average			83.81324	8,482	

Figure 5-5. Comparison between SWAT predicted and USGS measured flows. Flows after brush removal is also shown.



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

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6.1 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.

6.2 Introduction

As was reported in Chapter 4 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 (Figure 4-1). 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.

6.3 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 4. 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.

6.4 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 4 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 6-1. Year 0 in Table 6-1 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.

Table 6-1. 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

Table 6-1. Continued.

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

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

Table 6-1. Continued.

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

Table 6-1. Continued.

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

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

Table 6-1. Continued.

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

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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 6-1. Present values of control programs are used for comparison since some of the treatments will be required in the first year to initiate the program while others will not be needed until later years. Present values of total per acre control costs range from $33.75 for moderate mesquite that can be initially controlled with herbicide treatments to $159.45 for heavy mesquite that cannot be controlled with herbicide but must be initially controlled with mechanical tree bulldozing or rootplowing.

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

Rancher benefits were calculated for changes in existing wildlife operations. Most of these operations were determined to be simple hunting leases with deer, turkeys, and quail being the most commonly hunted species. For control of heavy mesquite, mixed brush and cedar, wildlife revenues are expected to increase from $0.50 to $1.50 per acre due principally to the resulting improvement in quail habitat and hunter access to quail. Increased wildlife revenues were included only for the heavy brush categories because no changes in wildlife revenues were expected with control for the moderate b7rush type-density categories.

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

As with the brush control methods and costs, estimates of vegetation (forage production/grazing capacity) responses used in the studies were obtained from landowner focus groups, Experiment Station and Extension Service scientists and USDA-NRCS Range Specialists with brush control experience in the respective watersheds. Because of differences in soils and climate, livestock grazing capacities differ by location; in some cases significant differences were noted between sub-basins of a watershed. Grazing capacity estimates were collected for both pre- and post-control states of the brush type-density categories. The carrying capacities range from 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 6-2).

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 6-2. Grazing capacity in acres per AUY before and after brush control by brush.

Type-Density Category

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

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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 6-3 for the control of moderate cedar in the Upper Colorado – West watershed.

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Table 6-3. 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

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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 6-3 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 6-4. 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 6-4. Landowner and State shares of brush control costs by brush type-density category by watershed.

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

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

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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 6-4. 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.

6.5 Costs of Added Water

The total cost of additional water is determined by dividing the total state cost share if all eligible acreage were enrolled in the program by the total added water estimated to result from the brush control program over the assumed ten-year life of the program. The brush control program water yields and the estimated acreage by brush type-density category by sub-basin were supplied by the Blacklands Research Center, Texas Agricultural Experiment Station in Temple, Texas (see Chapter 7). 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 6-5 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 6-5, 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 6-5 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.

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6.6 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.

6.7 Literature Cited in Chapter 6

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

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

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

7. CANADIAN RIVER WATERSHED - ECONOMIC ANALYSIS

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7.1 Introduction

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

7.2 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 $35.95 for moderate mesquite that can be initially controlled with herbicide treatments to

$72.71 for heavy mixed brush. The costs of treatments, year those treatments are needed and treatment life for each brush type density category are detailed in Table 7-1.

7.3 Landowner and State cost shares

Rancher benefits are the total benefits that will accrue to the rancher as a result of the brush control program. These total benefits are based on the present value of the improved net returns to the ranching operation through typical cattle, sheep, goat and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, an improvement in net returns would result from increased amounts of usable forage produced by controlling the brush and thus eliminating much of the competition for water and nutrients within the plant communities on which the enterprise is based. The differences in grazing capacity with and without brush control for each of the brush type-density categories in the watershed draining to Lake Meredith are shown in Table 7-2. Data relating to grazing capacity was entered into the investment analysis model (see Chapter 6).

Table 7-1. Cost of water yield brush brush control programs by type-density category.

Heavy Mesquite - Chemical

Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	26.50	26.50
6	Aerial Spray Herbicide	26.50	16.70
9	Chemical IPT or Prescribed.Burn	15.00	7.50
		Total:	$ 50.70

Heavy Mixed Brush - Chemical

Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	34.00 - 40.00	34.00 - 40.00
6	Aerial Spray Herbicide	34.00 - 40.00	21.43 - 25.21
9	Chemical IPT or Prescribed Burn	15.00	7.50
		Total:	$ 62.93 - 72.71

Moderate Mesquite - Chemical

Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	26.50	26.50
6	Chemical IPT or Prescribed Burn	15.00	9.45
		Total:	$ 35.95

Moderate Mixed Brush - Chemical

Year	Treatment Description	Cost/Unit	Present Value
0	Aerial Spray Herbicide	34.00 - 40.00	34.00 - 40.00
6	Chemical IPT or Prescribed Burn	15.00	9.45
		Total:	$ 43.45 - 49.45

*Canadian River watershed.

Table 7-2. 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 Mesquite	Brush Control	30.0	28.0	25.0	25.0	23.0	20.0	20.0	20.0	20.0	20.0
	No Control	30.0	30.0	30.0	30.1	30.1	30.1	30.1	30.3	30.3	30.3
Heavy Mixed Brush (Sand Sage & Snakeweed)	Brush Control	40.0	37.0	33.0	33.0	30.0	25.0	25.0	25.0	25.0	25.0
	No Control	40.0	40.0	40.1	40.1	40.2	40.2	40.3	40.3	40.4	40.4
Heavy Mixed Brush (Cholla & Pear Cactus)	Brush Control	35.0	32.0	29.0	29.0	26.0	22.0	22.0	22.0	22.0	22.0
	No Control	35.0	35.0	35.1	35.1	35.2	35.2	35.3	35.3	35.4	35.4
Moderate Mesquite	Brush Control	25.0	23.0	22.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	No Control	25.0	25.1	25.3	25.4	25.6	25.7	25.8	25.9	26.1	26.3
Moderate Mixed Brush (Sand Sage & Snakeweed)	Brush Control	33.0	30.0	27.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	No Control	33.0	33.2	33.4	33.6	33.8	34.0	34.2	34.4	34.6	34.7
Moderate Mixed Brush (Cholla & Pear Cactus)	Brush Control	29.0	26.0	24.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
	No Control	29.0	29.1	29.3	29.4	29.6	29.7	29.9	30.1	30.3	30.5

*Canadian River watershed.

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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 20 acres per AUY for land on which mesquite is controlled to 40 acres per animal unit year (AUY) for land infested with heavy mixed brush.

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 and stocker calves) in the project areas is shown in Tables 7-3a and 7-3b. It is important to note once again (refer to Chapter 6) 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

Table 7-3a. Investment analysis budget, cow-calf production.*

Revenues

Production Item	Marketed Percentage	Quantity	Unit	$ Per Unit	$ Return
Beef Cull Bull	0.01 (Head)	19.50	Cwt	50.00	0.00
Beef Cull Cow	0.105 (Head)	11.00	Cwt	40.00	0.00
Calves	0.84 (Head)	5.55	Cwt	75.00	416.25
				Total:	$416.25

Partial Variable Costs

Variable Cost Description	Quantity	Unit	$ per Unit	$ Cost
Supplemental Feed	-	-	-	50.00
Cattle Marketing - All Cattle	-----	Head of Cow	-----	18.16
Vitamin / Salt / Mineral	60.0	Pound	0.183	11.00
Veterinary and Medicine	1.0	Head	14.50	14.50
Net Cost for Purchased Cows	-----	Head	700.00	37.80
Net Cost for Purchased Bulls	-----	Head	1500.00	3.50
			Total:	$134.96

*Canadian River Watershed

Table 7-3b. Investment analysis budget, stocker calf production.*

Partial Revenues

Revenue Item Description	Quantity	Unit	$ / Unit	$ Revenue
Net Gain on Stockers	1.0	Head	87.50	87.50
			Total:	$87.50

Partial Variable Costs

Variable Cost Item Description	Quantity	Unit	$ / Unit	$ Cost
Stocker delivery	1.0	Head	5.00	5.00
Interest	400.0	Dollars	.05	20.00
Vitamin / Salt / Mineral	15.0	Pound	0.233	3.50
Veterinary and Medicine	1.0	Head	10.00	10.00
Labor	1.2	Hour	7.00	8.40
			Total:	$46.90

* Canadian River Watershed

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

Table 7-4. Landowner/State cost-shares of brush control.*

Brush Category by Type & Density	PV Total Cost ($/Acre)	Landowner Share ($/Acre)	Landowner Share (Percent)	State Share ($/Acre)	State Share (Percent)
Heavy Mesquite	50.7	10.37	20.45	40.33	79.55
Heavy Mixed (Sand Sage & Snakeweed)	62.93 - 72.71	9.87	15.68 - 13.57	53.06 - 62.84	84.32 - 86.43
Heavy Mixed (Cholla & Pear Cactus)	62.93	11.02	17.51	51.91	82.49
Moderate Mesquite	35.95	9.85	27.4	26.1	72.6
Moderate Mixed (Sand Sage & Snakeweed)	77.93 – 49.45	9.59	22.07 - 19.39	33.86 – 39.86	70.37 - 80.61
Moderate Mixed (Cholla & Pear Cactus)	43.45	11.36	26.14	32.09	73.86
Average[1]	$54.09	$10.34	21.14%	$40.87	78.23%

* Canadian River Watershed

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

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each of the livestock enterprises. From these budgets, data was entered into the investment analysis model, which was also described in Chapter 6.

Ranchers in the Canadian watershed felt that the brush control program would not have an impact on net returns to wildlife related enterprises.

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 6. They range from $9.59 per acre for control of moderate mixed brush to $11.37 per acre for the control of heavy mesquite (Table 7-4).

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 $26.10 for control of moderate mesquite with chemical treatments to $62.84 for control of heavy mixed brush. 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 7-4.

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 $26.10 for control of moderate mesquite with chemical treatments to $62.84 for control of heavy mixed brush. 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 7-4.

7.4 Cost Of Additional Water

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

The cost of added water was determined to average $111.37 per acre-foot for the entire watershed and ranges from $26.16 per acre foot for Subbasin 5101 to $91,399.96 per acre foot for Subbasin 3021. Details of the costs of added water for each Subbasin of the Canadian are shown in Table 7-5. Subbasins in the Canadian Watershed outside the State were excluded from the analysis and added water yields and costs for subbasins partially outside the State were prorated based on the proportion of the total area in the subbasin lying inside the state boundary.

Table 7-5. 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)
1001	564,979.10	356.77	2,783.55	202.97
1002	1,301,980.00	753.56	5,879.31	221.45
1003	456,212.10	190.21	1,484.01	307.42
1005	1,293,985.00	526.19	4,105.36	315.19
1006	821,929.40	469.13	3,660.15	224.56
1009	611,072.50	446.14	3,480.80	175.55
1010	419,438.90	200.67	1,565.61	267.91
1011	1,061,113.00	632.30	4,933.20	215.10
1012	75,089.80	33.21	259.09	289.82
1013	399,208.10	214.81	1,675.97	238.19
1014	224,750.30	88.09	687.31	327.00
1015	226,749.10	144.09	1,124.21	201.70
1016	300,204.70	148.94	1,162.02	258.35
1017	105,395.70	57.79	450.84	233.78
1018	256,551.20	72.68	567.02	452.45
1019	530,581.50	89.94	701.72	756.12
1020	205,569.10	150.26	1,172.30	175.36
1021	501,014.20	363.53	2,836.27	176.65
1022	634,792.80	253.17	1,975.21	321.38
1023	142,408.50	70.76	552.07	257.95
1024	480,651.90	242.85	1,894.75	253.68
1025	64,313.54	53.13	414.51	155.16
1026	29,818.30	8.56	66.81	446.33
1027	455,232.70	1,024.56	7,993.65	56.95
1028	79,341.20	49.77	388.33	204.31
1029	6,370.18	1.41	10.98	580.36
1030	630,935.60	924.78	7,215.10	87.45
1031	268,803.70	261.09	2,037.00	131.96
1032	1,067,469.00	1,363.34	10,636.78	100.36
1033	24,985.65	18.58	144.99	172.33
1034	436,468.90	408.49	3,187.01	136.95
1035	95,402.37	4.65	36.29	2,628.62
1036	518,968.80	23.28	181.66	2,856.79
1037	1,157,597.00	327.10	2,552.03	453.60
1038	145,955.50	8.28	64.60	2,259.24
1039	288,545.00	430.75	3,360.73	85.86
1040	470,225.20	926.09	7,225.34	65.08
1041	262,680.30	612.01	4,774.88	55.01

Table 7-5. Continued.

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)
1042	210,075.80	219.68	1,713.95	122.57
1043	496,248.90	614.85	4,797.08	103.45
1044	838,780.50	529.73	4,132.97	202.95
1045	636,666.00	215.05	1,677.81	379.46
1046	411,452.80	1,189.50	9,280.47	44.34
1047	167,773.40	473.30	3,692.66	45.43
1048	$93,711.78	92.11	718.61	$130.41
1049	258,176.60	72.43	565.10	456.87

1052	265,353.30	137.31	1,071.32	247.69
1056	492,143.80	422.91	3,299.54	149.16
1058	96,627.58	286.71	2,236.91	43.20
1063	295,546.70	12.61	98.37	3,004.42
2020	513,897.10	198.41	1,548.03	331.97
2024	905,910.70	218.77	1,706.86	530.75
2025	295,420.80	105.23	820.99	359.83
2026	666,332.50	274.45	2,141.25	311.19
2028	843,069.50	716.77	5,592.28	150.76
2031	139,455.50	32.89	256.65	543.38
2032	978,103.30	552.60	4,311.37	226.87
2033	203,664.00	211.35	1,648.97	123.51
2035	618,027.50	155.89	1,216.22	508.15
2037	310,215.10	370.89	2,893.66	107.21
2038	590,841.70	275.92	2,152.75	274.46
2040	75,864.65	18.52	144.46	525.17
2042	30,451.99	47.94	373.99	81.42
2043	2144,043.00	874.59	6,823.55	314.21
2044	1050,076.00	431.66	3,367.80	311.80
2045	456,667.30	297.57	2,321.67	196.70
2046	168,201.40	181.77	1,418.19	118.60
2047	761,723.90	565.86	4,414.87	172.54
2048	841,006.90	467.20	3,645.09	230.72
2049	469,472.10	289.99	2,262.47	207.50
2050	467,516.50	470.96	3,674.40	127.24
3006	460,052.90	124.78	973.56	472.55
3009	27,506.66	12.31	96.02	286.46
3010	89,556.54	34.06	265.71	337.05
3012	260,651.80	79.27	618.48	421.44

Table 7-5. Continued.

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)
3017	135,450.00	37.18	290.06	466.97
3018	435,867.50	8.93	69.70	6,253.41
3021	38,154.53	0.05	0.42	91,399.96
3022	238,465.40	74.43	580.71	410.65
3023	216,300.60	7.04	54.94	3,936.98
3024	222,573.20	33.29	259.73	856.94
3025	274,117.40	51.77	403.89	678.69
3026	170,980.10	40.25	314.04	544.46
3027	178,845.00	75.13	586.15	305.12
3028	264,991.60	131.53	1,026.21	258.22
3030	60,189.32	13.68	106.76	563.76
3031	576,996.60	200.55	1,564.72	368.75

3033	$138566.50	43.79	341.67	$405.56
3034	390,563.20	214.54	1,673.82	233.34
3035	115,048.40	33.65	262.55	438.19
3036	106,533.50	30.87	240.82	442.38
3038	536.16	0.00	0.02	31,396.24
3040	1,041,884.00	666.82	5,202.52	200.27
3043	15,551.17	0.35	2.71	5731.25
3044	200,683.20	94.54	737.63	272.07
3045	71,482.56	34.13	266.27	268.46
3046	100,472.30	40.89	319.01	314.95
3048	176,440.00	86.39	674.01	261.78
3050	258,842.40	95.86	747.88	346.10
3054	432,227.50	118.94	928.00	465.76
3055	281,202.30	120.45	939.77	299.22
3056	545,502.30	485.15	3,785.12	144.12
3061	5,494.74	5.18	40.43	135.91
4031	58,017.46	18.02	140.56	412.77
4032	19,727.21	7.95	62.02	318.07
4034	97,758.73	29.78	232.37	420.70
4035	18,869.74	6.55	51.11	369.20
4037	71,027.77	23.42	182.70	388.78
4040	67,910.98	15.00	117.02	580.34
4042	212,286.80	68.31	532.93	398.34
4043	10,139.88	4.35	33.94	298.77
4045	166,365.30	56.05	437.32	380.42

Table 7-5. Continued.

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)
4046	207,899.60	66.37	517.78	401.52
4047	49,106.76	16.32	127.36	385.56
4048	335,053.90	111.01	866.09	386.86
4050	34,059.69	4.30	33.55	1,015.23
4057	75,399.14	30.53	238.21	316.52
5002	291,927.00	398.22	3,106.91	93.96
5003	543,986.10	670.47	5,231.01	103.99
5004	643,358.00	706.07	5,508.74	116.79
5005	401,813.80	402.63	3,141.36	127.91
5006	225,611.90	231.45	1,805.75	124.94
5008	290,922.50	368.58	2,875.65	101.17
5009	425,740.40	821.30	6,407.79	66.44
5010	190,755.00	574.28	4,480.56	42.57
5011	622,386.70	868.66	6,777.25	91.83
5012	196,878.00	339.89	2,651.81	74.24
5013	165,666.10	283.68	2,213.29	74.85

5014	1,269,218.00	2058.29	16,058.77	79.04
5015	$664,461.30	604.86	4,719.08	$140.80
5016	470,610.70	619.82	4835.87	97.32
5017	27,335.56	21.11	164.73	165.94
5018	28,155.02	31.86	248.58	113.27
5019	261,788.20	503.38	3,927.38	66.66
5020	634,470.40	434.36	3,388.88	187.22
5021	770,421.90	1,315.89	10,266.58	75.04
5022	705,136.00	1,416.85	11,054.29	63.79
5023	260,506.10	612.74	4,780.56	54.49
5024	280,596.80	490.00	3,823.01	73.40
5025	586,534.70	1,633.99	12,748.42	46.01
5026	688,933.20	1,164.57	9,085.99	75.82
5027	248,627.10	468.64	3,656.35	68.00
5028	570,375.80	206.08	1,607.81	354.75
5029	590,979.20	1,081.42	8,437.22	70.04
5030	330,431.20	493.58	3,850.94	85.81
5031	473,766.40	774.62	6,043.58	78.39
5032	303,182.60	326.96	2,550.96	118.85
5033	126,694.20	351.51	2,742.50	46.20
5034	489,721.70	624.01	4,868.53	100.59

Table 7-5. Continued.

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)
5035	265,614.50	207.53	1,619.16	164.04
5037	532,184.00	935.49	7,298.70	72.91
5038	474,241.50	874.39	6,822.01	69.52
5039	128,632.60	288.94	2,254.33	57.06
5040	424,312.70	1,096.81	8,557.33	49.58
5041	305,448.10	1,093.14	8528.65	35.81
5042	268,572.30	318.94	2488.36	107.93
5043	466,448.70	1,076.87	8401.78	55.52
5044	83,871.24	87.82	685.17	122.41
5045	24,605.93	29.48	230.01	106.98
5046	198,792.80	275.25	2,147.53	92.57
5047	100,894.40	141.37	1,102.93	91.48
5048	157,066.10	131.15	1,023.23	153.50
5049	28,877.84	51.83	404.40	71.41
5050	451,511.50	609.62	4,756.24	94.93
5051	167,649.20	230.81	1,800.80	93.10
5053	35,473.21	34.55	269.53	131.61
5054	538,575.60	1,183.37	9,232.64	58.33
5055	707,385.70	286.81	2,237.67	316.13
5056	81,723.06	24.97	194.85	419.42

5057	154,274.20	47.21	368.35	418.82
5058	405,931.30	401.78	3,134.66	129.50
5059	480,345.60	375.11	2,926.63	164.13
5060	$27,471.59	54.22	423.01	$64.94
5061	372,978.20	642.89	5,015.80	74.36
5062	476,487.40	169.20	1,320.14	360.94
5063	96,651.97	226.44	1,766.70	54.71
5064	189,319.50	296.39	2,312.41	81.87
5065	579,506.80	1,298.89	10,133.95	57.18
5066	265,781.80	510.87	3,985.77	66.68
5067	102,702.20	196.42	1,532.44	67.02
5068	25,787.44	51.43	401.29	64.26
5069	385,276.20	328.69	2,564.42	150.24
5070	405,549.70	919.25	7,171.97	56.55
5071	716,347.90	991.04	7,732.10	92.65
5072	18,791.30	26.62	207.71	90.47
5073	32,173.54	46.23	360.70	89.20

Table 7-5. Continued.

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)
5074	263,128.80	386.76	3,017.51	87.20
5075	434,394.50	491.35	3,833.54	113.31
5076	414,508.20	1,264.92	9,868.90	42.00
5077	224,899.70	307.41	2,398.42	93.77
5078	480,354.70	518.49	4,045.22	118.75
5079	276,418.20	620.95	4,844.68	57.06
5080	740,413.70	1,736.86	13,550.95	54.64
5081	386,268.80	954.02	7,443.26	51.90
5082	982,999.50	3,609.73	28,163.09	34.90
5083	272,910.80	377.45	2,944.89	92.67
5084	1,106,133.00	1,676.67	13,081.36	84.56
5085	158,177.50	197.52	1,541.08	102.64
5086	259,785.50	415.51	3,241.85	80.14
5087	74,812.67	53.62	418.33	178.84
5088	48,504.07	20.29	158.33	306.35
5089	49,534.05	70.38	549.14	90.20
5090	153,968.80	237.94	1,856.44	82.94
5091	406,820.10	572.11	4,463.62	91.14
5092	334,510.40	786.69	6,137.73	54.50
5093	468,569.80	1,952.07	15,230.06	30.77
5094	179,880.00	504.24	3,934.10	45.72
5095	698,821.20	1,897.58	14,804.88	47.20
5096	349,341.70	451.42	3,521.96	99.19
5097	633,727.60	1,059.81	8,268.64	76.64

5098	463,062.10	489.66	3,820.34	121.21
5099	208,087.50	342.02	2,668.47	77.98
5100	408,577.40	610.58	4,763.71	85.77
5101	977,652.50	4,789.68	3,7369.1	26.16
5103	65,327.78.00	299.59	2,337.41	27.95
Totals:	$77,844,501.00	----------	698,958.66	Average: $111.37

*Canadian River watershed.