NORTH CONCHO RIVER
WATERSHED RESTORATION
HYDROLOGIC RESPONSE MONITORING & RESEARCH
2000 - 2006

PREPARED BY
UPPER COLORADO RIVER AUTHORITY
TEXAS INSTITUTE FOR APPLIED ENVIRONMENTAL RESEARCH
AT TARLETON STATE UNIVERSITY

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EXECUTIVE SUMMARY

Since 2000, the Upper Colorado River Authority, which is based in San Angelo, Texas, has been involved in a response monitoring effort within the North Concho River watershed. This approximate 905,000 acre watershed has been the subject of a $17.8 million hydrologic restoration program dedicated to the removal or treatment of phreatophytes (mostly honey mesquite and juniper) to enhance watershed yields. The program began with the publication of a 1998 feasibility study presented to the Texas Legislature. Historical hydrological data reported in the study indicated that since 1960 the watershed has undergone a significant change in hydrologic characteristics including a significant decrease in the production of surface water runoff to O.C. Fisher Reservoir. It was also within this time period that the watershed's brush condition matured to its pre program condition. In the feasibility study, approximately 435,000 acres within the watershed were identified for brush treatment. To date, approximately 302,000 acres has been treated.

The response monitoring effort has focused on measuring various hydrologic parameters such as regional groundwater elevations, measurements of base flows, the number, frequency, duration and distribution of flood flows, in–stream losses, and flood flow hydrograph characteristics. Hydrologic research has also occurred during the period and has generally focused on the collection of experimental hydrologic data in paired watershed situations (treated sites vs. untreated sites).

Even though the watershed response monitoring has occurred primarily under record drought conditions and the implementation of brush control is phased biennially, the data collected to date indicates a gradual shift in hydrologic characteristics to the pre-brush condition. Ground water levels have continued to trend in an upward fashion and numerous previously dry springs and seeps have begun to be active again. Base flows on previously dry or intermittent tributaries have become perennial and base flows on the North Concho River at several locations have steadily increased with time. For the first time in many decades, the North Concho River experienced perennial base flows throughout the entire stream reach. The fact that stream channel losses during storm events have declined significantly since 2000 and the results of a comparative analysis of flood flow hydrographs from similar storm events indicate the onset of a shift in the river's hydrologic behavior to the pre-brush condition. Stream flow monitoring conducted on two almost identical 25,000 acres sub-watersheds (East and West

Forks of Grape Creek) indicates that, on the treated watersheds, perennial base flows have been re-established and produce significant water yield on an annual basis. The untreated sub-watersheds have produced virtually no water yield during the same period. The water produced from the treated watersheds closely matches the quantities predicted not only by the SWAT model, which was used in the feasibility study, but also by the data collected in the ongoing evapotranspiration (ET) hydrologic research project.

INTRODUCTION

On September 1, 1999, the Upper Colorado River Authority (UCRA) was awarded a contract from the Texas State Soil And Water Conservation Board (TSSWCB) to provide services resulting in effective monitoring and assessment of an on-going brush control program on the North Concho River watershed. This award and funding for the brush removal project was provided by the Texas Legislature in response to recommendations contained in the *North Concho River Watershed Brush Control Planning, Assessment and Feasibility Study* prepared in 1998 by the UCRA, the Texas A&M Agricultural Research program and TSSWCB. The purpose of the feasibility study was to determine the potential hydrologic benefits that might be gained through implementation of a brush removal project on the watershed. To measure the effectiveness of the brush control program, the UCRA was tasked with the development and implementation of a multi-task and multi-year hydrologic response monitoring program that included paired watershed research studies, ground water monitoring and surface water flow monitoring. In the subsequent program years, and as the watershed restoration progressed, several other study elements were added, including special studies on Chalk Creek and Grape Creek. Since the initial contract, the watershed response monitoring has taken several forms due to funding methods, but data collections on the watershed have been generally consistent to date. Since 1999, the response monitoring and research on the watershed has been funded through several agencies including the UCRA, Texas Water Development Board, TSSWCB, and the United States Environmental Protection Agency (TSSWCB 319 program). Currently, the program is primarily administered by the UCRA with assistance from the Texas Institute of Applied Environmental Research at Tarleton University. In addition, assistance is obtained from the Sterling County Underground Water Conservation District and the Texas Water Development Board. A project advisory committee made up of Concho River Basin stakeholders also assist UCRA staff in project oversight and planning.

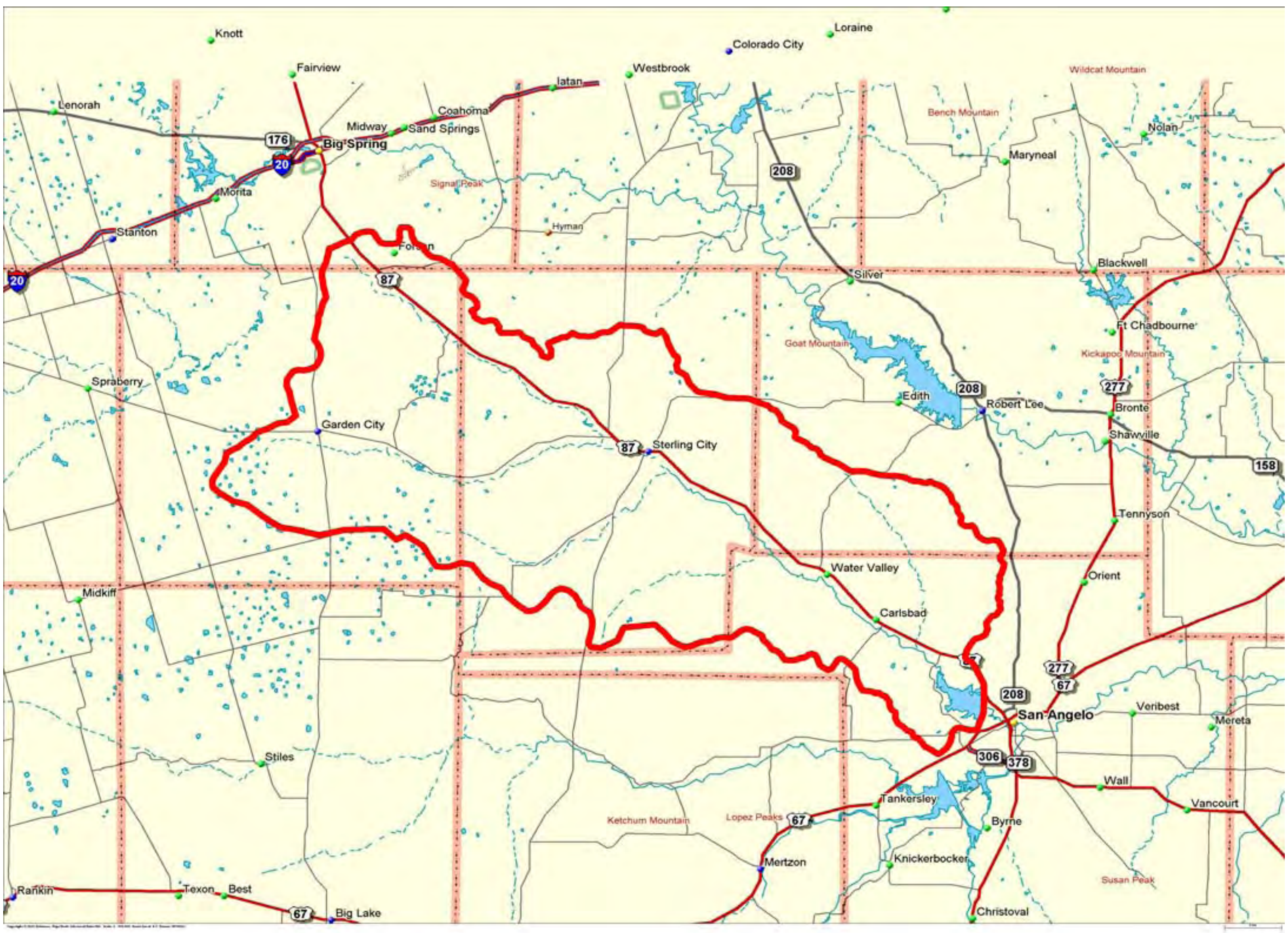
The long term comprehensive monitoring of the North Concho River watershed including both the surface and ground water resources of the watershed is extremely valuable, especially since this is the first program of it's type in the state. The data collected from these on-going studies and the experience derived from implementation of the program will likely effect brush control strategies and programs for decades.

At the outset of the program, the Texas Legislature, TSSWCB and UCRA projected a ten year monitoring period. At the end of the 2006 FY, the program will have been in operation for seven years. The paired watershed and other research studies are entering the sixth year of on-line status and are currently providing research data that has not previously existed in the scientific literature. This information is considered to be of critical importance to the future of brush control efforts and will likely have a considerable impact on every phase of the program from modeling to implementation. The carefully controlled monitoring of the water budget within these sites and the brush removal from the target sites offer opportunities for future research into a variety of other related issues that will be difficult to duplicate elsewhere.

The purpose of this report is to make available the data and information collected to date in the response monitoring and research effort. This data and preliminary conclusions will assist various state and local agency staff and lawmakers in planning future restoration projects and in making critical decisions regarding existing and planned projects. In addition, it is hoped that the data and observations presented herein will provide the impetus to develop new, rational research efforts into the potential water production and water conservation benefits associated with brush removal (particularly the control of honey mesquite within watersheds similar to the North Concho River in hydrologic and geologic characteristics).

DESCRIPTION OF THE WATERSHED

The North Concho river watershed is located in West Central Texas within Tom Green, Sterling, Glasscock and Coke counties. A location map of the North Concho Watershed follows. West Central Texas has a sub-tropical climate; dry in winter, and warm and humid in summer. Average annual rainfall varies from approximately 20 inches in Tom Green County to approximately 16 inches in Glasscock County. Most of the precipitation is received from thunderstorms during 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. While the North Concho river watershed originates in Southern Howard County no significant water course 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 River converge to become 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 storage for a primary water supply. Since construction, O.C. Fisher Reservoir has performed below expectations as a water supply.



In its fifty year history, municipal water has been available from the reservoir for brief and sporadic periods of time. The watershed is utilized primarily for ranch pasture with the propagation of cattle and sheep as 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 in the watershed.

The assumption for this report is that the watershed terminates at O.C. Fisher Reservoir. The City of San Angelo, with a population of 100,000, is the largest metropolitan area located within the watershed. Other communities in the watershed include Grape Creek, Carlsbad, Water Valley, Sterling City and Garden City. There is 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. The area is generally comprised of broad valleys near the rivers and tributaries which consist primarily of geologically recent terrace deposits flanked by hills, buttes and plateaus of Edwards Limestone. Much of the hills and plateaus are covered with juniper, live oaks and small brush, while the valleys are typified by dense mesquite thickets.

- SWAT modeling looked at a 904,926 acre watershed, 37,283 acres was non-productive (1998 Feasibility Study).
- The SWAT model identified (15) sub-basins (most are tributary systems).
- In 1998 432,485 acres of brush was identified as eligible for treatment under the State program.
- Topographically, the watershed consists of broad valleys near the river and tributary systems primarily made up of geologically recent terrace deposits flanked by hills, buttes and plateaus of Edwards Limestone.
- Characteristically, brush distribution within the watershed consists of hills and plateaus covered with juniper and valleys covered by dense mesquite thickets.

Brush Program Status:

- The TSSWCB entered into brush treatment cost share contracts in the fall of 2000.
- Approximately 302,000 acres of brush have been treated at a cost to the state of nearly $13.7 million with the landowners share equaling close to $4.1 million.

Watershed Ecological Changes:

- From historic accounts beginning in the mid 19th century, there has been a dramatic ecologic shift from a grassland prairie to complete infestation of the watershed by juniper and mesquite.
- This shift to the present vegetative condition was generally complete by the mid 20th Century.
- Based on historical accounts and hydrologic records, a “normal” condition of perennial stream flows and the existence of significant aquatic habitats throughout the watershed was enjoyed by the main stem and major tributaries. This changed gradually during the first half of the 20th century to its present condition. This change seems to have been complete following the record drought of the 1950’s.

Watershed Climate:

- Average annual rainfall for the watershed ranges from approximately 16 inches per year on the western edge to approximately 20 inches in Tom Green County.
- Regional rainfall records do not indicate any significant long term changes in annual precipitation.
- Most of the annual rainfall occurs during the spring and fall months in the form of thunderstorms.

Water Consumption within the Watershed:

- Categories of direct water consumption, related to human activities, include organized domestic use, individual domestic use, crop irrigation and livestock uses.

- Direct water consumption within the watershed is almost totally from groundwater sources.
- The total annual direct water consumption within the watershed is currently less than 5,000 acre feet or 0.06316 inches per year per acre.
- Historically, total direct water consumption has steadily declined from a peak period in the 1930's and 1940's.

Watershed Hydrology:

- Based on TWDB water well data, there appears to have been a significant decline in static water levels in water wells within the watershed from the 1940's to the 1960's.
- Based on records obtained at the USGS station near Carlsbad from 1925 through 1959 the following hydrologic characteristics were calculated:

  Average annual stream flow was 38,617 acre feet per year.

  Rainfall runoff events occurred 7.31 times per year.

  Average runoff event produced 4,560 acre feet.

  Runoff events occurred in every month, typically with the most activity occurring in May and the least in December.

  The average annual mean flow was 48 CFS.

  The base flows could be expected to be greater than 2.0 CFS 60.5% of the year.

  Base flows greater than 30 CFS could be expected 20 days per year.
- Based on records obtained at the USGS station near Carlsbad from 1960 through 1996, the following hydrologic characteristics were calculated:

  Average annual stream flow was 8,358 acre feet per year.

  Rainfall runoff events occurred 2.89 times per year.

  Average runoff events produced 3,145 acre feet.

  No runoff events occurred during summer months.

  The average annual mean flow was 30 CFS

  The base flow could be expected to be greater that 2.0 CFS 36.3 % of the time.

  Base flows greater than 30 CFS could be expected 7.3 days per year.
- "Typical" storm water hydrographs from pre and post 1960 storm events contain significantly different characteristics.

FEASIBILITY STUDY

As stated previously, a study was published by the UCRA in 1998 entitled, *"North Concho River Watershed Brush Control: Planning, Assessment and Feasibility*". The study was funded by the UCRA, the TWDB and the Texas Clean Rivers Program, through the Texas Commission on Environmental Quality (TCEQ). Participants in the study included the UCRA, Texas A&M Agricultural Research Station (San Angelo), Blackland Research Facility (Temple), TSSWCB, USDA Natural Resources Conservation Service and others. The study also included considerable input from watershed landowners and the general public. The purpose of the study was to define ecological changes in the watershed over time and determine if those changes altered the hydrologic conditions. The study determined (through modeling) that removal of brush from the watershed could produce hydrologic benefits, and quantitatively estimated those benefits. The study also provided cost/benefit analysis that estimated economic benefits to the landowners and the state. Recommendations to the cost share program were eventually developed by the TSSWCB. The public and landowner participation in the study also proved to be extremely valuable to the resulting brush removal program. As a result, acceptable and workable program requirements were developed and implemented.

The following excerpts are discussions taken from the feasibility study as related to several pertinent topics. They have been included to provide the reader with insight into the content and organization of the feasibility study.

The Effects of Brush Control on Water Yield

"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 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."

"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."

Economic Analysis

"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."

"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."

Implementation

"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 participating in the program based on allocations from TSSWCB. The Districts 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."

PROGRAM IMPLEMENTATION

The feasibility study was distributed not only to state legislators, but also to stakeholders and interested entities located throughout Texas. Initial implementation funds for the North Concho River Pilot Brush Control Project were appropriated in 1999 during the 76th Texas legislative session. Additional funds were appropriated during the 77th and 78th legislative sessions in 2001 and 2003. As of this writing, a total of 314 landowner brush treatment contracts have been entered into with the TSSWCB. Since the program's inception, a total of 302,074 acres have been treated in the North Concho River watershed, with an additional 35,211 contracted acres remaining to be treated. A breakdown of the total acres treated by fiscal year follows:

FY2000- none
FY 2001- 75,000 acres
FY 2002 – 155,000 acres
FY 2003 – 207,537 acres
FY 2004 – 295,510 acres
FY2005 – 299,361 acres
Present – 302,074 acres

Thus far, the total cost has been $13.7 million to the state and $4.1 million to landowners. Program cost share rules call for the state to pay 70% of the cost of mechanical treatment (up to a maximum of $70 per acre) and 70% of the cost of aerial treatment for mesquite (up to a maximum of $27 per acre). These maximum amounts include a financial incentive for the deferment of grazing. Prior to the issuance of contracts or the treatment of brush, Soil and Water Conservation Planners or TSSWCB staff wrote a ten year Conservation Plan which addressed brush concerns, follow-up treatments, prescribed grazing and upland wildlife habitat management. Contracts were then written by a Soil And Water Conservation Planner or TSSWCB staff member. Included within a contract, are maps that delineate and quantify the areas to be treated, the method(s) of treatment and the treatment costs. After the work was performed, the Soil and Water Conservation Planner or TSSWCB staff member certified that the work performed by the landowner complied with the contractual obligations. The certification process was then concluded with the attachment to the file of a map of the actual areas treated and the actual costs of the treatment(s).

Although legislation for a brush control cost share program had existed for several years, until the North Concho River Pilot Project came to fruition, no project of this type had ever been attempted in Texas. The rules governing the administration and implementation of the program had to be developed by the TSSWCB, without the benefit of any previous experience regarding such programs. Similarly, there existed no familiarity or understanding by landowners with the governing rules of such a program. As a result, there existed an initial reluctance by landowners to elect to participate. In an effort to alleviate this situation, several well-publicized public meetings were held to not only explain the workings of program, but also to elicit stakeholder input. As a result, some of the rules were revised to encourage landowner participation. Ultimately, when landowners began to understand and have confidence in the program, the sign-up rate rapidly increased and a waiting list ensued. Contracts were issued on a first come basis and no attempt was made to prioritize areas to be treated.

These procedures and rationale were modified with the initiation of the Twin Buttes Reservoir watershed brush treatment program a few years later. In that program, an attempt was made to prioritize and treat the most productive sub-basins first, and contracts were entered into only with landowners whose land was located within the high priority sub-basins. In retrospect, from a hydrologic standpoint, this rationale provides for a much superior program. The fact that the North Concho program did not utilize this rationale was likely due to an intent by the planners to treat all of the identified brush areas located within the watershed. However, this intent has not been realized and likely cannot be realized, given the nature of a voluntary cost share program conducted on privately owned lands. The final outcome of the approach used in the North Concho River Pilot Project is that, nearing completion of the project, large areas of mesquite in high priority areas have not been treated.

HYDROLOGIC RESPONSE MONITORING

Rationale and Design

The UCRA is conducting a hydrologic response monitoring program In conjunction with the pilot North Concho Watershed Brush Control Project. Given the size of the watershed and the many variables involved, it is impossible to design a monitoring program capable of providing an all-inclusive accounting of water inputs and outputs from which to derive an accurate water balance. The rationale and design of the monitoring program was therefore necessarily based on measuring and comparatively analyzing certain parameters identified and reported in the feasibility study.

Hydrological changes that occurred concomitant with the proliferation of noxious brush were documented in the North Concho feasibility study. As part of that study, a comprehensive analysis of existing hydrological data was performed. The results of that analysis included the identification of various pre-brush and post-brush hydrologically characteristic “norms” for the watershed. These watershed “norms” include the frequency, annual distribution, duration and yield of storm water events, annual base flows and groundwater elevations. The monitoring program seeks to measure these (and similar parameters) and analyze the data to identify and document any indications of a return of watershed hydrologic characteristics from the post-brush condition existent at the inception of the brush control project, to the pre-brush conditions existent prior to 1960. The data collected and analyses performed to date are discussed in the following portions of this report.

Prior to the inception of this monitoring project, two (2) USGS maintained stream flow gauging stations existed on the North Concho River. These stations are the North Concho River near Carlsbad Station, station number 08134000, with flow records available from 1925 to present, and the North Concho River at Sterling City Station, station number 08133500, with flow records available from 1940 to 1984, (at which time the station’s measuring configuration was changed from a total flow to a flood flow station). To enhance coverage, two additional USGS stream flow stations were installed on the river at critical locations and have since operated continuously. The North Concho River above Sterling City Station, station number 08133250, was installed near the source springs of the river on the “U” Ranch north of Sterling City. The North Concho River near Grape Creek Station, station number 08134250, was installed immediately upstream of O.C. Fisher Reservoir.

In the second program biennium, two additional USGS gauging stations were installed on tributaries of the North Concho River. The Grape Creek near Grape Creek Station, station number 08134230, was installed near the mouth of Grape Creek and the Chalk Creek near Water Valley Station, station number 08133900, was installed near the mouth of Chalk Creek. These locations were selected for the installation of gauges because of the significant amount of brush removed within the Chalk Creek and Grape Creek sub-basins.

Additional flow monitoring sites were selected by the UCRA at which to manually measure flows on a periodic basis. Data collected from these sites, used in conjunction with the USGS data, provide a good “snapshot” of the entire stream-reach flow characteristics of the North Concho River at regular points in time. In addition to the characterization of base flows, these data are also used to evaluate various storm event runoff characteristics including the analysis of channel transmission losses.

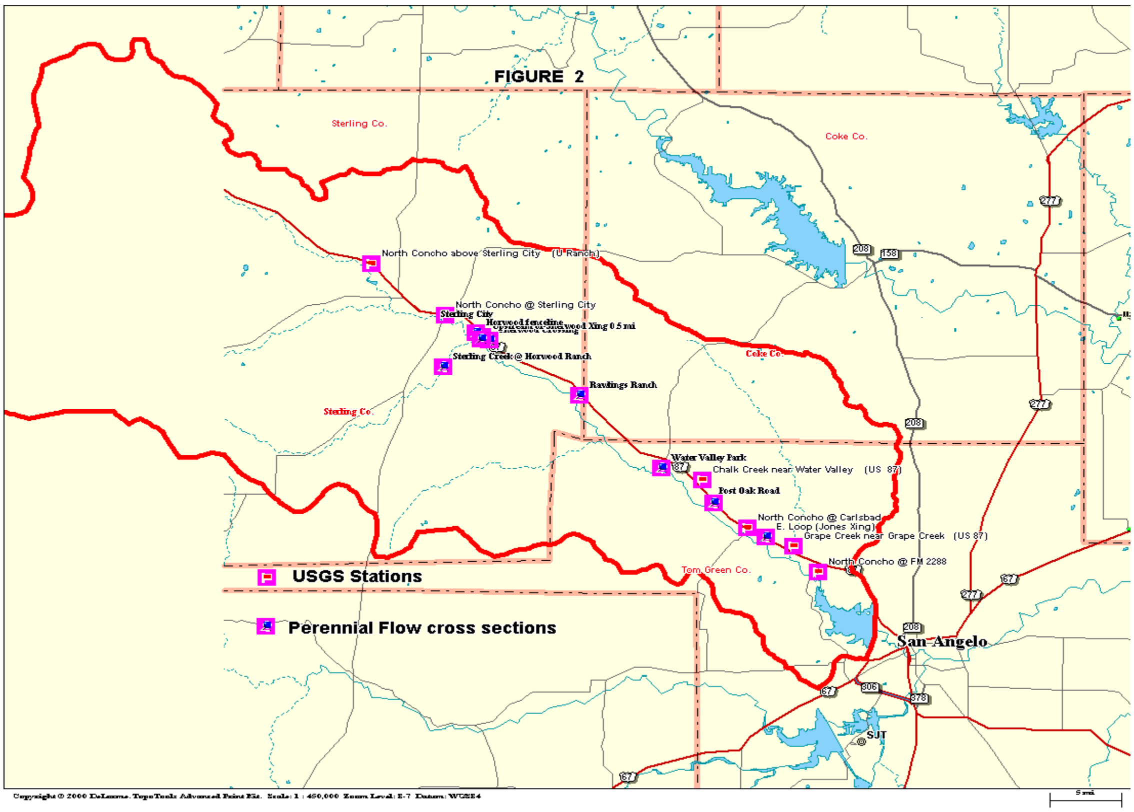
Existing water wells located throughout the watershed are utilized by the UCRA to periodically measure static ground water elevations. These data are used to evaluate water table fluctuations and their effects on surface water flows.

Surface Water Observations

The North Concho River is regaining perennial characteristics. In 2005, the North Concho River began to produce sustained base flows from the headwaters all the way to O.C. Fisher Lake. As of May 2006, approximately forty miles of perennial flow aquatic habitat now exists within the watershed that did not exist in 2000. This habitat presently exists along Sterling Creek, Grape Creek (East Fork) and the normally dry portions of the North Concho River.

Typically, over the last several years of monitoring, the river has had dry segments scattered along its reach. Some of the most notable dry areas were above Sterling City and also between Carlsbad and Grape Creek where the river just disappeared underground. This phenomenon is attributed to depleted alluvial aquifers. Through time, these alluvial deposits have become saturated and now the river runs throughout its reach. Since the North Concho is again transporting water, rainfall events that generate runoff deliver water to O.C. Fisher Lake.

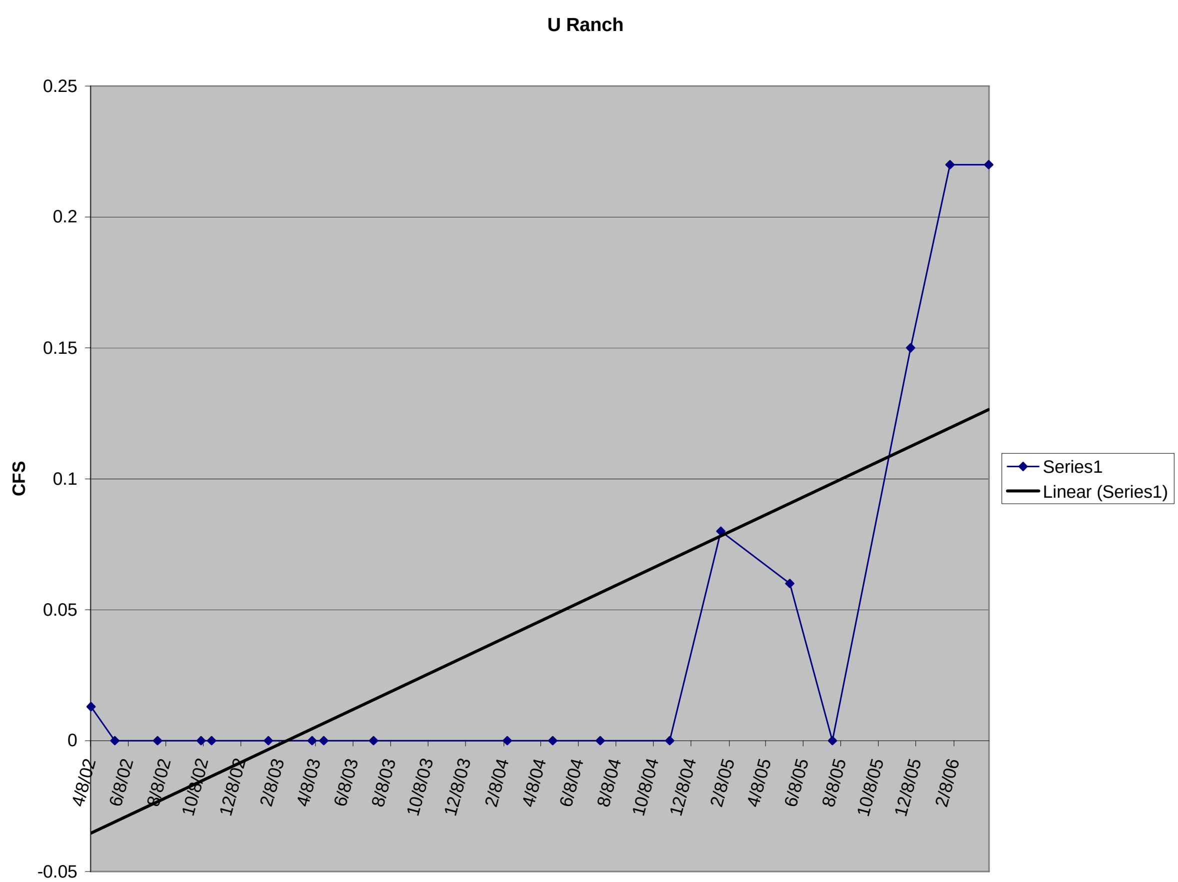
The UCRA currently monitors 10 surface water sites along the North Concho River and 1 site on Sterling Creek, just above the confluence of the North Concho. These stations are visited on at least a quarterly basis and flows are measured. The data accumulated since 2000 reflects a gradual gaining trend in base flows. Even more impressive are the perennial base flows that have continued “non-stop” over the last 18 months on both the North Concho River and Sterling Creek. During this same period, the region has experienced slightly below average precipitation, according to National Weather Service data recorded in San Angelo. Map of sites (fig. 2) as well as flow data are shown below.

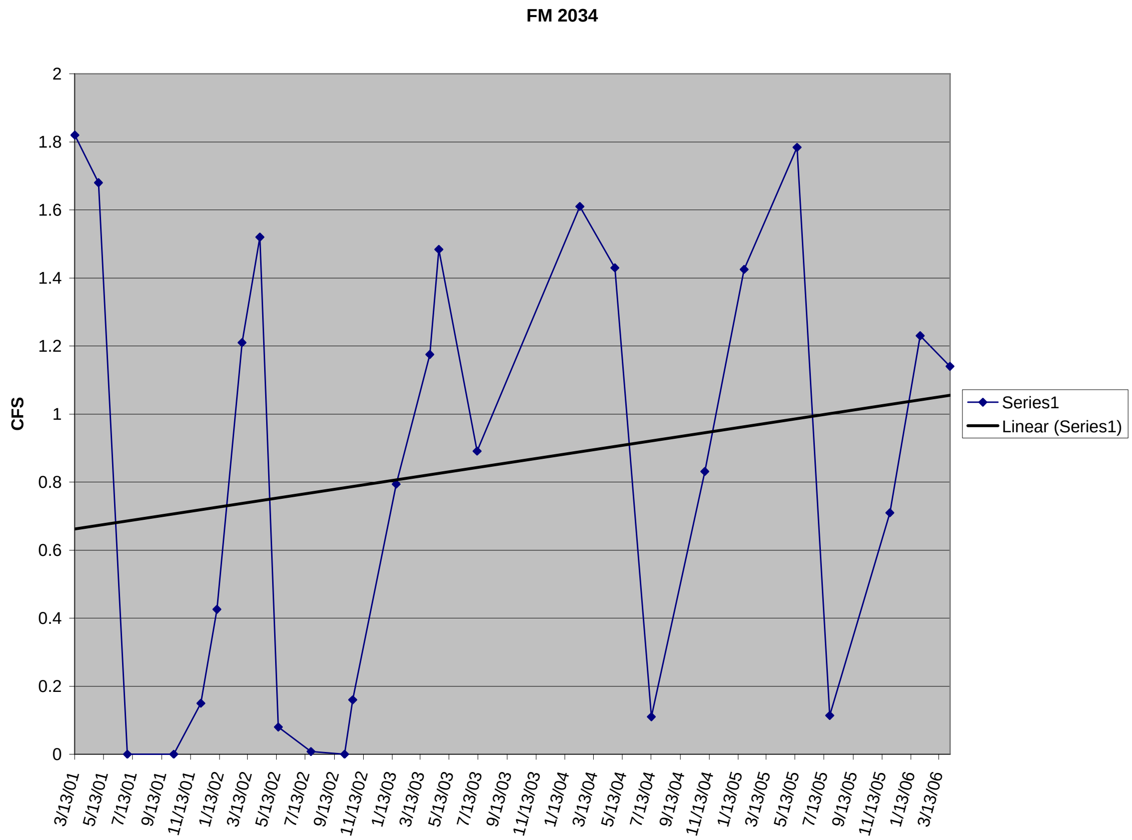


	U RANCH	STERLING CREEK	1.1mi UPST SHERWOOD XING	0.5mi UPST SHERWOOD XING	SHERWOOD XING	RAWLINGS	FM 2034	POST OAK RD	CARLSBAD	E. LOOP	FM 2288
3/29/2000					2.8		9.7	13.82			
5/9/2000								2.67			
12/7/2000					0		1.0	0.8	0	0	0.00067
1/20/2001					0		2.1	1.71	2.4	0.384	0.0013
2/5/2001					0			1.5	0.86		
3/13/2001		0.1026			0		1.82	2.14	1.4	1.04	0.352
5/2/2001		0.024			0	1.14	1.68	1.14	0.5	0.08	0.0035
7/2/2001		0			0	0	0	0	0	0	0
10/8/2001		0			0	0	0	0	0	0	0
12/4/2001		0			0	gate locked	0.15	0.16	0	0	0.013
1/7/2002		0			0	gate locked	0.426	0.058	0	0	0.0022
3/1/2002		0		0.06	0*	1.12	1.21	0.84	0	0	0
4/8/2002	0.013	0.052		0.11	0	1.15	1.52	1.988	0	0	0
5/17/2002	0	0		0.009	0	0.253	0.08	0.029	0	0	0
7/25/2002	0	0	0.054	0	0	0	0.0078	0.0063	0	0	0
10/4/2002	0	0	0	0	0	0	0	0	0	0	0
10/21/2002	0	0	0.023	0	0	0.17	0.16	0.033	0	0	0.097
1/21/2003	0	0.028	0.127	0	0	0.908	0.794	1.048	0	0	0
4/2/2003	0	0.057	0.208	0.0516	0	1.299	1.175	1.34	0.2	0	0
4/21/2003	0	0.055	0.205	0.0452	0	0.9303	1.484	0.873	0.5	0	0
7/11/2003	0	0	0.458	0.147	0	0.404	0.891	0.738	0.5	0	>0.01
2/13/2004	0	0.186	POOL	0.086	0	1.31	1.61	1.65	0.6	0	0
4/27/2004	0	0.17	POOL	0.121	0	1.1	1.43	1.75	1	0.57	0.13
7/13/2004	0	0	0.12	0	0	0.29	0.11	0	0	0	0
11/3/2004	0	0.042	POOL	0.06	0	0.925	0.831	0.223	0	0	0
1/25/2005	0.08	0.224	0.265	0.308	0	1.328	1.4253	1.474	2.2		
5/17/2005	0.06	0.2577	0.2291	0.4452	0.0038	1.078	1.784	1.868	3.5	0.678	0.48
7/25/2005	0	0.04	0.21	0.16	0	0	0.114	0	0	0	0
11/29/2005	0.15	0.31	0.356	0.58	0.24	1.36	0.71	0.85	1.6	0	0
2/1/2006	0.22	0.38	0.71	0.98	1.5	1.32	1.23	3.26	6.2	0.72	0.86
4/5/2006	0.22	0.31	0.27	0.41	0.34	0.82	1.14	1.06	1.8	0.89	0.31

(1 CFS) x 449= GPM

Graphs of the data collected along with trend lines are shown below. These graphs are listed in hydrologic segments, beginning with the upper reach of the watershed at the U Ranch and continuing downstream through the middle reaches at FM 2034, and finally at the lower reaches of the watershed at Carlsbad.




FM 2034
CFS
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3/13/01
5/13/01
7/13/01
9/13/01
11/13/01
1/13/02
3/13/02
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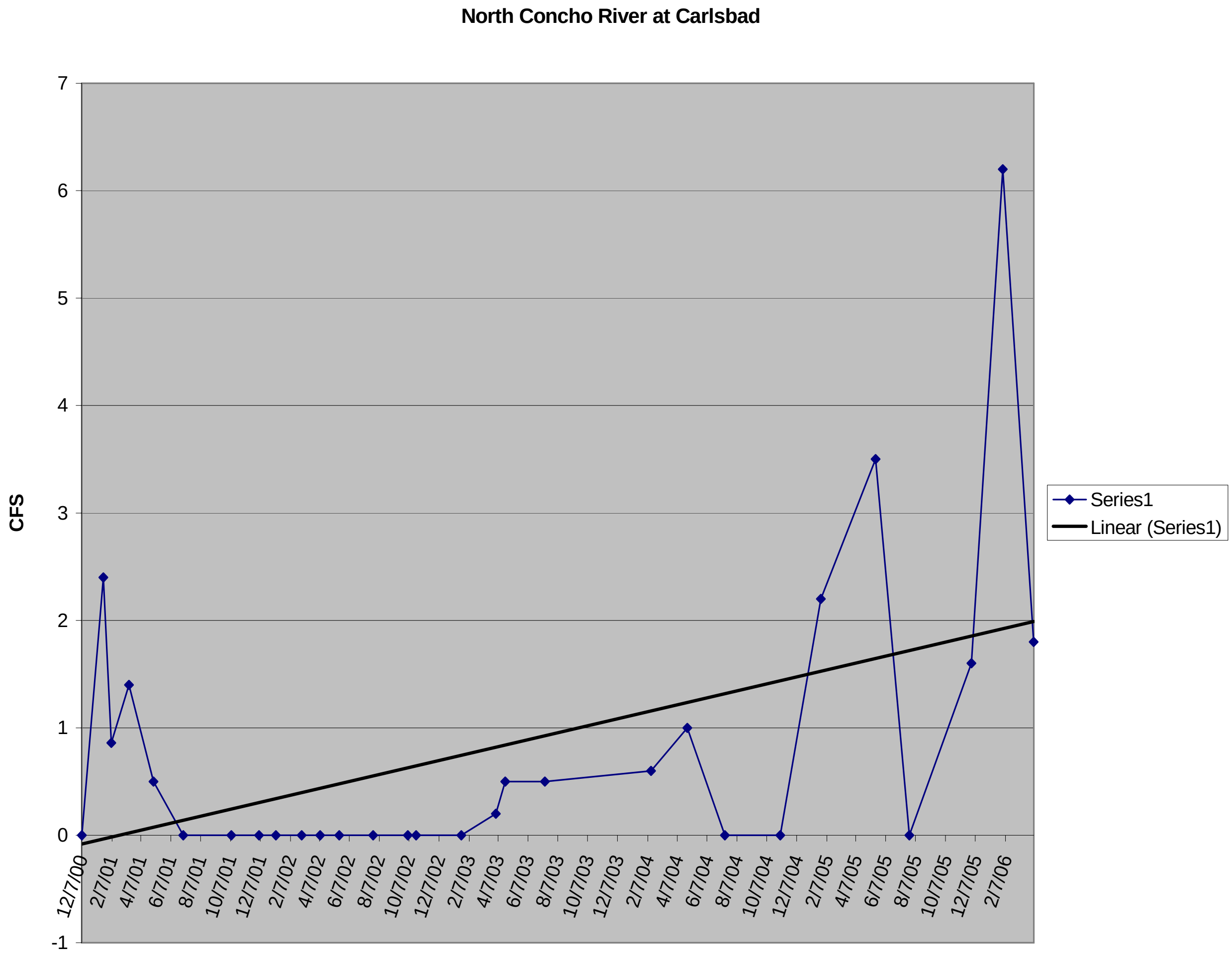
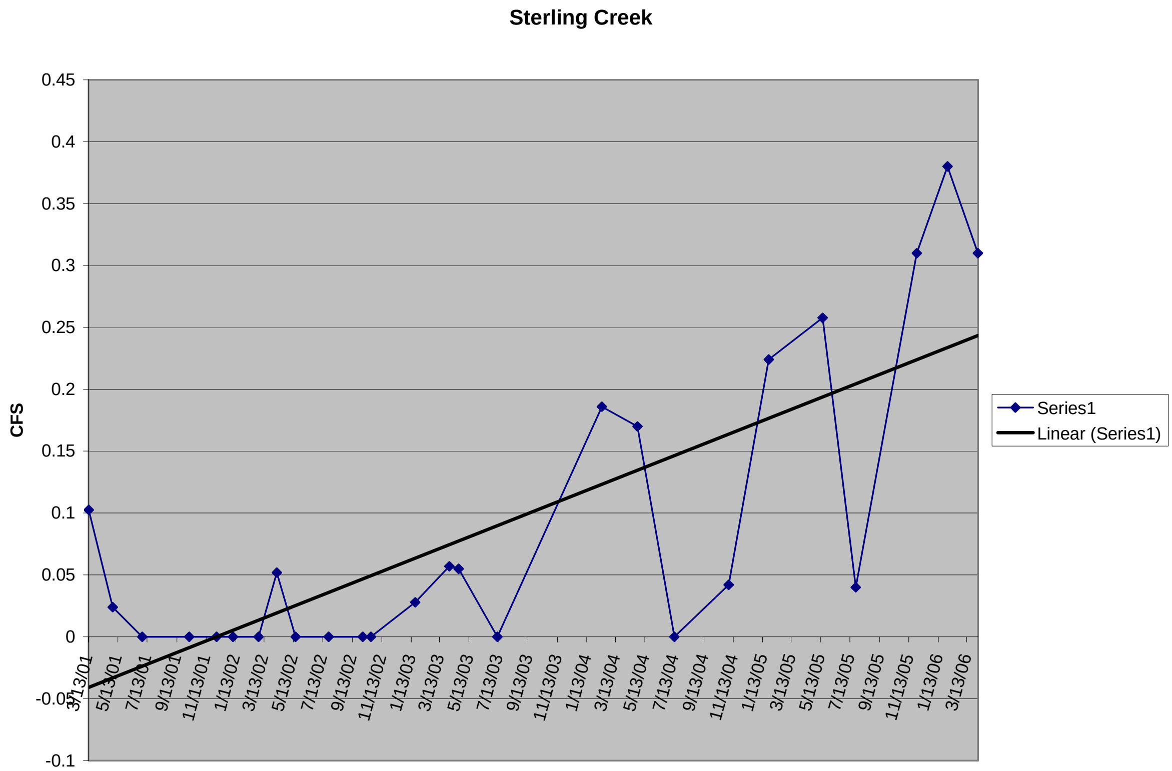
Series1
Linear (Series1)



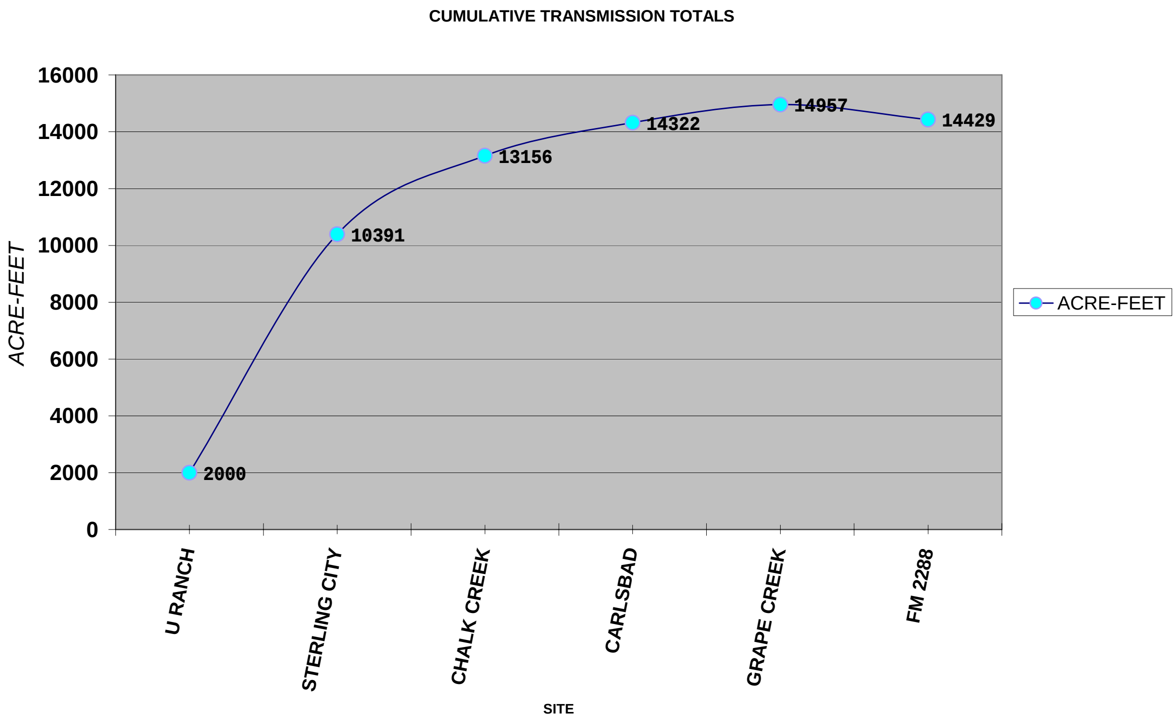
Sterling Creek, a tributary that flows into the North Concho River just below Sterling City is also showing the effects of brush control. A significant amount of the Sterling Creek watershed has been restored to the pre-brush condition and as a result, Sterling Creek has become perennial.

As shown on the following page, Sterling Creek has been flowing continuously since the fall of 2004.

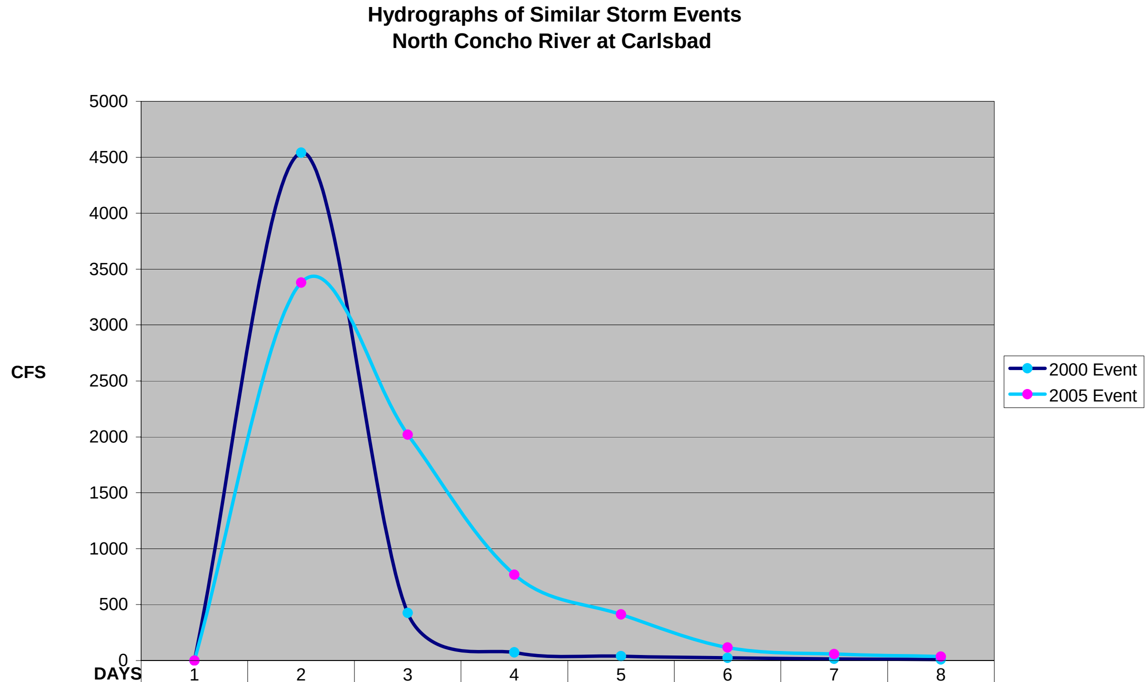


As previously shown in the surface water flow data, many of the monitoring sites had intermittent flows. This condition led to significant channel loss when rain events occurred, hence a significant reduction in the amount of water delivered to O.C. Fisher Lake. Eight run-off events occurred on the North Concho River between 2000 and 2004 when the river was not running and the channel was dry at many locations. Discharge Reports were performed on each storm event, which ranged from minor runoff events (200 CFS peak) to major events (>1000 CFS peak). These reports included Doppler rainfall estimates, USGS gaging station records and calculations of channel losses. For these eight events, the North Concho River failed to deliver on average, 66% of the water to OC Fisher that was gauged within the streambed. In some of the smaller events, >90% of the water was lost.

Conversely, as the streams along the reach became perennial, channel losses were significantly reduced. In contrast to the previously occurring storm events, one that occurred in August 2005 when the river channel was saturated, delivered 96% of the gauged stormwater to OC Fisher Lake. A graph of cumulative transmission totals follows.



For comparative analysis, hydrographs from the August 2005 storm and a similar storm that occurred in March of 2000 are shown on the following page. Both events occurred in the upper reaches of the watershed with very similar characteristics. Fifty percent of the water that flowed down the North Concho River during the 2000 storm did not make it to OC Fisher due to channel transmission losses. Additionally, it is important to note the different slopes of the hydrographs. Most significant is the slope of the falling limb. The falling limb of the 2005 event has a much more gradual decline than the one from the 2000 event. This indicates that a greater percentage of storm generated runoff is being delivered downstream. Not only is more runoff delivered downstream, but the more gradual slope also illustrates that the runoff event is sustained over a longer time interval. The shape of the 2005 storm event hydrograph is indicative of a much healthier ecological condition than the shape of the 2000 storm event hydrograph. It also represents a return to the hydrograph shapes that were typical of storm events occurring prior to 1960.



DAYS	1	2	3	4	5	6	7	8
2000 Event	0	4540	426	73	40	25	16	10
2005 Event	0	3380	2020	769	413	117	58	36

Ground Water Observations

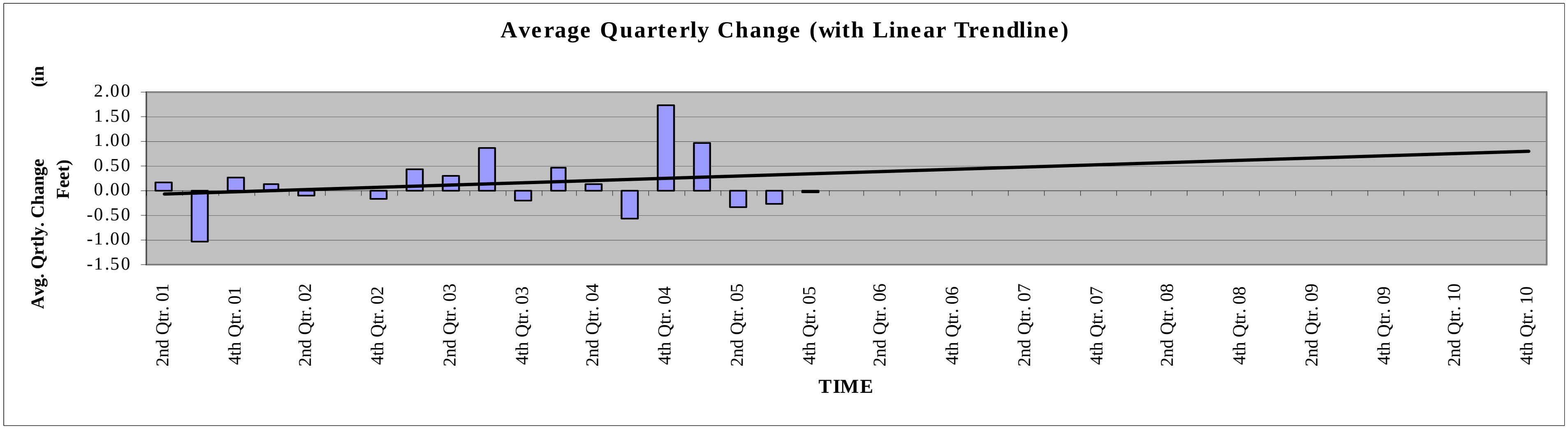
Ground water static elevations are regularly measured by the UCRA. A total of twenty-three (23) wells located in Tom Green and Coke Counties are regularly monitored by the UCRA in the North Concho river watershed. This number varies as access to some wells is lost and replacement wells are added. An additional eighteen (18) wells located in Sterling County are gauged on a quarterly basis by the Sterling County Underground Water Conservation District. Several of the original wells being monitored have become inaccessible due to various causes and can no longer be monitored. Nearby replacement wells have been added in some instances and replacements for others have yet to be located. Moreover, areas of needed additional coverage within the watershed have been identified. Suitably located replacement wells and additional coverage wells (owned by landowners who will allow access) are continually sought.

Discrete monitoring event changes as well as cumulative changes in measured static groundwater elevations are tabulated and graphed for each well that is monitored. For each monitoring event, wells are sorted into three categories, i.e.

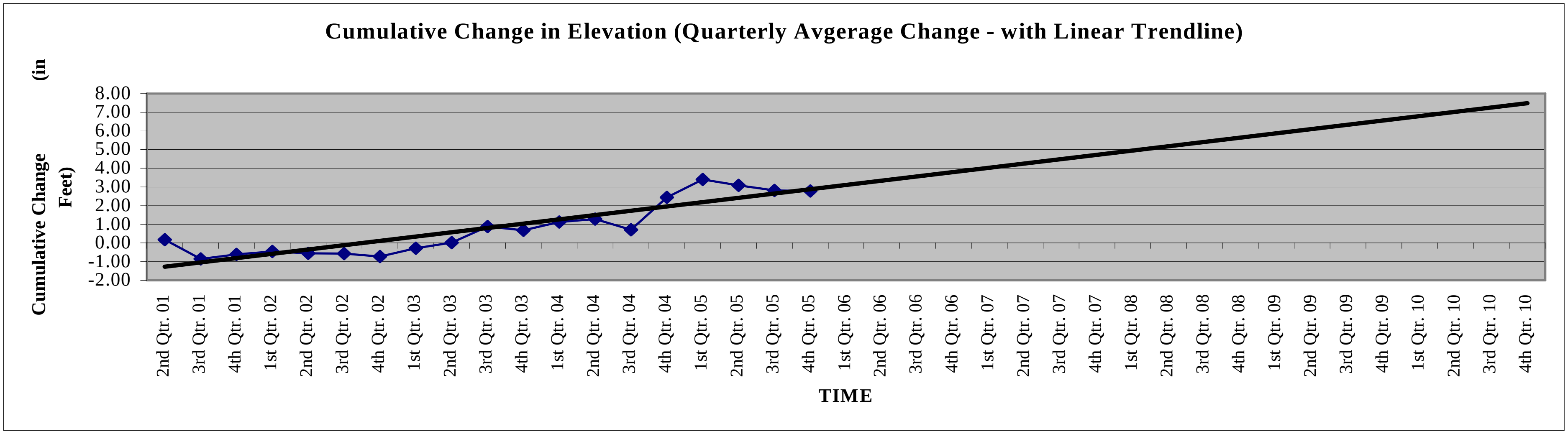
wells in which a decline, a steady state, or a rise in measured hydrostatic elevation has occurred relative to the previous measurement. These data are tabulated and graphed.

On the graphs presented that follow, cumulative quarterly average changes and cumulative annual average changes in static groundwater levels are plotted with trend-lines added. These graphs provide an illustration of hydrostatic groundwater changes through time and an indication of the direction of change in regional groundwater hydrostatic elevations.

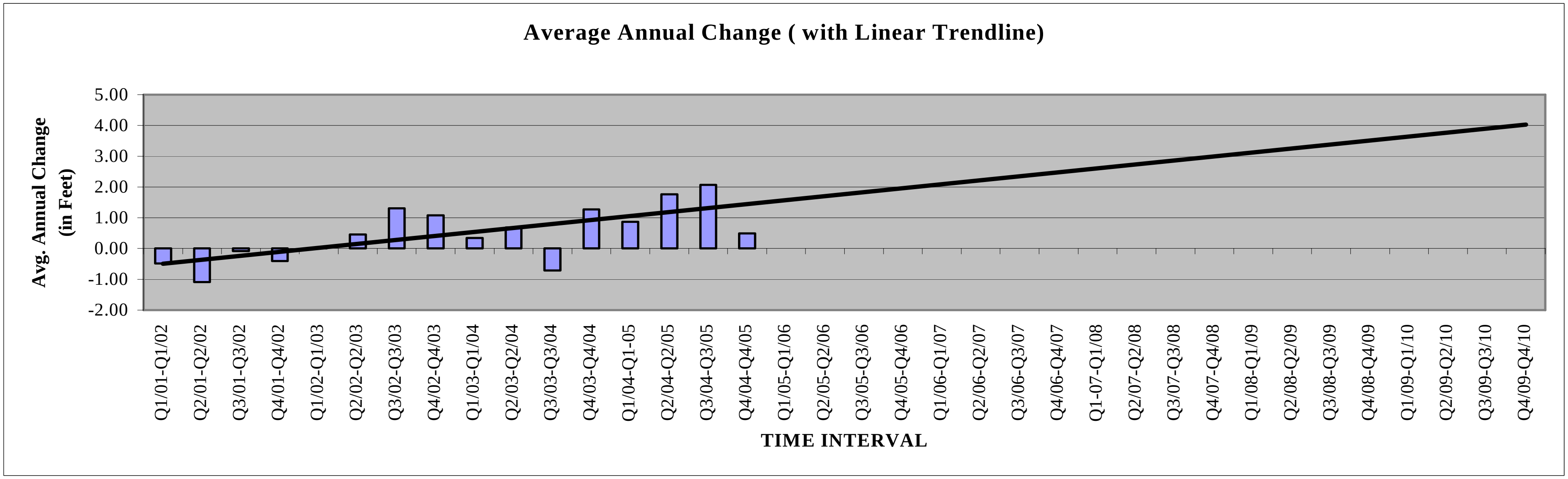
The cumulative changes that are illustrated on the graphs illustrate that hydrostatic ground water elevations are trending upward. As previously mentioned, an all-inclusive accounting of water inputs and outputs on a watershed scale is impossible to achieve. As a result, the determination of unerring cause and effect relationships for the observed hydrologic phenomena is also impossible. However, given that the only identified significant change that has taken place on the watershed over the monitoring period is brush control, it is reasonable to conclude that brush control is the dominant cause for the observed positive hydrologic effects on ground water elevations. The data indicate that alluvial aquifers are being recharged and holding more of the recharge water in storage for longer periods of time; or put another way, the aquifers are not being constantly depleted by deep-rooted mesquites. Moreover, the groundwater that moves from the uplands to riparian areas is not being intercepted by deep-rooted upland mesquites and is able to supply more recharge water to the riparian alluvial aquifers. Therefore, the recharged alluvial aquifers are able to sustain base flows for longer periods of time and curtail major channel transmission losses during storm events.

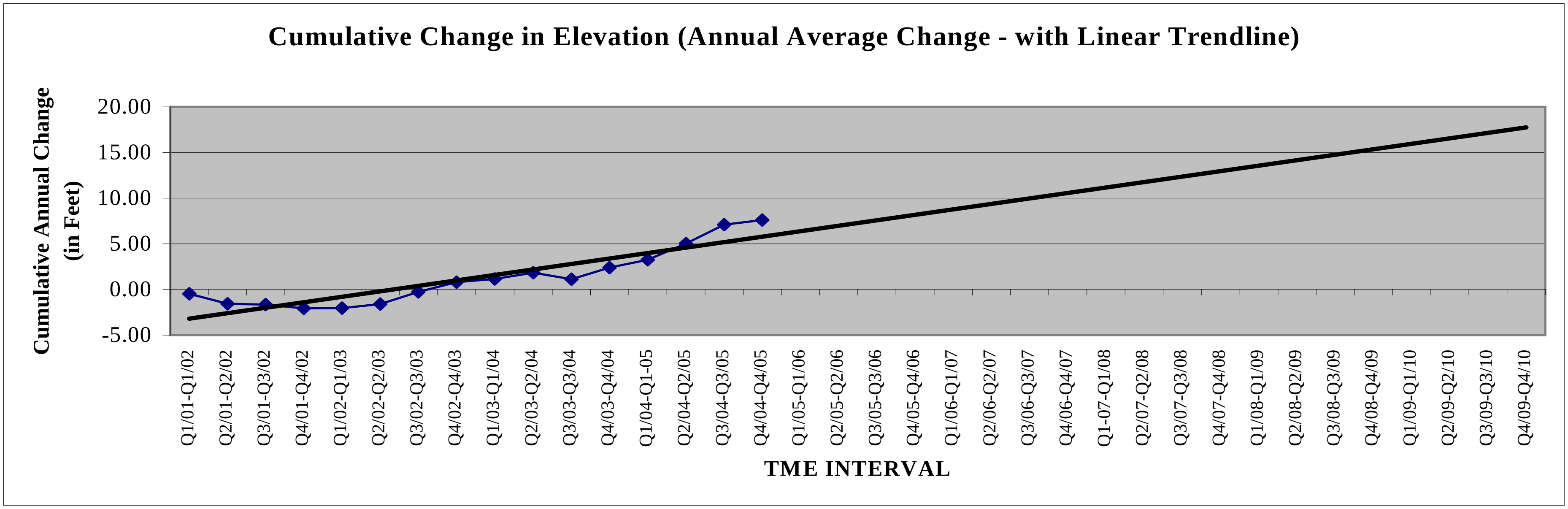


Average Quarterly Change (with Linear Trendline)
Avg. Qrtly. Change (in Feet)
2.00
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
2nd Qtr. 01
4th Qtr. 01
2nd Qtr. 02
4th Qtr. 02
2nd Qtr. 03
4th Qtr. 03
2nd Qtr. 04
4th Qtr. 04
2nd Qtr. 05
4th Qtr. 05
2nd Qtr. 06
4th Qtr. 06
2nd Qtr. 07
4th Qtr. 07
2nd Qtr. 08
4th Qtr. 08
2nd Qtr. 09
4th Qtr. 09
2nd Qtr. 10
4th Qtr. 10
TIME



Cumulative Change in Elevation (Quarterly Avgerage Change - with Linear Trendline)
Cumulative Change (in Feet)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
2nd Qtr. 01
3rd Qtr. 01
4th Qtr. 01
1st Qtr. 02
2nd Qtr. 02
3rd Qtr. 02
4th Qtr. 02
1st Qtr. 03
2nd Qtr. 03
3rd Qtr. 03
4th Qtr. 03
1st Qtr. 04
2nd Qtr. 04
3rd Qtr. 04
4th Qtr. 04
1st Qtr. 05
2nd Qtr. 05
3rd Qtr. 05
4th Qtr. 05
1st Qtr. 06
2nd Qtr. 06
3rd Qtr. 06
4th Qtr. 06
1st Qtr. 07
2nd Qtr. 07
3rd Qtr. 07
4th Qtr. 07
1st Qtr. 08
2nd Qtr. 08
3rd Qtr. 08
4th Qtr. 08
1st Qtr. 09
2nd Qtr. 09
3rd Qtr. 09
4th Qtr. 09
1st Qtr. 10
2nd Qtr. 10
3rd Qtr. 10
4th Qtr. 10
TIME


Average Annual Change (with Linear Trendline)
Avg. Annual Change (in Feet)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
Q1/01-Q1/02
Q2/01-Q2/02
Q3/01-Q3/02
Q4/01-Q4/02
Q1/02-Q1/03
Q2/02-Q2/03
Q3/02-Q3/03
Q4/02-Q4/03
Q1/03-Q1/04
Q2/03-Q2/04
Q3/03-Q3/04
Q4/03-Q4/04
Q1/04-Q1-05
Q2/04-Q2/05
Q3/04-Q3/05
Q4/04-Q4/05
Q1/05-Q1/06
Q2/05-Q2/06
Q3/05-Q3/06
Q4/05-Q4/06
Q1/06-Q1/07
Q2/06-Q2/07
Q3/06-Q3/07
Q4/06-Q4/07
Q1-07-Q1/08
Q2/07-Q2/08
Q3/07-Q3/08
Q4/07-Q4/08
Q1/08-Q1/09
Q2/08-Q2/09
Q3/08-Q3/09
Q4/08-Q4/09
Q1/09-Q1/10
Q2/09-Q2/10
Q3/09-Q3/10
Q4/09-Q4/10
TIME INTERVAL


Cumulative Change in Elevation (Annual Average Change - with Linear Trendline)
Cumulative Annual Change (in Feet)
20.00
15.00
10.00
5.00
0.00
-5.00
Q1/01-Q1/02
Q2/01-Q2/02
Q3/01-Q3/02
Q4/01-Q4/02
Q1/02-Q1/03
Q2/02-Q2/03
Q3/02-Q3/03
Q4/02-Q4/03
Q1/03-Q1/04
Q2/03-Q2/04
Q3/03-Q3/04
Q4/03-Q4/04
Q1/04-Q1-05
Q2/04-Q2/05
Q3/04-Q3/05
Q4/04-Q4/05
Q1/05-Q1/06
Q2/05-Q2/06
Q3/05-Q3/06
Q4/05-Q4/06
Q1/06-Q1/07
Q2/06-Q2/07
Q3/06-Q3/07
Q4/06-Q4/07
Q1-07-Q1/08
Q2/07-Q2/08
Q3/07-Q3/08
Q4/07-Q4/08
Q1/08-Q1/09
Q2/08-Q2/09
Q3/08-Q3/09
Q4/08-Q4/09
Q1/09-Q1/10
Q2/09-Q2/10
Q3/09-Q3/10
Q4/09-Q4/10
TME INTERVAL

HYDROLOGICAL RESEARCH PROJECTS

Evapotranspiration Studies (Honey Mesquite)
See Appendix A

Surface Runoff Studies (Juniper
See Appendix B

Continuous Groundwater Monitoring
See Appendix C

Grape Creek Project
The watersheds of the East Fork and West Fork of Grape Creek are each approximately 25,000 acres in size. Approximately 75-80% of the acreage comprising the watershed of the East Fork of Grape Creek has been mechanically cleared of mesquite and Juniper. With the exception of only a few acres (<300), the watershed of the West Fork of Grape Creek has received no brush treatment.

Following significant rains that fell over the area of these adjacent watersheds in November 2004, the East Fork of Grape Creek began to exhibit base flows. Beginning in January 2005, the UCRA gained permission from the landowners of both watersheds and began periodically measuring flows at various fixed sites on the East Fork and West Fork of Grape Creek. Flow measurements are obtained at fixed sites that cover the entire stream-reach of the East and West Fork from the source springs to sites located just above their confluence.

Cumulative base flows for the East Fork of Grape Creek for all of 2005 plus the first quarter of 2006 equal 2,025 acre feet. The mean annual flow for 2005 calculates to 2.61cfs. These values are based on the measured flows at the measurement site located furthest downstream (just above the confluence with the West Fork of Grape Creek). Although some base flows were measured in the upper reaches of the West Fork of Grape Creek, channel transmission losses resulted in no net flow at the furthest downstream measurement site (located just above the confluence with the East Fork of Grape Creek).

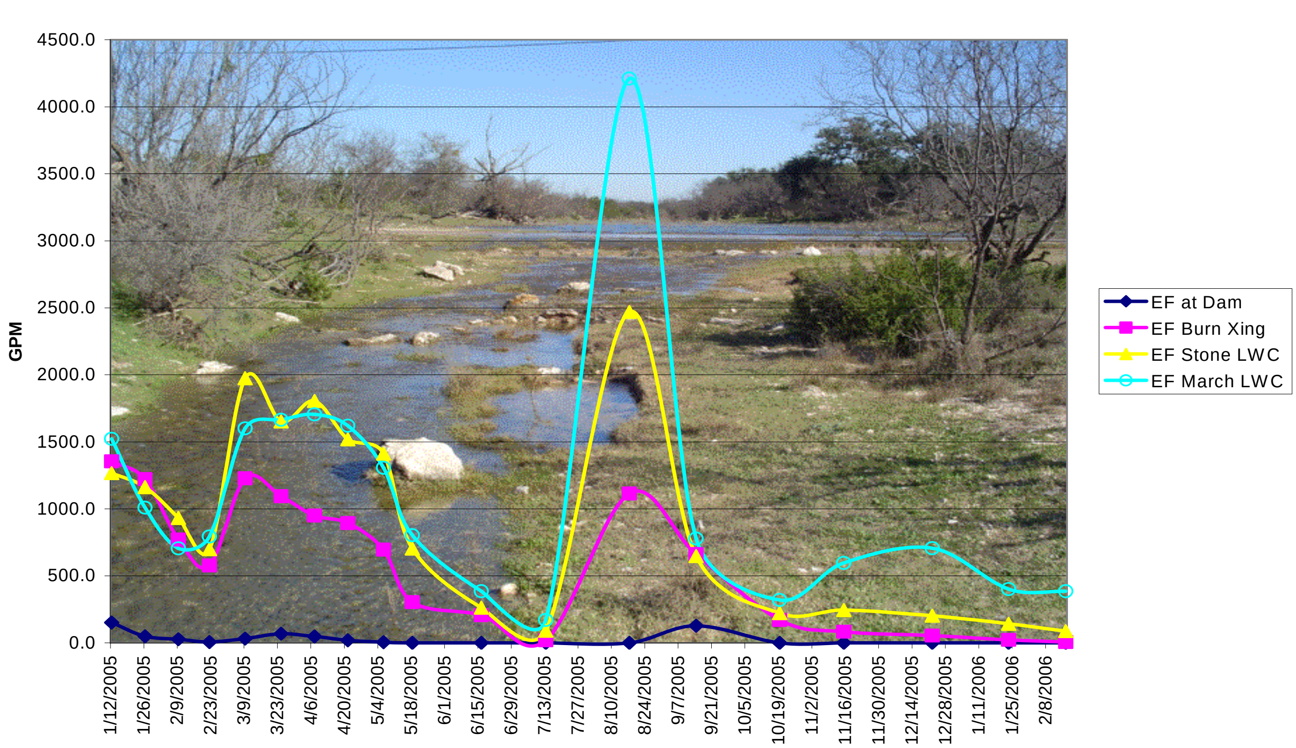
On February 23, 2005, the UCRA installed pressure transducers in the streambeds of the East and West Forks of Grape Creek at the furthest downstream measurement sites of each. These were installed for the purposes of measuring storm event runoff. There have not been enough runoff events and thus, not enough data collected to generate rating curves for either site. Consequently, a quantitative assessment of how much storm water runoff has passed each of these transducers has not been possible. However, it should be noted that during most of the rainfall events that have occurred on the watersheds, the East Fork of Grape Creek experiences small runoff events while the West Fork does not. These small runoff events occur even during relatively minor rainfall events. This phenomenon illustrates the benefit of having perennial conditions existent within a watershed, i.e. even small rainfall events contribute to the total stream conveyance. Conversely, the West Fork of Grape Creek experienced no such benefits from these small rainfall events.

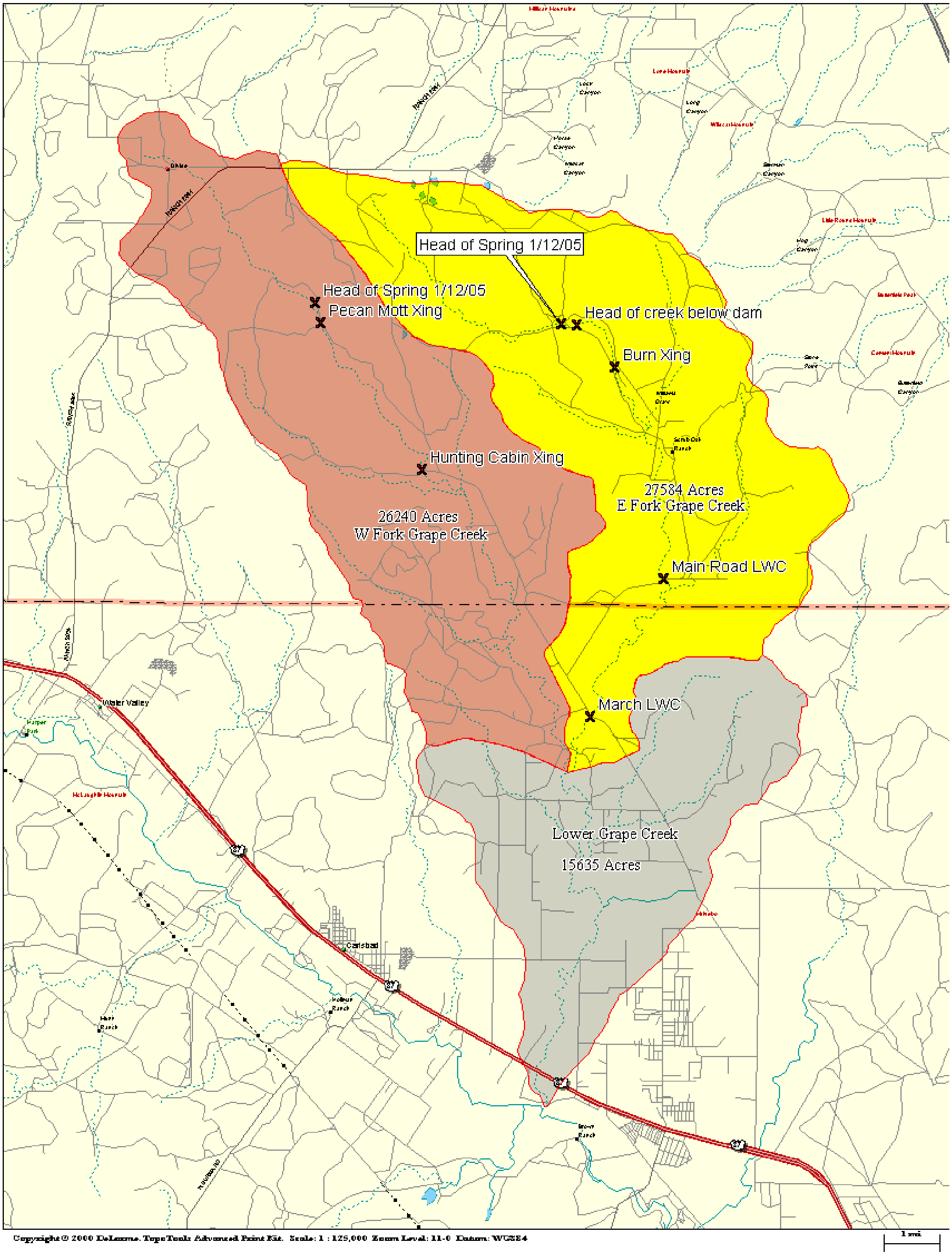
Another meaningful observation, resulting from the work performed by UCRA on Grape Creek, relates to the different characteristics exhibited by the East and West Forks of Grape Creek during a large runoff event that occurred on both watersheds in the middle of August 2005. While the West Fork experienced a large, flashy, one day event, the East Fork experienced not only a large, one day event, but also had significantly increased flows for several days afterward. Moreover, the pools of water that existed in the channel of the West Fork of Grape Creek after the runoff event were rapidly lost to groundwater recharge into depleted alluvial aquifers. This event was the only event for the entire year of 2005 and the first quarter of 2006 during which the West Fork of Grape Creek conveyed any water past its confluence with the East Fork of Grape Creek.

There exists no known plausible cause for the different hydrological behaviors displayed by these two watersheds other than brush control. These flow data are tabulated and graphed below

West Fork Grape Creek

East Fork Grape Creek




Head of Spring 1/12/05
Head of Spring 1/12/05
Pecan Mott Xing
Head of creek below dam
Burn Xing
Hunting Cabin Xing
27584 Acres
E Fork Grape Creek
26240 Acres
W Fork Grape Creek
Main Road LWC
March LWC
Lower Grape Creek
15635 Acres
Water Valley
Carlsbad
Copyright © 2000 DeLorme. Topo Tools: Advanced Print Kit. Scale: 1 : 125,000 Zoom Level: 11-0 Datum: WGS84
1 mi

APPENDIX A

APPENDIX B

APPENDIX C