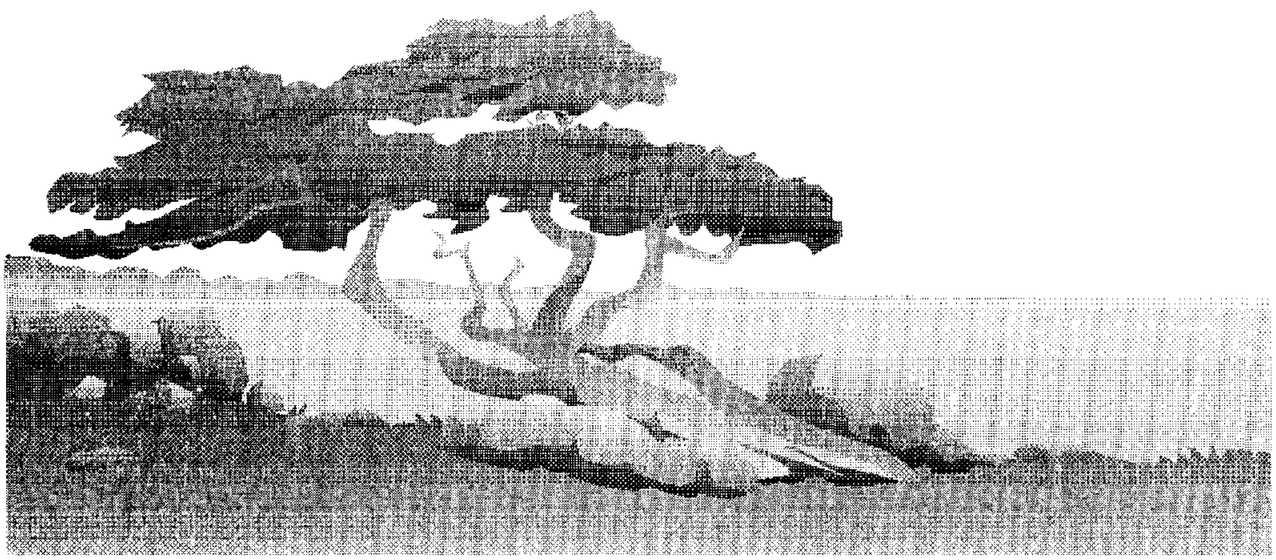
North Concho River Watershed

Brush Control Planning, Assessment & Feasibility Study



Prepared by the:
Upper Colorado River Authority

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Upper Colorado River Authority

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Final Report
amended January 1999

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BRUSH CONTROL PLANNING, ASSESSMENT & FEASIBILITY STUDY

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ACKNOWLEDGMENTS

The preparation of this report is the result of more than a dozen state, federal and local entities uniting under a common brush control banner to marshal all possible resources which would develop data conclusions and recommendations for feasible and practical means of providing water for the North Concho River Watershed.

The catalyst for this cooperation is due to *State Representative Robert Junell* and his efforts to unite all parties into a common goal. Special thanks are also due to *Craig Pedersen*, Executive Administrator of the Texas Water Development Board for support of this project.

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INTRODUCTION 1.0

During the last 35 years, stream flow on the North Concho River has decreased to less than 22% of that of the previous 35 years, even though average annual rainfall has increased slightly in the same period.

Records and historical accounts indicate that the North Concho River and its main tributaries generally experienced continuous perennial flows from 1925 to 1959 . Official USGS stream measuring stations immediately north of San Angelo recorded a total of 1,351,593 acre feet of water stream flow during that period for an average of 38,617 acre feet of water per year. Annual average rainfall at the measuring station was 19.48 inches for that same period.

From 1960 through 1996 a total of 309,255 acre feet of water stream flow was recorded (or an average of 8,358 acre feet per year). Average annual rainfall from 1960 through 1996 was 20.31 inches. The North Concho River and its tributaries have ceased to have perennial continuous flow. The river and its tributaries have evolved into small areas of water impoundments replenished solely by major storm events and minor sporadic stream flow.

There may be several factors contributing to the decrease in stream flow during this comparison period. Infestation of noxious brush, which has robbed and is continuing to degrade the underground aquifers, may account for a major portion of the decreased flow on the North Concho River watershed. This study has been executed to document the role of brush control in watershed restoration.

The watershed of the North Concho River and its main tributaries consists of approximatley 950,000 acres, much of which has become infested with brush. It is believed that brush has robbed the underground aquifers of their once prolific outcrop springs. This has resulted in a drastic reduction in average annual stream flow in the river and subsequently into the only reservoir on the watershed--O.C. Fisher. As a consequence of the diminished North Concho River stream flow, landowners in the watershed have experienced water shortages, major degradation of underground aquifers (causing irrigation practices to be limited), deteriorated water quality, annihilated aquatic habitats and steadily decreased public water supplies for a reservoir intended to sustain a major metropolitan center of Texas.

In an effort to determine the exact damage noxious brush caused on the North Concho River watershed, as well as to evaluate methods and procedures for eradication or removal of certain areas of heavily infested brush, several entities have united into a compact. These entities have been assisted by additional state and federal agencies to undertake this comprehensive study. This assessment will provide the Texas Water Development Board and the people of Texas with means, procedures, and recommendations of how to recapture and utilize water, now being stolen, for increased public benefit on an entire watershed.

EXECUTIVE SUMMARY 2.0

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 sources that are now being robbed from the people of Texas by non- productive and noxious brush.

Nowhere is that thievery more apparent than in an already water poor West Texas.....and specifically the North Concho River watershed, which encompasses more than 950,000 acres.

There are more than 130 million mesquite trees and 100 million juniper trees which have tentacle roots serving as straws sucking water from the North Concho River watershed. The potential transpiration by mesquite and juniper on this watershed is to rob almost 2 million acre feet of water annually from productive use. By way of contrast, mesquite and juniper on the North Concho watershed use 100 times more water than the City of San Angelo uses annually.

Therefore, the objective of this study is to recapture some of this water which is being needlessly wasted. The North Concho River Watershed Brush Control Study is the result of a year-long cooperative study of the watershed, detailing its history, hydrology, geology, land use, past and present characteristics. It makes dynamic and conclusive recommendations which call for immediate action from state government, political subdivisions and landowners to initiate an action program which will result in removal of mesquite and juniper and restore underground aquifers and natural stream flow for public benefit.

The study was accomplished through a partnership composed of the Upper Colorado River Authority, Texas A&M Research & Extension Center and The Texas State Soil & Water Conservation Board through a grant obtained through the Texas Water Development Board. In addition, other participants include the Texas Parks & Wildlife Department, U.S.D.A. Natural Resources Conservation Service, Blackland Research Center, and Soil & Water Conservation Districts from Tom Green, Coke, Sterling and Glasscock County.

The following pages of this executive summary outline the study and program, its effects, costs, implementation and administration. The text and graphics show the detail, methodology and procedures utilized in finalizing recommendations and conclusions.

However, the paramount conclusion flowing through the report is that with successful brush control on the watershed, stream flow in the North Concho river can increase five times over the current amount, underground aquifers can be recharged and water for the people of Texas made available at a cost to the state a fraction of the cost of what a West Texas city or individual pays for water.

Prior to simulation of stream flow in the North Concho River, a Geographic Information System (GIS) was developed to characterize the area and provide inputs for the simulation model. Data layers in the GIS included soils, topography, climate and vegetation type. The present amount of land in different vegetation types was determined using satellite imagery that was ground truthed for accuracy. The vegetation types and amounts of acreage of primary interest to this study were heavy cedar - 110,508 acres; heavy mesquite - 155,896 acres; moderate mesquite - 92, 735 acres; and light brush - 73,346 acres. Thus a total of 432,485 acres or 45% of the watershed should be considered for some form of a brush control program to restore stream flow in this river.

The amount of additional water expected as a result of controlling brush in the North Concho River Watershed was estimated using the Soil and Water Assessment Tool (SWAT). SWAT is a simulation model that predicts the impact of management (climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water sediment and agricultural chemical yields in large un-gauged basins.

The model was calibrated to predict historical discharge from the watershed using precipitation records from 11 weather stations located in or near the watershed. Calibration is the process of adjusting model input parameters so that simulated output tracks measured flows accurately. Although discharge records exist as early as 1925 for some gauge locations on the North Concho River, complete weather and discharge data are only available beginning in 1949. Because measured stream flow changed drastically around 1961. The model was calibrated for two periods, 1949 - 61 and 1962 -96. Both amounts of land in different vegetation types and stream channel transmission efficiencies were altered between the two periods so that simulated flows matched measured flows. Because quantitative information was not available during the pre-1962 period, brush cover was reduced by categorizing the heavy mesquite areas (as determined from the satellite imagery), as moderate mesquite and all other areas with natural vegetation cover were classified as open rangelands in poor condition. In addition to differences in the vegetation cover, the condition of the stream channel of the river and its major tributaries was parameterized to reflect the loss of their perennial nature after 1961. Prior to 1962 ground water levels in the Quaternary Alluvium deposits (shallow aquifers) that surround the stream bed were assumed to be sufficiently recharged so that they contribute to the flow of the river and to its perennial nature. Thus stream channel transmission losses were minimized for calibration during this period. However, after 1961 it was assumed that the water table dropped and no longer contributed to stream flow and direct irrigation withdrawals from the river were set at 10 cubic feet per second. Prior to that time irrigation withdrawals were zero. The different assumption concerning change in conditions of the watershed over time were based on historical accounts, personal interviews of long-term residents of this area and irrigation records.

Based on these assumptions the simulated flow accounted for 46% of the variation in the measured discharge rate at Carlsbad, Texas during the pre-1962 period and 76% of the variation at that location in the post 1962 period. The agreement between actual and simulated flow was considered accurate enough to use the model to estimate the effect of various brush management scenarios on water yield. For the simulation of different brush management scenarios, it was assumed that the underground aquifer was replenished to pre -1962 levels. Thus the simulated increases would not be expected to occur until some future time following the initiation of a watershed scale brush control program when the underground aquifers would be replenished.

Four Brush Control alternatives were simulated:

1) Removal of all brush from areas classed as moderate mesquite, heavy mesquite and heavy cedar brush canopy, and replacement with open rangeland.

2) Removal of all brush from areas classed as moderate mesquite and replacement with open rangeland.

3) Removal of all brush from areas classed as heavy mesquite and replacement with open rangeland.

4) Removal of all brush from areas classed as heavy cedar and replacement with open rangeland.

Greatest reduction in evapotranspiration resulted from the removal of heavy cedar. However, this did not yield the greatest increase in flow to the river because cedar is located further from the stream bed. Following recharge of the shallow aquifer, reduction of brush cover on all eligible lands to a 5% canopy which would increase the North Concho River flow at Carlsbad by 33,515 acre feet above the current discharge rate. This represents over a five-fold increase in stream flow and in more water annually than the City of San Angelo uses.

Percentages of simulated annual increases in stream flow after recharge of shallow aquifer to pre-1962 levels associated with clearing each of the three brush categories were; heavy cedar - 31%, heavy mesquite - 46% and moderate mesquite - 23%.

Economic analysis of the different brush control alternatives was based on estimating control costs of the different options and comparing them to the rancher estimated benefits of brush control. Control costs include initial and follow-up treatment required to reduce brush canopy to 5% or less and maintaining it at the reduced level for at least 10 years. Obviously, the costs will vary with brush type categories. Present values of control programs are used for comparison because some of the treatment will be required in the first and second years of the program, whereas others will not be needed until year 6 or 7. Present values of total control costs per acre range from $75 for heavy cedar- that must be initially controlled with tree dozing, to $20 for moderate mesquite that can be initially controlled with individual plant herbicide treatments. The estimated present cost of controlling heavy mesquite with an initial aerial herbicide application and two follow up individual plant treatments was $53 per acre.

The rancher benefits are based on the present value of improved net returns to the ranching operation for livestock and wildlife enterprises that would occur because of increased forage production and quail hunting opportunities. Present values of these benefits differ by location within the basin. In the portion northwest of Sterling City (NW), they range from $19 per acre for control of heavy cedar to $8 for control of moderate mesquite. Southeast of Sterling City (SE) they range from $17 per acre for control of heavy cedar to $7 for control of moderate cedar.

The state cost share is estimated as the difference between the present value of the total cost per acre of the control program and the present value of the rancher benefits. Present values of the state cost share per acre of the brush control in the southeast range from $56 for control of heavy cedar with tree dozing to $9 for control of heavy cedar with two way chaining and burning. In the northwest, the state cost share ranges from $58 to $11 for the same control practices. Present value of state cost share for control of heavy mesquite was estimated at $39 per acre.

Based on these analyses, $12 million in state funding is required for state cost share of brush control on all of the qualifying acreage in the watershed. Of this total $6 million should be appropriated in 2000-2001 biennium and the remaining 6 million over the following three bienniums.

The total cost of additional water was determined by dividing the total state cost share if all eligible acreage was 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. An adjustment for the differences in time of water availability and time of cost share expenditures would be made. The brush control program water yields and the estimated acreage eligible for enrolling in the program discussed above are used to estimate the average annual added water yields for each brush type density category.

Likewise, the total state cost share is estimated by multiplying the per acre state cost share for each brush type density category by the eligible acreage in each category. The cost of added water resulting from the control of each brush type density category is then estimated by adjusting the water yields for the delay in time of availability over the 10 year period, summing and dividing into the total state cost share.

Brush control costs of added water averages $53 per acre foot for the 10 year contract period used in the economic analysis. Even without follow-up treatment after the contract period the benefits of brush control would provide additional water for 10 more years. Therefore this cost would be cut in half or equal to $27 per acre foot.

By contrast, Lake Ivie Water delivered to contact cities costs $160 per acre foot per year and includes all debt, supply and transmission costs.

Implementation

Given the size of this project and the narrow time window of ideal conditions for herbicide application, it is recommended that initial treatments be spread over a minimum of 4 years. Because follow-up treatments will be required to obtain the necessary level of brush control for the length of time required to recharge the aquifer and increase the stream flow in the North Concho River, a long term funding commitment by the state must be made for this program to succeed. The North Concho Brush Management Program should be administered at the state level through the Texas State Soil and Water Conservation Board under the Texas Brush Control Plan, developed in accordance with Chapter 203 of the Agricultural Code. This code should be amended to allow greater flexibility in cost share to accomodate the North Concho as well as other projects to come throughout Texas. Funds for implementation should be deposited in the State Brush Control Fund. Cost share funds will be administered at the local level by those Soil and Water Conservation Districts (SWCD's) participating in the program based on allocations from TSSWCB. The SWCD's should contract with individual landowners for developing and implementing individual brush control plans. However, TSWCB and Texas A & M should initiate quality control measures to insure proper herbicide mix and applications.

Because of this desperate need for water in this region of the state and San Angelo in particular, it would be desirable to minimize as many restrictions as possible on cost share contracts and maximize the cost share rate in order to maximize enrollment of eligible acreage in the program. Therefore, it would be desirable to minimize deferments and other requirements that place undue burdens on the landowners. Likewise, it is recommended that the cost share limitation in Secion 203.153 of the Agricultural Code be increased to reflect the cost share rates suggested in this study and to allow landowners to receive an additional 5% statewide share if a grazing deferment is incorporated during initial chemical treatment phases. Deferment will be required on all prescribed burns or dense tree grubbing mechanical applications. Local Soil & Water Conservation Districts in conjunction with the landowner, will determine deferment needs.

Follow Up Monitoring and Research

If the proposed project is funded, it will provide a unique opportunity to enhance the tools used to perform other feasibility studies. Because of the size and complexity of watersheds, the estimation of the effect of brush control on water yield is dependent upon simulation models. The current project represents a landmark for the computer model" SWAT" in evaluating the effect of brush control on water yield. It will be important to monitor the effect of this program on water yield and to determine if the simulated increases in stream flow were accurate.

The evaluation costs of the North Concho Brush Control Project is estimated to require $1 million over a six year period to be conducted by Texas A & M, UCRA and the Texas State Soil and Water Conservation Board. In addition, the opportunity should be taken to evaluate and/or develop better simulation models for determining priority areas for brush control in Texas. It is proposed that as an outgrowth of the experience gained on the North Concho River Project, feasibility studies should be done on other watersheds. Other areas or river basins deemed appropriate to consider for study include, the Frio, Edwards Aquifer, Nueces, Pedernales, Wichita, Canadian and Middle Concho Rivers.

In addition to efforts to monitor and extend the present study to other watershed areas in the State, it is recommended that empirical studies be conducted to provide information necessary to enhance future brush control projects. Study topics could include:

- Quantification of effects of environmental conditions on efficiency of herbicide applications.
- Quantification of the effect of brush control on upland spring flow
- Determination of factors that influence landowner participation in brush control programs
- Quantification of wildlife response to varying levels of brush control
- Quantification of the effect of brush reduction on livestock production systems

The cost of conducting these other proposed basin studies is $1.4 million.

In addition to the research aspects associated with this project, a significant educational component should be included. This would provide landowners the information they will need to plan brush control projects appropriately to enhance watershed function, wildlife populations and livestock enterprises. It is recommended that these extension activities be funded in the amount of $500,000 annually.

HYDROLOGIC EVALUATION 3.0

3.1 Description of the Watershed

The North Concho River watershed is located in West Central Texas within Tom Green, Sterling, Glasscock and Coke Counties (see Plates 1 and 2 for location and watershed map). West Central Texas has a sub-tropical climate; dry in winter and warm and humid in summer. Average annual rainfall varies from approximately 19 inches in Tom Green County to approximately 16 inches in Glasscock County. Most of the precipitation is received from thunderstorms during the period of May through October. Thunderstorm rainfall in West Texas is extremely variable. Large differences in rainfall amounts exist from year to year within small geographical areas. The North Concho River watershed actually originates in Southern Howard County, however, no significant watercourse or perennial stream flows are encountered until the stream enters northwestern Sterling County. The stream terminates within the City of San Angelo as the North and South fork of the Concho's confluence becomes what is commonly called the "Main" Concho or simply the Concho River. O.C. Fisher Reservoir was constructed in the early 1950's immediately above San Angelo for flood protection and as San Angelo's primary water supply. Since construction, O.C. Fisher Reservoir has performed below expectations as a water supply. In the 50 year history of the reservoir, municipal water has been available for only short and sporadic periods of time. The watershed is primarily utilized for ranch pasture with the propagation of cattle and sheep being the major land use. Some cultivation exists, but with the exception of portions in Glasscock County and minor areas in Tom Green County, farming consists of small grain production in support of livestock operations. Except for oil and gas production, no major industries are located on the watershed.

For the purposes of this study, the watershed has been assumed to terminate at O.C. Fisher Reservoir. This assumption results in placing the City of San Angelo, as the largest metropolitan area with approximately 100,000 persons in the watershed, out of the study area. Other communities that lie within the watershed study area include Grape Creek, Carlsbad, Water Valley, Sterling City and Garden City. There is a substantial rural subdivision development in the lower portion of the watershed primarily in Tom Green County.

Elevations within the watershed range from near 2700 Ft. MSL on the western side to near 1800 Ft. MSL near San Angelo. Topographically, the area generally consists of broad valleys near the river and tributaries consisting primarily of geologically recent terrace deposits flanked by

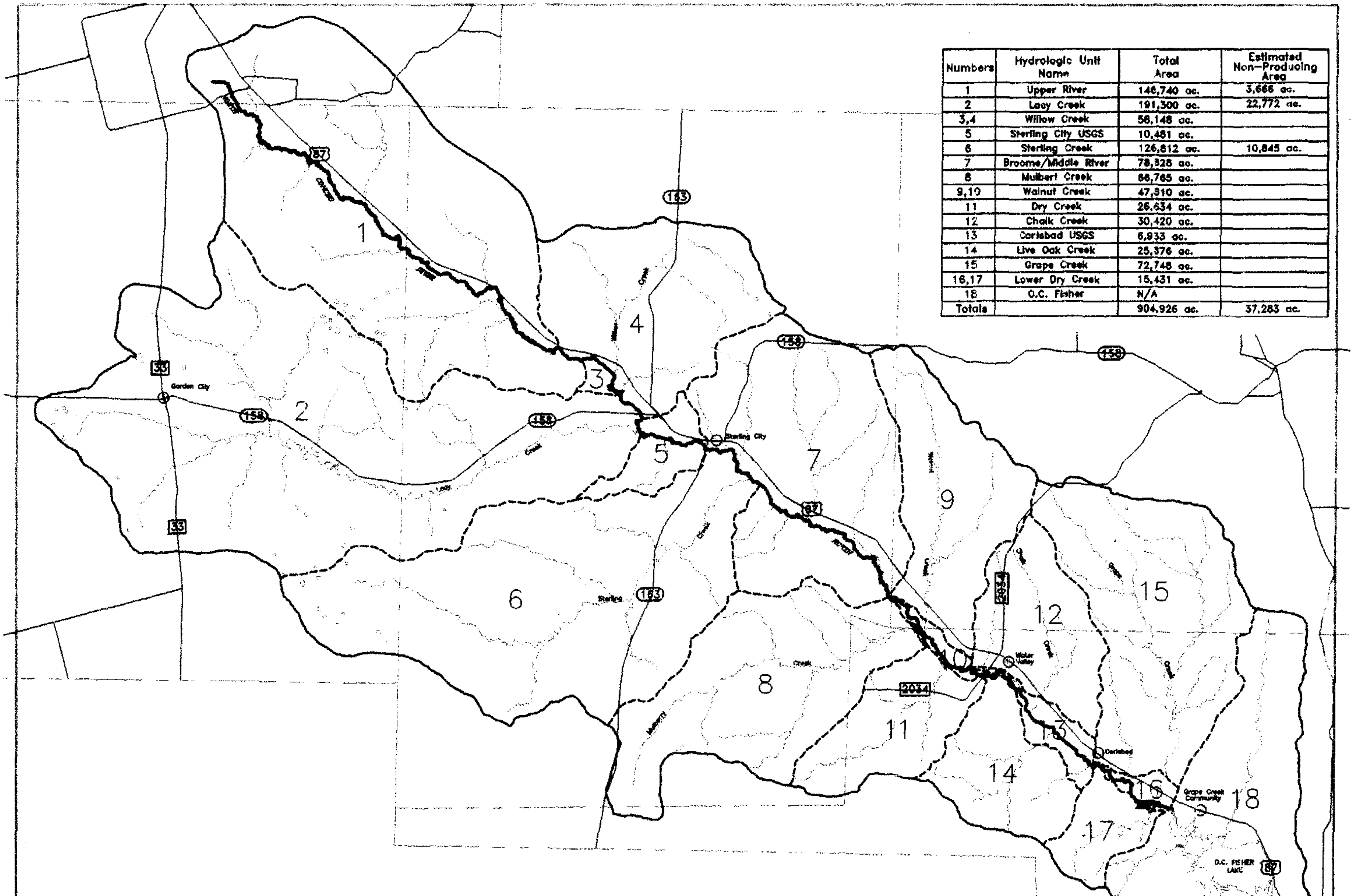
NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

Prepared By The Upper Colorado River Authority

(PROJECT LOCATION)

SK ENGINEERING GEO-SCIENCE LABORATORY



Numbers	Hydrologic Unit Name	Total Area	Estimated Non-Producing Area
1	Upper River	146,740 ac.	3,666 ac.
2	Lacy Creek	191,300 ac.	22,772 ac.
3,4	Willow Creek	58,148 ac.	
5	Sterling City USGS	10,481 ac.	
6	Sterling Creek	126,812 ac.	10,845 ac.
7	Broome/Middle River	78,528 ac.	
8	Mulbert Creek	66,765 ac.	
9,10	Walnut Creek	47,810 ac.	
11	Dry Creek	26,634 ac.	
12	Chalk Creek	30,420 ac.	
13	Carlsbad USGS	6,933 ac.	
14	Live Oak Creek	25,376 ac.	
15	Grape Creek	72,748 ac.	
16,17	Lower Dry Creek	15,431 ac.	
18	O.C. Fisher	N/A	
Totals		904,926 ac.	37,283 ac.

NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

Prepared By The Upper Colorado River Authority

(HYDROLOGIC UNIT LOCATIONS)

PLATE 2

hills, buttes and plateaus of Edwards Limestone. Much of the hills and plateaus are covered with Juniper, Liveoaks and small brush, while the valleys are typified by dense mesquite thickets.

As "Plate 1" illustrates, the watershed is subdivided into hydrologic units for the purpose of this study. The hydrologic units have generally been defined by sub-watersheds associated with major tributaries. These tributaries include Lacy Creek (which is the largest in the area), Willow Creek, Sterling Creek, Mulberry Creek, Walnut Creek, (upper) Dry Creek, Chalk Creek, Liveoak Creek, Grape Creek and (lower) Dry Creek. Other Hydrologic units were identified based on topographic or hydrologic critical features.

▸ 3.2 *Historical Considerations*

▸ 3.21 Ecological History

A significant reference used in the preparation of this ecological study is a dissertation by Terry Clyde Maxwell entitled "*Avifauna of the Concho Valley of West-Central Texas with Special Reference to Historical Change*", submitted to the Graduate College of Texas A&M University in May of 1979. Though the observations cited in the dissertation are in general of West Central Texas , the conditions of these areas are considered to be representative of the region actually within the watershed. Other sources used are, *Personal Narrative of Explorations and Incidents in Texas, New Mexico, California, Sonora and Chihuahua, 1850-1853*, by John Russell Bartlett (also cited by Maxwell) and interviews conducted with local residents.

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

Prior to 1849

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

> *"In this place were the first pecan trees we saw, for its bottoms have many groves of them; many nuts were gathered.. ... it also has shells, a variety*

of fish, and very lofty Liveoaks, so large that carts and other bulky things can be made of them. There is a great variety of plants and of wild hens which make noise at dawn. The river bottoms are very extensive and fertile, in its groves are many grape vines and springs, and many prickly pear patches; and all of the foregoing are on both sides of the river."

Maxwell makes note of the fact that Mendoza makes no mention of mesquite, and that the expedition would have passed the river bottom with difficulty if mesquite were present in the density that it is currently found. Another entry reads:

> *"The place is in a plaza which has several great groves of very tall pecan and live oak trees. There are a number of wild hens and other kinds of game."*

This area currently looks much as described by Mendoza, except for the dense mesquite woodland that now occupies it. Maxwell points out that the wild hens, referred to by Mendoza, preferred a habitat of tall grasses and short shrubs. An area of dense mesquite woodland would not be a suitable habitat for these birds.

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

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

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

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

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

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

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

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

Maxwell summarized the vegetation of the Concho Valley during the 1849-1885 time period as predominantly grassland. The prairies of Lipan Flat and the High

Plains were grasslands with scattered old mesquite trees and low mesquite bushes. He wrote that the *"undulating hills of the Eldorado and Colorado divides had scattered growth of Liveoaks and mesquite in some locations, and only 'barren' grassland in others."* Juniper was uncommon. Large pecan trees and Liveoaks with dense undergrowth lined the stream banks.

-1-------8--------8--------5-----------------------------------1--------9--------5-------0

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

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

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

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

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

3.22 Hydrological History

Prior to installation and continuous maintenance of the United States Geological Survey flow monitoring station No 08134000 near Carlsbad in 1925, little hard data was provided to document the hydrologic history of the watershed. The best source of information regarding earlier history comes from personal accounts. A review of the previous section concerning ecological history of the region (3.21) reveals numerous accounts of prolific springs and flowing streams.

An early government publication entitled " *Major Texas Floods of 1936*", reported flood marks from a record flood on the North Concho in June, 1853. The publication was written by Mr. Tate Dalrymple of the Federal Emergency Administration, Dept. of the Interior and published in 1937. Ironically, the publication was written prior to the 1936 San Angelo Flood. Reportedly, the 1853 flood deposited a very large pecan tree near the site of the previous Tom Green County Court House (several blocks south and west of the current site). The tree was reportedly removed in the 1930's. The report also documented several large floods on the river in the late 1800's and early 1900's. From reported flood marks it is likely that the 1853 flood was the flood of record for the watershed. A large flood in September of 1936 is the largest recorded flood on the watershed. That flood produced flows at the Carlsbad station of 94,600 cubic feet per second (CFS) and in combination with flood flows on the South Concho River caused considerable flood damage in San Angelo.

It is absolutely apparent that major changes in the hydrologic characteristics of the watershed have occurred through time, with the most dramatic change occurring in the decade of the 1950's. The changes in hydrologic conditions have effected both the frequency, duration and yield of flood flows and it has effected the perennial base flows of the springs, tributaries and river. At the present time, spring and tributary flow is infrequent and at best seasonal and dependent upon timely rainfall. Some surface flows are experienced at numerous locations within the watershed as seeps and springs during annual periods of low evapotranspiration (winter months) provided rainfall occurs in the fall and winter.

During the process of this investigation, no tributary to the North Concho River was discovered that has been capable of sustaining a fishery within the last 35 years. This has not always been true. An interview with Mrs. Maxwell Turner, whose husband and family are early area residents and ranch near Carlsbad revealed that Liveoak Creek historically was a perennial stream fed by springs primarily located on what is now the Munn Ranch. The creek reportedly would experience low flows during summer months but sustained a viable permanent fish population. Mrs. Turner stated that, *"Carlsbad children used to like to sneak across the river to fish in Liveoak Creek".* By 1960, Liveoak creek was intermittent and no longer provided fish habitat.

Fred Teagarden, who is a resident of San Angelo, first saw Grape Creek, (a major tributary in the lower watershed), in 1925 at the age of seven. He later resided for a short time as an early teen near the creek. His recollections of the creek were vivid due to a necessity to cross the creek in order to get to the ranch house. He reported that at that time stream flows were perennial and a viable fish population was maintained in the creek. Except for a short period in the mid-1980's, Grape Creek has not experienced perennial flows since the 1950's.

A long time resident and rancher on the Walnut Creek near Water Valley, Frank Demere, reported that the creek *"used to run all the time"* until after the drought of the 1950's. Walnut Creek flows originated at a place known locally as "Shelving Rock" which is a historical spring site.

Chalk Creek which is also near Water Valley has been reported by several long time residents as a historically perennial stream. An early resident that lived on the east fork of Chalk Creek (the Harrington Family) reportedly utilized the creek for most all domestic purposes on a continuous basis until the 1950's when the creek went dry. Since that time, the creek has been sporadic in flow and only during winter months when rainfall is above normal.

The following accounts were taken from a 1967 U.S. Department of Agriculture, Soil Conservation Service publication (TEX-47-157) entitled *"Grassland Restoration, Effect on Water Yield and Supply"* under the sub-title, *"Reservoirs Can't Store Water That Never Reaches Them".* The report states the following:

> *"The North Concho River story is happening all over the state to some degree. It is worthy of a real good look.*
>
> *Three centuries ago the first Spanish explorers on the Concho were delighted at the abundance of water, fish, and game, and proclaimed this to be the richest region in all New Spain. One hundred years ago when the Texans began to settle in the region, it hadn't changed much. The North Concho River was a running stream, fed by numerous springs and lined by pecan groves. Waterman Ormsby, reporter for the New York Herald, crossed the river on the first west bound trip of the Butterfield Overland Mail in 1848. He described the river as a flowing stream of considerable size. A concrete culvert had to be constructed for the stage crossing. Ormsby also described Grape Creek, a major tributary of the North Concho, as a flowing stream full of fish and the channel lined with grapevine-covered trees.*
>
> *John A. March, who ranches on the headwaters of Grape Creek, told Soil Conservation Service employees that in the early 1900's, Grape Creek was fed mostly by three permanent springs. Each of them flowed into deep pools of clear water which were favorite fishing and swimming holes for the ranch residents.*
>
> *The late J.R. Mims of Water Valley worked on Grape Creek and North Concho River ranges as a cowboy, wagonboss, and rancher since about 1890. He had a vivid memory of the region and remembered that Grape Creek was the site of their first night stop when traveling via horseback or wagon from San Angelo. There was a deep hole at the campsite, a welcome fishing and swimming place. Mims once caught an 18-pound catfish in the hole on an overnight camp.*

The springs on the North Concho River have failed because the aquifers are no longer being recharged.

With a thick cover of grass that originally grew on the Concho River watershed, most of the rainfall was absorbed. A portion of it percolated downward into the aquifers which fed the springs.

Heavy grazing, uncontrolled prairie fires, and drought removed the protective grass cover. Mesquite, lotebush, catclaw and other undesirable woody plants moved in and now dominate much of the watershed. Some of the rainfall from heavy rains runs off to produce flash floods. Most of the water that is absorbed by the soil is lost by evaporation from the bare surfaces, or is used by the woody plants. The deep-rooted shrubs reach deeply into the soil to intercept percolation waters. Little or no water succeeds in moving downward into the aquifers.

Failing springs, not only in the North Concho watershed, but all over the state are a tragic and evil omen. The dying springs and streams indicate a decline in our water balance in the bank - the underground reservoirs from which the springs flow.

The infestation of brush and wastage of water on Texas rangelands is affecting every citizen of the state who is interested in conserving its most valuable resource - water!"

Personal accounts abound as to how the river and tributaries appeared and performed in years past. No one interviewed, who has lived along and around the North Concho River during the seventy year record of available stream flows (since 1925), would acknowledge that there have not been dramatic changes in the river. Available stream flow records also indicate dramatic changes in the hydrologic characteristics of the river. Initial examination of the data indicated a clear delineation of change in the hydrologic characteristics of the river following the decade of the 1950's. This time period also experienced two other well recognized events, general completion of the mesquite infestation of the watershed to the conditions we now recognize as "normal" and a historical drought.

Some of the most valuable hydrologic records to this study have proven to be the United States Geological Survey (USGS) stream flow records for Station No. 08134000 near Carlsbad, Texas and groundwater elevation data collected by the Texas Water Development Board. The stream flow data record spans from 1925 through the present and the groundwater measurement records began in the late 1930's and early 1940's.

The surface water records have been analyzed by the project staff through several different techniques. "Table 1" indicates the total annual stream discharge by year of the record period in acre feet of water per year and also the annual rainfall for the year at San Angelo. A careful review of "Table 1" reveals that the period of record hydraulically can be divided into two distinct approximate 35 year periods. Total stream discharge in the first period (1925-1959) of 1,351,593 acre feet (38,617 acre feet per year) declined to 309,255 acre feet (8,358 acre feet per year) during the second period (1960-1996), while rainfall conditions remained nearly unchanged.

"Table 2" indicates the mean daily discharge in cubic feet per second (CFS) at the station for the months indicated during the period from 1925-1959. "Table 3" represents the identical hydraulic representation for the period from 1960-1996. "Figure 1" shows a graphic representation of the data on Tables 2 and 3. The changes in the hydraulic characteristics of the stream flow from the first 35 year period to the second period is apparent. The 1925-59 period experienced a mean daily flow of over 48 CFS while the 1960-96 period experienced a mean daily flow of near 12 CFS. The mean daily stream flow for the entire period of record is approximately 30 CFS.

Examination of the monthly mean daily stream flows from each period indicates that every month of the year experienced greater flows during the first period (1925-59) although many months of the year do not normally experience flood flows. This data would indicate that perennial flows as well as flood flows have been effected by watershed changes.

On Tables 2 and 3, mean monthly daily flows in excess of the period of record mean stream flow (30CFS) have been bracketed for identification. Of the 420 months contained within the first period (1925-59), 67 months experienced daily mean flows in excess of the record mean. During the second period (444 months) only 34 months experienced daily flows greater than 30 CFS. Also during each

NORTH CONCHO RIVER @ CARLSBAD
RAINFALL* AND STREAM DISCHARGE**

Year	Rainfall (IN.)	Total Flow (AC.FT.)	Year	Rainfall (IN.)	Total Flow (AC.F.T)
1925	27.09	133278	1960	14.74	15658
1926	31.19	33438	1961	21.39	31723
1927	21.19	13056	1962	10.53	521
1928	22.69	28496	1963	13.95	3400
1929	16.56	11482	1964	12.18	9215
1930	19.21	24153	1965	16.25	8297
1931	15.96	5148	1966	15.82	9458
1932	32.57	60904	1967	19.98	908
1933	8.57	5907	1968	23.30	2563
1934	16.40	11441	1969	30.04	2174
1935	27.91	79529	1970	12.88	0
1936	40.40	245650	1971	24.25	6955
1937	24.17	25065	1972	22.93	2260
1938	17.42	27623	1973	18.41	3829
1939	17.45	4861	1974	25.10	47360
1940	25.21	10339	1975	21.58	8077
1941	15.79	41918	1976	21.80	2040
1942	25.82	9689	1977	12.95	3833
1943	14.61	4600	1978	14.67	9682
1944	19.51	3934	[illegible]	16.16	1822
1945	18.97	52365	1980	30.09	25996
1946	10.84	2198	1981	30.17	4321
1947	13.46	21166	1982	18.18	6295
1948	12.51	79895	1983	15.26	1945
1949	24.51	37878	1984	19.14	3221
1950	15.27	14474	1985	21.83	1250
1951	12.00	5259	1986	32.93	25810
1952	9.01	1210	1987	31.90	32464
1953	21.06	28441	1988	14.06	6763
1954	9.92	23272	1989	17.64	3372
1955	12.87	4966	1990	27.20	1738
1956	7.41	10218	1991	24.29	4019
1957	22.16	70156	1992	21.03	14289
1958	18.35	94867	1993	15.63	4372
1959	33.86	8468	1994	19.40	3629
			1995	21.15	933
			1996	22.50	9063
TOTALS		1,351,593	TOTALS		309,255
AVERAGE	19.48	38,617	AVERAGE	20.31	8,358

*Rainfall records from San Angelo weather station.
**Flow records from United States Department of Interior - Geological Survey - Texas District, Station No. 08134000, North Concho River @ Carlsbad.

Table 1

North Concho River Flow Data (1925-1959)
Station No. 08134000 @ Carlsbad

Mean Daily Discharge (cfs)

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Annual Daily Mean*
1925	5.00	5.00	5.00	7.60	5.65	1.50	631.00	1,355.00	49.30	6.12	108.00	11.40	182.548
1926	6.03	17.80	11.60	15.00	11.00	307.00	76.00	21.20	18.80	4.63	3.82	56.70	45.798
1927	10.60	12.20	12.90	10.80	12.10	7.76	69.50	24.80	6.22	38.20	0.055	11.60	18.061
1928	4.60	1.81	4.04	4.82	5.91	7.19	9.19	48.00	13.00	353.00	7.65	5.01	38.685
1929	1.94	5.70	7.08	6.47	8.17	41.70	12.80	59.10	2.35	0.70	0.00	43.80	15.818
1930	118.00	7.90	3.91	4.08	3.95	3.60	4.34	145.00	242.00	0.54	0.00	0.00	44.443
1931	15.10	1.97	20.10	5.09	10.20	5.51	5.56	18.00	3.32	0.084	0.00	0.00	7.078
1932	43.30	4.78	3.69	4.62	9.51	6.10	40.00	637.00	131.00	15.60	4.57	100.00	83.348
1933	9.66	12.30	18.10	14.00	11.90	12.00	9.55	6.15	1.25	0.00	2.95	0.087	8.162
1934	0.00	0.00	0.98	2.50	3.80	4.04	6.96	2.96	0.00	0.00	155.00	10.80	15.587
1935	0.00	65.20	1.26	1.45	85.00	4.13	41.50	1,007.00	33.90	37.10	8.43	29.80	109.564
1936	4.24	4.73	5.78	6.45	6.63	10.40	5.69	25.70	3.45	0.10	0.10	4,019.00	341.023
1937	43.10	20.60	19.70	16.00	15.30	22.40	12.20	9.35	252.00	6.20	1.31	0.15	34.859
1938	0.57	1.64	3.75	7.82	12.90	11.90	210.00	11.00	95.30	98.70	5.40	1.81	38.399
1939	3.64	5.62	5.96	7.03	6.02	6.20	6.50	22.00	1.37	0.15	15.40	0.083	6.664
1940	0.00	0.22	2.69	2.98	3.88	2.51	3.12	5.59	50.80	5.88	38.60	55.70	14.331
1941	0.10	0.92	3.66	2.50	7.25	36.10	189.00	167.00	217.00	42.70	20.60	9.16	57.999
1942	37.90	11.30	12.80	12.30	12.10	11.60	13.10	9.78	3.92	0.42	21.70	13.00	13.327
1943	5.40	4.99	6.09	7.09	6.74	8.33	6.43	14.80	2.41	13.30	0.20	0.16	6.328
1944	0.10	0.65	4.74	4.62	3.99	3.83	2.99	3.19	32.70	0.10	3.99	4.77	5.473
1945	1.34	1.75	3.43	3.90	3.75	3.91	21.70	1.87	0.59	806.00	3.79	1.10	71.094
1946	5.80	4.61	4.62	5.07	5.16	4.88	3.07	1.13	0.20	0.077	0.00	1.93	3.046
1947	3.31	0.71	12.50	1.85	3.34	4.05	3.33	308.00	3.42	3.98	0.34	0.10	28.744
1948	0.00	0.00	7.47	4.52	7.44	9.32	5.00	0.41	53.30	1,195.00	1.05	19.10	108.551
1949	1.27	1.72	2.41	3.79	3.69	3.48	350.00	205.00	53.50	3.20	1.13	0.37	52.463
1950	0.53	1.60	3.72	4.24	4.67	4.08	58.30	49.30	2.39	0.10	16.80	95.30	20.086
1951	3.67	3.45	3.94	4.20	4.35	3.97	3.92	40.00	0.57	0.10	8.33	0.043	6.379
1952	0.00	0.00	0.33	1.37	1.50	1.65	4.47	0.66	10.20	0.048	0.00	0.00	1.686
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.067	192.00	0.10	15.80	255.00	0.15	38.593
1954	32.80	0.46	0.88	1.56	1.26	1.04	92.00	203.00	47.90	2.45	0.00	0.00	31.946
1955	0.00	0.00	0.00	0.00	0.00	2.40	0.35	34.70	0.093	32.80	4.15	6.51	6.750
1956	2.74	0.00	0.00	0.00	0.00	0.00	26.60	111.00	0.033	26.30	0.00	0.47	13.929
1957	40.20	1.07	10.40	0.10	0.014	5.86	342.00	413.00	189.00	0.087	0.00	161.00	96.894
1958	1,463.00	2.81	1.78	1.69	2.17	2.56	16.00	4.79	29.40	0.59	14.30	5.66	128.729
1959	0.071	0.10	0.85	1.13	1.68	1.28	1.16	0.60	34.00	69.10	0.12	29.90	11.666
Monthly Mean*	**53.257**	**5.817**	**5.890**	**5.047**	**8.029**	**16.065**	**65.240**	**147.374**	**45.280**	**79.404**	**20.080**	**134.133**	**48.801**

Outline indicates mean flow greater than 30 cfs; 73 months outlined.

Table 2

North Concho River Flow Data (1960-1996)
Station No. 08134000 @ Carlsbad

Mean Daily Discharge (cfs)

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Annual Daily Mean
1960	225.00	2.83	2.19	2.58	2.44	2.09	7.63	1.94	0.35	8.64	0.003	0.00	21.308
1961	18.50	0.00	0.00	0.00	42.70	0.96	0.14	251.00	19.60	178.00	1.25	9.65	43.483
1962	1.44	1.21	1.39	1.27	1.10	1.17	1.03	0.048	0.00	0.00	0.00	0.00	0.722
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.90	17.60	0.00	2.53	0.00	4.253
1964	0.042	4.49	0.00	0.00	0.00	0.00	0.00	12.70	0.03	0.00	2.52	135.00	12.899
1965	0.12	6.30	0.013	0.00	0.00	0.00	0.00	89.90	36.50	0.00	2.26	1.54	11.386
1966	35.40	0.12	0.00	0.00	0.00	1.64	82.80	12.90	0.05	0.00	18.30	5.73	13.078
1967	5.44	0.072	0.044	0.044	0.018	0.012	0.00	0.00	0.00	0.00	9.16	0.00	1.233
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.80	0.00	0.00	0.00	0.00	3.483
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.20	0.00	0.00	9.58	9.97	2.979
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.80	8.81	0.00	15.70	72.70	9.668
1972	0.86	0.017	0.00	0.00	0.00	0.00	0.00	3.08	1.92	0.007	0.00	32.00	3.157
1973	0.01	0.00	0.00	0.00	0.00	55.50	5.58	0.44	0.007	1.00	0.00	0.00	5.211
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	795.00	66.417
1975	69.00	12.30	7.19	4.89	4.97	3.15	2.90	26.20	1.38	0.093	0.52	0.00	11.049
1976	0.00	1.94	2.40	2.57	2.10	1.85	1.89	2.48	0.12	0.93	0.001	17.80	2.840
1977	2.05	2.60	2.48	3.36	3.94	4.40	5.24	3.67	34.70	1.75	0.002	0.00	5.349
1978	0.00	0.00	0.00	0.95	2.57	2.19	5.92	51.10	7.01	0.007	88.60	0.024	13.198
1979	0.05	2.59	2.25	3.56	3.56	4.06	7.76	2.41	3.01	0.015	1.20	0.00	2.539
1980	0.00	0.00	0.29	1.86	2.62	2.50	1.74	1.89	0.41	0.00	73.10	351.00	36.284
1981	6.74	6.80	6.03	6.96	5.47	6.00	8.40	16.00	6.22	2.830	0.037	0.16	5.971
1982	27.30	7.77	5.63	5.75	4.84	5.32	5.29	21.40	14.60	5.49	0.56	0.00	8.663
1983	0.09	2.22	4.02	4.45	4.16	3.48	3.79	3.27	6.78	0.24	0.00	0.00	2.708
1984	35.90	1.34	3.12	3.11	3.18	2.97	2.44	0.78	0.00	0.00	0.00	0.00	4.403
1985	0.55	0.35	3.27	2.80	3.96	3.07	5.79	1.16	0.004	0.00	0.00	0.00	1.746
1986	14.20	0.00	0.23	2.11	3.64	2.58	1.48	32.70	173.00	0.048	163.00	34.30	35.607
1987	374.00	13.80	13.80	13.00	27.60	24.90	20.00	19.70	13.90	5.68	2.48	4.38	44.437
1988	3.91	4.60	6.90	9.03	8.81	8.42	9.12	8.94	3.85	6.67	0.32	42.10	9.389
1989	1.79	2.41	5.35	5.27	5.44	5.84	5.90	2.86	21.50	0.087	0.007	0.011	4.705
1990	0.005	0.20	2.48	2.69	3.48	5.36	4.73	3.80	0.38	3.19	0.16	2.44	2.410
1991	2.25	3.59	4.27	5.20	4.80	4.95	4.11	13.10	11.50	1.28	1.24	10.60	5.574
1992	3.80	5.37	9.72	12.00	35.90	18.10	38.60	46.50	42.10	10.90	8.45	6.74	19.848
1993	5.67	6.96	9.22	10.30	10.90	10.90	9.34	6.60	2.95	0.022	0.001	0.00	6.072
1994	0.00	0.70	3.71	5.58	5.38	5.18	4.17	33.30	1.85	0.014	0.00	0.00	4.990
1995	0.00	0.00	1.32	3.24	2.71	2.31	4.61	1.16	0.28	0.00	0.00	0.00	1.303
1996	0.00	0.00	0.00	0.57	1.34	1.45	2.84	0.16	0.00	0.00	110.00	32.90	12.438
Monthly Mean	22.544	2.448	2.630	3.058	5.341	5.145	6.844	21.051	11.633	6.132	13.864	42.271	11.914

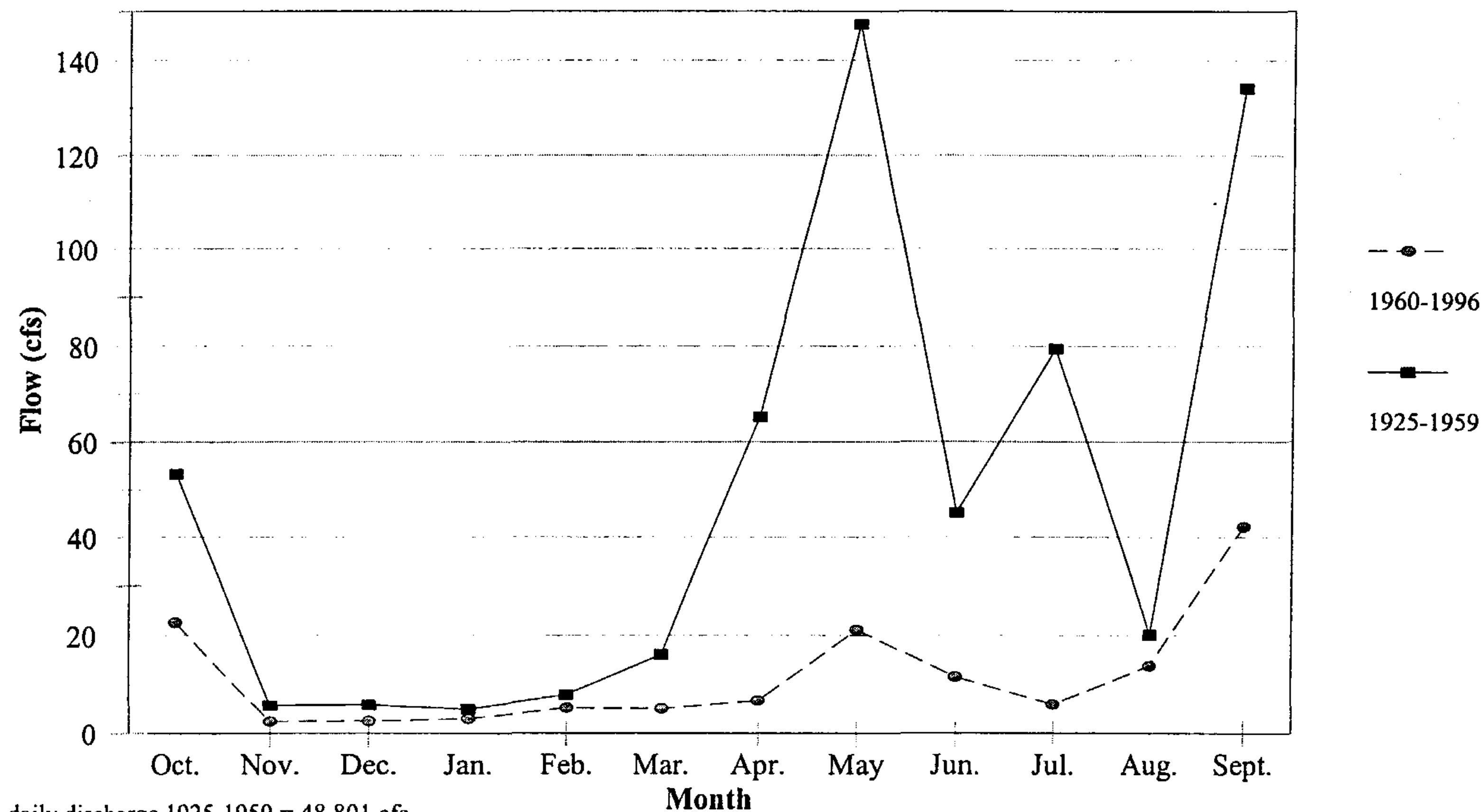
70 year mean = 30.3575 cfs

Outline indicates mean flow greater than 30 cfs; 35 months outlined.

Table 3

N. Concho River Flow Data
Station No. 08134000 @ Carlsbad

Mean Daily Flow by Month



Note: Mean daily discharge 1925-1959 = 48.801 cfs
Mean daily discharge 1959-1996 = 11.914 cfs
Mean daily discharge 1925-1996 = 30.358 cfs

Figure 1

period, the bracketed flows allow the identification of multiple month episodes during which the period mean was exceeded. During the first period, 15 multiple month episodes can be identified, while during the second period only 3 episodes are found.

"Table 4" and "Figure 2" are representations of the number of days per year in which the daily average stream flow exceeded the period of record mean flow (30CFS). During the period from 1925 through 1959, 695 days experienced daily flow rates above the mean for an average of near 20 days per year. In the second period (1960-96), 270 days experienced daily flow rates above the mean for an average of 7.3 days per year.

In examination of the flow record, an attempt has been made to evaluate the historical changes in the perennial stream flow, or those periods in which direct rainfall runoff is not manifested. These periods are characterized by low flows comparatively and originate primarily from de-watering of the groundwater aquifer (springs and seeps) both in the river and in the tributaries. Evaluation of these periods can be misleading if one uses arbitrary flow rates to identify base flow. The base flow is whatever it is due to the existing hydrogeologic conditions. Also, the stream flow monitoring station at Carlsbad, due to local hydrogeologic conditions, can and does indicate low flows while in reality the stream bed both above and below the station is dry. "Table 5" and "Figures 3 and 4" have been prepared to illustrate the existence and extent of very low stream flow periods. These graphics show that between 1925 and 1959 there were 4130 days in which the average daily flow rate was 1.0 CFS or less. During the 1959-1996 period 7252 days experienced flow rates 1.0 CFS or less. In addition, Figure 5 was prepared to illustrate the proportion of days each year in percentage during which stream flows were 2.0 CFS or greater. During the 1925-1959 period, stream flows were greater than 2.0 CFS 60.5% of the time. During the second period, stream flows were greater than 2.0 CFS 36.3% of the time. The record clearly indicates a greater and more perennial stream flow during the first 35 year period of record. The USGS stream flow station at Sterling City has a shorter period of record than the Carlsbad site, but an examination of the available data results in the discovery of hydraulic characteristic very similar to the lower river site. "Tables 6 and 7" and "Figure 6" are graphic presentations of the available data.

"Table 8 and Figure 7" have been prepared to illustrate the distribution of rainfall runoff storm events during the period of record. A rainfall runoff storm event is

North Concho River Flow Data Station No. 08134000 @ Carlsbad			
Water Year	# Days / Year Flow > 30 cfs	Water Year	# Days / Year Flow > 30 cfs
1925	38	1960	10
1926	25	1961	27
1927	17	1962	0
1928	21	1963	8
1929	28	1964	9
1930	13	1965	13
1931	11	1966	15
1932	46	1967	4
1933	5	1968	3
1934	8	1969	7
1935	40	1970	0
1936	24	1971	10
1937	30	1972	3
1938	36	1973	4
1939	9	1974	11
1940	11	1975	15
1941	39	1976	3
1942	13	1977	4
1943	5	1978	8
1944	6	1979	0
1945	18	1980	13
1946	2	1981	2
1947	14	1982	4
1948	15	1983	0
1949	34	1984	2
1950	23	1985	1
1951	5	1986	19
1952	3	1987	16
1953	17	1988	4
1954	32	1989	4
1955	9	1990	2
1956	20	1991	3
1957	48	1992	26
1958	19	1993	0
1959	11	1994	4
		1995	0
		1996	16
Totals	**695**	**Totals**	**270**
Average	**19.86**	**Average**	**7.30**

Note: 30 cfs is the 70 year mean.

Table 4

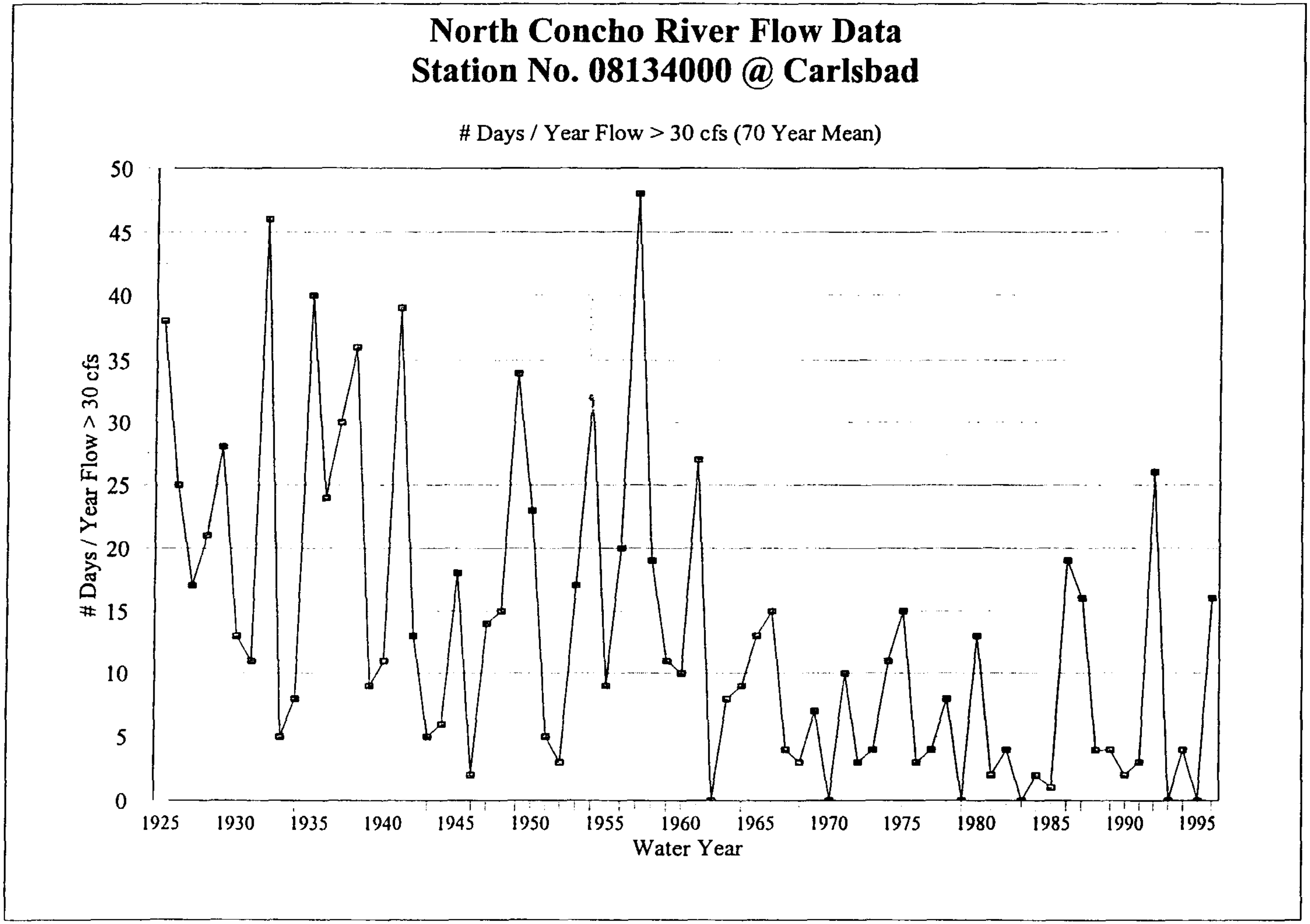

North Concho River Flow Data
Station No. 08134000 @ Carlsbad
Days / Year Flow > 30 cfs (70 Year Mean)
Days / Year Flow > 30 cfs
50
45
40
35
30
25
20
15
10
5
0
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Water Year

FIGURE 2

North Concho River Flow Data Station No. 08134000 @ Carlsbad			
Water Year	# Days Flow < 1.0 cfs	Water Year	# Days Flow < 1.0 cfs
1925	21	1960	116
1926	37	1961	243
1927	48	1962	199
1928	45	1963	350
1929	78	1964	346
1930	85	1965	328
1931	118	1966	310
1932	28	1967	358
1933	106	1968	358
1934	186	1969	358
1935	56	1970	365
1936	82	1971	343
1937	56	1972	354
1938	21	1973	319
1939	101	1974	319
1940	116	1975	103
1941	53	1976	135
1942	51	1977	106
1943	86	1978	205
1944	145	1979	133
1945	65	1980	199
1946	128	1981	74
1947	124	1982	59
1948	146	1983	127
1949	57	1984	172
1950	89	1985	98
1951	107	1986	143
1952	225	1987	0
1953	337	1988	43
1954	171	1989	100
1955	321	1990	168
1956	307	1991	44
1957	245	1992	0
1958	76	1993	95
1959	203	1994	162
		1995	204
		1996	233
Totals	**4130**	**Totals**	**7252**

Table 5

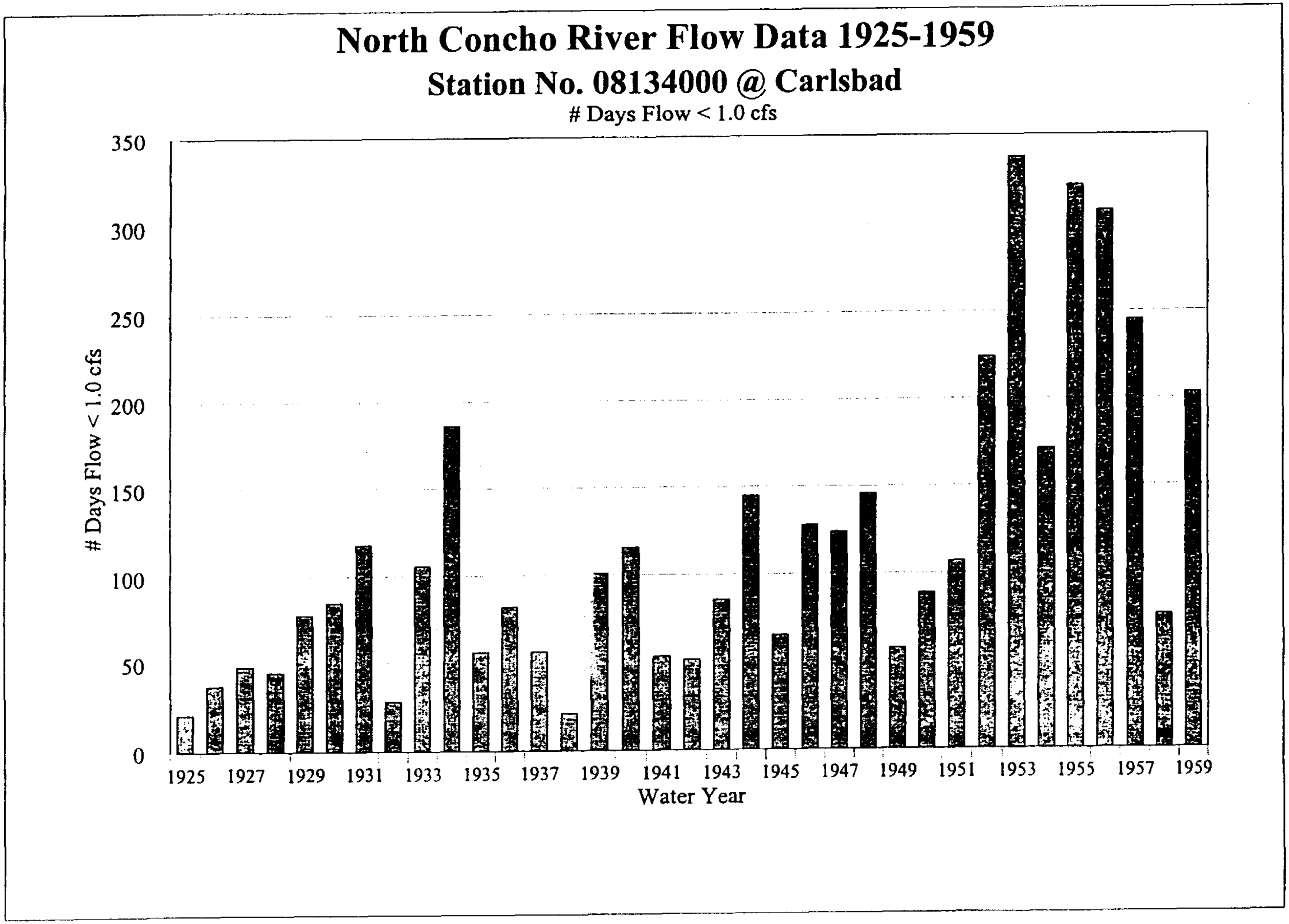

North Concho River Flow Data 1925-1959
Station No. 08134000 @ Carlsbad
Days Flow < 1.0 cfs
Days Flow < 1.0 cfs
350
300
250
200
150
100
50
0
1925
1927
1929
1931
1933
1935
1937
1939
1941
1943
1945
1947
1949
1951
1953
1955
1957
1959
Water Year

FIGURE 3

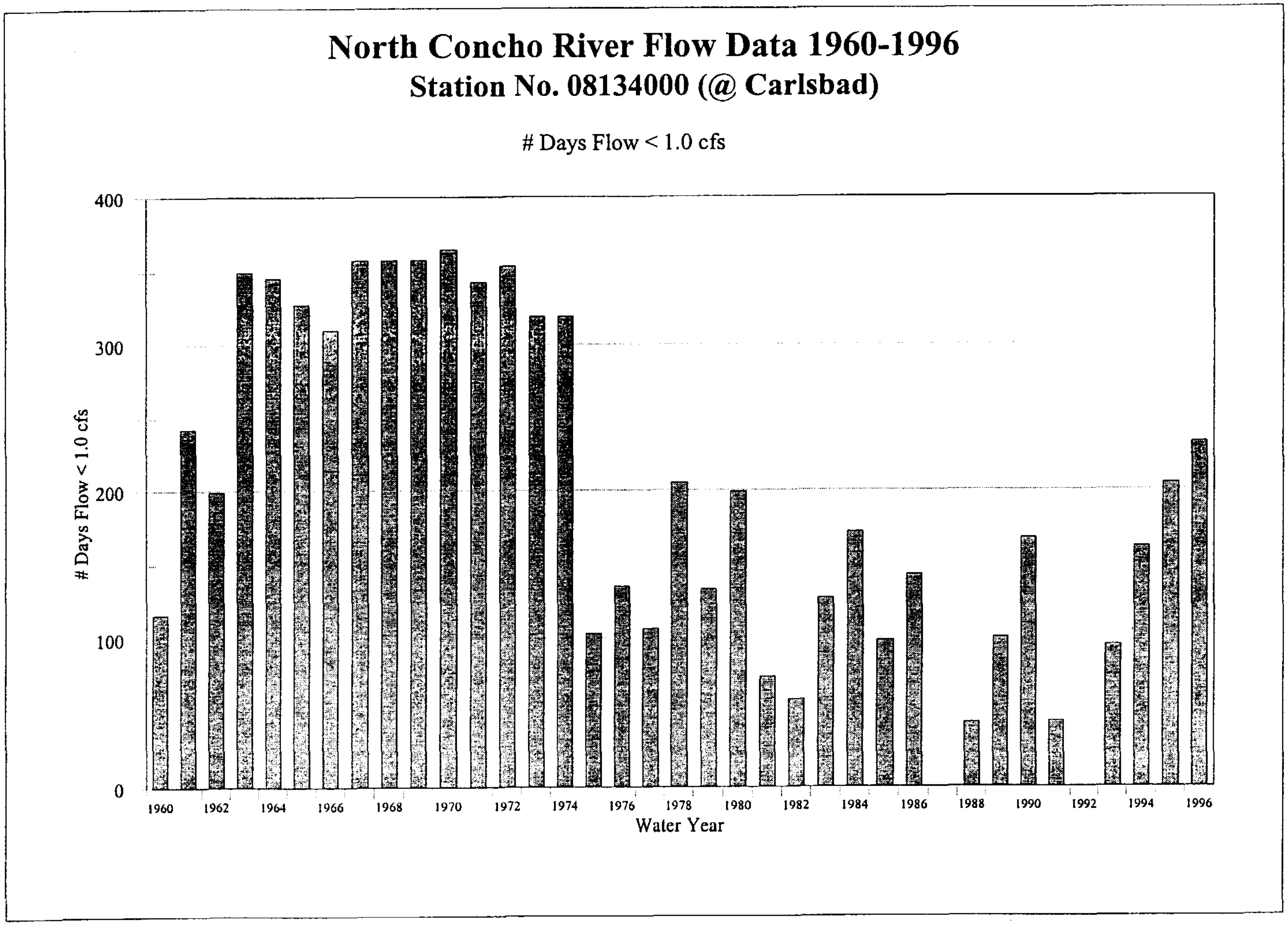

North Concho River Flow Data 1960-1996
Station No. 08134000 (@ Carlsbad)
Days Flow < 1.0 cfs
400
300
200
100
0
Days Flow < 1.0 cfs
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Water Year

Figure 4

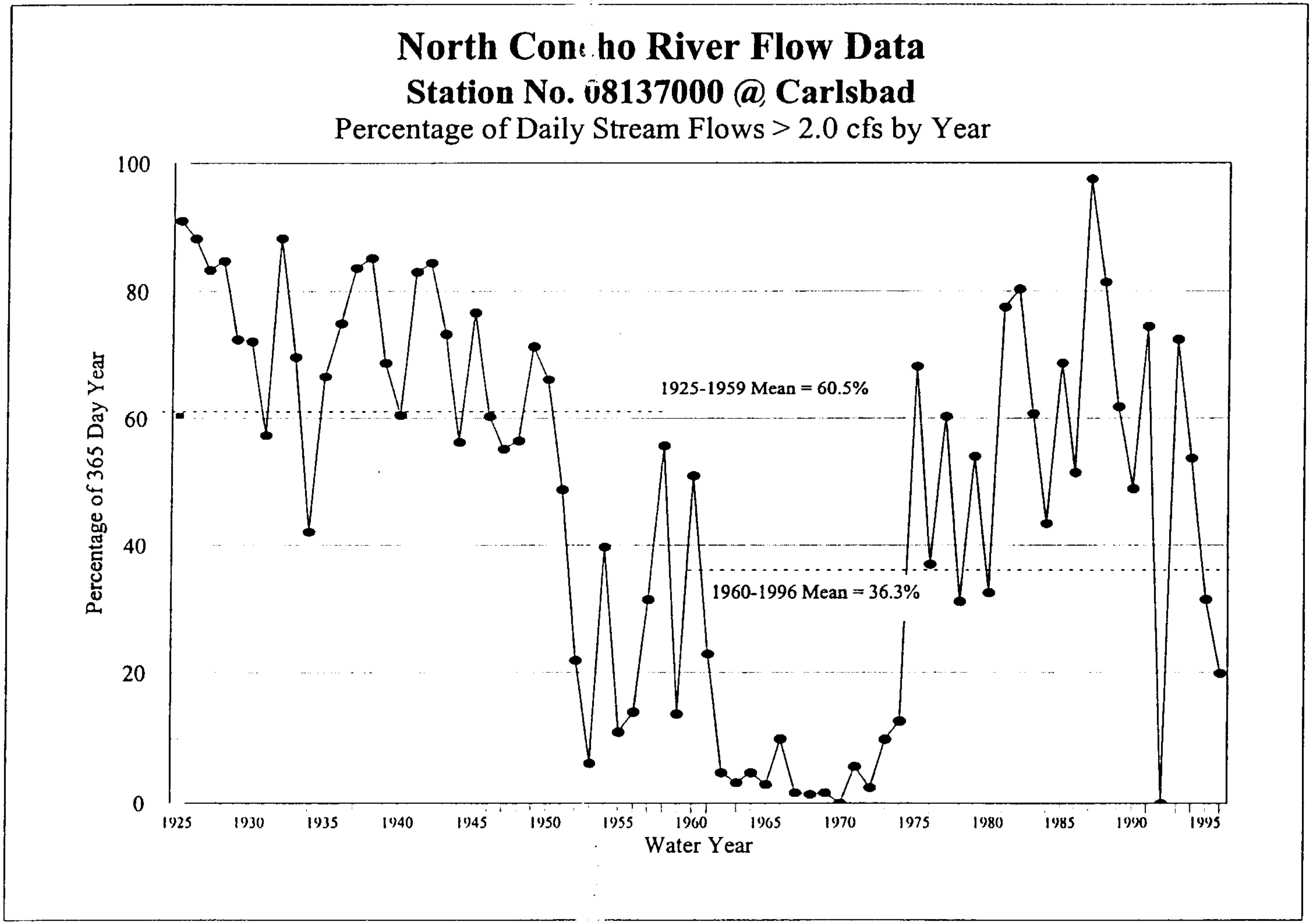

North Conc.ho River Flow Data
Station No. 08137000 @ Carlsbad
Percentage of Daily Stream Flows > 2.0 cfs by Year
Percentage of 365 Day Year
100
80
60
40
20
0
1925-1959 Mean = 60.5%
1960-1996 Mean = 36.3%
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Water Year

FIGURE 5

North Concho River Flow Data (1940 - 1959)
Station No. 08133500 at Sterling City

Mean Daily Discharge (cfs)

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Annual Daily Mean
1940	0.00	0.00	0.00	0.65	0.96	1.01	0.73	0.22	40.20	1.23	0.29	7.12	**4.37**
1941	0.61	0.00	0.50	0.69	1.17	39.30	15.00	6.74	29.20	30.10	0.88	3.74	**10.66**
1942	21.00	2.99	3.36	3.19	3.13	2.73	6.28	1.75	0.59	0.00	0.01	0.59	**3.80**
1943	0.40	0.82	1.44	1.40	1.29	1.76	0.74	1.88	0.12	3.34	0.00	0.00	**1.10**
1944	0.00	0.00	0.23	0.18	1.13	0.71	0.35	0.15	17.90	0.06	1.96	0.00	**1.89**
1945	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	2.00	405.00	0.49	0.03	**33.97**
1946	0.18	0.27	0.83	1.47	1.46	0.91	0.60	0.08	0.00	0.00	0.00	3.77	**0.80**
1947	7.18	0.00	0.00	0.05	0.11	0.42	0.03	45.80	0.35	0.00	0.00	0.00	**4.50**
1948	1.05	0.00	0.00	0.00	1.18	9.34	0.01	1.65	34.00	383.00	0.16	17.10	**37.29**
1949	0.00	0.00	0.00	0.50	0.66	0.79	80.10	112.00	33.20	0.65	0.02	0.02	**19.00**
1950	0.00	0.07	0.69	1.22	1.66	1.00	76.20	7.28	0.54	0.00	0.27	20.00	**9.08**
1951	0.01	0.17	2.25	0.62	1.49	0.78	0.49	0.75	0.08	0.00	0.00	0.00	**0.55**
1952	0.00	0.00	0.00	0.00	0.00	0.00	5.98	8.83	1.87	0.00	0.00	0.00	**1.39**
1953	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	3.50	0.48	2.07	0.00	**0.52**
1954	0.00	0.00	0.00	0.00	0.00	0.00	70.00	186.00	20.90	0.52	0.00	0.00	**23.12**
1955	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.10	0.03	8.22	0.00	1.24	**2.63**
1956	2.20	0.00	0.00	0.00	0.00	0.00	0.00	25.10	2.92	24.70	0.26	0.00	**4.60**
1957	9.02	0.10	0.81	0.00	0.00	0.00	166.00	201.00	94.40	0.02	0.00	64.40	**44.65**
1958	177.00	0.81	0.40	0.92	1.10	0.99	8.75	1.65	12.20	0.01	6.28	0.00	**17.51**
1959	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	5.18	70.10	0.10	1.03	**6.41**
Monthly Mean	**10.93**	**0.26**	**0.53**	**0.54**	**0.77**	**2.99**	**21.57**	**31.18**	**14.96**	**46.37**	**0.64**	**5.95**	**11.39**

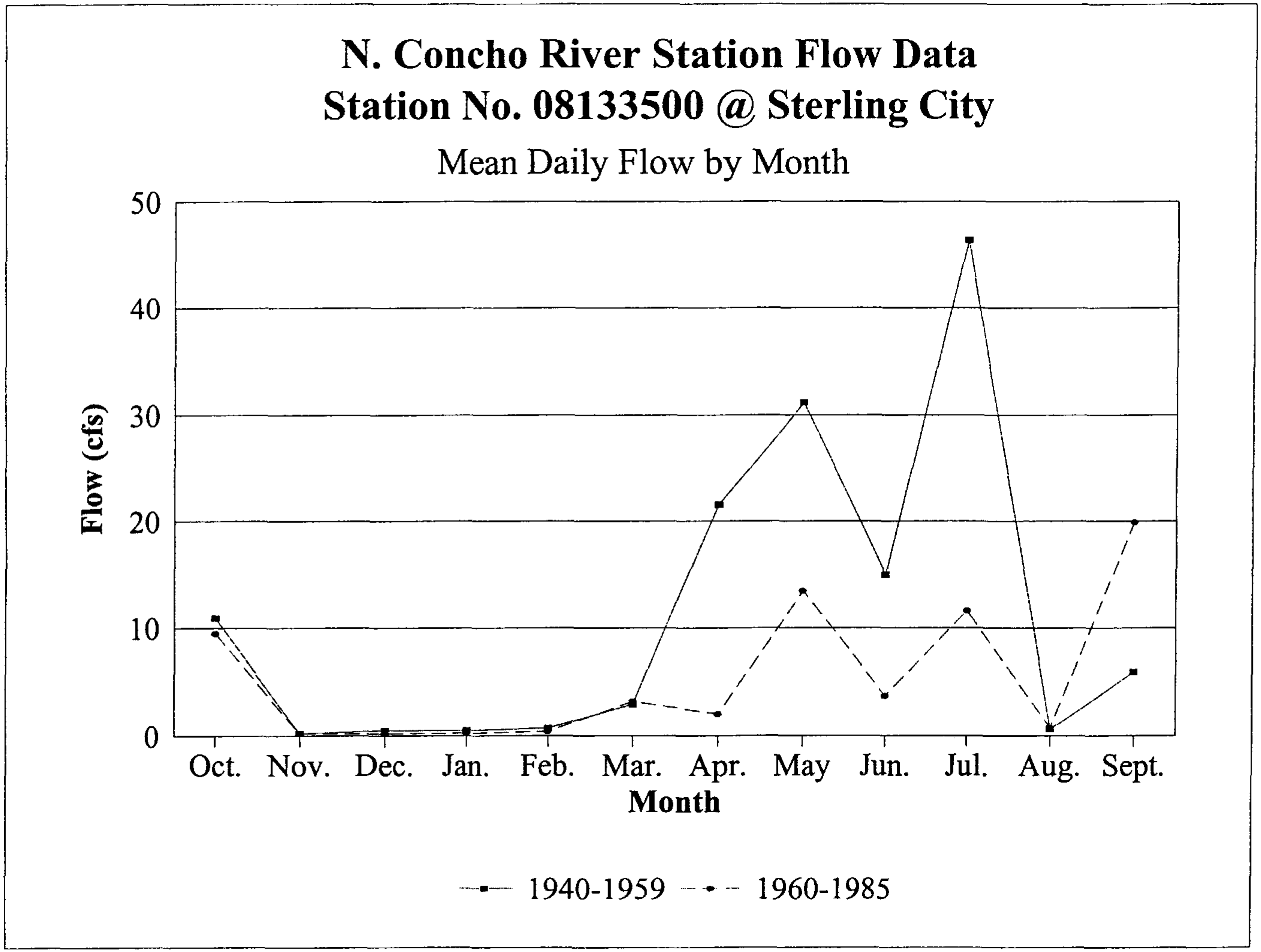
Outline indicates mean flow greater than 8 cfs; 35 months outlined.

North Concho River Flow Data (1960 - 1985)
Station No. 08133500 at Sterling City

Mean Daily Discharge (cfs)

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Annual Daily Mean
1960	170.00	1.61	1.32	1.46	1.33	1.25	0.99	0.03	0.00	20.50	0.00	0.00	16.54
1961	17.70	0.00	0.00	0.00	0.14	0.13	0.02	179.00	1.77	252.00	1.86	3.37	38.00
1962	0.29	0.89	1.17	1.23	1.01	1.06	1.16	0.29	0.00	0.00	0.03	0.56	0.64
1963	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.40	0.04	0.00	0.00	0.00	0.79
1964	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	6.23	102.00	9.15
1965	0.00	1.41	0.00	0.00	0.00	0.00	0.13	40.80	33.60	0.00	0.00	0.31	6.35
1966	22.20	0.10	0.00	0.00	0.00	3.90	37.20	0.42	0.00	0.00	0.00	0.02	5.32
1967	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	1.29	0.00	0.11
1968	0.00	0.00	0.00	0.00	0.00	0.00	0.00	59.40	0.14	0.00	0.00	0.00	4.96
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.90	0.00	0.00	0.00	4.49	2.12
1970	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.07
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	19.60	14.20	0.00	8.85	52.30	7.91
1972	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.44	0.00	1.83	5.19	0.79
1973	0.00	0.00	0.00	0.00	0.00	72.50	7.42	0.24	0.00	0.00	0.00	0.00	6.68
1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	0.37	0.00	0.03	115.00	9.66
1975	19.00	1.10	0.59	0.65	1.69	0.57	0.14	7.34	0.06	0.45	0.00	0.00	2.63
1976		0.00		0.07	0.08	0.08	0.63	0.24	0.01		0.22	31.40	3.64
1977	1.52	1.48	1.39	1.35	1.24	1.27	1.02	0.41	24.80	0.54	0.02	0.00	2.92
1978	0.00	0.00	0.04	0.32	0.75	0.52	0.40	2.13	3.44	0.00	0.00	0.00	0.63
1979	0.00	0.00	0.00	0.00	0.19	0.76	0.30	0.03	0.27	0.00	0.00	0.00	0.13
1980	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.21	0.00	0.00	202.00	17.01
1981	2.21	0.40	0.79	1.02	0.74	0.94	3.22	2.80	0.77	2.01	0.00	0.00	1.24
1982	0.00	0.08	0.21	1.08	3.28	0.65	0.30	3.30	10.50	0.47	0.00	0.00	1.66
1983	0.00	0.00	0.00	0.22	0.51	1.22	0.52	0.04	4.05		0.00	0.00	0.60
1984	3.66	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.32
1985	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.00	0.00	0.00	0.08
Monthly Mean	**9.463**	**0.272**	**0.220**	**0.285**	**0.421**	**3.263**	**2.056**	**13.423**	**3.757**	**11.565**	**0.783**	**19.903**	**5.38**

Outline indicates mean flow greater than 8 cfs; 23 months outlined.



N. Concho River Station Flow Data
Station No. 08133500 @ Sterling City
Mean Daily Flow by Month
Flow (cfs)
50
40
30
20
10
0
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sept.
Month
1940-1959
1960-1985

Figure 6

defined as a period of time, usually days, during which a typical storm flow hydrograph is manifested in the flow record. Storm flow hydrographs are described and examined in detail in the following portions of this report section. Approximately 363 rainfall runoff storm events have been identified from the flow records. Of these events, 256 occurred during the first period (1925-1959) while 107 occurred after (1960-1996). During the first period approximately 7.3 rainfall runoff storm events occurred on average each year while during the latter period only 2.9 events occurred on average each year. In addition, the yield on average of each event declined during the period. Prior to 1960, each event produced approximately 5,200 ac. ft. while after 1960 less than 3,000 ac. ft. was produced. Storm flow event frequency after 1960 was approximately 35% of the frequency before 1960 and the water yield per storm event was approximately 65% of the pre-1960 storms.

A storm flow hydrograph is the graphic representation of the hydraulic characteristics of storm water (rainfall runoff) within a drainage way. The hydrograph is composed of two elements: 1) Stream flow rates (usually measured in cubic feet per second) and; 2) Units of time. A storm flow hydrograph is typified by a curve beginning at "0" or base flow conditions with a rapidly increasing flow rate to the peak and then a decreasing flow rate to the return to "0" or a base condition. The increasing portion of the curve is generally much steeper than the declining portion of the curve. In order to evaluate storm flow conditions to determine any historical changes during the period of record, every storm event was identified as to date of occurrence and assigned a number (1-363). Following this, 10% of the total number of events (37) were generated as random numbers. These numbers now represented 37 individual storm events. A typical or composite storm flow hydrograph was prepared for these events falling within the period of 1925-1959 and composite hydrograph prepared for the period of 1960-1996. These hydrographs are shown on Figure 8.

Examination of Figure 8 reveals that a change in the stormwater flow characteristic has occurred during the period of record. After 1960, the storm water hydrographs tended to be steeper during the inclining portion of the curve and also steeper during the declining portion of the curve. This phenomena is likely due to an accelerated time of accumulation resulting from an increasing runoff coefficient value after 1960, or the effect represents the absence of stormwater in the upper portions of the watershed reaching the stream flow station

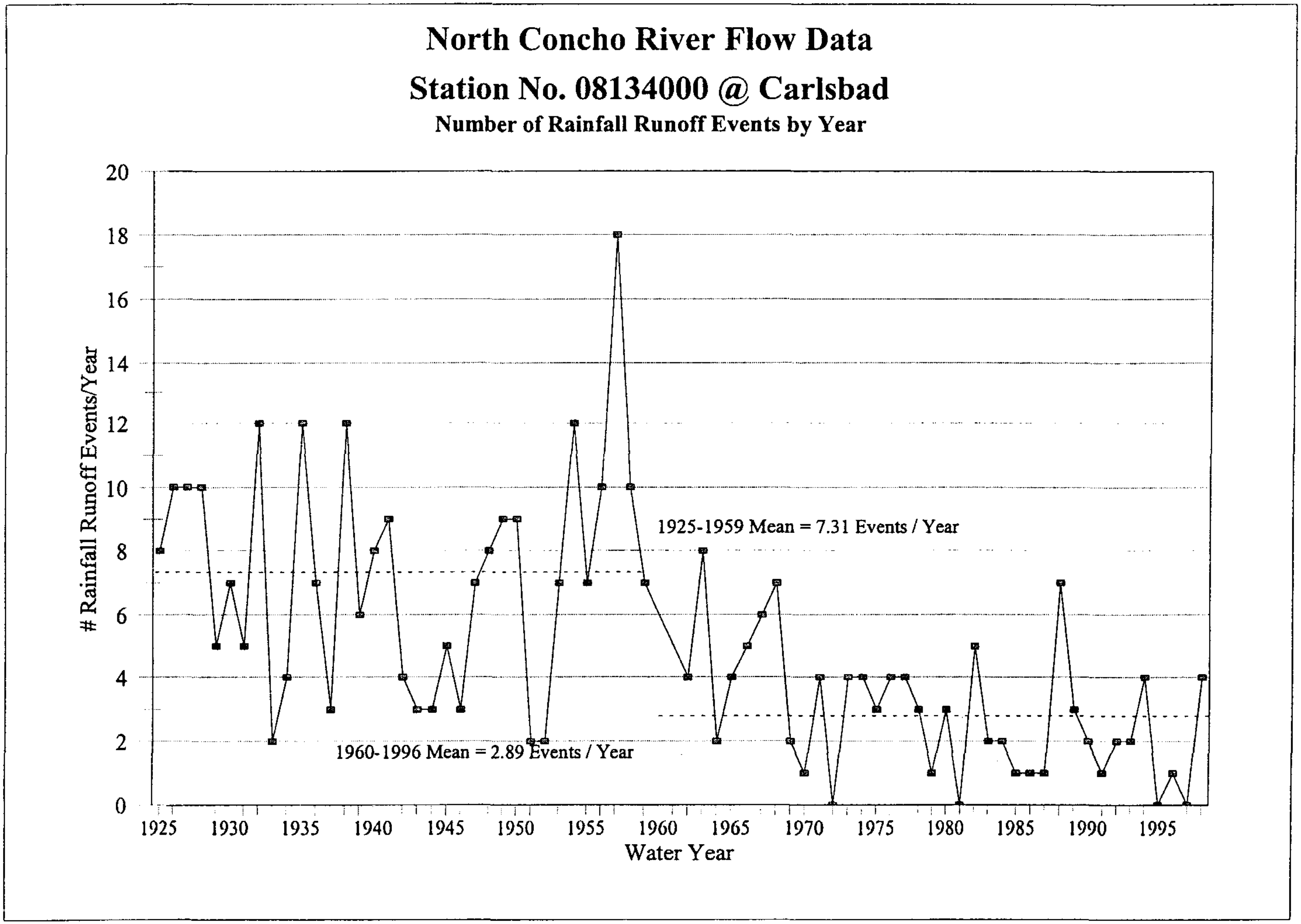

North Concho River Flow Data
Station No. 08134000 @ Carlsbad
Number of Rainfall Runoff Events by Year
Rainfall Runoff Events/Year
20
18
16
14
12
10
8
6
4
2
0
1925-1959 Mean = 7.31 Events / Year
1960-1996 Mean = 2.89 Events / Year
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
Water Year

FIGURE 7

North Concho River Flow Data
Station No. 08134000 @ Carlsbad

Water Year	# Rainfall Runoff Events / Year	Water Year	# Rainfall Runoff Events / Year
1925	8	1960	4
1926	10	1961	8
1927	10	1962	2
1928	10	1963	4
1929	5	1964	5
1930	7	1965	6
1931	5	1966	7
1932	12	1967	2
1933	2	1968	1
1934	4	1969	4
1935	12	1970	0
1936	7	1971	4
1937	3	1972	4
1938	12	1973	3
1939	6	1974	4
1940	8	1975	4
1941	9	1976	3
1942	4	1977	1
1943	3	1978	3
1944	3	1979	0
1945	5	1980	5
1946	3	1981	2
[illegible]	7	1982	2
1948	8	1983	1
1949	9	1984	1
1950	9	1985	1
1951	2	1986	7
1952	2	1987	3
1953	7	1988	2
1954	12	1989	1
1955	7	1990	2
1956	10	1991	2
1957	18	1992	4
1958	10	1993	0
1959	7	1994	1
		1995	0
		1996	4
Totals	**256**	**Totals**	**107**
Average	**7.31**	**Average**	**2.89**

Note: Rainfall runoff event is defined as an event in which stream flow displays typical storm flow hydrograph.

Table 8

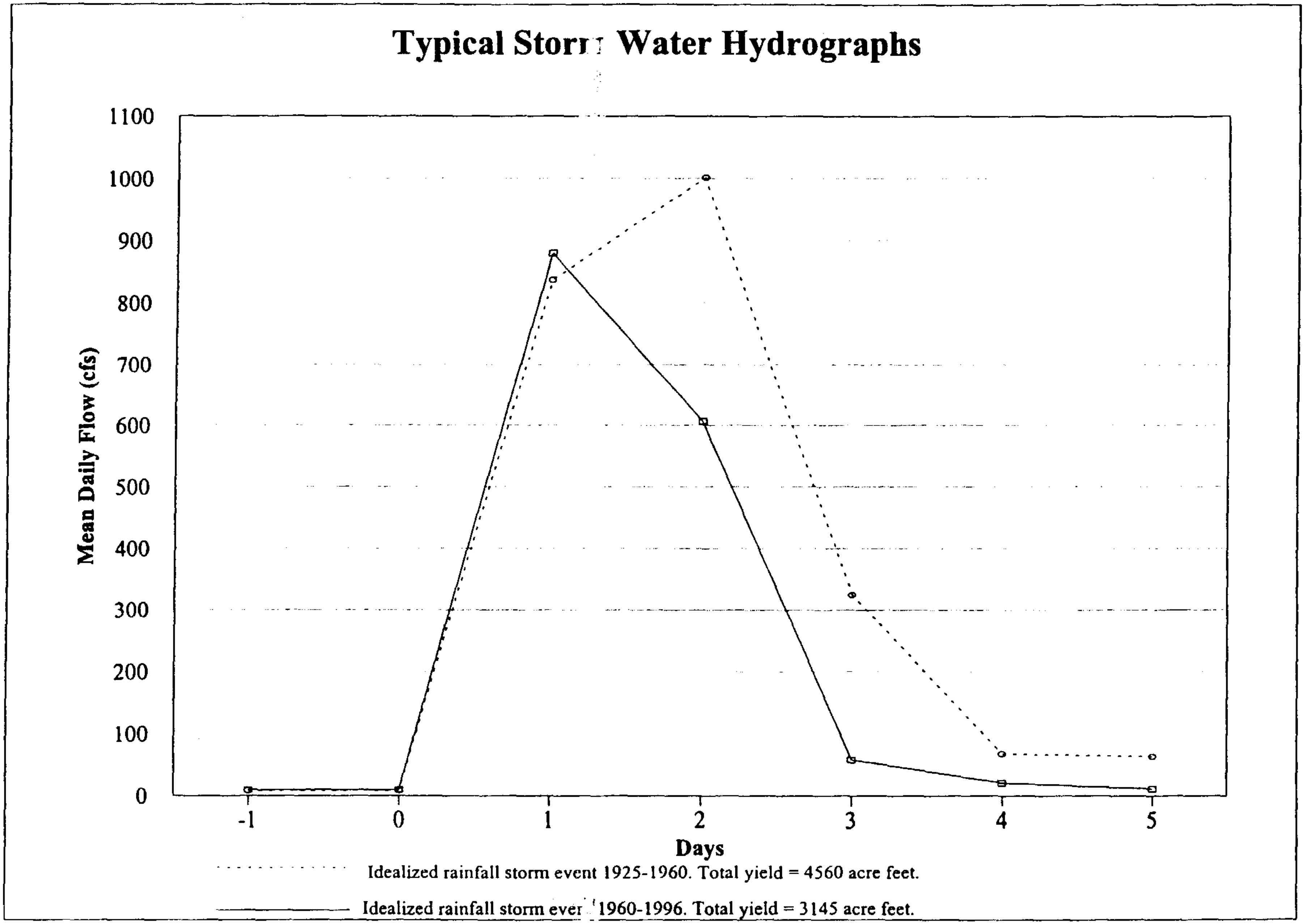
at Carlsbad. The time of travel of rainfall runoff entering the river at Sterling City and then passing the flow station at Carlsbad is approximately 24 hours.

Examination of "Figure 8" also reveals that the composite hydrographs for the period yield very close to the calculated storm water average yields. This observation tends to verify that the composite hydrographs prepared were statistically representative of each period storm events. The dates of each storm event and the 37 randomly generated numbers are included in the appendix to this report.

One interesting phenomenon regarding stormwater runoff was noted from the available record. This phenomena involves the total lack of runoff events during the month of July after 1961. Prior to this, July flood flows were common and occurred at least every four years. This phenomena is likely due to the change in perennial stream flows resulting in "dry" stream beds during summer months.

It would appear from the available records and personal recollections that there have been significant changes in the surface water hydrology of the North Concho River watershed during this century and particularly since 1960. The question now remains regarding corresponding changes in the groundwater environment of the area during the period. These changes would best be demonstrated by increases or decreases in the static (un-pumped) water levels within area water wells. A Texas Water Development Board (TWDB) publication entitled "Water Well and Groundwater Chemical Analysis Data, Sterling County, Texas", Report No. 148, appears to be one of the best sources of documented change.

The TWDB document contains water level records for hundreds of water wells in Sterling County. Eighty-one of the water wells had water levels measured in the early 1940's and the same wells monitored in the 1960's. This comparative data is shown on "Table 9". Of the water wells measured at both periods, 78% showed a decline in water levels from the 1940's readings. The average loss per water well that declined was 26.7 ft. Of the wells remaining static or increasing in water level during the period, the average gain was 4.2 ft. Except for municipal uses, there is no major irrigation or other significant groundwater users in Sterling County. For this reason, it would be anticipated that only minor variations in static water well levels as primarily related to climatic conditions would be the normal condition. It appears that the observed water well level decline from the 1940's



Typical Storm Water Hydrographs
1100
1000
900
800
700
600
500
400
300
200
100
0
Mean Daily Flow (cfs)
-1
0
1
2
3
4
5
Days
Idealized rainfall storm event 1925-1960. Total yield = 4560 acre feet.
Idealized rainfall storm event 1960-1996. Total yield = 3145 acre feet.

FIGURE 8

Sterling County Groundwater Elevations Historical Changes					
Well Number	**Measurement Date 1**	**Date 1 Elevations**	**Measurement Date 2**	**Date 2 Elevation**	**Elevation Change**
+28-62-606	04/25/41	2,535.00	09/01/66	2,494.00	-41.00
+28-62-908	04/25/41	2,560.53	09/13/66	2,511.30	-49.23
+28-62-909	03/18/37	2,523.30	09/13/66	2,519.10	-4.20
+28-63-505	05/14/41	2,476.95	04/08/69	2,476.10	-0.85
+28-63-506	05/14/41	2,477.40	07/27/61	2,474.99	-2.41
+28-63-603	05/13/41	2,359.36	04/04/69	2,366.00	6.64
+28-63-806	05/13/41	2,464.30	04/08/69	2,464.20	-0.10
+28-63-901	05/14/41	2,441.60	04/07/69	2,440.70	-0.90
+28-63-903	05/13/41	2,400.50	04/07/69	2,403.00	2.50
+43-1-305	06/13/41	2,421.00	04/24/69	2,414.90	-6.10
+43-1-604	06/12/41	2,406.18	04/24/69	2,374.50	-31.68
+43-1-701	05/22/41	2,402.05	05/25/69	2,379.50	-22.55
+43-1-801	05/23/41	2,356.00	03/25/69	2,357.50	1.50
+43-1-802	05/23/41	2,523.40	03/26/69	2,424.30	-99.10
+43-1-904	05/23/41	2,442.30	03/26/69	2,416.10	-26.20
+43-1-907	04/01/41	2,375.63	04/23/69	2,375.70	0.07
+43-2-101	05/29/41	2,152.75	04/22/69	2,145.80	-6.95
+43-2-402	06/11/41	2,277.50	05/23/61	2,271.70	-5.80
+43-2-713	06/11/41	2,407.75	04/22/69	2,342.60	-65.15
+43-2-717	06/11/41	2,410.80	04/23/69	2,398.00	-12.80
+43-9-106	05/22/41	2,265.00	04/24/69	2,251.20	-13.80
+43-9-107	05/22/41	2,360.00	03/24/69	2,364.70	4.70
+43-9-109	05/23/41	2,345.50	03/25/69	2,343.90	-1.60
+43-9-110	05/23/41	2,348.90	03/25/69	2,348.00	-0.90
+43-9-202	05/23/41	2,332.60	03/26/69	2,329.10	-3.50
+43-9-503	06/18/41	2,221.60	02/12/68	2,218.40	-3.20
+43-9-504	05/23/41	2,313.90	03/26/69	2,312.20	-1.70
+43-10-405	04/01/41	2,213.00	03/18/69	2,206.22	-6.78
+43-10-709	05/31/41	2,140.54	03/20/69	2,139.50	-1.04
+43-17-401	04/02/41	2,318.00	02/07/68	2,283.60	-34.40
+43-17-502	07/14/41	2,336.00	04/30/69	2,270.60	-65.40
+43-17-504	07/14/41	2,234.00	05/02/69	2,216.30	-17.70
+43-17-702	07/14/41	2,290.00	04/30/69	2,272.80	-17.20
+43-17-903	07/14/41	2,214.00	05/02/69	2,190.60	-23.40
+43-25-402	07/08/41	2,410.70	01/25/68	2,397.90	-12.80
+44-6-316	06/22/45	2,437.70	09/14/66	2,443.90	6.20
+44-6-904	04/30/41	2,480.00	10/10/66	2,486.00	6.00
+44-7-104	04/25/41	2,418.00	09/13/66	2,426.00	8.00
+44-7-201	05/14/41	2,435.13	07/27/61	2,427.75	-7.38
+44-7-209	05/14/41	2,470.94	07/27/61	2,447.90	-23.04
+44-7-401	04/30/41	2,435.20	07/29/61	2,445.38	10.18
+44-7-403	04/30/41	2,430.00	09/20/66	2,432.60	2.60
+44-7-404	04/30/41	2,406.82	09/14/66	2,409.90	3.08
+44-7-504	04/30/41	2,441.15	10/10/66	2,434.50	-6.65
+44-7-505	06/30/41	2,424.90	07/28/61	2,418.20	-6.70
+44-7-701	04/30/41	2,487.00	03/14/68	2,481.70	-5.30
+44-8-103	06/21/41	2,428.60	05/28/69	2,433.90	5.30
+44-8-202	06/22/41	2,439.85	05/26/69	2,423.50	-16.35
+44-8-301	06/27/41	2,436.00	05/15/61	2,431.40	-4.60
+44-8-305	06/27/41	2,533.50	05/23/69	2,539.70	6.20
+44-8-306	06/27/41	2,384.95	05/26/69	2,393.24	8.29
+44-8-503	05/16/41	2,385.20	03/21/69	2,384.00	-1.20
+44-8-504	05/16/41	2,388.20	03/21/69	2,390.30	2.10
+44-8-505	05/16/41	2,411.90	07/27/61	2,410.70	-1.20
+44-8-506	05/16/41	2,363.55	03/21/69	2,361.30	-2.25
+44-8-601	05/16/41	2,469.54	03/21/69	2,464.20	-5.34

Table 9

Number	Date 1	Elevations	Date 2	Elevation	Elevation Change
+44-8-602	05/16/41	2,435.25	03/21/69	2,411.20	-24.05
+44-8-706	06/20/41	2,353.85	07/17/61	2,350.70	-3.15
+44-8-801	06/10/41	2,327.30	07/20/61	2,325.84	-1.46
+44-8-901	06/20/41	2,457.80	03/24/69	2,447.90	-9.90
+44-14-601	04/17/41	2,456.46	07/06/61	2,427.40	-29.06
+44-15-201	12/08/54	2,373.72	12/01/64	2,366.60	-7.12
+44-15-202	04/14/41	2,443.00	02/20/68	2,438.90	-4.10
+44-15-204	04/14/41	2,428.00	02/20/68	2,430.70	2.70
+44-15-702	04/17/41	2,445.00	01/16/68	2,446.00	1.00
+44-15-901	04/18/41	2,448.08	03/13/68	2,401.80	-46.28
+44-16-201	12/01/53	2,296.28	12/01/69	2,295.69	-0.59
+44-16-202	12/01/53	2,293.82	12/01/69	2,292.20	-1.62
+44-16-203	12/01/53	2,293.96	12/06/69	2,293.14	-0.82
+44-16-310	05/22/41	2,247.75	04/29/69	2,242.90	-4.85
+44-16-604	04/10/41	2,279.78	04/29/69	2,277.80	-1.98
+44-16-606	04/02/41	2,266.92	04/29/69	2,266.50	-0.42
+44-16-901	05/20/41	2,320.30	07/07/61	2,329.39	9.09
+44-23-102	04/17/41	2,469.78	01/16/68	2,467.10	-2.68
+44-23-501	04/03/41	2,438.26	08/02/61	2,424.15	-14.11
+44-23-802	04/04/41	2,488.75	04/08/68	2,453.10	-35.65
+44-24-205	04/03/41	2,353.84	05/26/69	2,347.30	-6.54
+44-24-206	04/03/41	2,367.00	05/26/69	2,352.10	-14.90
+44-24-301	04/03/41	2,314.50	05/29/68	2,304.60	-9.90
+44-24-805	04/04/41	2,381.00	05/21/69	2,364.50	-16.50
+44-32-201	05/26/41	2,424.00	02/08/68	2,419.50	-4.50
				Average	-10.03

Total number of wells: 81
Number of wells declining: 63, Average loss per [illegible]
Percentage of wells declining: 78%
Number of wells unchanged or increasing: 18, Average gain per well = 4.2 feet.
Percentage of wells unchanged or increasing: 22%

Table 9

to the 1960's is indicative of a major long term change in the groundwater environment.

3.3 Geological Considerations

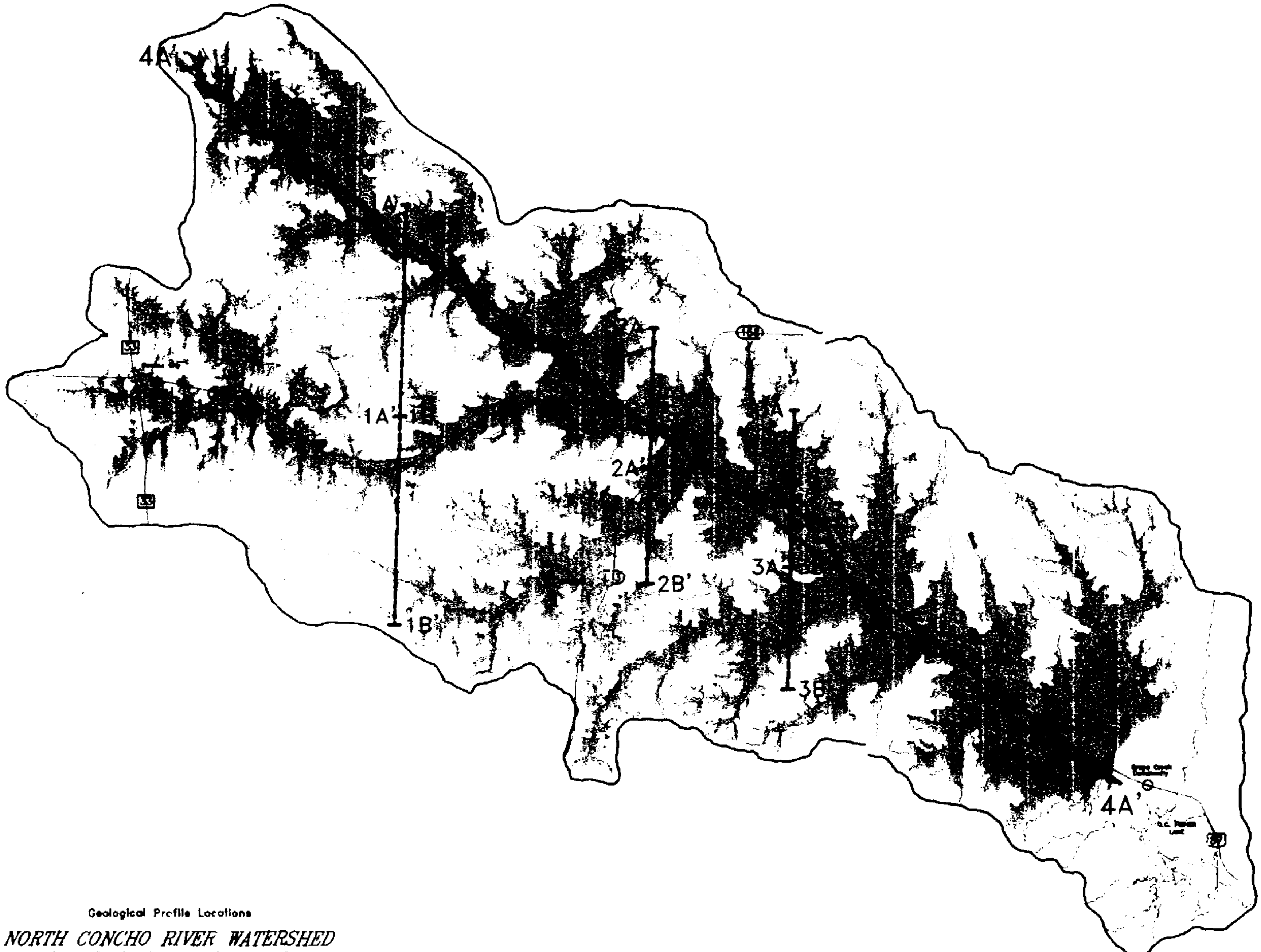
A total of four (4) geological profiles were prepared to illustrate the geology of the North Concho River Basin. Three (3) of these are tangential to the North Concho River and are oriented essentially north to south. These profiles are labeled 1A-1A' & 1B-1B', 2A-2A' & 2B-2B', and 3A-3A' & 3B-3B'. The other profile (4A-4A') is aligned in a northwest-southeast orientation, along the path of the North Concho River. It not only illustrates the subsurface geology but also the topographic relief and geology of the outcrops located within the flood plain valley. These profiles and a map illustrating their locations are included herein as Plates 3 - 7.

The San Angelo sheet and the Big Spring sheet of the Bureau of Economic Geology's Geologic Atlas of Texas, Texas Water Well Driller's logs, and USGS Quadrangle Maps (topographic maps) were used in the development of these geological profiles. Well logs were chosen based on the location of the well relative to the line of profile and by the usefulness of the lithologic descriptions. In some cases, because wells were not located directly along the lines of profile, they were "pulled into" their respective lines from a significant distance. However, care was exercised to position the "pulled in" wells at locations along the line of profile that were analogous in elevation and geomorphological expression.

Because of the large area involved and the relatively small number of well drillers logs used, these profiles have to be considered as generalized representations. However, enough data was located and analyzed to provide useful geological information.

The North Concho River heads out in southeastern Howard County at the northern limit of the Edwards Plateau. It is situated at the margins of the Edwards Plateau and the Llano Estacado or High Plains. The small tributaries that come together to form the North Concho River head out in Cretaceous limestones of the Edwards Group. The river traverses a large alluvial valley that it has cut into the Cretaceous limestones that mantle the Edwards Plateau. Its course includes portions of Howard, Glasscock, Sterling, Coke, and Tom Green Counties. Southeast of O.C. Fisher Reservoir in San Angelo, it joins with the South Concho River and the Middle Concho River to form the Concho River. Throughout the North Concho River's course, the river and tributary valleys get progressively wider with distance from their points of origin.

At the upper reaches of the North Concho River, the Cretaceous limestones are underlain by the Dockum Group of Triassic Age. The Dockum Group noncomformably underlies Cretaceous



Geological Profile Locations

NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

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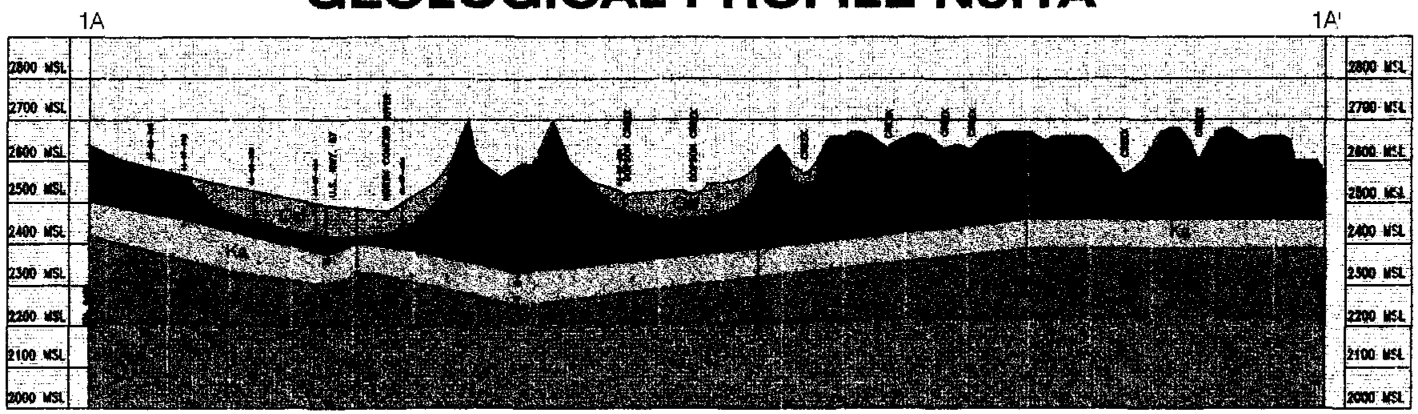
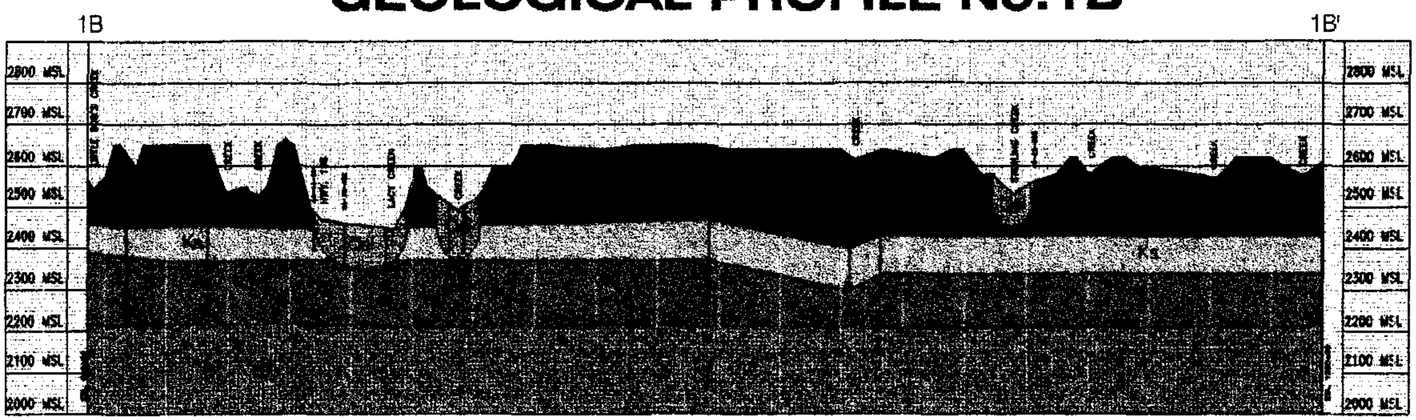
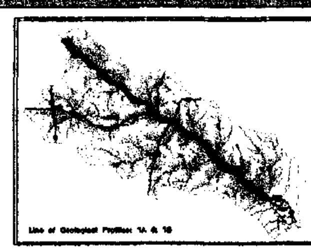
PLATE 3

GEOLOGICAL PROFILE No.1A



GEOLOGICAL PROFILE No.1B





QUATERNARY — Quaternary Alluvium

CRETACEOUS — Edwards and Associated Limestone; Antlers Sand

TRIASSIC — Dockum Group

PERMIAN — Permian (Undifferentiated)

Vertical Scale: 1"= 100'
Horizontal Scale: 1"= 2,000'

NORTH CONCHO RIVER WATERSHED

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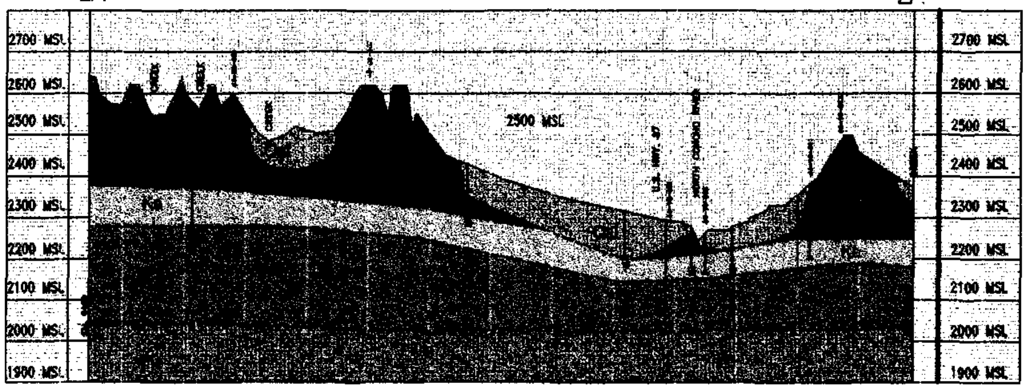
PLATE 4

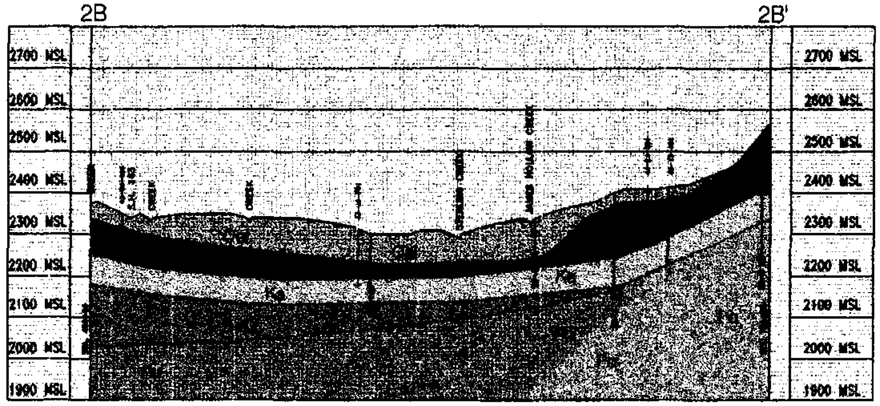
GEOLOGICAL PROFILE No.2A

2A 2A'



GEOLOGICAL PROFILE No.2B

2B 2B'



Vertical Scale: 1"= 100'
Horizontal Scale: 1"= 2,000'

NORTH CONCHO RIVER WATERSHED

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QUATERNARY — Qal — Quaternary Alluvium

CRETACEOUS — Edwards and Associated Limestone

CRETACEOUS — Ka — Antlers Sand

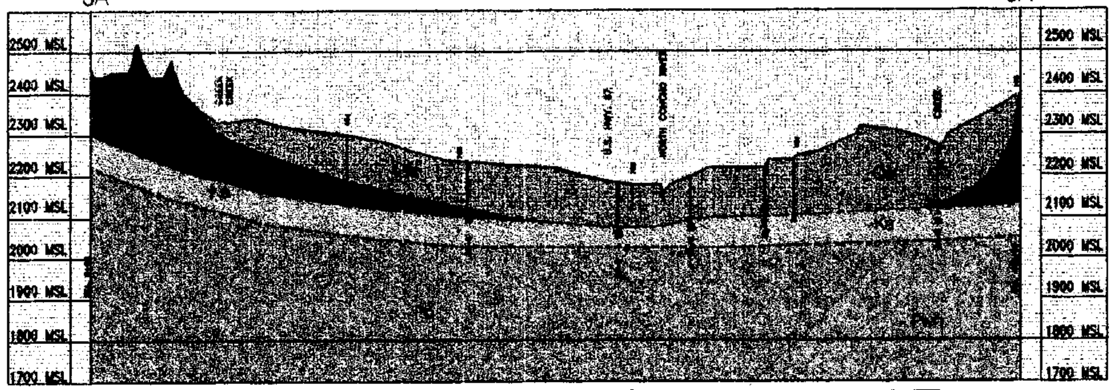
TRIASSIC — Dockum Group

PERMIAN — Permian (Undifferentiated)

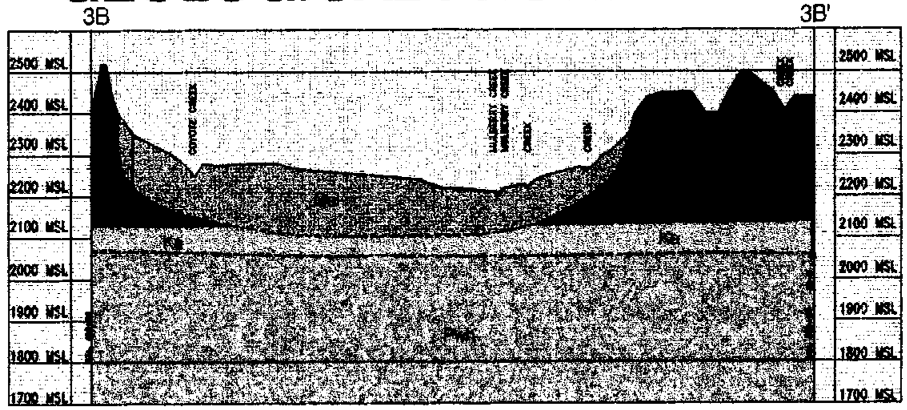
PERMIAN — Quartermaster Formation

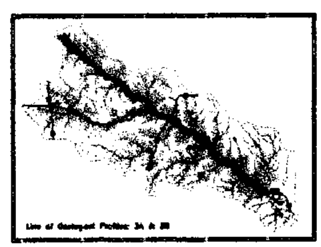
PLATE 5

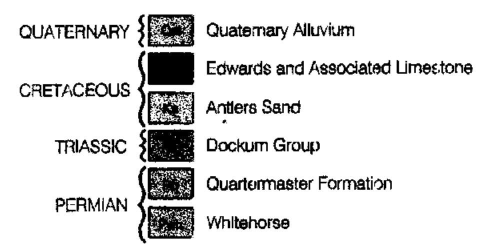
GEOLOGICAL PROFILE No.3A



GEOLOGICAL PROFILE No.3B







Vertical Scale: 1"= 100'
Horizontal Scale: 1"= 2,000'

NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

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PLATE 6

rocks and Permian deposits unconformably underlie the Dockum Group. The Dockum Group is absent in the subsurface east of approximately Sterling City. East of this point, Cretaceous rocks are unconformably underlain by Permian aged rocks. The Permian deposits dip to the west into the Midland Basin. At the eastern limit of the river's course, Permian rocks are exposed in the river bed. Alluvial deposits are present throughout the entire North Concho River Valley.

Abbreviated lithological descriptions of the geologic formations that significantly affect hydrogeological conditions in the North Concho River watershed are presented below in descending order:

- **QUATERNARY**

Alluvium	Floodplain and terrace deposits comprised predominantly of sand, silt, caliche, gravel, and conglomerate. Well-cemented to unconsolidated.

- **CRETACEOUS**

Edwards	Cherty, dolomitic, and argillaceous porous limestones that are irregularly to massively bedded with thin interbedded shales. Coloration is white, yellow, gray, and brownish.
Antlers	Sand, sandstone, siltstone, conglomerate. Locally argillaceous, poorly bedded and moderately indurated to friable. Coloration is white, brown, light gray, grayish yellow, and pale purple. Chert in basal conglomerate is black.

- **TRIASSIC**

Dockum Group	These rocks are composed of sandstones, clays, shales, and conglomerates. The predominant coloration of this group is reddish brown. Sands are fine to coarse grained and are thin bedded to massive.

- **PERMIAN**

Quartermaster	Interbedded shale, siltstone, sandstone, gypsum and dolomite. Coloration is predominantly various shades of red. Sandstones are mostly fine grained and indistinctly bedded to massive.

Whitehorse	Interbedded sandstone, sand, shale, conglomerate, gypsum, and dolomite. The coloration of the clastic deposits consists of various shades of red and brown. The gypsum and dolomite beds are various shades of white, gray, and pink.
Blaine	Interbedded shale, sandstone, gypsum and dolomite. Shale is calcareous in part. Sands are mostly fine grained, thin bedded to massive. The coloration of clastic deposits is red, yellow, brown, orange. Dolomite is calcitic and argillaceous and thinly bedded. Its coloration is various shades of gray with purple and pink streaks.
San Angelo	Sandstone, shale, and conglomerate. Sand is fine grained, thin bedded to massive, friable. Coloration is red, gray, yellow, and brown. Shale is indistinctly bedded, sandy, and red to bluish green in color. A basal quartz conglomerate is present.

In a permeable media, ground water flows in the direction of the hydraulic gradient. The same holds true in a geologic setting, i.e. the groundwater flow is from areas of recharge at higher elevations to areas of discharge at lower elevations. Also contributing to the direction of groundwater flow is the structural attitude of the aquifer. On a regional scale the groundwater flow direction of the Edwards-Trinity Plateau aquifer is to the south and southeast, which follows the south to southeast dipping base of the Cretaceous rocks. The groundwater flow direction of the North Concho River watershed, which is located at the northern edge of the Edwards-Trinity Plateau aquifer, also flows primarily to the southeast.

Based on the static groundwater elevations reported in Texas Water Development Board monitor wells and the private water well records reviewed, it is apparent that the Quaternary Alluvium, the Edwards Limestones, and the Antlers Sandstone are hydraulically connected. On a local scale, perched groundwater at shallow depths was observed to exist near surface waterways. However, on a basin wide scale, little or no discernable difference, other than expected regional dip, was noted in the measured hydrostatic groundwater levels from widely spaced wells. This observation held true regardless of the geological formation in which the wells were completed. Because these geological formations are hydraulically connected, they essentially function as a single aquifer and on a basin wide scale, can be viewed as such.

However, because of the complexity of the flow paths in geological media, the aquifer should not be thought of as a conduit through which groundwater readily flows.

From a hydrogeological perspective, groundwater movement in the North Concho River watershed is comprised of two components. One is the previously mentioned regional component in which groundwater moves to the southeast, in the same direction as the dip direction of the base of the Antlers Sandstone. The other component is comprised of groundwater movement from the higher limestone deposits (the recharge areas located on either side of the river) toward the river (the discharge area). This groundwater is stored in the porous alluvial deposits situated along its course. Alluvial deposits are typically comprised of flood plain deposits characterized by channels and clay lenses, which can locally reduce permeability. Because of this attribute, the alluvial deposits likely provide a more effective storage media for the groundwater than the Edwards limestones and Antlers Sandstone.

During periods of high rates of recharge the hydrostatic water elevation rises, groundwater storage increases, and natural discharge increases. Where erosion has incised the Cretaceous rocks to an elevation that intersects the water table, springs issue forth. The major rivers and tributaries located within the boundaries of the Edwards-Trinity Plateau aquifer, are headed by such springs. As evidenced by historical accounts, the number and prevalence of spring fed creeks in the North Concho River watershed, through time, have decreased. This condition is presumed to be due to excessive groundwater discharge through evapotranspiration.

The previously referenced geological profiles illustrate the increased width and thickness of the alluvial deposits with increased distance from the head of the river valley. This is the typical geometric expression of alluvium deposited in an erosional river valley. This means that aquifer storage capacity increases as distance from the head of the river increases. However, it also means that the surface area of the aquifer increases, the depth to groundwater decreases, and thus, natural discharge through evapotranspiration increases.

The largest aquifer storage capacity and the largest evapotranspiration withdrawals occur at the same location, i.e. at the "mouth" of the river and/or tributaries. Because of this, it is considered likely that the greatest and fastest positive influence from brush control can be realized by beginning brush control efforts at the lower portions of the river and/or tributaries and moving toward the head of the watercourse. Initiating the program at these locations should provide the quickest and greatest relief from evapotranspiration withdrawals at the locations where, geologically, the most groundwater storage capacity is available.

3.4 *Existing Surface Water Hydrology*

The existing surface water environment now typically found within the North Concho River watershed has been generally described in Section 3.22 of this report related to Hydrological history. During the conduct of this study, no tributary to the North Concho River was discovered that is capable of maintaining a long term aquatic habitat. As a general rule, the extreme upper portions of tributaries will experience temporary spring flow and seeps during wet weather and during winter months when evapotranspiration is low. It is extremely rare, even during wet years, that perennial tributary flow would reach the river.

Portions of the North Concho River can be expected to experience measurable stream flow during winter months and often extending into late spring. During February, 1998 the study staff in cooperation with the United States Geological Survey Water Resource Staff in San Angelo conducted a stream flow survey of the river. The results of this study appear to be very typical of the existing condition and are shown as follows:

LOCATION		FLOW MEASURED	
LAT/ LONG	DESCRIPTION	CFS	GPM
31°54'0"/101°7'19.73"	"U"Ranch, Initial Spring Area	0.04	18
31°53'56"/101°6'43.69"	"U"Ranch, Below Springs	0.41	184
31°51'22.58"/101°3'10.22"	S-4.158 Bridge above S.C.	0.39	175
31°50'18.46/101°29'3.9"	Hunt Rd. above S.C.	0.00(dry)	0
31°49'48.03/100°59'35.96"	USGS Sta @ S.C.	0.00(dry)	0
31°48'10.67/100°56'36.63"	Sherwood Lane Bridge	0.49	220
31°45'15.91"/100°51'27.58"	Rawlings Ranch (Sterling Co.)	0.07	31.4
31°40'34.84"/100°46'52.51"	Rawlings Ranch (Tom Green)	2.36	1059
31°39'38.91"/100°44'28.54"	F.M. 2034 (Water Valley Park)	4.21	1890
30°37'15.74"/100°40'43.69"	Post Oak Rd	4.31	1934
31°35'33.94"/100°38'14.01"	USGS Station @ Carlsbad	2.64	1185
30°34'47.26"/100°36'32.51"	Jones crossing(E.Carlsbad loop)	2.82	1266
31°32'34.96"/100°32'20.29"	F.M. 2288	2.15	965

As can be seen from the data cited on the previous page (which is listed sequentially from upstream to downstream), the river displays both gaining (increasing flow downstream) stream characteristics and loosing (decreasing flow downstream) stream characteristics. This condition is apparently "normal" within recent years, particularly since some brush control activities have occurred along the river, primarily in Sterling County. The historic source springs located on the "U" Ranch northwest of Sterling City began to flow in recent years following brush control work within a narrow band adjacent to the river.

By June, 1998 stream flow at the above cited locations had generally ceased, which is the "normal" summer condition. Also, long stretches of the stream bed was dry, which is also the "normal" summer condition. The ability of the stream to display stream flow is dependent upon the static water level or location of the saturated zone within the Quaternary Alluvium deposits which are adjacent to and underlie the stream bed. This factor also determines which stream condition the river will display a "gaining" situation or a "loosing" condition.

The existing stormwater flow characteristics are also generally shown in Section 3.22 of this report. The existing frequency, duration and total water yields of runoff events are greatly reduced from historic and previous periods. The "normal" condition since 1960 produces less than three rainfall runoff events per year and less than 3,000 acre feet of water per event. Also, the storm flow rate at the Carlsbad USGS station will peak within 24 hours of the onset of the event with the highest mean daily flow rate at less than 900 CFS.

Due to the existing surface water hydrology, water quality is impacted both above and below O.C. Fisher Reservoir. The ultimate impact on an aquatic environment is a dry stream bed. This phenomena is a reality during portions of the year for significant segments of the stream and for most of the tributaries during most of the year. In addition, low or no stream flow results in the absence of the natural process involved in the type of aquatic environment responsible for re-aeration and consumption of nutrients. As a result, eutrophic characteristics are often displayed within the isolated pools during summer months. The changes in the frequency, duration and intensity of scouring flood flows are also impacting water quality.

Below O.C. Fisher Reservoir through San Angelo, the North Concho River has become one of the state's most heavily impacted stream segments from non-point source urban runoff water pollution. This is due primarily to the lack of downstream flows from the reservoir. These releases are not generally possible due to current and historic lake levels.

▸ 3.5 *Existing Groundwater Hydrogeology*

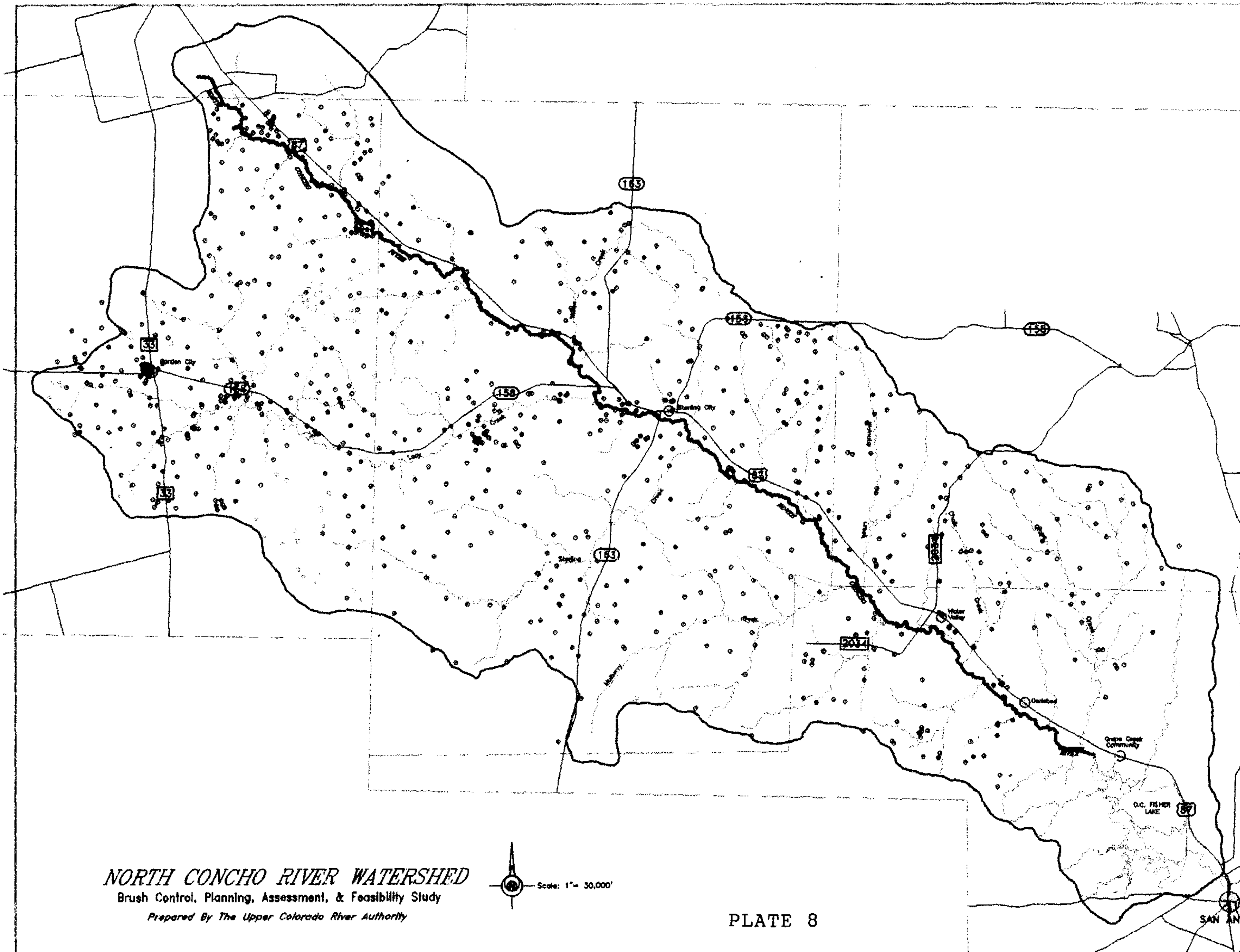
As stated previously in this report, the principal water bearing formations within the watershed are the Quaternary Alluvium deposits, the Antlers Sand and to a lesser degree, the Edwards and associated limestones. Plotting of water level data converted to mean sea level (MSL) confirms the existence of regional groundwater movement trends.(See "Plate 8" for water well locations within the watershed). Hydraulic gradients throughout the watershed indicate groundwater movement down slope and at right angles to surface drainage features. Also as stated previously, there is an intimate relation in existence between the groundwater environment and the surface water environment. At the present time, wet weather and winter months when evapotranspiration is low often produce a groundwater level that intercepts the surface drainage and produces a dewatering of the aquifer, or seeps and springs. This phenomena is most often observed in the extreme upper portions of the tributaries and is most often temporary. As the surface flows of these tributaries move down slope they encounter dry alluvial deposits and are lost into these deposits.

There are stream bed elevations that encounter groundwater during portions of the year primarily in the lower portions of the watershed that are dependent upon climate conditions that will produce localized stream flow.

The North Concho River watershed, including the tributaries, contains approximately 394,000 acres with the Quaternary alluvial deposits exposed at the land surface (see Plate 9). The thickness of the Quaternary deposits range from a few feet at the higher elevation to 50-60 feet in the lower portions. A portion of these deposits and the underlying limestone or antlers generally comprise the aquifer. The most prolific water wells in the watershed will be producing from the Quaternary deposits as these deposits are also in the most intimate contact with the river and tributaries. Assuming average existing and historical depths of the saturated zone and average formations porosity, it is estimated that within the boundaries of the quaternary deposits, the "natural" or "native" condition groundwater volume was near 6 million acre feet of water. The existing groundwater volume is likely near 4 million acre feet of water which is the normal volume with the existing brush cover over the Quarternary deposits.

▸ 3.6 *Description of the Watershed Hydrologic System*

The hydrologic system described in this report section is reflective of the "native" conditions encountered by the first settlers to the region. This condition is typified by a groundwater potentiometric surface that generally interacts positively with surface water drainage. The river proper (from head springs) and most tributaries display "gaining" stream characteristics or

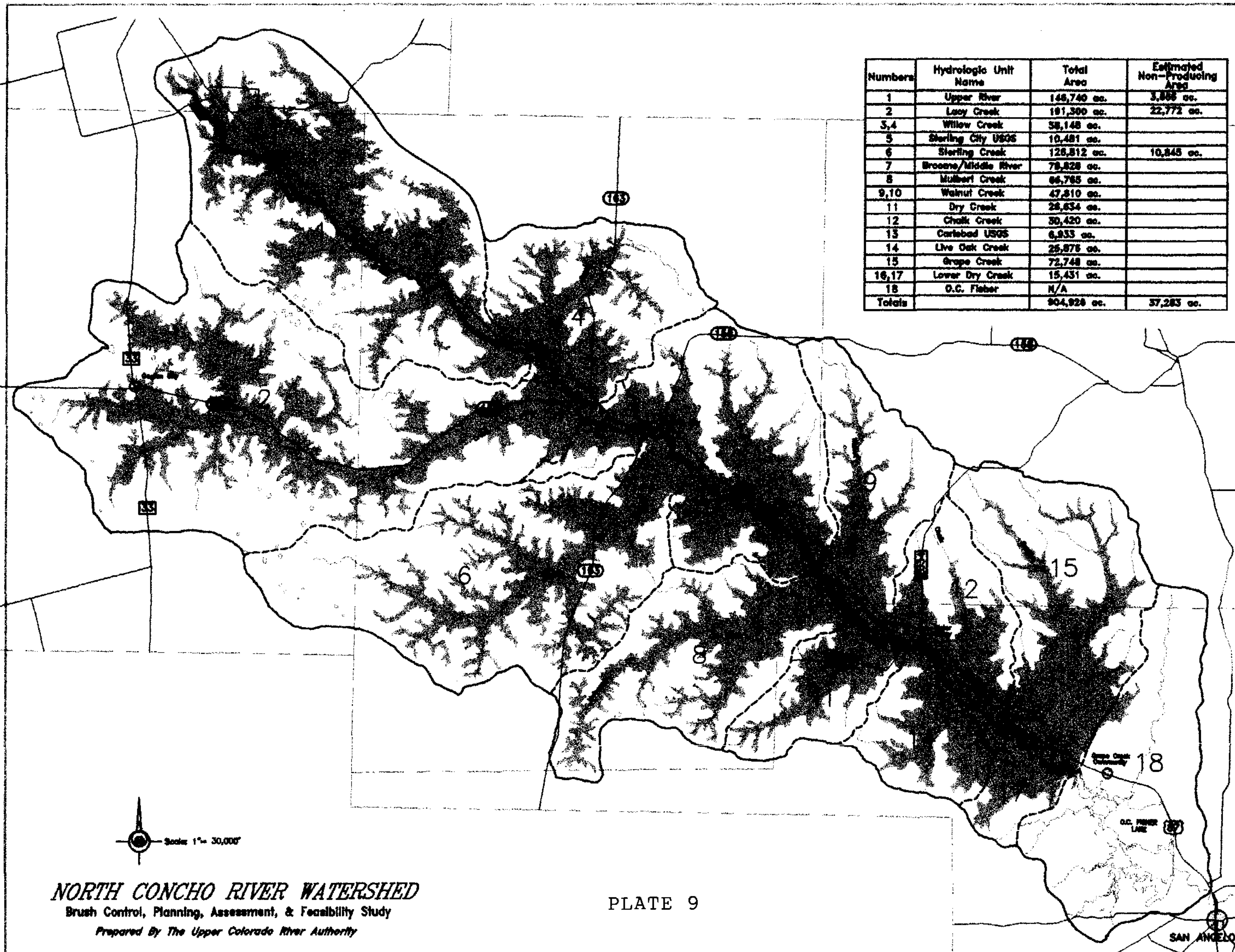


NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

Prepared By The Upper Colorado River Authority

PLATE 8



Numbers	Hydrologic Unit Name	Total Area	Estimated Non-Producing Area
1	Upper River	146,740 ac.	3,666 ac.
2	Lacy Creek	191,300 ac.	22,772 ac.
3,4	Willow Creek	58,148 ac.	
5	Sterling City USGS	10,481 ac.	
6	Sterling Creek	126,812 ac.	10,845 ac.
7	Broome/Middle River	79,828 ac.	
8	Mulberry Creek	66,765 ac.	
9,10	Walnut Creek	47,810 ac.	
11	Dry Creek	28,634 ac.	
12	Chalk Creek	30,420 ac.	
13	Carlsbad USGS	6,933 ac.	
14	Live Oak Creek	25,876 ac.	
15	Grape Creek	72,748 ac.	
16,17	Lower Dry Creek	15,431 ac.	
18	O.C. Fisher	N/A	
Totals		904,928 ac.	37,283 ac.

NORTH CONCHO RIVER WATERSHED

Brush Control, Planning, Assessment, & Feasibility Study

Prepared By The Upper Colorado River Authority

PLATE 9

stream flow generally increasing as you proceed downstream. Source springs, due to the existing hydraulic gradient and aquifer storage capacity, may diminish during summer months and during dry periods, but are generally perennial. For this reason, any rainfall that produces runoff entering the stream or perennial tributaries anywhere within the watershed will result in the delivery of that runoff to downstream receptors. One could expect the USGS flow monitoring station at Carlsbad to experience a rainfall runoff event 7.31 times per year on average. This event would result in approximately 4560 acre feet of water flowing past the station over a 5 day period. The peak flow period for the event would most likely occur during the second day of the event. Flood flows would be expected during any month of the year (even summer months) but is least likely in December and most likely in May of each year.

The perennial or base flow at the Carlsbad USGS flow station can be expected to be greater than 2.0 CFS 60.5% of the time and an annual mean flow near 48 CFS. During approximately 20 days per year we can expect stream flows in excess of 30CFS.

Utilizing the 35 year average annual rainfall (1960-1996) amount experienced in the lower watershed (20.31 in./yr.) to calculate the total available water within the watershed, we find that an average of over 1.5 million acre feet of water is available per year. Existing known water users have been estimated and are shown on Tables 10 through 14. Use categories include domestic water consumption, surface water evaporation losses, livestock and wildlife users, surface runoff and irrigation uses. All of this data is summarized on "Table 15". It has been determined that all known water losses exclusive of evapotranspiration can account for only slightly over 0.2 acre inches of water which is approximately 16,000 acre feet of water annually. These calculations result in conclusions that 99% of all of the available water in the watershed cannot be accounted for except from losses due to evapotranspiration processes. Water yields from the watershed in the form of rainfall runoff presently amounts to less than 0.6% as an annual average. Historically, water yields in the form of rainfall runoff (prior to 1960) amounted to approximately 2.4% annually or approximately 38,000 acre feet per year average.

▸ *3.7 Hydrologic Evaluation, Summary and Conclusions*

Based on the evaluation of the North Concho River Watershed including the analysis of all available climatic, ecological, hydrologic, hydrogeologic and geologic data, the following conclusions have been prepared to summarize study findings:

1) There have been no significant historical changes in rainfall frequency, duration or intensity within the watershed.

2) Ecological changes within the watershed though time have been significant. The major change has been a transformation from prairie grasslands to brush infested valleys (primarily mesquite) and hills (primarily juniper).

3) The ecological transformation was completed during the decade of the 1950's.

4) There are good stream flow records for the lower stream area for an approximate 70 year period.

5) The available stream flow record indicates a major hydrologic change in stream characteristics occurring in the decade of the 1950's.

6) Numerous "old time" residents confirm the perennial flow characteristics of the river and most major tributaries finally ending during the decade of the 1950's.

7) No tributaries to the river are presently capable of maintaining a permanent aquatic habitat. This is also true of several segments of the North Concho River proper.

8) After the 1950's, the frequency, duration and total yield of the rainfall runoff events on the watershed greatly diminished.

9) After the 1950's the rainfall runoff event characteristic (storm hydrograph) changed significantly from pre-1960 events. Flood flow peaks occurred more quickly in the event and flood flows diminished sooner.

10) Following a July 1961 flood flow event, no storm runoff flow events occurred during July up to the present time. Prior to that, July flood flows were common.

11) 78% of the water wells monitored in Sterling County by the Texas Water Development Board during the early 1940's and again in the early 1960's declined in water level by an average loss of more than 25 feet.

12) The "native" hydrologic characteristics of the river and most tributaries is sustainable "gaining" or increasing downstream flows due to de-watering of the groundwater aquifer, primarily within the Quaternary deposits.

Direct Surface Water
Evaporation Losses
North Concho River Watershed

		1	2	3	4	5	6	7	8
Numbers	Hydrologic Unit Name	Total Area	AC. Total Tributary Surface Area at 43.1 ft 2/ac	AC. Exposed Tributary Surface Area at 5.5%	AC. Groundwater Storage at 0.67 ft 2/ac	AC. Perennial Stream Surface Area at 13.24 ft 2/ac	Total Surface Area AC.	ac/ft. Evaporation Loss at 65 in./yr.	Total Watershed Water Loss Annual ac./in.
1	Upper River	146,740 ac.	145	7.98	2.26	44.6	54.84	297.2	0.0243
2	Lacy Creek	191,300 ac.	189	10.4	2.94	58.1	71.44	387.2	0.0243
3,4	Willow Creek	58,148 ac.	57.5	3.16	0.89	17.7	21.75	117.9	0.0243
5	Sterling City USGS	10,481 ac.	10.4	0.57	0.16	3.2	3.93	21.3	0.0243
6	Sterling Creek	126,812 ac.	125.5	6.9	1.95	38.5	47.35	256.6	0.0243
7	Broome/Middle River	78,828 ac.	78	4.29	1.21	24	29.5	159.9	0.0243
8	Mulberry Creek	66,765 ac.	66	3.63	1.03	20	24.66	133.7	0.0243
9,10	Walnut Creek	47,810 ac.	47.3	2.6	0.74	14.5	17.84	96.7	0.0243
11	Dry Creek	26,634 ac.	26.4	1.45	0.41	8.1	9.96	54	0.0243
12	Chalk Creek	30,420 ac.	30.1	1.66	0.47	9.2	11.33	61.4	0.0243
13	Carlsbad USGS	6,933 ac.	6.9	0.38	0.11	2.1	2.59	14	0.0243
14	Live Oak Creek	25,876 ac.	25.6	1.4	0.4	7.86	9.66	52.4	0.0243
15	Grape Creek	72,748 ac.	72	3.96	1.12	22.1	27.18	147.3	0.0243
16,17	Lower Dry Creek	15,431 ac.	15.3	0.84	0.24	4.7	5.48	29.7	0.0243
18	O.C. Fisher								
Totals		904,926	895	49.22	13.93	274.66	337.51	1829.3	0.0243

2 Calculated tributary (stream bed) length multiplied by 10 ft. average width

3 Percentage of exposure time $\frac{\text{20 days/yr}}{\text{365 days}}$ to estimate annual exposed surface

4 Groundwater storage, estimated at 853 facilities at 30 ft. diameter for total watershed and calculated as sq. ft. /ac total watershed to estimate sub-watershed exposed sq. ft/acre

5 Perennial Stream bed length X 50 ft. average width to estimate total watershed exposed area. Sub-watershed areas estimate at exposed ft. 2/acre

6 Calculated as 2 + 3 + 4 to estimate total surface areas exposed

7 AC./Ft. evaporation losses at 65/yr (5.42 ft.) 6 X 5.42

8 $\frac{\text{7 X 12 in.}}{\text{1 sub-watershed \& watershed area}}$

Livestock & Wildlife
Water Consumption
North Concho River Watershed

		1	2	3	4
Numbers	Hydrologic Unit Name	Total Area	Gal/Dat Consumption 1.2 gal/ac.	Annual Consumption ac. ft.	Total Annual Watershed Water Losses ac/in.
1	Upper River	146,740 ac.	176,088	197.3	0.016
2	Lacy Creek	191,300 ac.	229,560	257.2	0.016
3,4	Willow Creek	58,148 ac.	69,778	78.2	0.016
5	Sterling City USGS	10,481 ac.	12,577	14.1	0.016
6	Sterling Creek	126,812 ac.	152,174	170.5	0.016
7	Broome/Middle River	78,828 ac.	94,594	106	0.016
8	Mulberry Creek	66,765 ac.	80,118	89.8	0.016
9,10	Walnut Creek	47,810 ac.	57,372	64.3	0.016
11	Dry Creek	26,634 ac.	31,960	35.8	0.016
12	Chalk Creek	30,420 ac.	36,504	41	0.016
13	Carlsbad USGS	6,933 ac.	8,320	9.3	0.016
14	Live Oak Creek	25,876 ac.	31,051	35	0.016
15	Grape Creek	72,748 ac.	87,298	97.8	0.016
16,17	Lower Dry Creek	15,431 ac.	18,517	21	0.016
18	O.C. Fisher				
Totals		904,926	1,085,911	1217.3	0.016

2	Livestock Calculated as (1) animal unit/20 acres and 12 gal/day/animal unit 12/20 = 0.6 gal/acre. Wildlife consumption estimated to be approx. equal to livestock use, thus total consumption in gal/acre equals 0.6 + 0.6 = 1.2 gal/acre/day
3	$\frac{1}{325{,}800 \text{ gal/acre ft.}} \times 365$
4	2 X 12 in.
1	Sub-watershed & watershed area (ac)

Table 11

Water Losses as Surface Runoff Discharged From Watershed
North Concho River Watershed

Hydrologic Unit Name	1 Total Area ac.	2 Estimated Non-Producing Area (ac)	3 Producing Area ac.	4 ac/ft/yr Annual Runoff 0.0107 ac ft/ac	5 Total Annual Watershed Water Losses ac/in.
Upper River	146,740 ac.	3,666 ac.	143,074	1,530	0.1284
Lacy Creek	191,300 ac.	22,772 ac.	168,528	1,803	0.1284
Willow Creek	58,148 ac.	0	58,148	622	0.1284
Sterling City USGS	10,481 ac.	0	10,481	112	0.1284
Sterling Creek	126,812 ac.	10,845 ac.	115,967	1,241	0.1284
Broome/Middle River	78,828 ac.	0	78,828	843	0.1284
Mulberry Creek	66,765 ac.	0	66,765	714	0.1284
Walnut Creek	47,810 ac.	0	47,810	478	0.1284
Dry Creek	26,634 ac.	0	26,634	285	0.1284
Chalk Creek	30,420 ac.	0	30,420	325	0.1284
Carlsbad USGS	6,933 ac.	0	6,933	74	0.1284
Live Oak Creek	25,876 ac.	0	25,876	277	0.1284
Grape Creek	72,748 ac.	0	72,748	778	0.1284
Lower Dry Creek	15,431 ac.	0	15,431	165	0.1284
O.C. Fisher					
	904,926	37,283 ac.	867,643	9,247	0.1284

1 Total Area

2 Non-Producing (runoff) area

3 1 - 2

4 35 year average runoff @ Carlsbad USGS = 8358 ac ft. for 779,964 acre watershed

$\frac{8,358}{779,464}$ equals 0.0107 ac. ft./ac./yr., then 3 X 0.0107 = annual runoff (ac.ft./yr.

5 $\frac{4 \text{ X } 12 \text{ in.}}{\text{-watershed area (ac)}}$

Table 12

Water Losses from Crop Irrigation *
Ground & Surface Waters
North Concho River Watershed

		1	2	3
Numbers	Hydrologic Unit Name	Total Area	Irrigation Use at 0.0034 ac.ft./ac.	Average Total Watershed Consumption
1	Upper River	146,740 ac.	499	0.041
2	Lacy Creek	191,300 ac.	650	0.041
3,4	Willow Creek	58,148 ac.	198	0.041
5	Sterling City USGS	10,481 ac.	36	0.041
6	Sterling Creek	126,812 ac.	431	0.041
7	Broome/Middle River	78,828 ac.	268	0.041
8	Mulberry Creek	66,765 ac.	227	0.041
9,10	Walnut Creek	47,810 ac.	163	0.041
11	Dry Creek	26,634 ac.	91	0.041
12	Chalk Creek	30,420 ac.	103	0.041
13	Carlsbad USGS	6,933 ac.	24	0.041
14	Live Oak Creek	25,876 ac.	88	0.041
15	Grape Creek	72,748 ac.	247	0.041
16,17	Lower Dry Creek	15,431 ac.	52	0.041
18	O.C. Fisher			
Totals		904,926	3,077	0.041

2 Irrigation use rate in Sterling Co. has been assumed to be typical for entire watershed. Sterling Co. 35 yr. avg. irrigation consumption is 1975 ac. ft./yr. and Sterling Co. contains 584,960 acres.

$$\frac{1975 \text{ ac. ft.}}{584{,}960 \text{ ac.}}$$ equals 0.0034 ac. ft./ac./yr.

3 $$\frac{2 \times 12 \text{ in.}}{\text{sub-watershed \& watershed area}}$$

* Data Source: Report 347 (Jan. '96) "Surveys of Irrigation in Texas", TWDB

Table 13

Domestic Water Consumption
North Concho River Watershed

		1	2	3	4	5	6		7
Numbers	Hydrologic Unit Name	Total Area	Municipal/ Institutional Use MG/yr.	Est. Rural Pop. Density pn./acre	Populations Total Pns.	Water Use at.052 mg/yr MG	Total Water Use		Total Watershed Annual Water Use Ac/In.
							MG	Ac/Ft.	
1	Upper River	146,740 ac.		0.001	147	7.644	7.664	23.5	0.0019
2	Lacy Creek	191,300 ac.	6	0.001	191	9.932	15.932	48.9	0.0031
3,4	Willow Creek	58,148 ac.		0.001	58	3.016	3.016	9.3	0.0019
5	Sterling City USGS	10,481 ac.	69.635	0.0015	16	0.832	70.467	216.3	0.2476
6	Sterling Creek	126,812 ac.		0.001	127	6.604	6.604	20.3	0.0019
7	Broome/Middle River	78,828 ac.		0.001	79	4.108	4.108	12.6	0.0019
8	Mulberry Creek	66,765 ac.		0.001	67	3.484	3.484	10.7	0.0019
9,10	Walnut Creek	47,810 ac.		0.001	48	2.496	2.496	7.7	0.0019
11	Dry Creek	26,634 ac.		0.001	27	1.404	1.404	4.3	0.0019
12	Chalk Creek	30,420 ac.		0.001	30	1.56	1.56	4.8	0.0019
13	Carlsbad USGS	6,933 ac.	68.164	0.0045	31	1.612	69.776	214.2	0.3707
14	Live Oak Creek	25,876 ac.		0.004	103	5.356	5.356	16.4	0.0076
15	Grape Creek	72,748 ac.		0.0045	327	17.004	17.004	52.2	0.0086
16,17	Lower Dry Creek	15,431 ac.		0.0035	54	2.808	2.808	8.7	0.0068
18	O.C. Fisher								
Totals		904,926	143.799		1305	67.86	211.679	649.9	0.0086

2	Reported usage from municipal and institutional entities within the watershed
3	Estimated from 1990 U.S. Census Data
4	1 X 3
5	Calculated from average domestic use within organized systems
6	2 + 5
7	7 X 12 in.

1 (Sub)watershed & watershed area (ac)

Table 14

Water Losses & Availability
Annual Water Budget
North Concno River Watershed

No's	Hydrologic Unit Name	Domestic Water Consumption		Surface Water Evaporation Losses		Livestock & Wildlife Water Consumption		Surface Runoff Water Losses	
		ac. ft.	watershed ac. in.	ac. ft.	watershed ac. in.	ac. ft.	watershed ac. in.	ac. ft.	watershed ac. in.
1	Upper River	23.5	0.0019	297.2	0.0243	197.3	0.016	1,530	0.1284
2	Lacy Creek	48.9	0.0031	387.2	0.0243	257.2	0.016	1,803	0.1284
3,4	Willow Creek	9.3	0.0019	117.9	0.0243	78.2	0.016	622	0.1284
5	Sterling City USGS	216.3	0.2476	21.3	0.0243	14.1	0.016	112	0.1284
6	Sterling Creek	20.3	0.0019	256.6	0.0243	170.5	0.016	1,241	0.1284
7	Broome/Middle River	12.6	0.0019	159.9	0.0243	106	0.016	843	0.1284
8	Mulberry Creek	10.7	0.0019	133.7	0.0243	89.8	0.016	714	0.1284
9,10	Walnut Creek	7.7	0.0019	96.7	0.0243	64.3	0.016	478	0.1284
11	Dry Creek	4.3	0.0019	54	0.0243	35.8	0.016	285	0.1284
12	Chalk Creek	4.8	0.0019	61.4	0.0243	41	0.016	325	0.1284
13	Carlsbad USGS	214.2	0.3707	14	0.0243	9.3	0.016	74	0.1284
14	Live Oak Creek	16.4	0.0076	52.4	0.0243	35	0.016	277	0.1284
15	Grape Creek	52.2	0.0086	147.3	0.0243	97.8	0.016	778	0.1284
16,17	Lower Dry Creek	8.7	0.0068	29.7	0.0243	21	0.016	165	0.1284
18	O.C. Fisher								
Totals		649.9	0.0086	1829.3	0.0243	1217.3	0.016	9,247	0.1284

Irrigation Usage Water Losses		Total ** Evapotranspiration Water Losses		Total Water Available***		Hydrologic Unit Name	No's
ac. ft.	watershed ac. in.	ac. ft.	watershed ac. in.	ac. ft.	watershed ac. in.		
499	0.041	245810	20.0984	248,357	20.31	Upper River	1
650	0.041	320028.7	20.1116	323,775	20.31	Lacy Creek	2
198	0.041	97389.6	20.0984	98,415	20.31	Willow Creek	3,4
36	0.041	17339.3	19.8527	17,739	20.31	Sterling City USGS	5
431	0.041	212509.6	20.0984	214,629	20.31	Sterling Creek	6
268	0.041	132026.5	20.0984	133,416	20.31	Broome/Middle River	7
227	0.041	116824.8	20.0984	118,000	20.31	Mulberry Creek	8
163	0.041	80108.3	20.0984	80,918	20.31	Walnut Creek	9,10
91	0.041	44607.9	20.0984	45,078	20.31	Dry Creek	11
103	0.041	50950.8	20.0984	51,486	20.31	Chalk Creek	12
24	0.041	11398.5	19.7296	11,734	20.31	Carlsbad USGS	13
88	0.041	43326.2	20.0927	43,795	20.31	Live Oak Creek	14
247	0.041	121803.7	20.0917	123,126	20.31	Grape Creek	15
52	0.041	25840.6	20.0935	26,117	20.31	Lower Dry Creek	16,17
						O.C. Fisher	18
3077	0.041	1519964.5	20.0542	1,536,585	20.31		Totals

* All of the water loss categories calculated have been assumed to represent 100% water loss.
In actual conditions, many of the categories represent only usage and a portion of the water used is returned.

** Calculated by difference between known water uses and total water available

*** Based on 35 year avaerage rainfall @ San Angelo NWS of 20.31 Inches

TABLE 15

13) It is estimated that the net groundwater deficit for the watershed areas with exposed Quaternary deposits is near 2 million acre feet of water. It is assumed that the deficit has resulted from brush infestation.

14) It is assumed that a successful brush control program will result through time in restoration of the watershed aquifer and restoration of stream and tributary perennial and flood flows to pre - 1960 characteristics.

15) Brush Control activities will have the greatest impact on the watershed hydrologic system when conducted on the areas comprising the surface outcrops of the Quaternary deposits. The area of these outcrops is approximately 394,000 acres.

16) Brush Control activities will have the greatest impact on the watershed hydrologic system when conducted on a downstream to upstream basis, whether on the watershed as a whole or on sub-watersheds or tributary systems.

DATABASE & GIS DEVELOMENT ANALYSIS OF WATERSHED MODELING 4.0

Average annual stream flow in the North Concho River from 1962 through present day has been dramatically less than the annual flow prior to 1962. As a result, the storage volume in O.C. Fisher Reservoir (constructed in 1952), which is situated at the outlet of the North Concho, has been much lower than anticipated (Figure 9). The storage volume exceeded the planned conservation pool during only one short period in 1957. Since 1964 the storage volume has exceeded 40,000 acre-feet (about 33% of the conservation pool) for only three months. There is adequate capacity in O.C. Fisher for increased inflows.

There was a dramatic reduction in stream flow during the period 1958 to 1962 (Figures 10 and 11). From discussions with local landowners and others, mesquite and juniper brush began encroaching much of the previously open rangeland in the watershed during the drought of the 1950's, and the propagation, expansion and growth of this brush continues to present day. The brush infestation may be one factor that is contributing to the decrease in stream flow because of increased ET (evapotranspiration) from rangeland dominated by brush versus rangeland dominated by native grasses (Dugas *et al.*, 1998).

In this study, we have used a surface hydrology computer model to determine if removal of certain areas of brush will increase the surface water yield in the North Concho River Watershed. Any gain in water yield would provide increased public benefit for the watershed.

▸ 4.1 *Hydrology & Methods*

The analysis was performed using a GIS (Geographic Information System) integrated with the SWAT (Soil and Water Assessment Tool) (Arnold *et al.*, 1998) computer model. We examined the effects of brush removal on ET and the resulting stream flow to O.C. Fisher Reservoir.

Databases and GIS layers were an integral part of the North Concho River Watershed overall study. All available databases at the highest level of detail possible were assembled in order to define the physical characteristics of the watershed ecosystem.

The GIS is integrated with the SWAT computer hydrologic model to automatically provide input parameters to SWAT. The public domain raster GIS associated with the current version of SWAT is known as GRASS (Geographical Resources Analysis Support System) and was

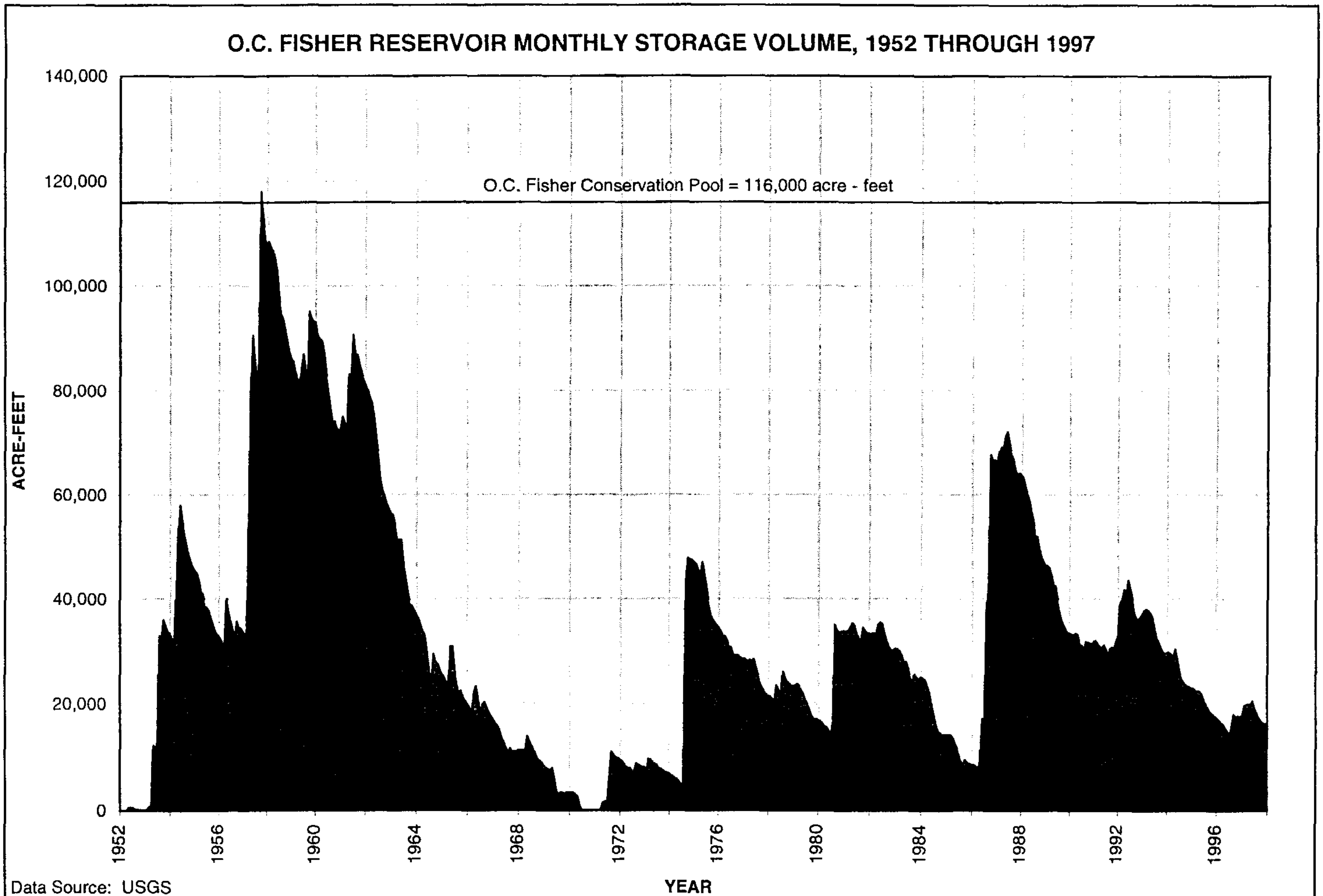


FIGURE 9

O.C. Fisher Measured Storage Volume by Month, 1952 through 1997

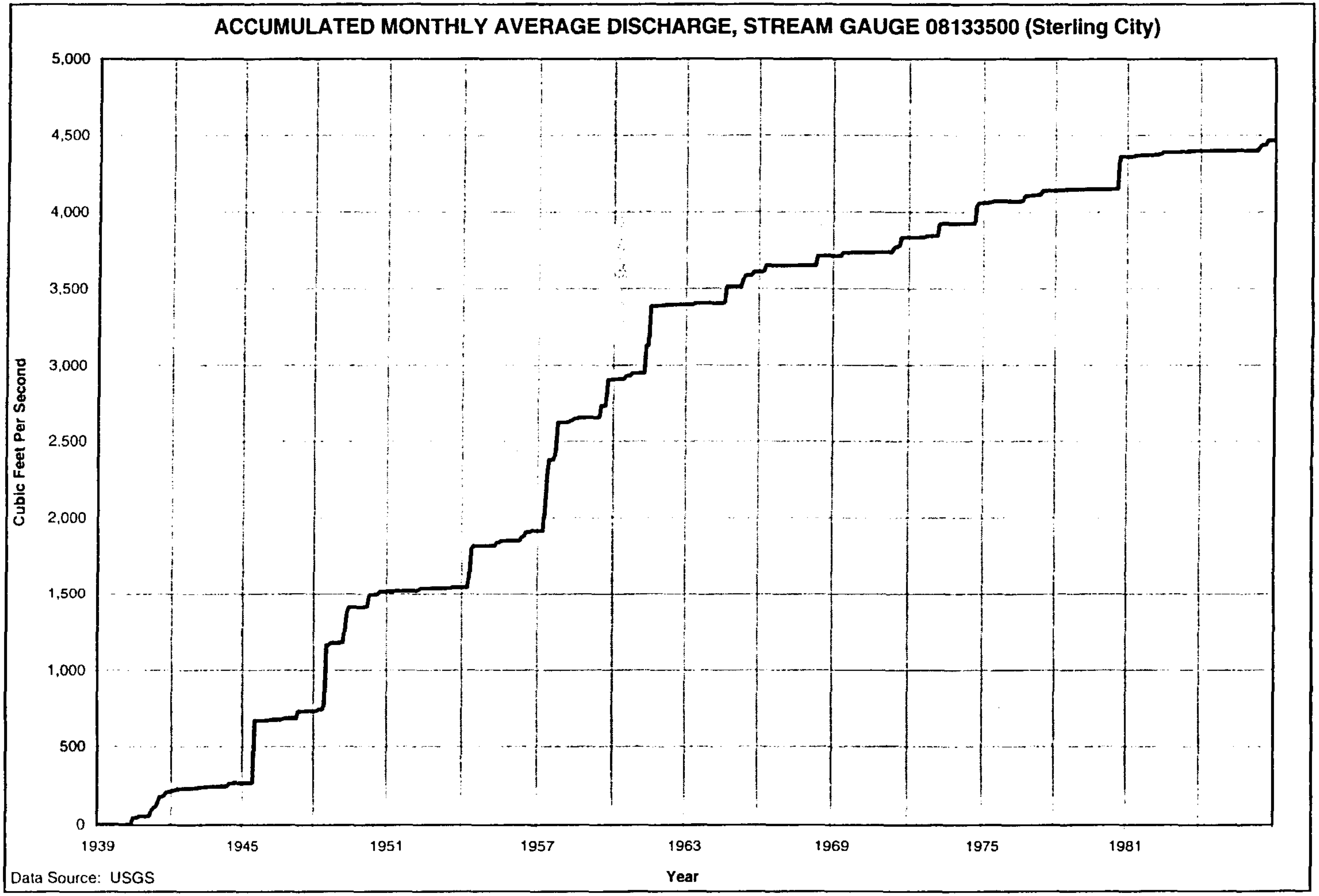


FIGURE 10

Measured Flow (Accumulated Monthly Average) at Gage 08133500 (Sterling City), Sept. 1939 through Sept. 1986

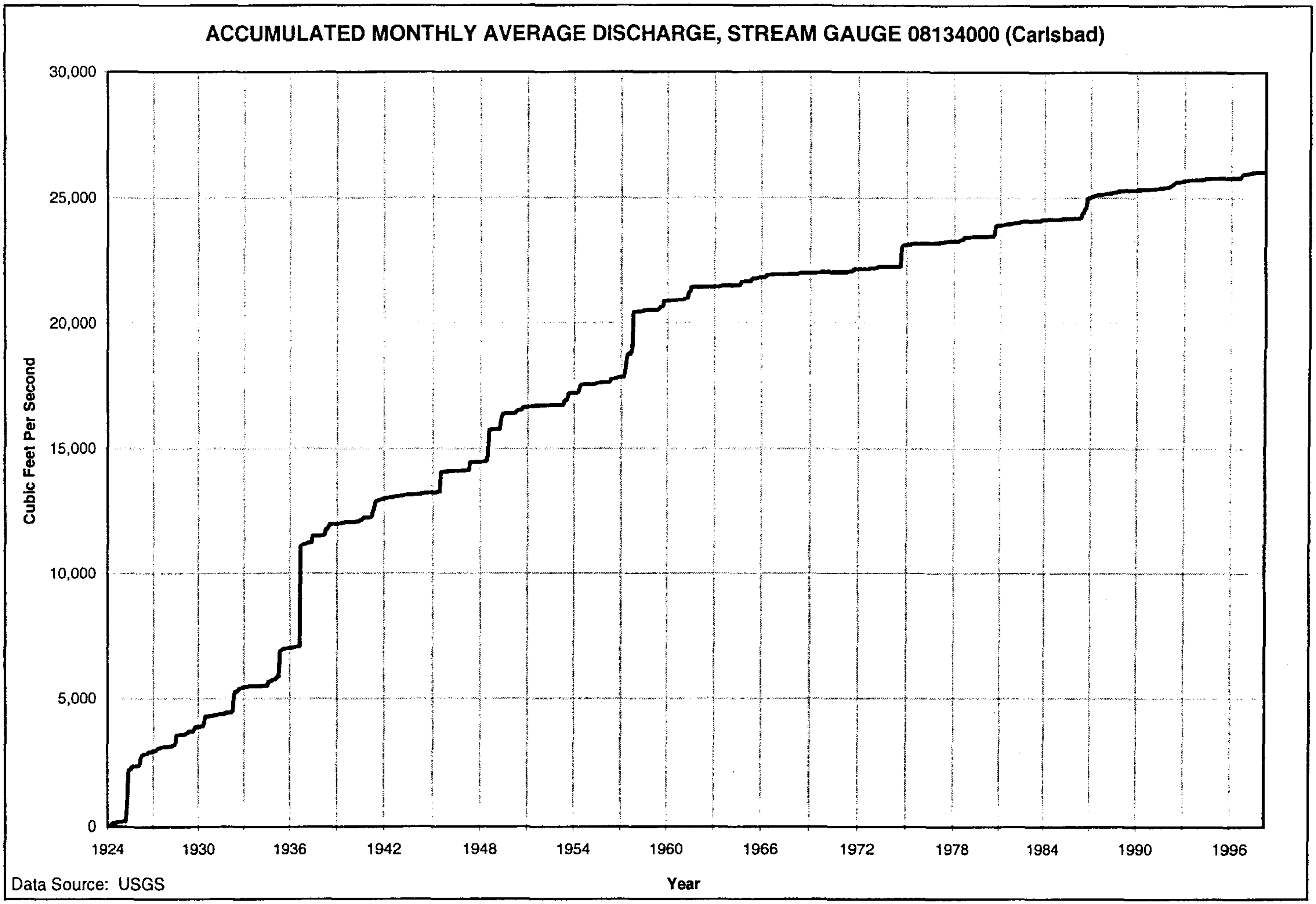


FIGURE 11

Measured Flow (Accumulated Monthly Average) at Gage 08134000 (Carlsbad), Apr. 1924 through Jan. 1998 developed by the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (U.S. Army, 1988). GRASS and SWAT operate in the UNIX operating system. The integration of GIS to SWAT also allows visualization and analysis of the input and output of the computer model.

Numerous federal, state and local agencies and private consultants use GRASS. Most GRASS coverages can be easily converted to other common GIS formats. The major GIS data layers assembled for this study are discussed in detail in the following narrative.

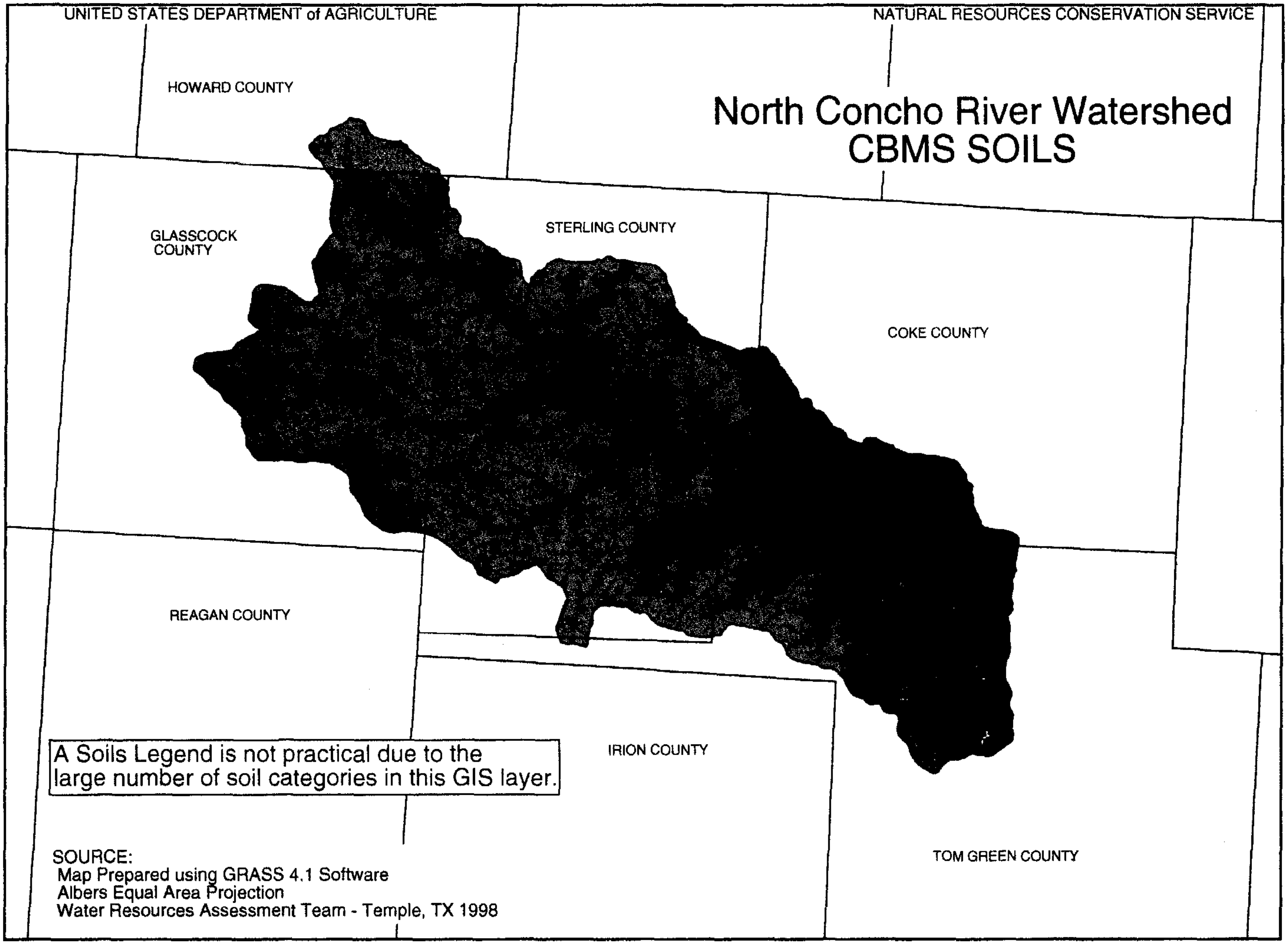
- **SOILS:**

The soils database describes the surface and upper subsurface of a watershed. The SWAT model uses information about each soil horizon. Parameters describing horizon thickness, depth, texture, water holding capacity, dispersion, etc. must be available to the model. These parameters are used to determine a water budget for the soil profile, daily runoff and erosion.

The NRCS (USDA-Natural Resources Conservation Service) soils database used for this project was a grid cell digital map created from 1:24,000 scale soil sheets with a cell resolution of 250 meters. This database is known as the Computer Based Mapping System (CBMS) or Map Information Assembly Display System (MIADS) (Nichols, 1975) soils data. SWAT uses the soils series name as the data link between the soils GIS layer and the soils properties tabular database. Figure 12 shows the soils layer for the North Concho Watershed. The apparent change in soil types across county lines reflects different map codes and does not reflect different soils. This increased the number of different colors on the map.

- **CLIMATE:**

Historical climatic data was obtained from the NRCS Water and Climate Center in Portland, Oregon (Figure 13). The data originated from United States National Weather Service but was processed by NRCS to make it available in a format usable for computer models. The SWAT model uses daily precipitation and maximum and minimum temperatures. The available period of record for most of the stations in the North Concho watershed begins between 1946 and 1953 and runs through present day. Only the Garden City and Sterling City stations contain data prior to 1946.



CBMS Soils GIS Map

FIGURE 12

Most of the climate stations also have at least some days of missing data for the simulation periods. For these periods weather data was generated by SWAT to fill in the missing data.

- **LAND USE/LAND COVER**

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

Landsat-5 Remotely Sensed Data

Development of more detailed land use/land cover information for the North Concho River watershed was accomplished by classifying Landsat-5 Thematic Mapper (TM) data. The TM scene from August 22, 1992 was classified using the NRCS NRI (National Resources Inventory) of 1992 (USDA NRCS, 1992) to ground truth the image. The Landsat-5 satellite was equipped with a TM10 sensor and the resulting imagery had a spatial resolution of 30 meters and a spectral resolution of six channels (the thermal band had been stripped from the image).

The classification was performed using ArcInfo™, Imagine™, and Informix™. The Landsat-5 image was imported into ArcInfo (GIS software). The Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing system) road layers were used to insure that the imagery was correctly geo-referenced. An Informix database was developed to select and further define the NRI points used in the initial classification and verification of the satellite imagery. Each point defined the land use/land cover that existed at that location (and a surrounding two-acre circle) in 1992. ERDAS's Imagine was used for imagery classification. Major divisions of the image's spectral properties were separated utilizing an unsupervised classification process. The NRI points were then employed to instruct the software to recognize differing land uses based on their spectral properties. A supervised classification of the image was then performed with the spectral signatures for various land use classes. The NRI data was used to perform an accuracy assessment of the resulting image.

A sampling of the initial classification was plotted and taken to the field for further verification of land use/land cover. Supplementary ground-truth areas were observed at this time. These additional data were then used to further refine the land use layer.

The use of remote sensed data and the process of classifying it with ground truthing has resulted in a current land use/land cover GIS map that includes more detailed divisions of land use/land cover. Rangeland areas have been separated into four classes as follows:

Heavy Cedar: Mostly pure stands of juniper (cedar) with average canopy cover greater than 25 percent.

Heavy Brush: Mixture of brush species, but mostly mesquite, with average canopy cover greater than 25 percent.

Moderate Brush: Mixture of brush species, but mostly mesquite, with a canopy cover of 10 to 25 percent.

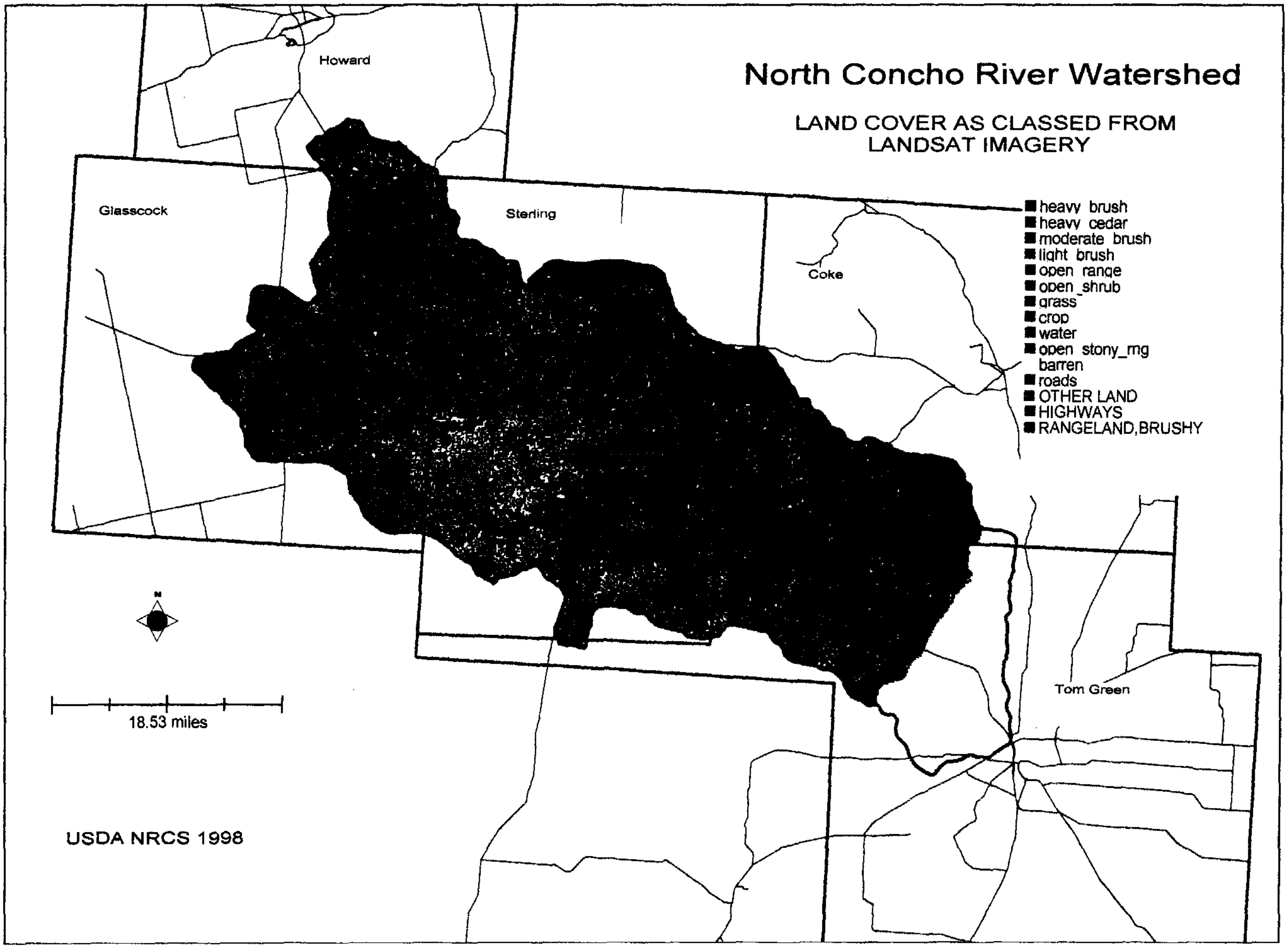
Light Brush: Mixture of species with canopy cover of less than 10 percent. It was assumed this class did not presently need treatment, but will need some amount of maintenance in the future to prevent further invasion of brush.

The assessment of the classified image (utilizing the additional ground control points) indicates an accuracy of approximately 70%. The land use/land cover map created from the classified image is shown in Figure 14. Table 16 (A-F) summarizes land use/land cover categories for each subbasin in North Concho River Watershed.

A very small area of the CBMS 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 portion of the watershed, which was not included in the satellite scene.

- **TOPOGRAHPY**

The United States Geological Survey (USGS) database known as a DEM (Digital Elevation Model) describes the surface of a watershed as a topographical database. The only DEM available for the North Concho watershed is the 1:250,000 scale map (U.S.



GIS Map of Landuse from Classified Landsat Imagery

FIGURE 14

LAND USE BY SUBBASIN - NORTH CONCHO RIVER WATERSHED

#	description	acres	% cover
1	Upper River	123,629.07	12.97
1	heavy_brush	10,388.08	8.40
2	heavy_cedar	14,064.93	11.38
3	moderate_brush	18,344.70	14.84
4	light_brush	16,743.50	13.54
5	open_range	8678.15	7.02
6	open_shrub	22,693.66	18.36
7	grass	8668.27	7.01
8	crop	4724.55	3.82
10	open_stony_rng	8124.65	6.57
11	barren	4586.18	3.71
12	roads	6157.73	4.98
15	HIGHWAYS	9.88	0.01
32	RANGELAND, BRUSHY	444.78	0.36
2	Lacy Creek	190,444.91	19.98
1	heavy_brush	17,672.59	9.28
2	heavy_cedar	20,272.08	10.64
3	moderate_brush	24,077.42	12.64
4	light_brush	16,338.25	8.58
5	open_range	24,739.65	12.99
6	open_shrub	19,847.07	10.42
7	grass	15,428.92	8.10
8	crop	11,020.66	5.79
10	open_stony_rng	18,502.85	9.72
11	barren	9735.74	5.11
12	roads	8648.50	4.54
14	OTHER LAND	59.30	0.03
32	RANGELAND, BRUSHY	4101.86	2.15
3	Concho 1	1650.63	0.17
1	heavy_brush	98.84	5.99
2	heavy_cedar	79.07	4.79
4	light_brush	29.65	1.80
5	open_range	415.13	25.15
6	open_shrub	59.30	3.59
7	grass	276.75	16.77
8	crop	296.52	17.96
10	open_stony_rng	197.68	11.98
11	barren	118.61	7.19
12	roads	79.07	4.79

TABLE 16A

Landuse by Subbasin From Satellite Imagery for North Concho River Watershed

LAND USE BY SUBBASIN - NORTH CONCHO RIVER WATERSHED

4	Willow Creek		55,646.92	5.84
	1	heavy_brush	7511.84	13.50
	2	heavy_cedar	8539.78	15.35
	3	moderate_brush	5337.36	9.59
	4	light_brush	5426.32	9.75
	5	open_range	11,238.11	20.20
	6	open_shrub	3489.05	6.27
	7	grass	4605.94	8.28
	8	crop	1551.79	2.79
	10	open_stony_rng	3795.46	6.82
	11	barren	1512.25	2.72
	12	roads	2421.58	4.35
	32	RANGELAND, BRUSHY	217.45	0.39
5	Concho 2		10,338.66	1.08
	1	heavy_brush	1739.58	16.83
	2	heavy_cedar	1156.43	11.19
	3	moderate_brush	869.79	8.41
	4	light_brush	840.14	8.13
	5	open_range	879.68	8.51
	6	open_shrub	929.10	8.99
	7	grass	859.91	8.32
	8	crop	266.87	2.58
	10	open_stony_rng	1532.02	14.82
	11	barren	612.81	5.93
	12	roads	652.34	6.31
6	Sterling Creek		126,287.87	13.25
	1	heavy_brush	9617.13	7.62
	2	heavy_cedar	8994.44	7.12
	3	moderate_brush	13,274.21	10.51
	4	light_brush	5485.62	4.34
	5	open_range	19,728.46	15.62
	6	open_shrub	19,945.91	15.79
	7	grass	8045.58	6.37
	8	crop	3498.94	2.77
	9	water	9.88	0.01
	10	open_stony_rng	18,621.46	14.75
	11	barren	12,206.74	9.67
	12	roads	6711.24	5.31
	32	RANGELAND, BRUSHY	148.26	0.12

TABLE 16B

Landuse by Subbasin From Satellite Imagery for North Concho River Watershed

LAND USE BY SUBBASIN - NORTH CONCHO RIVER WATERSHED

7	Broome/Middle River	78,439.42	8.23
1	heavy_brush	8806.64	11.23
2	heavy_cedar	11,821.26	15.07
3	moderate_brush	6622.28	8.44
4	light_brush	13,422.47	17.11
5	open_range	6997.87	8.92
6	open_shrub	7126.36	9.09
7	grass	8717.69	11.11
8	crop	3528.59	4.50
10	open_stony_rng	5614.11	7.16
11	barren	1976.80	2.52
12	roads	3795.46	4.84
32	RANGELAND, BRUSHY	9.88	0.01
8	Mulberry Creek	65,965.82	6.92
1	heavy_brush	8737.46	13.25
2	heavy_cedar	5940.28	9.01
3	moderate_brush	10,822.98	16.41
4	light_brush	5001.30	7.58
5	open_range	5446.08	8.26
6	open_shrub	9884.00	14.98
7	grass	3232.07	4.90
8	crop	602.92	0.91
10	open_stony_rng	10,625.30	[illegible]
11	barren	3123.34	4.73
12	roads	2451.23	3.72
15	HIGHWAYS	9.88	0.01
32	RANGELAND, BRUSHY	88.96	0.13
9	Walnut Creek	44,636.14	4.68
1	heavy_brush	10,071.80	22.56
2	heavy_cedar	7096.71	15.90
3	moderate_brush	3370.44	7.55
4	light_brush	2243.67	5.03
5	open_range	10,220.06	22.90
6	open_shrub	1097.12	2.46
7	grass	3904.18	8.75
8	crop	2273.32	5.09
10	open_stony_rng	1690.16	3.79
11	barren	1097.12	2.46
12	roads	1541.90	3.45
32	RANGELAND, BRUSHY	29.65	0.07

TABLE 16C

Landuse by Subbasin From Satellite Imagery for North Concho River Watershed

LAND USE BY SUBBASIN - NORTH CONCHO RIVER WATERSHED

10	Concho 3		3014.62	0.32
	1	heavy_brush	1393.64	46.23
	2	heavy_cedar	9.88	0.33
	3	moderate_brush	177.91	5.90
	4	light_brush	9.88	0.33
	5	open_range	454.66	15.08
	6	open_shrub	9.88	0.33
	7	grass	286.64	9.51
	8	crop	464.55	15.41
	11	barren	19.77	0.66
	12	roads	187.80	6.23
11	Dry Creek		26,528.66	2.78
	1	heavy_brush	5317.59	20.04
	2	heavy_cedar	2214.02	8.35
	3	moderate_brush	998.28	3.76
	4	light_brush	1245.38	4.69
	5	open_range	7353.70	27.72
	6	open_shrub	444.78	1.68
	7	grass	2342.51	8.83
	8	crop	385.48	1.45
	10	open_stony_rng	3459.40	13.04
	11	barren	1443.06	5.44
	12	roads	1314.57	4.96
	32	RANGELAND, BRUSHY	9.88	0.04
12	Chalk Creek		30,175.85	3.17
	1	heavy_brush	10,338.66	34.26
	2	heavy_cedar	5060.61	16.77
	3	moderate_brush	2589.61	8.58
	4	light_brush	474.43	1.57
	5	open_range	5228.64	17.33
	6	open_shrub	217.45	0.72
	7	grass	1759.35	5.83
	8	crop	1700.05	5.63
	10	open_stony_rng	800.60	2.65
	11	barren	889.56	2.95
	12	roads	1116.89	3.70

TABLE 16D

Landuse by Subbasin From Satellite Imagery for North Concho River Watershed

LAND USE BY SUBBASIN - NORTH CONCHO RIVER WATERSHED

13	Concho 4	6928.68	0.73
1	heavy_brush	2134.94	30.81
2	heavy_cedar	227.33	3.28
3	moderate_brush	266.87	3.85
4	light_brush	108.72	1.57
5	open_range	1255.27	18.12
6	open_shrub	148.26	2.14
7	grass	761.07	10.98
8	crop	1314.57	18.97
10	open_stony_rng	29.65	0.43
11	barren	187.80	2.71
12	roads	494.20	7.13
14	Live Oak Creek	25,708.28	2.70
1	heavy_brush	4220.47	16.42
2	heavy_cedar	4180.93	16.26
3	moderate_brush	1008.17	3.92
4	light_brush	2530.30	9.84
5	open_range	6404.83	24.91
6	open_shrub	573.27	2.23
7	grass	1848.31	7.19
8	crop	355.82	1.38
10	open_stony_rng	2253.55	8.77
11	barren	968.63	3.77
12	roads	1314.57	5.11
32	RANGELAND, BRUSHY	49.42	0.19
15	Grape Creek	72,390.42	7.59
1	heavy_brush	25,767.59	35.60
2	heavy_cedar	15,033.56	20.77
3	moderate_brush	4536.76	6.27
4	light_brush	1176.20	1.62
5	open_range	10,516.58	14.53
6	open_shrub	563.39	0.78
7	grass	4665.25	6.44
8	crop	5989.70	8.27
10	open_stony_rng	800.60	1.11
11	barren	869.79	1.20
12	roads	2283.20	3.15
32	RANGELAND, BRUSHY	187.80	0.26

TABLE 16E

Landuse by Subbasin From Satellite Imagery for North Concho River Watershed

Geological Survey, 1993). The DEM (Figure 15) was used as a base map to manually digitize subbasin boundaries within the GRASS GIS for use in the SWAT model.

- **OWNERSHIP**

A GIS map of ownership boundaries is being prepared to aid in the implementation of brush management in the watershed. USGS quad sheets (1:24,000) containing original land survey data were purchased to aid in this task. Local personnel of NRCS and soil and water conservation districts updated the quad sheets to indicate current ownership (data not shown). These data will be scanned into a digital GIS format.

- **SUB-BASIN BOUNDARY**

Subbasin boundaries used in SWAT modeling (Figure 16) were hand digitized in GRASS GIS as close as possible to published map delineation of tributaries to the North Concho River. Additional small subbasins were added on the main stem of the North Concho River to accommodate proper stream routing within the SWAT computer model and to match a subbasin outlet with all USGS stream flow gauge locations for flow calibration. The extent of the North Concho River Watershed Brush Control study does not include Subbasin Number 18 (the farthermost downstream subbasin). This subbasin was added for purposes described above related to hydrologic modeling.

Miscellaneous Layers and Data Bases

- **Range Sites**

The NRCS soils GIS layer was reclassified using county NRCS technical guide information to develop a map indicating range sites within the watershed (Figure 17). This GIS map is useful in determining coincidence of brush type and density with range sites for use in the economic analysis.

- **Irrigation Data**

Summaries of past irrigation surveys conducted jointly every five years (Texas Water Development Board, 1996) were tabulated by county (Table 17). This data was used to estimate withdrawals from the North Concho River and the shallow aquifer near the river.

MODEL DESCRIPTION

The Soil and Water Assessment Tool (SWAT) model is the continuation of a long-term effort of nonpoint source pollution modeling with 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).

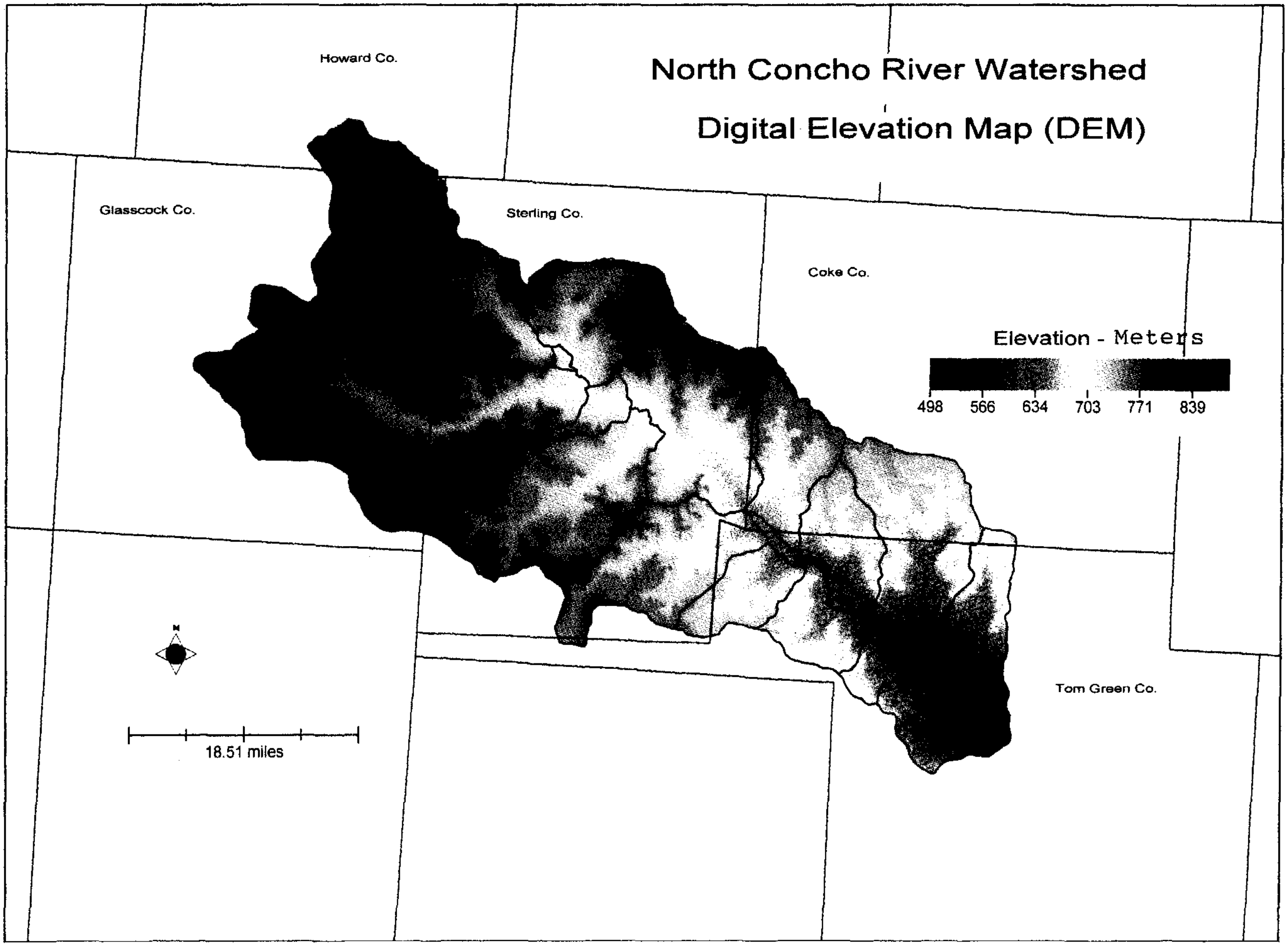


FIGURE 15
GIS Map of Digital Elevation Map

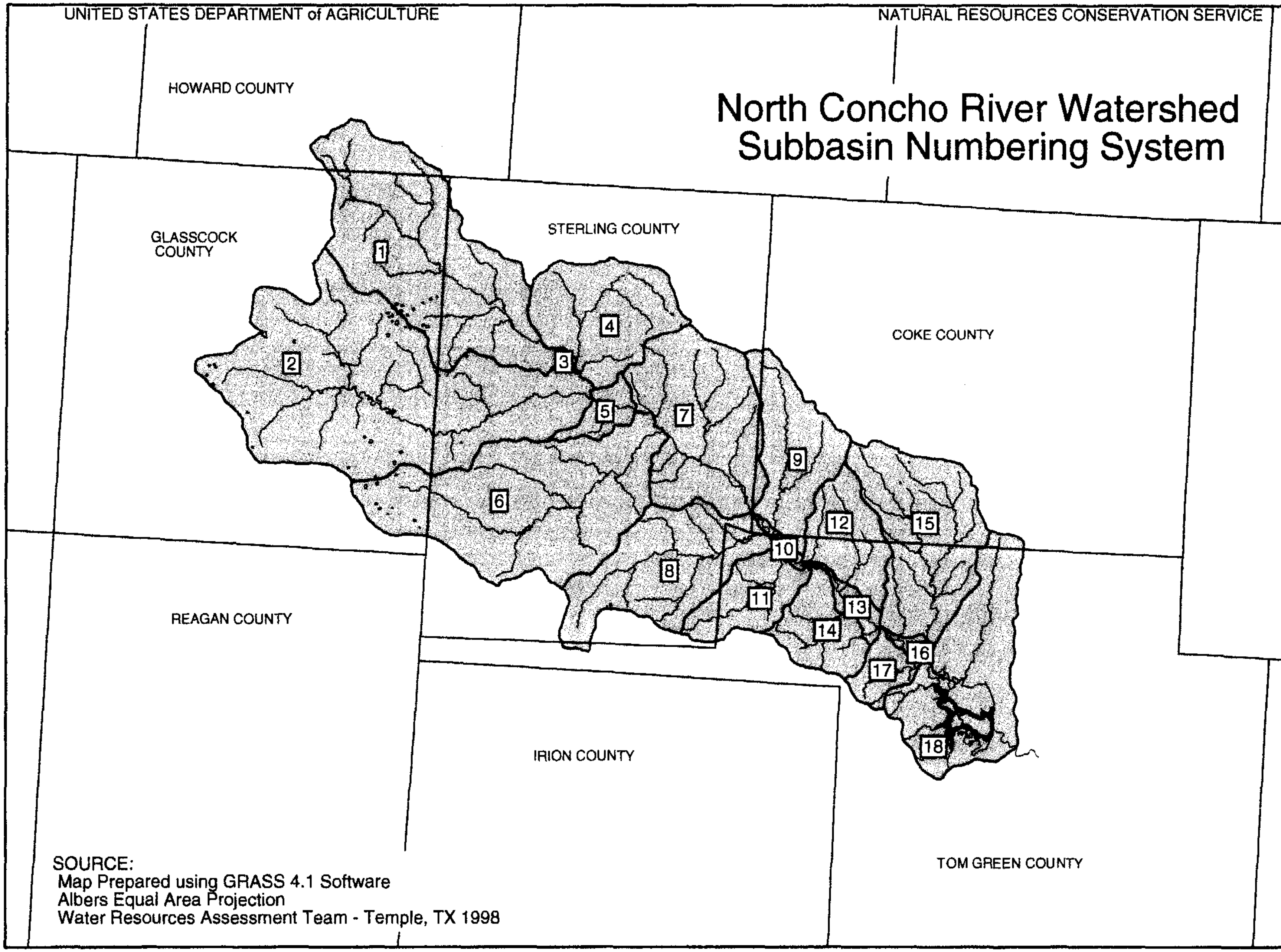


FIGURE 16

Map of Numbered Subbasins

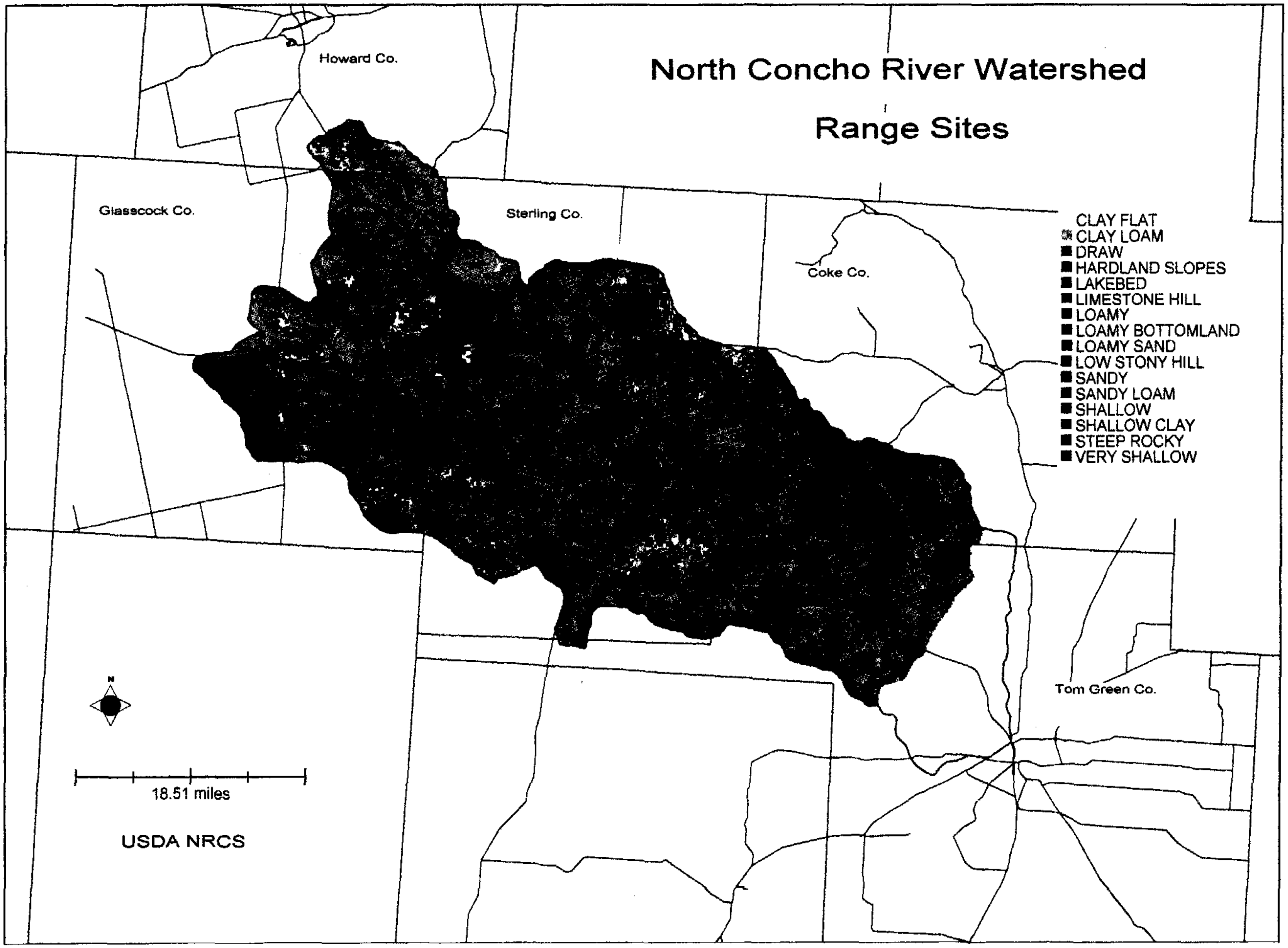


FIGURE 17 GIS Map of Range Sites

NORTH CONCHO RIVER WATERSHED - IRRIGATION DATA Data is Countywide - Not Limited to Watershed Boundaries										
COUNTY or AREA	Year	TOTAL		SURFACE H2O		GROUND H2O		SURF & GRND		No. of Irr.Wells
		Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	Acres	Ac-Ft	
Coke	1958	173	219	141	176	32	43	0	0	3
	1964	639	931	639	931	0	0	0	0	2
	1969	718	1306	555	1128	163	178	0	0	3
	1974	497	766	477	746	20	20	0	0	5
	1979	316	554	88	132	228	422	0	0	7
	1984	310	513	0	0	310	513	0	0	7
	1989	390	571	77	102	313	469	0	0	9
	1994	390	572	77	102	313	470	0	0	9
Glasscock	1958	10800	11597	0	0	10800	11597	0	0	94
	1964	17540	24577	0	0	17540	24577	0	0	327
	1969	23139	34185	0	0	23139	34185	0	0	468
	1974	28186	55103	0	0	28186	55103	0	0	873
	1979	33614	38956	0	0	33614	38956	0	0	950
	1984	31854	41647	0	0	31854	41647	0	0	1150
	1989	26535	31108	0	0	26535	31108	0	0	1350
	1994	49999	58028	0	0	49999	58028	0	0	1650
Sterling	1958	215	224	0	0	145	163	70	61	0
	1964	1356	2336	0	0	1099	1819	257	517	1027
	1969	2081	4824	95	190	1986	4634	0	0	368
	1974	2252	4169	0	0	2252	4169	0	0	2227
	1979	633	1468	[illegible]	0	633	1468	0	0	633
	1984	505	1206	0	0	505	1206	0	0	499
	1989	580	935	0	0	580	935	0	0	580
	1994	580	637	0	0	580	637	0	0	580
Tom Green	1958	10775	12415	5324	6746	4511	4582	940	1087	88
	1964	16858	28551	4694	10139	11414	17065	750	1347	241
	1969	13820	13464	5463	6715	8257	6604	100	145	248
	1974	26316	23449	12773	12476	10923	8306	2620	2667	318
	1979	30560	50495	15900	33188	13500	15880	1160	1427	525
	1984	33600	49085	7100	17938	26500	31146	0	0	800
	1989	38790	58741	14390	25888	22750	30378	1650	2475	1000
	1994	48050	105546	15450	39571	30300	60300	2300	5675	1300
N. CONCHO Sum of All Counties	1958	21963	24455	5465	6922	15488	16385	1010	1148	185
	1964	36393	56395	5333	11070	30053	43461	1007	1864	1597
	1969	39758	53779	6113	8033	33545	45601	100	145	1087
	1974	57251	83487	13250	13222	41381	67598	2620	2667	3423
	1979	65123	91473	15988	33320	47975	56726	1160	1427	2115
	1984	66269	92451	7100	17938	59169	74512	0	0	2456
	1989	66295	91355	14467	25990	50178	62890	1650	2475	2939
	1994	99019	164783	15527	39673	81192	119435	2300	5675	3539

Data Source: Texas Water Development Board

TABLE 17

Summary of Irrigation Reports for Counties

SWAT is a result of the merging of the SWRRB and ROTO models into one basin scale model. The objective in model development was to predict the impact of management (climate and vegetative changes, reservoir management, groundwater withdrawals, and water transfer) on water, sediment, and agricultural chemical yields in large ungauged basins. To satisfy the objective, the model (a) is physically based (calibration is not possible on ungauged basins); (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 subwatersheds. It is still a continuous time model (daily time step) that is required to look at long-term impacts of management (i.e., reservoir sedimentation over 50-100 years) and also timing of agricultural practices within a year (i.e., crop rotations, planting and harvest dates, irrigation, fertilizer, and pesticide application rates and timing).

Major enhancements from SWRRB include the following:

- **New Input File Structure** - The previous SWRRB file structure consisted of one large file with data for all subbasins on weather, soils, land use, topography and management. SWAT files are split into separate files by subbasin and data type. This facilitates more subbasins and simplifies GIS linkages.

- **Reach Routing Structure** - SWRRB routed from subbasin outlets directly to the basin outlet for simplicity. The new routing structure allows large basins to be simulated, providing more realistic routing. More subbasins can be easily added and GIS linkages and data base management are simplified. A set of commands is used to control the routing. These commands route and add flows through the watershed through reaches and reservoirs. The model reads each command and performs the given hydrologic command.

- **Groundwater Component** - Total stream flow from large basins is the sum of surface runoff and groundwater flow. Groundwater flow volumes and timing must be simulated to accurately predict stream flow, sediment concentrations, and chemical concentrations in the stream flow. Water percolating past the root zone is assumed to recharge the shallow aquifer. Shallow aquifer components include recharge, revap, flow to the stream, percolation to the deep aquifer, and pumping withdrawals. The shallow aquifer interacts with the stream - channel transmission losses and pond/reservoir seepage replenish it. Once water reaches the deep aquifer it cannot return to the stream.

- **Revised Management** - SWRRB management files were awkward and only allowed for a three crop rotation. Also, irrigation, nutrient and pesticide application data were in three separate files making crosschecking difficult. Tillage in SWRRB was simplified to handle only four possible options that all occurred at harvest. In SWAT a specific date and specific tillage implement can be selected. SWAT can have an unlimited number of years of rotation.

- **Irrigation Water Transfer** - SWRRB did not simulate water transfer within a watershed, however, for the large basins simulated by SWAT there may be a need to simulate water transfer. Given the reach routing command structure, it is relatively easy to transfer water within a basin. This can account for irrigation flow paths and could provide a management tool for irrigation management districts and other agencies concerned with irrigation water rights. The algorithm developed here will allow water to be transferred from any reach or reservoir to any other reach or reservoir in the watershed. It will also allow water to be diverted and applied directly to irrigate a subwatershed.

In recent years, there has been considerable effort devoted to utilizing GIS to extract inputs (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 (1991 Srinivasan and Engel, Rewerts and Engel, 1991). An interface was developed for SWAT (Srinivasan and Arnold, 1993) using the Graphical Resources Analysis Support System (GRASS) (U.S. Army, 1988). The input interface will extract 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.

CALIBRATION- GENERAL

The North Concho River watershed contains one small reservoir and two inventory sized ponds. Physical data for ponds and reservoirs in the watershed were obtained from NRCS and TNRCC (Texas Natural Resources Conservation Commission) records.

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 of the 18 subbasins into a maximum of 30 virtual subbasins. A single land use and soil were selected for each virtual subbasin. The number of virtual subbasins within a subbasin was determined by: (1) creating a virtual subbasin for each land use that equaled or exceeded 5 percent of the area of a subbasin; and (2) creating a virtual subbasin for each soil type that equaled or exceeded 10 percent of any of the land uses selected in (1). Consequently, the interface created over 200 virtual subbasins. The soil properties for each of the selected soils were automatically extracted from the model-supported soils database.

The SWAT model was calibrated to measured flow at two USGS stream gauging stations: Sterling City (Gauge 08133500) and Carlsbad (Gauge 08134000) (Figure 18). Both weather data and stream gauge data were available for the period 1949 through 1996. Two periods of time, 1949 through 1961 and 1962 through 1996 were chosen for calibration of the SWAT model for stream flow (Figures 9 and 10) because historical measured stream flow record trends changed drastically in 1961-62. The runoff curve number, revap coefficient, evaporation compensation factor, shallow aquifer minimum storage, available water content of the soil, transmission loss and soil flow length were model parameters adjusted to give the best results for the time periods. A description of plant growth parameters and other inputs for the various SWAT simulations is given in Table 18.

Flow Calibration: 1949 Through 1961

For the 1949 through 1961 simulation, the land use/land cover map prepared from the 1992 satellite imagery was reclassified in order to approximate the assumed land use/land cover conditions in the watershed prior to 1962. It was assumed that all of the existing heavy cedar and heavy brush was poor condition moderate brush, and the existing moderate brush category was poor condition open rangeland with no brush. It also was assumed the shallow aquifer in the North Concho River watershed was full and that transmission loss in the stream channels and required minimum shallow aquifer storage before ground water flow could occur were minimal; the portion of shallow aquifer that could be re-evaporated was assumed to be low (0.2); and there were no direct withdrawals from the river for irrigation.

With these inputs the SWAT model was calibrated for flow by adjusting the runoff curve number and available soil water capacity until the predicted flow matched the measured flow at the two USGS stream gauges. Flow calibration was accomplished with a curve number reduction of 8 and an increase in available soil water capacity (%) of 0.06. The results of this simulation are shown in Figures 19 through 22. For the 1949 to 1961 period, average monthly predicted and measured flows were within 10% of each other for both Carlsbad and Sterling City. At both locations, the model over- or under-

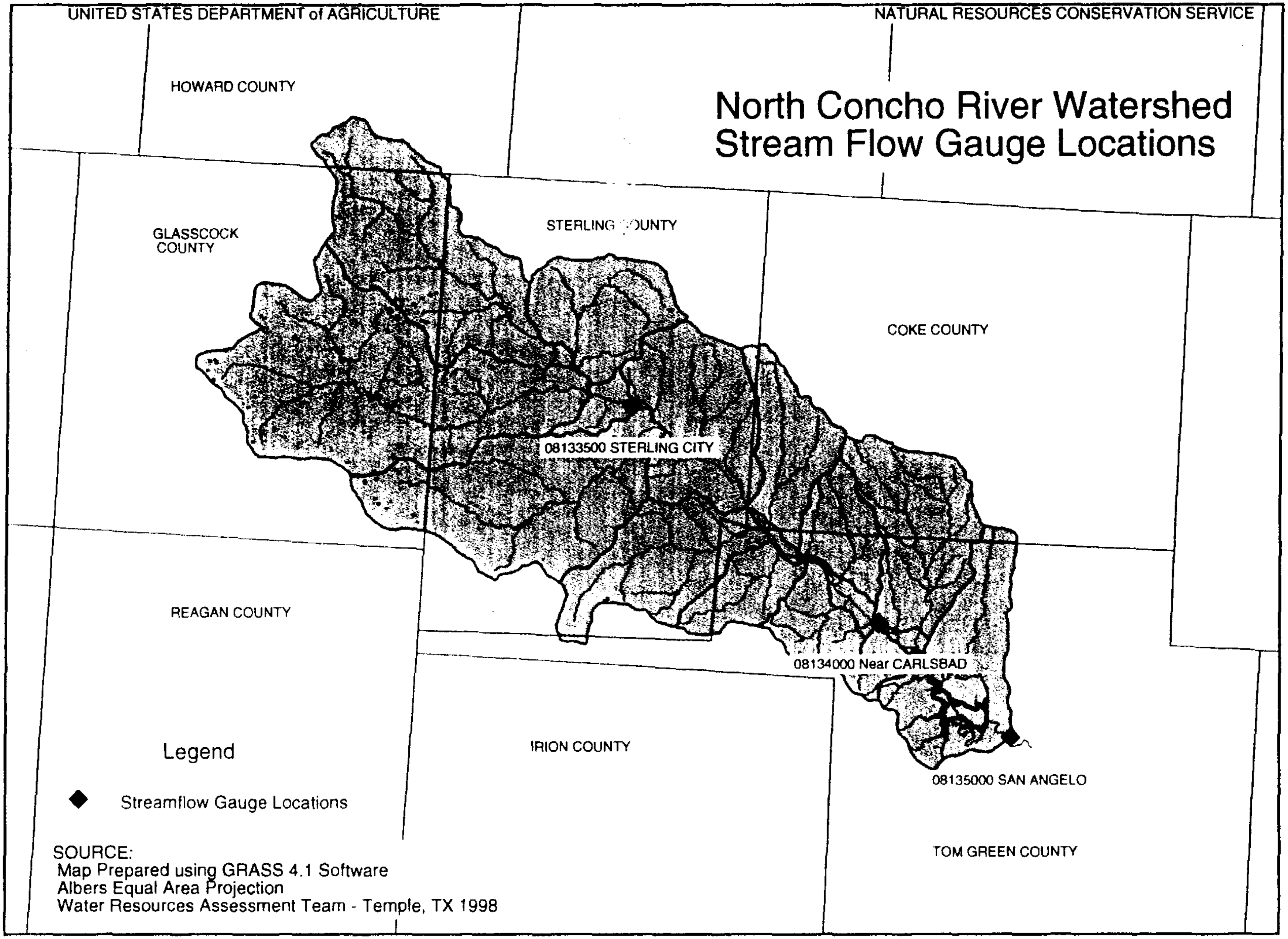


FIGURE 18

Locatic⁻ of Stream Flow Gauges

SWAT INPUT DATA AND WATER YIELD FOR NORTH CONCHO

(Water yield shown does not include channel transmission loss)

SIMULATION PERIOD	1949 - 1961	1962 - 1996	1962 - 1996	1962 - 1996	1962 - 1996	1962 - 1996
SCENARIO	LT-MOD BRUSH (calibration)	HVY BRUSH/CEDAR (calibration)	REMOVE ALL BRUSH	REMOVE ONLY HEAVY CEDAR	REMOVE ONLY HEAVY BRUSH	REMOVE ONLY MOD. BRUSH
RUNOFF CURVE NUMBER (adjustment)	-8, -7 poor cond. range and brush	-8 fair cond range and brush	-8 fair cond. range	-8 fair cond range and brush	-8 fair cond range and brush	-8 fair cond range and brush
EVAP. COMP. FACTOR (soil)	0.1	0.1	0.1	0.1	0.1	0.1
IRR WITHDRAWAL (cfs per day)	NONE	10	10	10	10	10
MIN. AQ. STORAGE (mm)	1	100	1	1	1	15
CHANNEL LOSS (mm/h)	1	40, 150	1	10, 38	4, 15	10, 38
MAX. LEAF AREA INDEX: RANGE	0.5	1.0	1.5	1.5	1.5	1.5
HEAVY CEDAR		5.0			5.0	5.0
HEAVY BRUSH (MESQUITE)		4.0		4.0		4.0
MOD. BRUSH (MESQUITE)	2.5	2.5		2.5	2.5	
MAX. CROP HEIGHT (m): RANGE	0.1	1.0	1.0	1.0	1.0	1.0
HEAVY CEDAR		3.0			3.0	3.0
HEAVY BRUSH (MESQUITE)		5.0		5.0		5.0
MOD. BRUSH (MESQUITE)	2.0	2.0		2.0	2.0	
RAIN INTERCEPT (mm): CEDAR		20			20	20
MESQUITE & RANGE	NONE	NONE	NONE	NONE	NONE	NONE
REVAP COEF (shallow aquifer)	0.2	0.4	0.1	0.2	0.2 - 0.1	0.2
POT. HEAT UNITS: RANGE	2000	2000	2000	2000	2000	2000
HEAVY CEDAR		3000			3000	3000
HEAVY BRUSH (MESQUITE)		2600		2600		2600
MODERATE BRUSH (MESQUITE)	2600	2600		2600	2600	
SOIL FLOW LENGTH (m): RANGE	91 - 122	91 - 122	91 - 122	91 - 122	91 - 122	91 - 122
HEAVY CEDAR/BRUSH		400		400	400	400
MODERATE BRUSH (MESQUITE)	200	200		200	200	
ROOT DEPTH (m): RANGE	2	2	2	2	2	2
HEAVY CEDAR		2			2	2
HEAVY /MOD. BRUSH (MESQUITE)	3.5	3.5		3.5	3.5	3.5
WATER YIELD (mm/yr)	12.16	10.47	17.53	13.81	13.27	11.87
WATER YIELD (ac-ft/yr)	38,036	32,750	54,833	43,197	41,508	37,129

TABLE 18

SWAT Input Data and Water Yield for North Concho River Watershed.

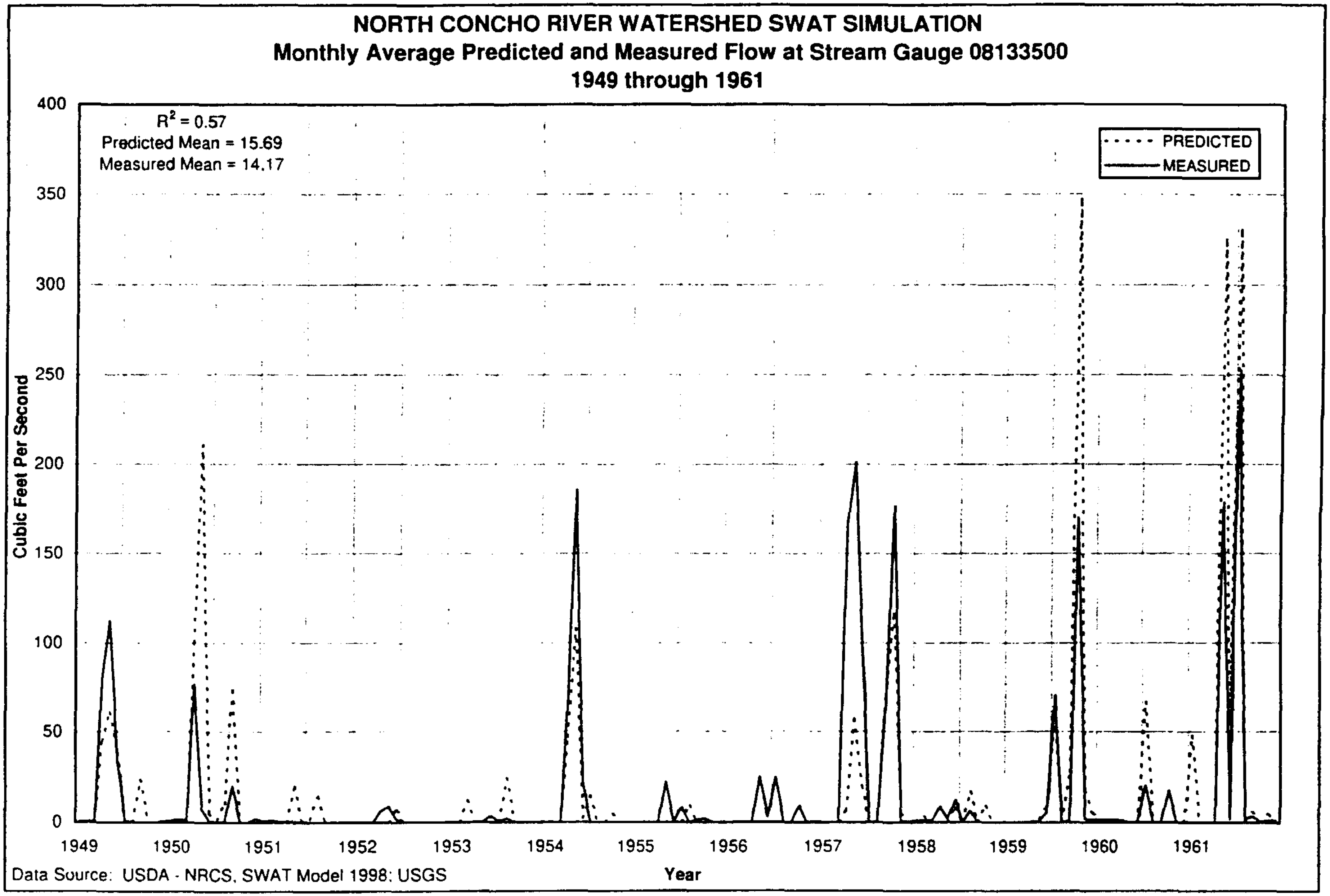


FIG. 19

Monthly Average Predicted and Measured Flow at Gage 08133500 (Sterling City), 1949 through 1961 for North Concho River Watershed.

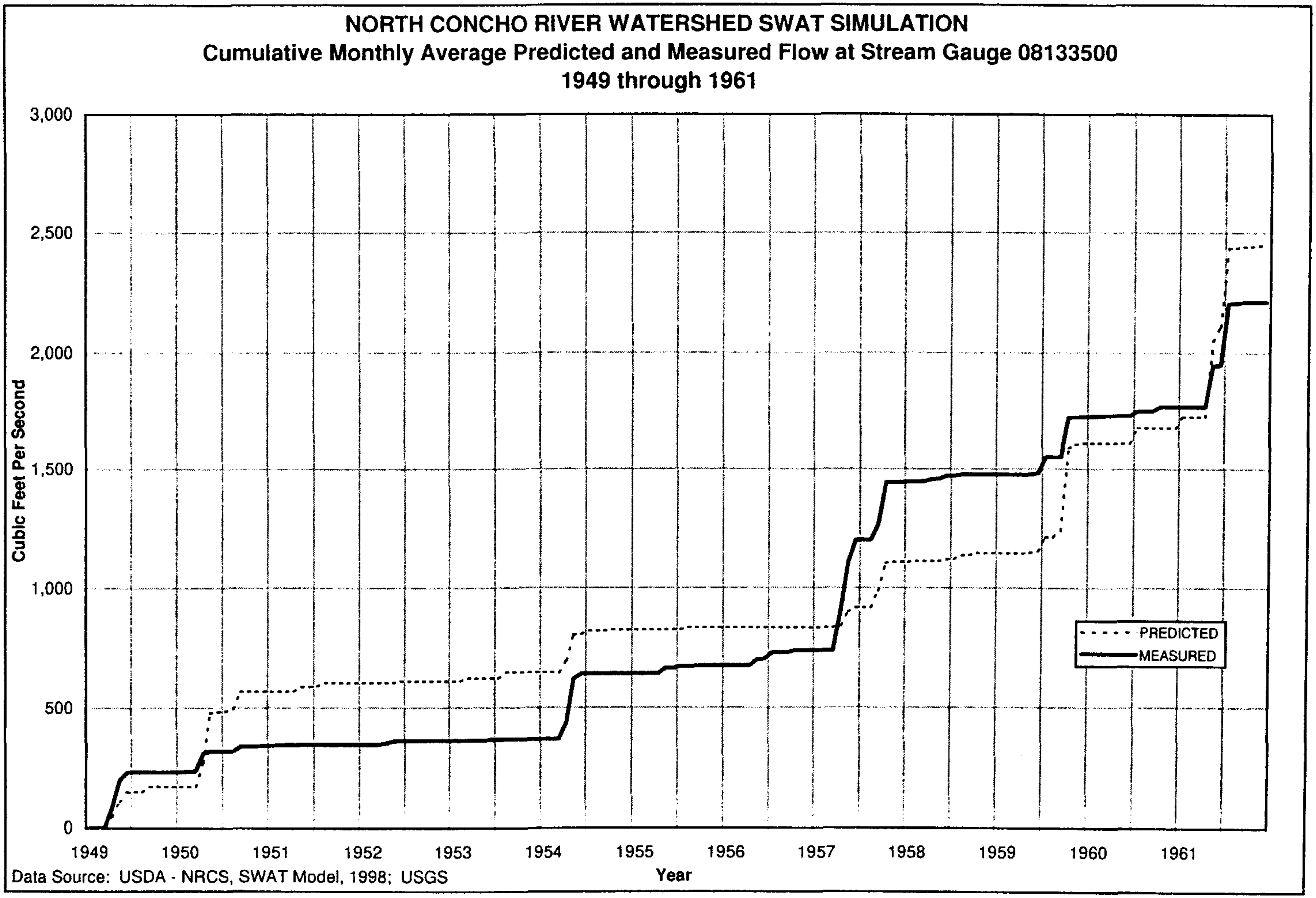


FIGURE 20 Cumulative Monthly Average Predicted and Measured Flow at Gage 08133500 (Sterling City), 1949 through 1961 for North Concho River Watershed.

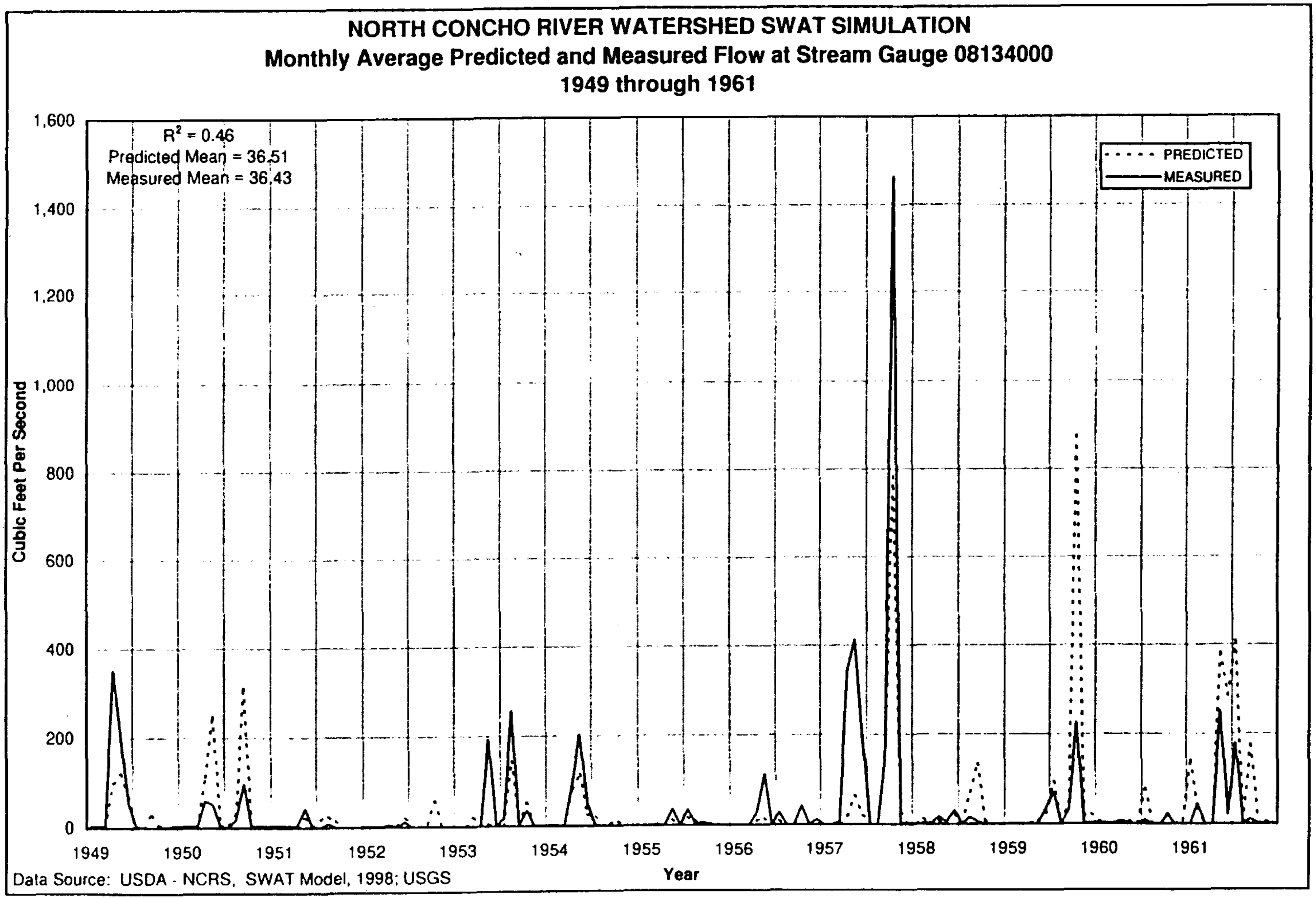


FIGURE 21 Monthly Average Predicted and Measured Flow at Gage 08134000 (Carlsbad), 1949 through 1961, for North Concho River Watershed.

predicted several storm events (likely due to spatial variability of actual precipitation totals within the watershed compared to measured precipitation at the various gauges). As expected, predicted and measured flows were considerably greater at Carlsbad.

Flow Calibration: 1962 Through 1996

The current land use/land cover map from the satellite imagery was used for this simulation. The following assumptions were made: the open rangeland and brush were in fair condition, the shallow aquifer was severely depleted, channel transmission loss and required minimum shallow aquifer storage were high, and the re-evaporation from the shallow aquifer was high (coefficient = 0.4, representing the withdrawal of water by deep-rooted mesquite). Flow calibration for this period was accomplished with the same adjustments in runoff curve number and soil available water capacity as the 1949 – 1962 simulation. Ten cubic feet per second of water was withdrawn from the river for irrigation when available.

The transmission loss and minimum shallow aquifer storage were adjusted until the predicted flow matched the measured flow at the two stream gauges. The resulting adjustments for transmission loss were 40 mm/hr above Sterling City (gauge 08133500) and 150 mm/hr for the remainder of the watershed. These values are appropriate for clean sand and gravel under field conditions (high loss rate). The minimum shallow aquifer storage was set at 100 millimeters for the entire watershed, which reduced ground water flow to a minimal amount.

The results of this simulation are shown on Figures 22 through 26. Predicted and measured flows compared reasonably well, with R^2 values of 0.53 for gauge 08133500 and 0.76 for gauge 08134000. Predicted and measured averages flows were essentially equal, and were both considerably smaller than flows from the 1949 to 1961 period.

At gauge 08134000, SWAT under-predicted flow for about the first eight years. This may be because of the transmission loss and minimum shallow aquifer storage used in the simulation were too high for this period (Figure 26). As invading brush became more prominent, the water level in the aquifer likely declined gradually over several years and the related transmission loss and minimum required shallow aquifer storage gradually increased over the same period. After the first eight years, predicted flow matches the measured flow very well.

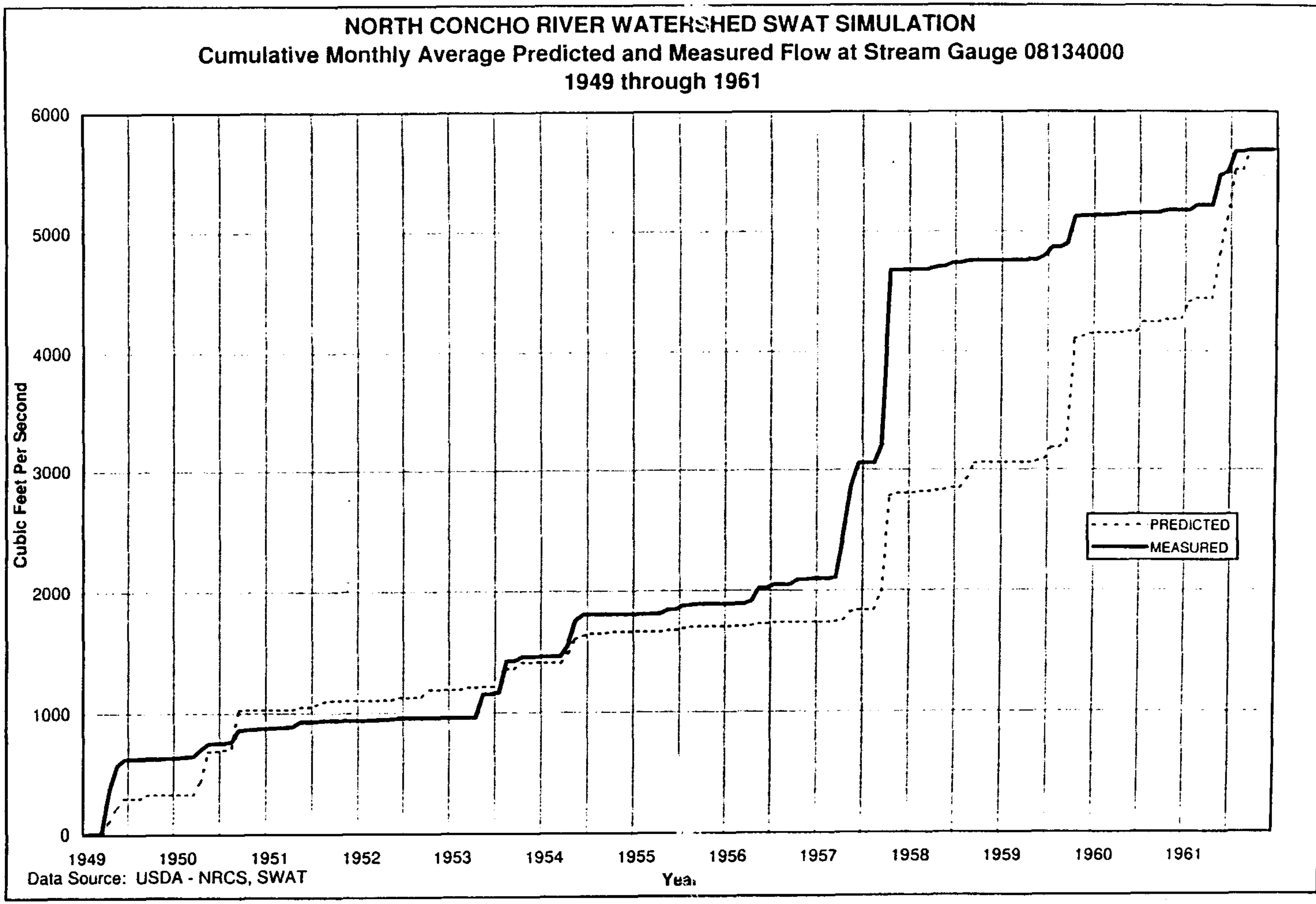


FIGURE 22- Cumulative Monthly Average Predicted and Measured Flow at Gage 08134000 (Carlsbad), 1949 through 1961, for North Concho River Watershed.

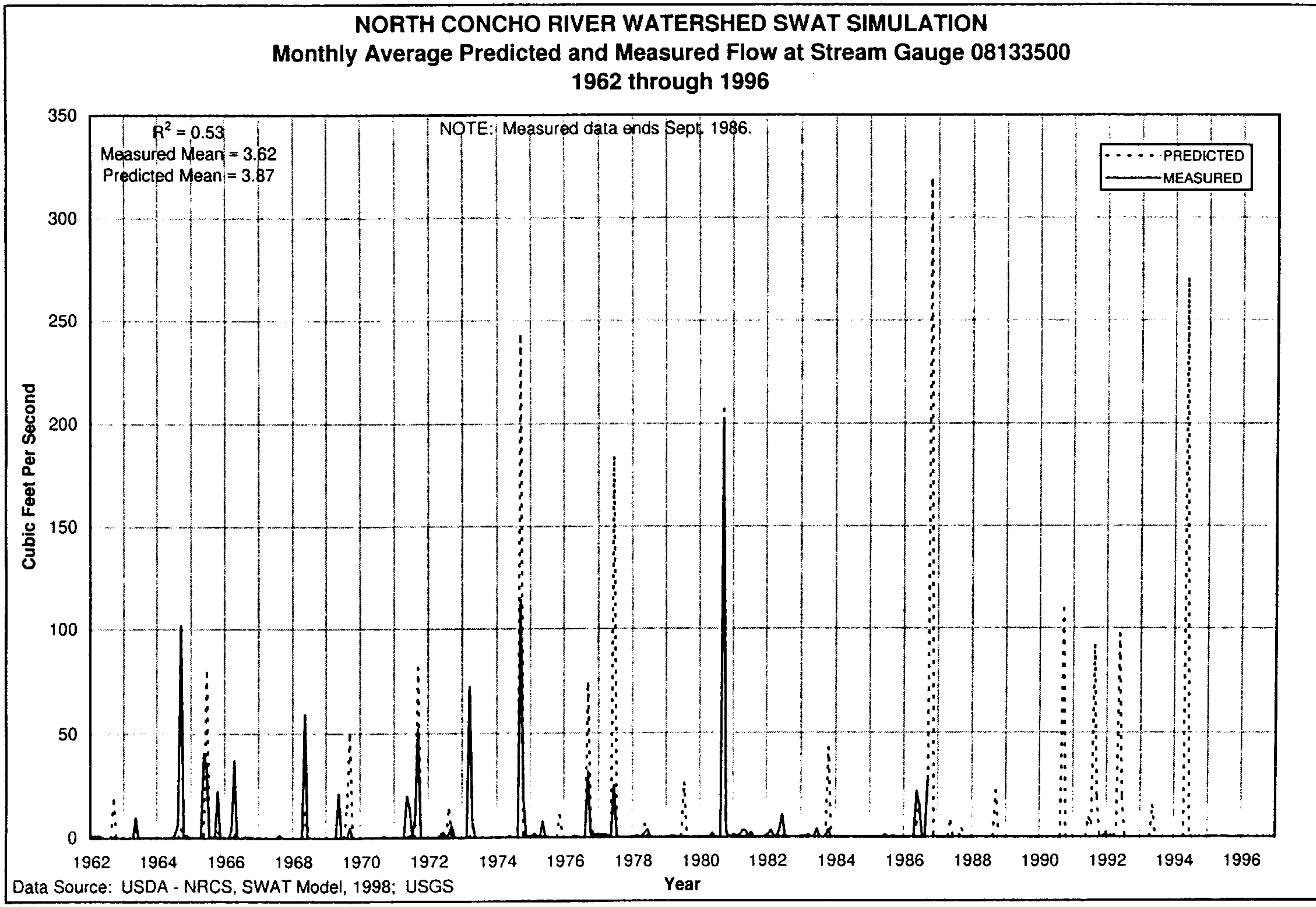


FIGURE 23 Monthly Average Predicted and Measured Flow at Gage 08133500 (Sterling City), 1962 through 1996, for North Concho River Watershed.

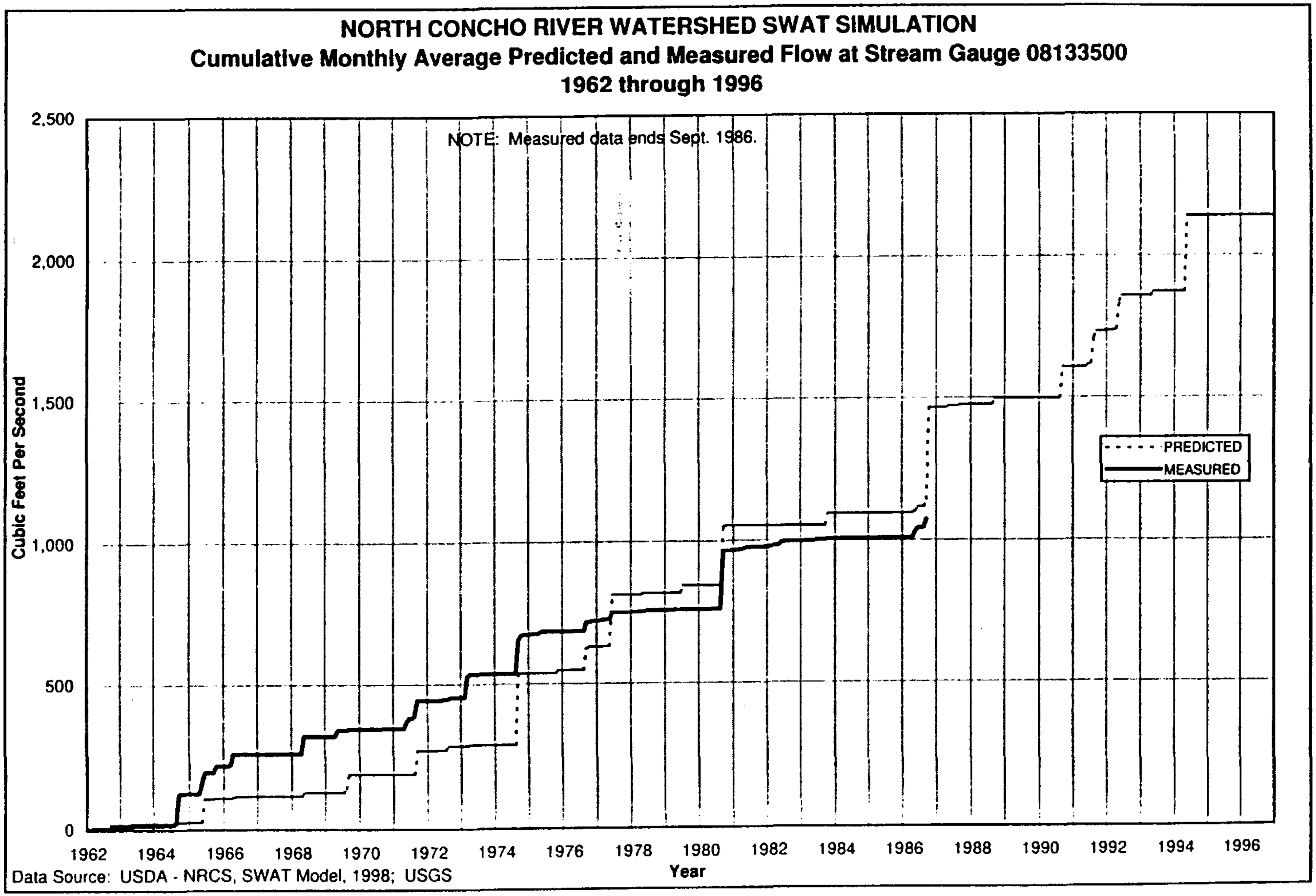


FIGURE 24 Cumulative Monthly Average Predicted and Measured Flow at Gage 08133500 (Sterling City), 1962 through 1996, for North Concho River Watershed.

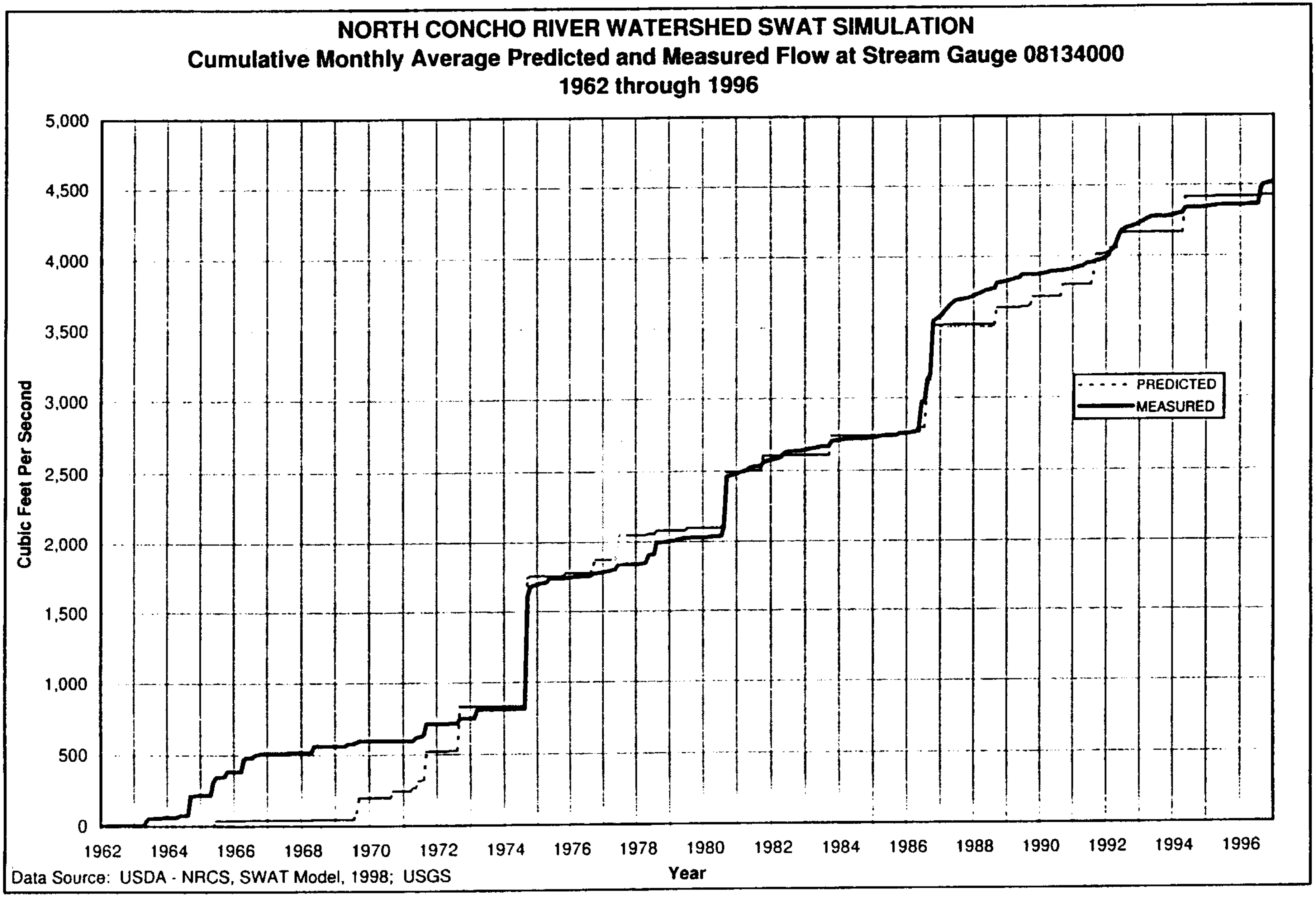


FIGURE 26- Cumulative Monthly Average Predicted and Measured Flow at Gage 08134000 (Carlsbad), 1962 through 1996, for North Concho River Watershed.

Development of Alternatives

The alternative scenarios for the period 1962 to 1996 simulated with SWAT were:

- Present land use/land cover
- Removal of all brush from areas classed as moderate, heavy and heavy cedar brush canopy with a resulting open rangeland cover condition.
- Removal of all brush from areas classed as moderate brush canopy with a resulting open rangeland cover condition.
- Removal of all brush from areas classed as heavy brush canopy with a resulting open rangeland cover condition.
- Removal of all brush from areas classed as heavy cedar canopy with a resulting open rangeland cover condition.
- The incremental removal of brush allowed an economic evaluation on the scenario that was most cost effective relative to increased water yields.
- The 1962 through 1996 flow calibration represented the present condition of the watershed.

For the "removal of all brush" simulation the following was assumed: the underground aquifer has been replenished to pre-1962 levels, the transmission loss and minimum shallow aquifer storage had also returned to the pre-1962 values, the re-evaporation from the shallow aquifer had returned to a minimal amount (coefficient = 0.1), and irrigation withdrawals of 10 cfs were still occurring. These parameters were adjusted as shown in Table 18 for the three remaining scenarios (partial removal of brush).

▸ *4.2 Results*

Simulated average annual flow (1962-1996) to O. C. Fisher Reservoir was about 7,873 acre-feet for the present condition (with brush)(Figure 27). If all heavy brush, heavy cedar, and moderate brush were removed from the watershed, the average annual flow to the reservoir was about 41,388 acre-feet, or an increase of about 33,515 acre-feet. **However, this amount of increase would not occur until the underground aquifer is refilled to pre-1962 levels.** Removal of

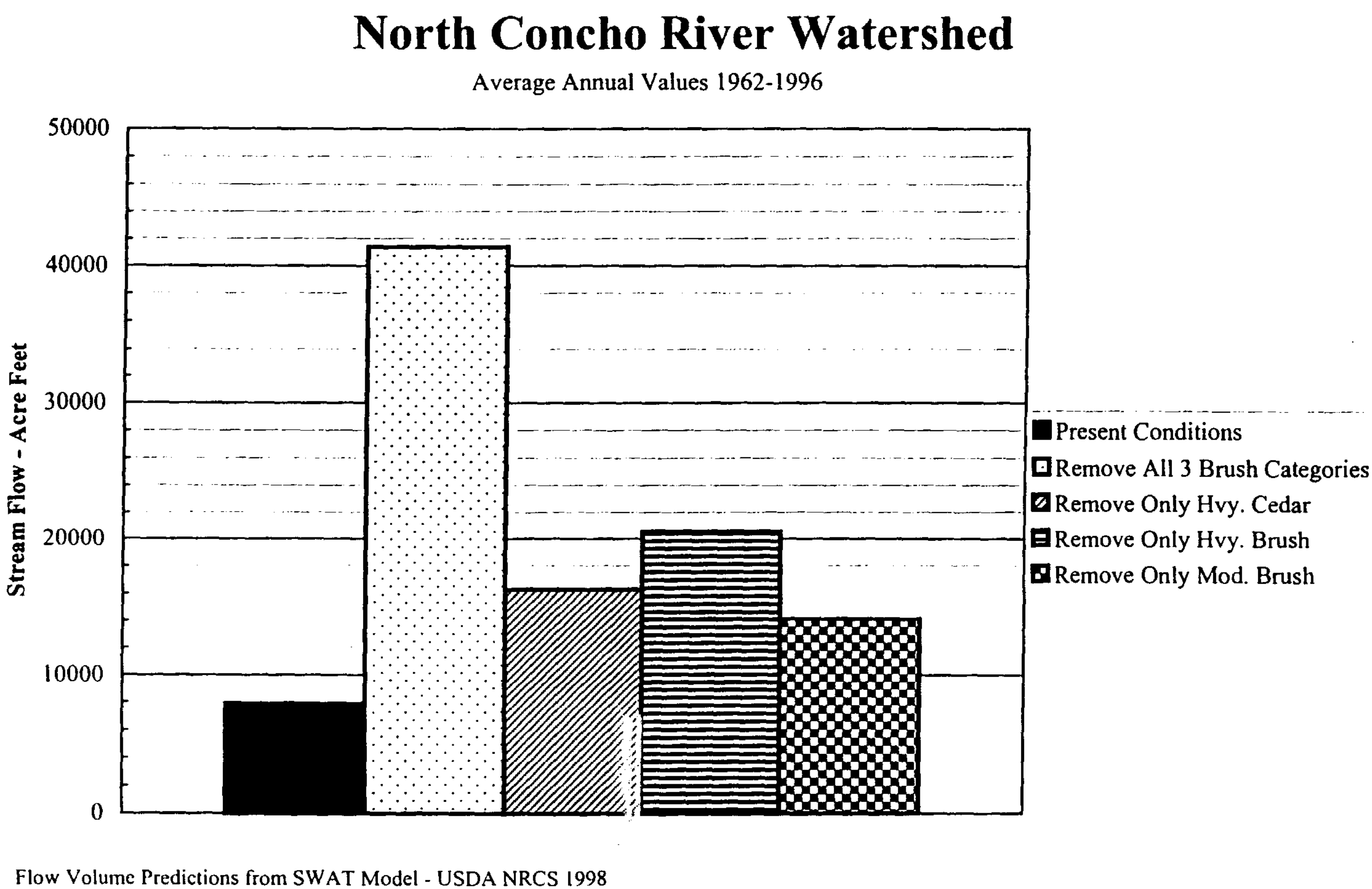


FIGURE 27 - Average Annual Flow Volume Predictions from SWAT Model

heavy cedar increased annual flow by 8,421 acre-feet, and removal of heavy brush increased annual flow by 12,684 acre-feet. Removal of moderate brush increased flow by 6,262 acre-feet.

A summary of the water yield and flow volume into O.C. Fisher for the entire watershed is shown in Table 19. Water yield does not include channel transmission loss. The flow to O.C. Fisher includes transmission and other losses. The increase in flow is shown for each scenario relative to the present condition.

Figure 28 shows a comparison of the average monthly precipitation, evapo-transpiration and water yield (transmission loss not included) for the present condition and the removal of all brush condition. In all months, there was a small decrease in ET with all brush removed. These ET rates are similar to those measured by Dugas et al. (1998) in the Seco Creek watershed. Water yield was increase with brush removal in all months, and the largest increased water yields occurred in September through November.

Figure 29 shows a relationship between subbasin area/area of brush removed and the average annual increase in flow volume for each of the 18 subbasins. Subbasins with large increases in water yields were also the subbasins where a large area of brush was removed.

The increase in flow volume by subbasin for each of the four brush removal scenarios is shown in Tables 20 through 23. The average annual increase for each subbasin is calculated from the unit increase given in Table 19 (for the entire watershed) and the area of each brush category within individual subbasins.

▸ *4.3 Summary & Conclusions:*

The bar graph in Figure 29 displays the "bottom line" of the hydrologic modeling exercise. These results are strictly based on hydrologic modeling; the economic analysis will determine which scenario is most feasible from an economic and practical viewpoint. The hydrologic modeling scenarios assumed total removal of each category of brush and it is acknowledged that this will not be implemented. Economics and consideration of wildlife habitat will be the major considerations on specific amounts and locations of brush removal. Each of the scenarios of brush removal will provide an average annual increase in surface water yield at the watershed outlet.

Response of the surface water hydrology is directly dependent on receiving precipitation/rainfall events in the future that provide an opportunity for surface runoff. Data review for this project revealed that a majority of the historic flow passing stream flow gauges occurred in high intensity

NORTH CONCHO RIVER WATERSHED SWAT SIMULATIONS

SCENARIO	AVERAGE ANNUAL VALUES 1962 - 1996									
	RAINFALL (inches)	ET (inches)	DEEP PERC. (acre-feet)	WATER YIELD (acre-feet)	CHANNEL LOSS (acre-feet)	OTHER ** LOSSES (acre-feet)	FLOW TO O.C.FISHER (acre-feet)	INCREASE IN FLOW (acre-feet)	AREA OF BRUSH REMOVED (sq. mile)	UNIT FLOW INCREASE (ac-ft/sq.mi.)
Present Condition	19.97	19.60	407	32,750	- 24805	- 72	7,873	0	0	0.00
Remove All Brush	19.97	18.80	1,189	54,833	- 10291	- 3154	41,388	33,515	571.40	58.65
Remove Only Hvy.Cedar	19.97	18.84	751	43,197	- 24054	- 2849	16,294	8,421	172.06	48.94
Remove Only Hvy.Brush	19.97	19.50	751	41,508	- 19331	- 1620	20,557	12,684	244.86	51.80
Remove Only Mod.Brush	19.97	19.59	813	37,129	- 21677	- 1317	14,135	6,262	154.47	40.54

**Other losses includes difference between beginning and ending soil water/shallow aquifer storage, loss to snow sublimation, loss to surface evaporation in streams and rivers, etc)

TABLE 19

Summary of Water Yield and Flow Volume for the Five Scenarios, North Concho River Watershed.

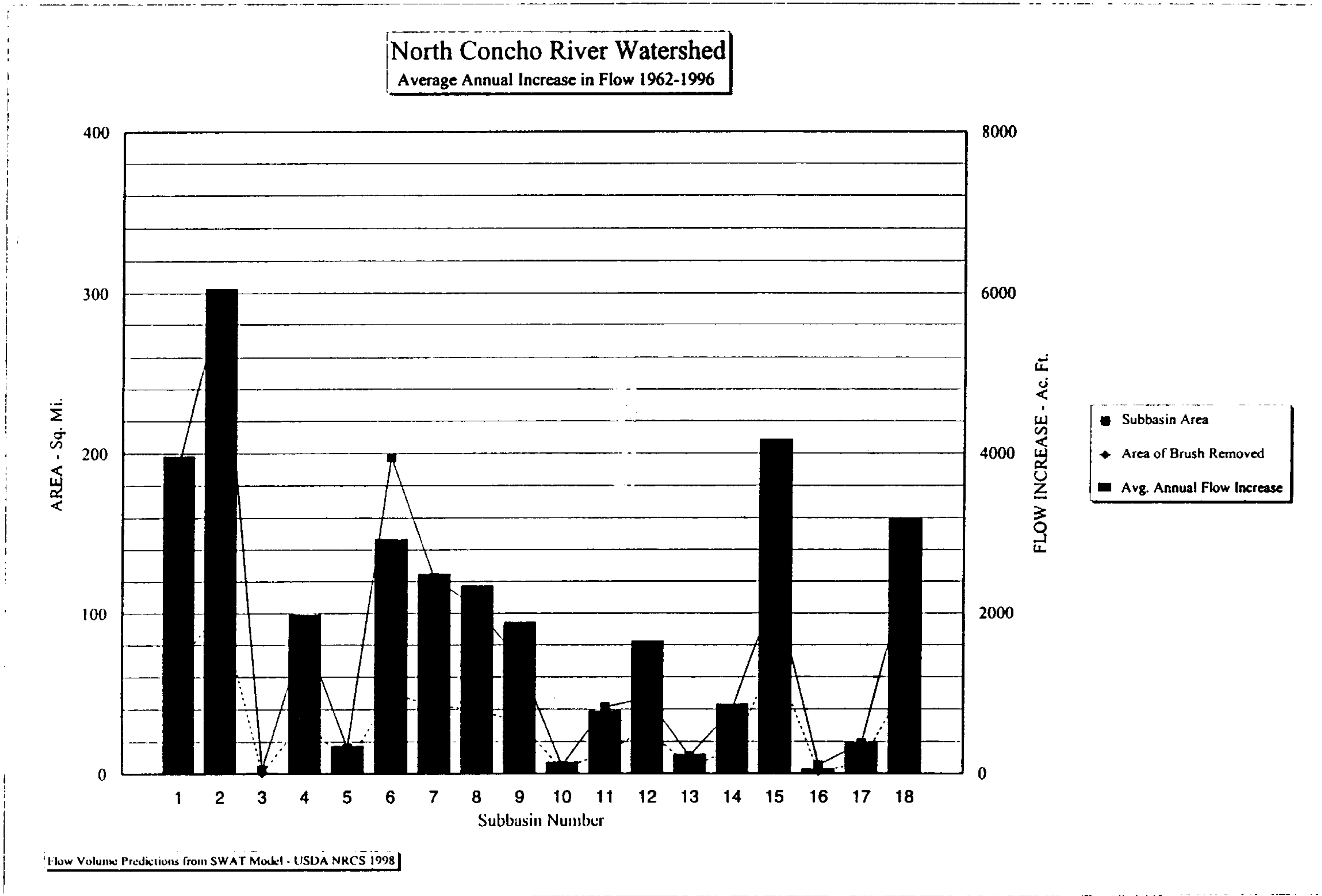


FIGURE 29 - Average Annual Flow Increase by Subbasin

TABLE 20
AVERAGE ANNUAL INCREASE IN FLOW VOLUME FOR REMOVAL OF ALL BRUSH
NORTH CONCHO RIVER WATERSHED SWAT SIMULATION

SUBBASIN	SUBBASIN AREA (sq. miles)	ALL BRUSH AREA (square miles)	PERCENT ALL BRUSH (%)	INCREASE PER UNIT OF ALL BRUSH (acre-feet/square mile)	AVE. ANNUAL INCREASE (acre-feet)
1	193.17	67.57	35	58.65	3,963
2	297.57	103.32	35	58.65	6,060
3	2.58	0.28	11	58.65	16
4	86.95	33.76	39	58.65	1,980
5	16.15	5.88	36	58.65	345
6	197.33	50.05	25	58.65	2,936
7	122.56	42.59	35	58.65	2,498
8	103.07	39.98	39	58.65	2,345
9	69.74	32.14	46	58.65	1,885
10	4.71	2.47	52	58.65	145
11	41.45	13.34	32	58.65	783
12	47.15	28.11	60	58.65	1,649
13	10.83	4.11	38	58.65	241
14	40.17	14.78	37	58.65	867
15	113.11	71.14	63	58.65	4,172
16	5.02	0.96	19	58.65	56
17	19.00	6.61	35	58.65	388
18	119.10	54.30	46	58.65	3,185
TOTALS	1490	571	38	--	33,514

TABLE 21
AVERAGE ANNUAL INCREASE IN FLOW VOLUME FOR REMOVAL OF HEAVY CEDAR
NORTH CONCHO RIVER WATERSHED SWAT SIMULATION

SUBBASIN	SUBBASIN AREA (sq. miles)	HVY. CEDAR AREA (square miles)	PERCENT HVY. CEDAR (%)	INCREASE PER UNIT OF HEAVY CEDAR (acre-feet/square mile)	AVE. ANNUAL INCREASE (acre-feet)
1	193.17	21.98	11.4	48.94	1,076
2	297.57	31.68	10.6	48.94	1,550
3	2.58	0.12	4.8	48.94	6
4	86.95	13.34	15.3	48.94	653
5	16.15	1.81	11.2	48.94	88
6	197.33	14.05	7.1	48.94	688
7	122.56	18.47	15.1	48.94	904
8	103.07	9.28	9.0	48.94	454
9	69.74	11.09	15.9	48.94	543
10	4.71	0.02	0.3	48.94	1
11	41.45	3.46	8.3	48.94	169
12	47.15	7.91	16.8	48.94	387
13	10.83	0.35	3.3	48.94	17
14	40.17	6.53	16.3	48.94	320
15	113.11	23.49	20.8	48.94	1,150
16	5.02	0.06	1.2	48.94	3
17	19.00	2.10	11.1	48.94	103
18	119.10	6.32	5.3	48.94	309
TOTALS	1490	172	11.6	--	8,421

TABLES 20&21. Increase in Flow Volume by Subbasin for Brush Removal Scenarios, North Concho River Watershed.

TABLE 22
AVERAGE ANNUAL INCREASE IN FLOW VOLUME FOR REMOVAL OF HEAVY BRUSH
NORTH CONCHO RIVER WATERSHED SWAT SIMULATION

SUBBASIN	SUBBASIN AREA (sq. miles)	HVY. BRUSH AREA (square miles)	PERCENT HVY. BRUSH (%)	INCREASE PER UNIT OF HEAVY BRUSH (acre-feet/square mile)	AVE. ANNUAL INCREASE (acre-feet)
1	193.17	16.23	8.4	51.80	841
2	297.57	27.61	9.3	51.80	1,430
3	2.58	0.15	6.0	51.80	8
4	86.95	11.74	13.5	51.80	608
5	16.15	2.72	16.8	51.80	141
6	197.33	15.03	7.6	51.80	778
7	122.56	13.76	11.2	51.80	713
8	103.07	13.65	13.2	51.80	707
9	69.74	15.74	22.6	51.80	815
10	4.71	2.18	46.2	51.80	113
11	41.45	8.31	20.0	51.80	430
12	47.15	16.15	34.3	51.80	837
13	10.83	3.34	30.8	51.80	173
14	40.17	6.59	16.4	51.80	342
15	113.11	40.26	35.6	51.80	2,086
16	5.02	0.82	16.3	51.80	42
17	19.00	3.95	20.8	51.80	205
18	119.10	46.63	39.1	51.80	2,415
TOTALS	1490	245	16.4	--	12,684

TABLE 23
AVERAGE ANNUAL INCREASE IN FLOW VOLUME FOR REMOVAL OF MODERATE BRUSH
NORTH CONCHO RIVER WATERSHED SWAT SIMULATION

SUBBASIN	SUBBASIN AREA (sq. miles)	MOD. BRUSH AREA (square miles)	PERCENT MOD. BRUSH (%)	INCREASE PER UNIT OF MODERATE BRUSH (acre-feet/square mile)	AVE. ANNUAL INCREASE (acre-feet)
1	193.17	29.36	15.2	40.54	1,190
2	297.57	44.03	14.8	40.54	1,785
3	2.58	0.00	0.0	40.54	0
4	86.95	8.68	10.0	40.54	352
5	16.15	1.36	8.4	40.54	55
6	197.33	20.97	10.6	40.54	850
7	122.56	10.36	8.5	40.54	420
8	103.07	17.05	16.5	40.54	691
9	69.74	5.31	7.6	40.54	215
10	4.71	0.28	5.9	40.54	11
11	41.45	1.58	3.8	40.54	64
12	47.15	4.05	8.6	40.54	164
13	10.83	0.42	3.9	40.54	17
14	40.17	1.65	4.1	40.54	67
15	113.11	7.38	6.5	40.54	299
16	5.02	0.08	1.5	40.54	3
17	19.00	0.56	2.9	40.54	23
18	119.10	1.36	1.1	40.54	55
TOTALS	1490	154	10.4	--	6,262

TABLES 22/23 Increase in Flow Volume by Subbasin for Brush Removal Scenarios, North Concho River Watershed.

storm events with a very long recurrent interval. Thus, a series of years with average rainfall will produce much less runoff than would come from a year with a hurricane generated rainfall event passing through the watershed. **In addition, the increase in flow will not match modeling results until the underground aquifer is refilled to pre-1962 levels.**

Developing a land use/land cover map by classification of satellite imagery appears to be a practical methodology for basin scale assessments. The costs and resources utilized to classify the imagery was very reasonable for the quality of final product. Selection of the dates the satellite scenes were developed along with possibly using multiple scenes for classification should enhance the accuracy of the final product. Digital orthophotography is not yet available for this portion of the State. Having good recent photo images would also help in assessing land use/land cover data layers.

This modeling exercise is a landmark for using the SWAT computer model in evaluating a watershed with focus on detailed rangeland and brush species. This is also the first attempt at classification of land use/land cover from Landsat-5 imagery to yield various rangeland categories such as open range, light brush canopy, moderate brush canopy, heavy brush canopy and heavy cedar/juniper canopy.

Channel Transmission Loss — This is the effective hydraulic conductivity (mm/hr) in channel alluvium. The values range from greater than 127 for clean gravel and large sand (d50>2 mm) to less than 1 for consolidated bed material with high silt-clay content.

Evaporation Compensation Factor — This factor allows the soil evaporation routine in SWAT to compensate for moisture deficits in the soil surface layer by extracting additional moisture from lower layers. A low value (0.1) represents maximum allowable compensation from lower layers, and a value of 1.0 represents no compensation (normal evaporation from lower layers).

Leaf Area Index — The surface area of leaves of a plant divided by ground area of the plant canopy.

Minimum Aquifer Storage — The shallow aquifer storage must exceed the Minimum Aquifer Storage before ground water flow can begin. A low value (1.0 mm) represents an aquifer that is full, resulting in immediate groundwater flow when percolation occurs from the soil profile to the shallow aquifer.

Potential Heat Units — The heat units required by a growing plant to reach maturity.

Rain Interception — The amount of initial rainfall that is intercepted by plant canopy or litter under the plant, and does not reach the soil surface.

Re-Evaporation Coefficient — This coefficient controls the amount of evaporation from the shallow aquifer. The amount is determined by multiplying potential evapo-transpiration (ET) by the re-evaporation coefficient.

Runoff Curve Number

The runoff curve number is the SCS antecedent moisture condition 2 curve number. SWAT adjusts the curve number up or down depending on soil moisture content at the time precipitation occurs.

Soil Flow Length (m)

The length over which lateral sub-surface soil flow must occur before flow enters the surface runoff.

Soil Available Water Content (%)

Maximum water content that each layer of the soil profile is capable of storing for use by plants.

4.5 LITERATURE CITED

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ECONOMIC ANALYSIS 5.0

Land 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 are discussed in other sections of this report. The data created by these categorizations are the basis for this economic analysis. This section is devoted to explaining how brush control costs and benefits were calculated for the different brush type-densities and provides for their use in determining total project costs, benefits, and cost-share amounts for private landowners-ranchers and the State of Texas.

It should be noted that public benefit in the form of additional water in the North Concho watershed depends on landowner participation and proper implementation of the brush control practices outlined in this project. It is also important to understand that rancher participation in a brush control program to increase water yield will, to a large degree, depend on the economic consequences resulting from participation. With this in mind, the analyses described in this section 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 his participation in the brush control program.

It is explicitly assumed that the difference between the total cost of the brush control practices and the value of landowner-rancher participation would have to be contributed by the state in order to encourage implementation of the brush control practices which result in public benefits in the form of water for public use. Administrative costs (state costs) which would be incurred in implementing, administering and monitoring a brush control project or program in the North Concho watershed are not included in this analysis.

BRUSH CONTROL PRACTICES

Land cover categories identified and quantified in other sections of this study report included four brush type-density categories: heavy mesquite, heavy cedar (juniper), moderate (mixed) brush, and light (mixed) brush. Increases in water yield that would be expected with brush control were, however, only estimated for the heavy and moderate categories. For purposes of estimating total costs, rancher participation, and the amount of cost-share that would be required of the state, a total of six type-density categories are considered herein: heavy mesquite, heavy cedar, moderate mesquite, moderate cedar, light mesquite and light cedar.

Brush control practices include initial and follow-up treatments required to reduce brush canopy to a target range of 3-8% and maintain it at the reduced level for at least 10 years. These practices, or brush control treatments, are outlined in Table 24. The control practices and their impacts on plant communities and herbacious growth represent a consensus of expert opinion obtained through discussions with Texas Agricultural Experiment Station and Extension Service Scientists and USDA-NRCS Range Specialists with extensive brush control experience in the project area.

Year 0 in Table 24 is the year that the initial practice is applied while years 1 - 9 refer to the number of years following the initial practice. Light mesquite and cedar control practices are included because it is expected that without control, these categories of brush would continue to expand so that within 10 years they would reach higher density categories.

CONTROL COSTS

Costs and the present value of costs for the brush control practices (assuming an 8% discount rate-opportunity cost for rancher investment capital) are displayed in Table 25. Obviously, the costs vary with brush type-density categories. Present values of control programs are used for comparison since some of the treatments will be required in the first year to initiate the program while others will not be needed until year 6 or 7. Present values of total per acre control costs range from $20.42 for moderate mesquite that can be initially controlled with individual plant herbicide treatments to 75.42 for heavy cedar that must be initially controlled with mechanical tree bulldozing.

RANCHER BENEFITS FROM BRUSH CONTROL

As was mentioned above, one objective of the analysis is to equate rancher benefits with rancher costs, therefore, the task was reduced to estimating the benefits that would be expected to accrue to a rancher participating in the program. These benefits are based on the present value of the improved net returns made available to the ranching operation through increases or expansions of the typical cattle, sheep and wildlife enterprises that would be reasonably expected to result from implementation of the brush control program. For the livestock enterprises, an improvement in net returns would result from increased amounts of usable forage produced by controlling the brush and thus eliminating much of the competition for water and nutrients within the plant communities on which the enterprise is based. The differences in grazing capacity with and without brush control for each of the brush type-density categories are shown in Table 26.

As with the brush control practices, the grazing capacity estimates represent a consensus of expert opinion obtained through discussions with Texas Agricultural Experiment Station and

. **Brush Control Practices**

A. Heavy Mesquite[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	35%	Aerial Herbicides	50%	25%[3]
2 or 3	7%[2]	Chemical IPT	80%	
7	5%	Prescribed Burn	80%	

[1] Control Methods: Initial Treatment: Aerial herbicide application. Retreatment: Chemical IPT (Brush Busters) and prescribed burning. No mechanical treatments were viable for heavy mesquite.
[2] An efficacy (kill) of 50% will yield greater than a 50% canopy cover reduction. An 80% canopy cover reduction was used.
[3] Without brush control, the carrying capacity of this site continues to diminish with an increasing brush cover. The percent loss in carrying capacity without the inclusion of brush control is constant at 0.5% per year.

B. Heavy Juniper - Alternative "1"[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	35%	Tree Doze and Burn	90%	50%[2]
6	6%	Mechanical IPT or Prescribed Burn	80%	

[1] Control Methods: Initial Treatment: Tree Dozing with Grubber or Bulldozer, followed by buring of piles. Retreatment: Mechanical IPT or prescribed burning. No chemical treatments are currently available for control of heavy cedar.
[2] Without brush control, the carrying capacity of this site continues to diminish with an increasing brush cover. The percent loss in carrying capacity without the inclusion of brush control is constant at 0.5% per year.

C. Heavy Juniper - Alternative "2"[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	35%	Two-Way Chain	75%	50%[2]
1-2	9%	Prescribed Burn[3]	50%	
7	7%	Mechanical IPT or Prescribed Burn	80%	

[1] Control Methods: Initial Treatment: Two-way Chaining which must be followed by a fire for slash reduction. Retreatment: Mechanical IPT or prescribed
burning. No chemical treatments are currently available for control of heavy cedar.
[2] Without brush control, the carrying capacity of this site continues to diminish with an increasing brush cover. The percent loss in carrying capacity without the inclusion of brush control is constant at 0.5% per year.

TABLE 24

(Continued)

D. Moderate Mesquite[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	15%	Chemical IPT	80%	5%[2]
6	8%	Chemical IPT or Prescribed Burn	80%	

[1] Control Methods: Initial Treatment: Chemical IPT by Brush Busters methods. Retreatment: Chemical IPT or prescribed burning. No mechanical treatment is suggested for control of moderate mesquite.

[2] Without brush control, the carrying capacity of this site continues to diminish with an increasing brush cover. The percent loss in carrying capacity without the inclusion of brush control is constant at 1.0% per year.

E. Moderate Juniper[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	15%	Chemical IPT, Power Grubber, or Tree Shearing	80%	10%[3]
6	8%	IPT or Prescribed Burn	80%	

[1] Control Methods: Initial Treatment: Chemical IPT by Brush Busters, power grubber or tree doze, or tree shearing. Retreatment: Chemical IPT or prescribed burning.

[2] IPT treatments for moderate juniper are combined and assigned an average price. Chemical by Brush Busters methods costs $15.00. Power grubbing cost is $28.80 according to Chapter 8 in the 1997 Juniper Symposium (TAES Tech. Rpt. 97-1). Tree shearing cost is $14 according to Dow Range & Pasture Press Vol. 7 #3, May, 1995.

[3] Without brush control, the carrying capacity of this site continues to diminish with an increasing brush cover. The percent loss in carrying capacity without the inclusion of brush control is constant at 1.0% per year.

F. Light Mesquite[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	7-8%	Chemical IPT	90%	0%[2]
6	7%	Chemical IPT or Prescribed Burn	50%	

[1] Control Methods: Initial Treatment: Chemical IPT by Brush Busters. Retreatment: Chemical IPT or prescribed burning.

[2] No increase in stocking rate occurs with brush reductions starting at less than 10% canopy cover. However, without brush control, carrying capacities for sites with light brush decrease rapidly (1.0% per year). Practices are implemented in the light brush categories to *maintain* carrying capacities.

G. Light Juniper[1]

Year	Canopy Cover (%)	Treatment Description	Kill (%)	Forage Increase (%)
0	7-8%	IPT (Chemical or Mechanical)	95%	0%[2]
6	7%	IPT or Prescribed Burn	50%	

[1] Control Methods: Initial Treatment: Chemical IPT by Brush Busters or mechanical IPT. Retreatment: Chemical/mechanical IPT or prescribed burning.

[2] No increase in stocking rate occurs with brush reductions starting at less than 10% canopy cover. However, without brush control, carrying capacities for sites with light brush decrease rapidly (1.0% per year). Practices are implemented in the light brush categories to *maintain* carrying capacities.

TABLE 24
cont.

North Concho Water Yield Brush Control Programs Cost and Present Value in Dollars per Acre by Type - Density Category

A. Heavy Mesquite[1]

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	Aerial Herbicides	$38.00	$36.00
2 or 3	Chemical IPT	$15.00	$12.86
7	Prescribed Burn[1]	$8.60	$5.02
	Totals:	$59.60	$53.88

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

B. Heavy Juniper - Alternative "1"

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	Tree Doze and Burn	$70.00	$70.00
6	Mechanical IPT or Prescribed Burn[1]	$8.60	$5.42
	Total:	$78.60	$75.42

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

C. Heavy Juniper - Alternative "2"

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	Two-Way Chain	$15.00	$15.00
1-2	Prescribed Burn[1]	$8.60	$7.96
7	Mechanical IPT or Prescribed Burn[1]	$8.60	$5.02
	Total:	$32.20	$27.98

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

TABLE 25

(Continued)

D. Moderate Mesquite

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	Chemical IPT	$15.00	$15.00
6	Chemical IPT or Prescribed Burn[1]	$8.60	$5.42
	Total:	$23.60	$20.42

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

E. Moderate Juniper

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	Chemical IPT, Power Grubber, or Tree Shearing	$20.00	$20.00
6	IPT or Prescribed Burn[1]	$8.60	$5.42
	Total:	$28.60	$25.42

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

F. Light Mesquite

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	chemical IPT	$7.50	$7.50
6	Chemical IPT or Prescribed Burn[1]	$8.60	$5.42
	Total:	$16.10	$12.92

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

G. Light Juniper

Year	Treatment Description	Treatment Cost (Acre)	Present Value
0	IPT (Chemical or Mechanical)	$10.00	$10.00
6	IPT or Prescribed Burn[1]	$8.60	$5.42
	Total:	$18.60	$15.42

[1] Prescribed burning costs are $2.00 (NRCS guideline cost for fireline construction) + $3.00 for equipment and labor + $1.80 for deferment for fuel loading ($8.50/AUM / 30 AC/AUY = $.30 per AUM and six months for a deferment period).

TABLE 25
cont.

Annual expected grazing capacity in animal units per section with and without brush control by type-density brush category for the Northwest and Southeast sections of the North Concho River Basin.

YEAR	0	1	2	3	4	5	6	7	8	9
NORTHWEST										
Heavy Mesquite										
Controlled	20	22	24	25	25	25	25	25	25	25
No Control	20	19.9	19.8	19.7	19.6	19.5	19.4	19.2	19.1	19
Heavy Cedar										
Controlled	14.2	17.1	19.9	21.3	21.3	21.3	21.3	21.3	21.3	21.3
No Control	14.2	14.2	14.1	14	13.9	13.8	13.7	13.7	13.6	13.5
Moderate Mesquite										
Controlled	23.7	24.6	25	25	25	25	25	25	25	25
No Control	23.7	23.5	23.3	23.1	22.8	22.5	22.2	21.9	21.6	21.3
Moderate Cedar										
Controlled	19.4	20	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3
No Control	19.4	19.2	19	18.8	18.6	18.3	18.1	17.9	17.7	17.5
Light Mesquite										
Controlled	25	25	25	25	25	25	25	25	25	25
No Control	25	24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.7	22.5
Light Cedar										
Controlled	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3	21.3
No Control	21.3	21.1	20.9	20.7	20.5	20.3	20.1	19.8	19.5	19.2
SOUTHEAST										
Heavy Mesquite										
Controlled	27.8	30.6	33.4	34.8	34.8	34.8	34.8	34.8	34.8	34.8
No Control	27.8	27.7	27.5	27.4	27.2	27.1	26.9	26.8	26.6	26.4
Heavy Cedar										
Controlled	18.3	22.1	25.6	27.8	27.8	27.8	27.8	27.8	27.8	27.8
No Control	18.3	18.2	18.1	18	17.9	17.8	17.7	17.6	17.5	17.4
Moderate Mesquite										
Controlled	32	33	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6
No Control	32	31.6	31.2	30.8	30.4	30	29.6	29.2	28.8	28.8
Moderate Cedar										
Controlled	25.3	26.2	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
No Control	25.3	25	24.7	24.4	24.1	23.8	23.5	23.2	22.9	22.8
Light Mesquite										
Controlled	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6
No Control	33.6	33.3	33	32.7	32.4	32.1	31.7	31.3	31	30.6
Light Cedar										
Controlled	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
No Control	27.8	27.5	27.3	27	26.7	26.4	26.1	25.8	25.4	25

1. Year 0 is the initial year of application of a brush control practice, years 1 - 9 refer to the years following the initial application.

TABLE 26

Extension Service Scientists and USDA-NRCS Range Specialists with brush control experience in the North Concho area. Because of differences in soils and climate, livestock grazing capacities differ by location within the basin. In the portion northwest of Sterling City (NW) (sub-basins 1-6) they range from about 14 animal units per section for land infested with heavy cedar to about 25 for land on which mesquite is controlled. Southeast of Sterling City (SE), the grazing capacities range from about 18 animal units per section for land infested with heavy cedar to about 34 for land on which mesquite has been controlled.

Livestock production practices, revenues, and costs representative of the NW and SE portions of the basin were obtained from personal interviews with focus groups of local ranchers. Estimates of the variable costs and returns associated with the livestock and wildlife enterprises typical of each area were then developed from this information into production investment analysis budgets. This information is shown by enterprise and area in Table 27. The data are reported per animal unit for the livestock enterprises. From these budgets, baseline data was entered into the investment analysis model. This baseline information is provided in Table 28 for both the NW and SE North Concho areas.

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

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. These annual estimates of net revenue differences were discounted (8%) and summed to get an estimate of the net present value of rancher benefits over the ten-year planning period for each brush category type for both areas of the basin. An example of this process is shown in Table 29 for the control of heavy mesquite in the NW portion of the North Concho watershed.

This analysis was done assuming a theoretical 1,000 acre management unit which was to represent a standard for the economic analysis. Therefore to get per acre benefits, the

Investment Analysis Budgets

Cow-Calf Production - Northwest North Concho Area[1]

Revenues[2]

Production Item	Marketed Percentage	Quantity	Unit	$ Per Unit	$ Return
Beef Cull Bull	0.01 (Head)	19.50	Cwt	0.50	0[3]
Beef Cull Cow	0.105 (Head)	11.00	Cwt	0.40	0[3]
Calves	0.90 (Head)	5.75	Cwt	0.75	388.13
				Total:	$388.13

Partial Variable Costs[4]

Variable Cost Description	Quantity	Unit	$ per Unit	$ Cost
Range Cubes	0.18	Ton	188.00	32.40
Cattle Marketing - All Cattle	—	Head of Cow	—	18.16
Protein / Vitamin / Salt / Mineral	60.0	Pound	0.183	11.00
Vet Medicine	1.0	Head	12.50	12.50
Net Cost for Purchased Replacement Cows[3]	—	Head	700.00	37.80
Net Cost for Purchased Replacement Bulls[3]	—	Head	1500.00	3.50
No change in labor, equipment, or facilities costs due to investment decision.				
			Total:	$115.36

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

[1] Cost and returns are based on a per animal unit basis. This budget is representative of a typical ranch in the northwestern portion of the North Concho River basin. The death loss for cows is 1.5%. The culling percentage for cows is 10.5%. Calf crops are 90%. Fixed costs were not included in the analysis.
[2] Revenues were used in the investment analysis to figure the stream of benefits available to the rancher based on the inclusion of brush control as implemented for specific brush type-density categories.
[3] No revenues are listed for either cows or bulls, for the investment analysis model uses a net replacement cost for replacement breeding animals.
[4] Variable costs listed here include only items which change as a result of implementing a brush control program and adjusting livestock numbers to meet changes in grazing capacity.

TABLE 27

(Continued)

Sheep Production - Northeast North Concho Area[1]

Revenues[2]

Production Item	Marketed Percentage	Quantity	Unit	$ Per Unit	$ Return
Cull Ram	0.01 (Head)	4.85	Pounds	0.15	0[3]
Cull Ewe	0.15 (Head)	82.5	Pounds	0.15	0[3]
Weaned Lambs	0.95 (Head)	4.75	Head	60.0	285.00
Wool	—	48.0	Pounds	1.00	48.00
				Total:	$333.00

Partial Variable Costs[4]

Variable Cost Description	Quantity	Unit	$ per Unit	$ Cost
Range Cubes	300.0	Pounds	.1175	35.25
Sheep Marketing - All Sheep	—	AU	—	8.92
Shearing	1.0	AU	11.25	11.25
Wool Marketing	48.0	Pound	0.08	3.84
Protein / Vitamin / Salt / Mineral	60.0	Pound	0.183	11.00
Vet Medicine	1.0	Head	4.00	4.00
Net Cost for Purchased Replacement Ewes[3]	1.0	Head	70.00	57.65
Net Cost for Purchased Replacement Rams[3]	0.03	Head	200.00	5.85
No change in labor, equipment, or facilities costs due to investment decision.				
			Total:	$137.76

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

[1] Cost and returns are based on a per animal unit basis. This budget is representative of a typical ranch in the northwestern portion of the North Concho River basin. The death loss for sheep is 5%. The culling percentage for ewes is 15%. Lamb crops are 95%. Fixed costs were not included in the analysis.
[2] Revenues were used in the investment analysis to figure the stream of benefits available to the rancher based on the inclusion of brush control as implemented for specific brush type-density categories.
[3] No revenues are listed for either ewes or rams, for the investment analysis model uses a net replacement cost for replacement breeding animals.
[4] Variable costs listed here include only items which change as a result of implementing a brush control program and adjusting livestock numbers to meet changes in grazing capacity.

TABLE 27
cont.

(Continued)

Cow-Calf Production - Southeast North Concho Area[1]

Revenues[2]

Production Item	Marketed Percentage	Quantity	Unit	$ Per Unit	$ Return
Beef Cull Bull	0.01 (Head)	19.50	Cwt	0.50	0[3]
Beef Cull Cow	0.10 (Head)	10.00	Cwt	0.40	0[3]
Calves	0.90 (Head)	5.52	Cwt	0.75	372.60
				Total:	$372.60

Partial Variable Costs[4]

Variable Cost Description	Quantity	Unit	$ per Unit	$ Cost
Range Cubes	0.175	Ton	188.00	31.50
Cattle Marketing - All Cattle	——	Head of Cow	——	18.16
Protein / Vitamin / Salt / Mineral	60.0	Pound	0.183	11.00
Vet Medicine	1.0	Head	12.50	12.50
Net Cost for Purchased Replacement Cows[3]	——	Head	700.00	40.50
Net Cost for Purchased Replacement Bulls[3]	——	Head	1500.00	5.25
No change in labor, equipment, or facilities costs due to investment decision.				
			Total:	$118.91

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

[1] Cost and returns are based on a per animal unit basis. This budget is representative of a typical ranch in the southeastern portion of the North Concho River basin. The death loss for cows is 1.5%. The culling percentage for cows is 10%. Calf crops are 90%. Fixed costs were not included in the analysis.
[2] Revenues were used in the investment analysis to figure the stream of benefits available to the rancher based on the inclusion of brush control as implemented for specific brush type-density categories.
[3] No revenues are listed for either cows or bulls, for the investment analysis model uses a net replacement cost for replacement breeding animals.
[4] Variable costs listed here include only items which change as a result of implementing a brush control program and adjusting livestock numbers to meet changes in grazing capacity.

(Continued)

Sheep Production - Southeast North Concho Area[1]

Revenues[2]

Production Item	Marketed Percentage	Quantity	Unit	$ Per Unit	$ Return
Cull Ram	0.01 (Head)	4.85	Pounds	0.15	0[3]
Cull Ewe	0.20 (Head)	110.0	Pounds	0.15	0[3]
Weaned Lambs	0.92 (Head)	4.6	Head	60.0	276.00
Wool	----	46.0	Pounds	1.00	46.00
				Total:	$322.00

Partial Variable Costs[4]

Variable Cost Description	Quantity	Unit	$ per Unit	$ Cost
Range Cubes	520.0	Pounds	.1175	61.32
Sheep Marketing - All Sheep	----	AU	----	8.78
Shearing	1.0	AU	11.25	11.25
Wool Marketing	46.0	Pound	0.08	3.68
Protein / Vitamin / Salt / Mineral	60.0	Pound	0.183	11.00
Vet Medicine	1.0	Head	4.00	4.00
Net Cost for Purchased Replacement Ewes[3]	1.0	Head	70.00	71.00
Net Cost for Purchased Replacement Rams[3]	0.03	Head	200.00	5.30
No change in labor, equipment, or facilities costs due to investment decision.				
			Total:	$176.33

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

[1] Cost and returns are based on a per animal unit basis. This budget is representative of a typical ranch in the southeastern portion of the North Concho River basin. The death loss for sheep is 5%. The culling percentage for ewes is 20%. Lamb crops are 92%. Fixed costs were not included in the analysis.
[2] Revenues were used in the investment analysis to figure the stream of benefits available to the rancher based on the inclusion of brush control as implemented for specific brush type-density categories.
[3] No revenues are listed for either ewes or rams, for the investment analysis model uses a net replacement cost for replacement breeding animals.
[4] Variable costs listed here include only items which change as a result of implementing a brush control program and adjusting livestock numbers to meet changes in grazing capacity.

TABLE 27
Cont.

North Concho Baseline Economic Information[1]

General Economic Information

Production Information Category	Unit	Southeast	Northwest
Planning Horizon	Years	10	
Discount Rate	Percent	8.00	

Cattle Baseline Information

Production Information Category	Unit	Southeast	Northwest
Cows	Dollar/Head	700.00	
Bulls	Dollar/Head	1500.00	
Cows per Bull	Head	20	30
Herd Composition	Percent	50	
Animal Unit Equivalency	AUE	1.00	
Calf Prices	Dollars/Pound	0.75	
Calf Crop	Percent	90	
Calf Selling Weight[2]	Pounds	552	575
Variable Costs	Dollars	118.91	115.36

Sheep Baseline Information

Production Information Category	Unit	Southeast	Northwest
Ewes	Dollar/Head	70.00	
Rams	Dollar/Head	200.00	
Ewes per Ram	Head	33	30
Lamb Price	Dollars/Pound	0.80	
Wool Price	Dollars/Pound	1.00	
Herd Composition	Percent	50	
Animal Unit Equivalency	AUE	0.20	
Lamb Prices	Dollars/Pound	0.80	
Lamb Crop	Percent	92	95
Lamb Selling Weight[2]	Pounds	75	
Annual Wool Production	Pounds	9.2	9.6
Variable Costs	Dollars	176.33	137.76

Wildlife Baseline Information

Production Information Category	Unit	Southeast	Northwest
Year 0-2 Revenue	Dollars	2500	2500
Year 3-9 Revenues	Dollars	3000	3000
Variable Costs	Dollars	500	500

[1] Only those costs that change with changes in the numbers of the herd were included, ie. no variable costs for a 3/4 ton pickup or stock trailer were included, for the change in herd numbers is not significant enough for changes to be necessary in these types of variable costs.

[2] Calf and lamb selling weights were average weights for both males and females.

Table 28

Net Present Value - Northeast North Concho for Control of Heavy Mesquite

Year	Added Units Due to Investment in Brush Control							
	Animal Units (AU)	Sales ($)	Investment ($)	Costs ($)	Wildlife Revenues ($)	Cash Flow ($)	Annual NPV ($)	Accumulated NPV ($)
0	0.2	0	0	0	0	0	0	0
1	3.5	1312	1890	424	0	-1002	-928	-928
2	6.9	2690	1260	759	0	671	575	-353
3	8.8	3413	980	985	500	1948	1546	1194
4	9.1	3413	0	985	500	2928	2152	3346
5	9.3	3480	0	985	500	2995	2038	5384
6	9.6	3547	0	985	500	3062	1929	7313
7	9.9	3547	0	985	500	3062	1787	9100
8	10.1	3614	0	985	500	3129	1690	10790
9	10.4	3681	0	985	500	3196	1599	12389
				Salvage Value:		$4,130	$2,066	$14,455

[1] Results include carrying capacity changes resulting from the investment decision. Analysis was performed on a 1,000 acre basis, making the per acre accumulated NPV for this investment decision $14.455.

TABLE 29

accumulated net present value of $14,455 shown in Table 29 must be divided by 1,000, which results in $14.46 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 the NW and SE portions of the basin are shown in Table30. Present values of these benefits differ by location within the basin. In the SE portion they range from $5.62 per acre for control of light mesquite to $19.40 per acre for control of heavy cedar. In the NW portion they range from $4.58 per acre for control of light cedar to $17.08 per acre for control of heavy cedar.

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 in the SE range from $8.58 for control of heavy cedar with 2-way chaining and burning to $56.02 for control of heavy cedar with tree dozing. In the NW, the state cost share ranges from $10.90 to $58.34 for the same control practices. Total treatment cost, rancher participation or cost-share, and state cost-share for all brush type-density categories are shown in Table 30.

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.

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. This figure is adjusted for the differences in time of water availability and time of cost share expenditures. As was mentioned above, added water from brush control was only estimated for the heavy and moderate categories. The water yields resulting from the brush control program and the estimated acreage eligible for enrolling in the program discussed above are used to estimate the average annual added water yields for each brush type-density category. Likewise, the total state cost share for these two categories is estimated by multiplying the per acre state cost share for each brush type-density category by the eligible acreage in each category.

Present Value of Costs for Brush Control Investment in Dollars per Acre

Southeastern Part - North Concho River

Brush (Type and Density)	Rancher Cost Share	Percent	State Cost Share	Percent	Total Cost
Heavy Mesquite	16.06	29.81	37.82	70.19	53.88
Heavy Cedar (TD)[1]	19.40	25.72	56.02	74.28	75.42
Heavy Cedar (2CB)[2]	19.40	69.34	8.58	30.66	27.98
Moderate Mesquite	8.35	38.15	12.07	61.85	20.42
Moderage Cedar	10.06	39.58	15.36	60.42	25.42
Light Mesquite	5.62	43.50	7.30	56.50	12.92
Light Cedar	5.87	38.07	9.55	61.93	15.42
	Average:	40.60%	Average:	59.40%	

Northwestern Part - North Concho River

Brush (Type and Density)	Rancher Cost Share	Percent	State Cost Share	Percent	Total Cost
Heavy Mesquite	14.46	26.84	39.42	73.16	53.88
Heavy Cedar (TD)[1]	17.08	22.65	58.34	77.35	75.42
Heavy Cedar (2CB)[2]	17.08	61.04	10.90	38.96	27.98
Moderate Mesquite	7.55	36.97	12.87	63.03	20.42
Moderage Cedar	7.53	29.62	17.89	70.38	25.42
Light Mesquite	4.97	38.47	7.95	61.53	12.92
Light Cedar	4.58	29.70	10.84	70.30	15.42
	Average:	35.04%	Average:	64.96%	

TABLE 30

The cost of added water resulting from the control of each brush type-density category is then estimated by adjusting the water yields for the delay in time of availability over the 10 year period, summing them, and then dividing them into the total state cost. By this technique, the cost of added water averages $49.75 per acre foot for the entire North Concho basin and ranges from $47.29 per acre foot for the NW portion to $51.72 per acre foot for the SE portion. Details of the costs of added water for the different brush type-density categories and different sections of the basin are shown in Table 31.

Again, the costs discussed in the previous paragraph only include cost sharing for brush control of the heavy and moderate type-density categories. It could be argued that if the light brush type-density categories are not also controlled, that the estimated 10 year added water yields will not be achieved because the light brush will increase in density and be expected to be in either of the two higher categories by the end of the ten-year period. If the light brush were included in the cost share program and all of the light brush eligible acres were enrolled, it would add another $654,000 to the state's total cost and make the cost of an added acre foot of water cost $52.65, which is only $2.90 more per acre foot.

CONCLUSIONS

The state's 10-year average cost of added water (per acre foot) does not include the cost of purification and distribution as would be needed if the water were to be used by a municipality like San Angelo, Midland, or Abilene. To compare this cost to the current cost of similar existing water supplies, one can calculate their annual cost per acre foot from the investment in their procurement. According to Stephen Brown of the Upper Colorado River Authority (UCRA), the cost of an acre foot of O.H. Ivie Reservoir water (available at Lake Ivie) is $80. An additional $80 per acre foot is needed for transmission of Ivie water to the city of San Angelo, where it must still undergo a similar treatment as would water from O.C. Fisher on the North Concho.

Again, according to the UCRA, the city of San Angelo incurs an expense of $.47 per 1,000 gallons for water to be available from Lake Ivie. This cost does not include a cost for treatment or for the energy to pump the water to the city of San Angelo. At the per acre foot price found for additional available water in the North Concho River, the per 1,000 gallon price of Concho water would be $.15. Given these figures for alternative water supplies, the North Concho brush control program appears to be an economically attractive alternative.

ADDITIONAL CONSIDERATIONS

Total state cost and total possible added water discussed above are based on the assumption that 100% of the eligible acres in each type-density category would be enrolled in the program. There are several reasons why this will not likely occur. Foremost, there are wildlife

Estimated cost to state of brush control and total added water yield per year; with 100% enrollment of eligible acres.

Southeastern (SE) part of N. Concho Basin.

Brush type-density	Total acres	Pres. Val. of State cost share / acre ($)	Pres. Val. of total cost if all enrolled (mil.$)	Ac.ft. added water / ac. / yr.	Total possible added water / yr.
Heavy Mesq.	109,773	37.82	4.15	.081	8,892
Heavy Cedar	56,973	32.30[1]	1.84	.076	4,330
Mod. Brush	31,744	13.72[2]	0.44	.067	2,127
Total (SE)	198,490	32.39[3]	6.43	.077[3]	15,349
10-Year Avg. Cost/Ac.ft. =		$51.72[4]			

Northwestern (NW) part of N. Concho Basin.

Brush type-density	Total acres	Pres. Val. of State cost share / acre ($)	Pres. Val. of total cost if all enrolled (mil.$)	Ac.ft. added water / ac. / yr.	Total possible added water / yr.
Heavy Mesq.	47,027	39.42	1.85	.081	3,809
Heavy Cedar	53,107	34.62[1]	1.84	.076	4,036
Mod. Brush	66,816	15.42[2]	1.03	.067	4,477
Total (NW)	166,950	28.27[3]	4.72	.074[3]	12,322
10-Year Avg. Cost/Ac.ft. =		$47.29[4]			
	Total acres	Pres. Val. of State cost share / acre ($)	Pres. Val. of total cost if all enrolled (mil.$)	Ac.ft. added water / ac. / yr.	Total possible added water / yr.
Total Basin	**365,440**	30.51[3]	**11.15**	.076[3]	**27,671**
10-Year Avg. Cost/Ac.ft. =		**$49.75 Table 1. Treatment Scenarios and Ecological Response Information (Continued, Page2)** [4]			

[1] Cost based on assumption that 50%of cedar is cleared with tree dozing and 50% with 2-way chaining and burning.
[2] Cost based on assumption that 50%of each part cleared is moderate cedar and 50% is moderate mesquite.
[3] Weighted (by brush type acreage) average.
[4] Assuming a 4 % discount rate and a program life of 10 years.

TABLE 31

Cost of including light brush control in the state cost share program

Location	Light brush acres	P.V. of state cost share ($/ac.)[1]	P.V. of total cost (mil.$)	P.V. of total cost for heavy and moderate brush control (mil.$)	10-yr. Avg. Cost /Ac.ft. added water with light brush control
NW	44,863	9.40	0.422		
SE	27,576	8.42	0.232		
Total Basin	72,440	9.03	0.654	11.15	**$52.65**

[1]. Cost based on assumption that 50%of each part cleared is light cedar and 50% is light mesquite.

TABLE 32

considerations. Ranchers will want to leave some brush in strategic locations to provide escape cover and travel lanes for wildlife, especially white tailed deer. It has been suggested that no more than 75 -85% of the brush should be cleared from a given management unit in order to insure maintenance of good wildlife habitat.

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 for many different reasons. An additional consideration is found in research work by Thurow, *et.al.* that indicated that only about 66% of ranchers surveyed were willing to enroll their land in a similarly characterized program. 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.

PROGRAM IMPLEMENTATION 6.0

Given the size of this project and the narrow time window of ideal conditions for herbicide application, it is recommended that initial treatments be spread over a minimum of 4 years. Because follow up treatments will be required to obtain the necessary level of brush control for the length of time required to recharge the aquifer and begin increasing the stream flow in the North Concho River, a long-term funding commitment by the state must be made for this program to succeed.

▸ *Quality Control*

To insure the best possible efficacy of aerial herbicide applications inspection and monitoring of quality control should be performed by the appropriate state agencies. The following items should be considered in inspection/monitoring programs:

- Trained inspectors should be on site to properly mix the herbicides, water, adjuvants, and other spray ingredients. A less desirable alternative would be to train the landowners to perform this duty.

- If the herbicide, water, adjuvants, and other spray ingredients are measured through flow meters on commercial applicators= mixing rigs, then these flow meters should be inspected and proven accurate by inspectors of the Texas Department of Agriculture.

- The speed of aircraft being used to make broadcast applications of herbicides for mesquite control should be monitored by GPS equipment on the aircraft and trained inspectors should verify that air speed does not exceed the maximum deemed acceptable for achieving the appropriate droplet size pattern. The total volume (in gallons per acre) of spray applied to each target area should be monitored by both Geographical Positioning Systems (GPS) output data and direct calculation [(number of loads X gallons/load)/acres covered] to assure adequate coverage of mesquite by the spray and to assure compliance with the contract and spray Aprescription@. This monitoring should be done by trained inspectors who are on site during herbicide applications.

- On site inspectors should collect information on conditions at the time of application to such as shrub phenology, air and soil temperature, soil moisture.

- All aircraft should be equipped with GPS and a standard download format should be required. A trained inspector should carefully examine the download from each target area. The download should be maintained for a period of three (3) years to facilitate correlating mesquite kill with the application data.

- The efficacy (mesquite root kill) on each target area should be monitored at the end of two (2) full growing seasons after treatment by trained inspectors.

▸ ***Administration***

The North Concho Brush Management Program will be administered and implemented at the state level by the Texas State Soil and Water Conservation Board as outlined the Texas Brush Control Plan, developed in accordance with Chapter 203 of the Texas Agricultural Code. Cost share funds will be administered at the local level by soil and water conservation districts based on allocations made by the State Board. Districts will work with individual landowners for developing individual brush control plans, and will enter into cost-share agreements to implement them.

▸ ***Prioritization***

Implementation priorities will be based on the potential for water yield enhancement determined in this feasibility study. Priorities will be established by the local SWCD as requests are received from landowners. Before areas are considered, eligibility determinations will be made by the district to determine if and how much of the area for which assistance has been requested is actually in an identified priority area. Brush density and other necessary on site determinations will also be made by the district or its designee.

▸ ***Cost Share Program***

Cost share funding for this program will be administered by the State Board. Although the Board has rules for cost share programs in place, they do not address the needs for a brush control program. The State Board with input from districts and landowner will adopt rules necessary for implementation of the program prior to September 1, 1999.

The districts that encompass all or portions of the priority areas will have responsibility for implementing the program in those areas within their jurisdiction. The districts involved will be Glasscock County SWCD (251), North Concho River SWCD (252), Coke County SWCD (219), and Tom Green SWCD (248).

The State Board will allocate cost share funds to the responsible districts. Allocations will be based on anticipated amounts of work needed in each district. The districts will then enter into cost-share agreements with individual landowners in the priority areas. Cost share rates will be as set by law and consistent with findings of this study.

Cost share payments will be made by the State Board directly to the landowner upon completion of an identifiable unit of the practice and certification by the local district that the practice has been implemented consistent with specifications. Processing of cost share payments under existing programs requires about fourteen days after the certification is received in the State office in Temple. It is anticipated that processing cost share payment for brush control will take about the same time.

- ***Brush Management Plans***

The responsible district will, with any needed technical assistance provided by the NRCS field office and/or State Board, assist landowners with development of individual plans for brush management for the purposes of increasing watershed water yield. The extent and methods of brush management included in each plan will be determined in accordance with specifications in the Field Office Technical Guide, as approved by the local district. Each plan will include implementation of sound grazing management following treatment. Based on these plans, the district will enter into Cost-share agreements with landowners for the application of brush management in appropriate areas.

The need for grazing deferment is part of the planning process and will be determined by the local district in conjunction with the producer. Cost-share rates determined in this study reflect the cost to the producer for deferment following all practices except chemical brush control. Cost-share rates which include the cost of deferment after chemical treatment will by developed and will be used in cases where such deferment is used.

- ***Quality Control***

All applications of brush management will be in accordance with the Standards and Specifications contained in the Field Office Technical Guide. Certification of the acreage treated and adherence to practice standards will be made by the SWCD upon completion of each practice. Districts or their designees will make spot checks of chemical applicators and application practices during chemical application. The Natural Resources Conservation Service maintains a list of licensed applicators in each district. This list can be made available to producers to help them select reputable applicators. All chemical application will be in accordance with State regulations and by applicators licensed by the Texas Department of Agriculture.

- ***Maintenance***

Each Cost-share agreement will include a maintenance agreement by which the landowner agrees to maintain the brush management practice for a period of ten years after implementing the plan. Cost share rates determined in this study include the present value of future maintenance costs over a ten-year period.

- ***Program Evaluation***

The State Board in conjunction with soil and water conservation districts will work with other entities such as Texas A & M University Agriculture Program to determine the effectiveness of the brush control program as it relates to increasing water yield with in the North Concho Watershed.

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