A Watershed Protection Plan for the Pecos River in Texas

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List of Acronyms

AF	acre-feet
APHIS	USDA Animal and Plant Health Inspection Service
ARS	Agriculture Research Service
BMP	best management practice
BOD	biological oxygen demand
Ca	calcium
cfs	cubic feet per second
Cl	chloride
CMM	Coordinated Monitoring Meeting
CRP	Texas Clean Rivers Program
CSREES	USDA Cooperative State Research, Education and Extension Service
CWA	Federal Clean Water Act
DO	dissolved oxygen
EPA	United States Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FOTG	Field Office Technical Guide
GPS	global positioning system
IBI	Index of Biotic Integrity
I/E	information and education
mg/L	milligrams per liter
LPRB	Lower Pecos-Red Bluff
Na	sodium
NPS	nonpoint source
NRCS	USDA Natural Resources Conservation Service
OFCUF	Oil Field Cleanup Fund
ppm	parts per million
PRAC	Pecos River Advisory Committee
PRBAP	Pecos River Basin Assessment Project
PRCC	Pecos River Compact Commission
RGBI	Rio Grande Basin Initiative
SO_4	sulfate
SWCD	Soil and Water Conservation District
TCEQ	Texas Commission on Environmental Quality
TDS	total dissolved solids
TFS	Texas Forest Service
TNC	The Nature Conservancy
TPWD	Texas Parks and Wildlife Department
RRC	Railroad Commission of Texas
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
TWRI	Texas Water Resources Institute
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey

USIBWC	International Boundary and Water Commission, United States Section
WHIP	Wildlife Habitat Incentives Program
WPCD	Water and Power Control District
WPP	watershed protection plan
WQMP	water quality management plan

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Executive Summary

The Watershed Protection Plan (WPP) for the Pecos River in Texas is the culmination of the Pecos River Basin Assessment Program (PRBAP). The program, initiated in September 2004, was developed to assess the Pecos River watershed and to establish baseline data for a voluntary WPP for the Pecos River watershed.

The Pecos River Above and Below Interstate 10

As the Pecos River winds through arid West Texas, the river and the landscape undergo drastic changes. In the eyes of many landowners in the watershed, Interstate 10 (I-10) is an appropriate dividing line when describing the upper and lower portions of the river and watershed. North of I-10, the watershed consists predominantly of a flat or gently rolling landscape that is dominated by small brush species, such as creosotebush, blackbrush, and four-wing saltbush, interspersed with limited herbaceous ground covers, like gyp grama and alkali sacatone. South of I-10, the landscape changes to plateaus and valleys that are dominated by larger brush species, such as honey mesquite, ashe and redberry juniper, mohr oak and vasey oak interspersed with grasses, like grama species.

The volume of flow in the river below I-10 is starkly different from above I-10, especially below the confluence of Independence Creek in Terrell County. Above this point, inflow to the river is mostly irrigation waters from Red Bluff Reservoir, minimal inputs from intermittent streams, and spring flow. When water is released from the reservoir, the flow fills the river, and its banks become saturated. Once flow has ceased, the banks slowly release the stored water back to the channel. This limited volume of water flowing in the channel affects water quality and reduces any dilution effect that may improve the water quality in the river. Substantial increased flow in the Pecos River is not likely to happen anytime soon; therefore, appropriate management measures are needed to improve its water quality.

Freshwater inflow from Independence Creek more than doubles the quantity of water in the river and, as a result, improves the quality of the river drastically. Below this point, water quality supports healthy aquatic ecosystems; however, a large salt load still flows downstream through this reach. Although this stretch of the river is of better quality than the upper portion, it too can benefit from some components in this plan.

This WPP addresses water quality concerns throughout the watershed. Management measures will be implemented only at the landowners' voluntary request; therefore, management measures are general and can be applied in many locations.

Problem/Need Statement

Much of the Pecos River has extremely salty water, which, in some cases, is not suitable for human or animal use. Although the river has long been used for irrigation, continued use of the salty river water has led to declines in crop production and changes in the crops produced. Human and natural influences throughout the watershed have decreased the water quality and altered the volume of the river's flow over time. According to early documentation, the Pecos River's flow was significantly higher in the past, but the overall health of the watershed has declined enough to impact the economy, society and ecology of the region.

The high salt content in upstream irrigation waters is beginning to affect water quality further downstream. At the Amistad International Reservoir below the outlet of the river, recent evaluations of salinity show that, despite improvements in water quality over the length of the river, the Pecos River still adds about 26 percent of the reservoir's annual salt load while contributing only 9.5 percent of the annual inflow. This reservoir is used as a primary drinking water supply for municipalities in Texas and Mexico. In Texas the drinking water standard for potable water is a maximum of 1,000 parts per million of salts (total dissolved solids [TDS]). That level has been surpassed twice since the reservoir was completed. Long-term average salinity in the reservoir has steadily increased since construction was completed and is getting closer to the maximum drinking water standard.

Water quantity and quality issues also affect the environment. Two segments of the river were recently added to the *Texas Water Quality Inventory and 303(d) List*. Segments 2311_05 and 2311_06, which cover the river between Business I-20 and U.S. Highway 67 (Pecos to Girvin), were included on the 2006 *303(d) List* for depressed dissolved oxygen (DO) levels. To be removed from the list, these areas of the river must meet and maintain the state's water quality standards.

Biological diversity throughout the watershed has also suffered. Wildlife and vegetation surveys have detected significant declines in several plant and animal species, most notably in the river and its riparian corridor. Although some species have declined, the watershed supports healthy populations of many unique and desirable wildlife species, such as the desert bighorn sheep, mule deer, and pronghorn antelope.

Saltcedar, which took over much of the riverbank and choked out natural vegetation, caused much of the damage to these habitats. Recent efforts to control saltcedar with herbicides have been implemented with positive effects; however, both short- and long-term follow-up management measures are needed. In addition, landowners are encouraged to implement proper management strategies to prevent livestock and wildlife overuse of the critical areas.

Several segments of the river have been identified as having depressed DO levels, elevated golden algae levels, and high nutrient levels. DO and golden algae severely impact aquatic species and should be properly managed to improve the health of the river. Nutrients may also affect the quality of water in the river and may lead to excessive vegetation growth and other problems if their levels increase.

Sub-Watershed Approach

In developing this WPP, the size of the watershed and the ability to manage a land area of 10 million acres became problematic. Landowners involved in the development of the WPP suggested that management strategies target specific areas rather than the entire watershed. To address this issue, future watershed management activities will be tailored to one of 11 sub-watersheds within the Pecos River watershed.

Watershed Protection Plan Summary

The WPP for the Pecos River in Texas recommends management strategies that typically address more than one concern. The plan includes an in-depth overview that defines the watershed and its characteristics and provides some of the history behind the current issues. As a primer on management strategies, the WPP also discusses past and current uses of the river and watershed. Landowners' concerns about the Pecos River watershed are discussed, management strategies are recommended, costs are estimated, technical assistance is outlined, and timelines for implementing these strategies and a program to address each concern are included.

Framework of the Plan

The bulk of the WPP follows the U.S. Environmental Protection Agency's (EPA) *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*. This plan includes:

- Identification of the causes and sources of pollutants
- Estimation of expected pollutant reductions
- Identification of critical areas of the watershed
- Description of the management measures needed
- Estimation of the costs of technical assistance and sources of funding
- An information and educational outreach component
- A feasible implementation schedule
- Milestones to assess the effectiveness of plan implementation
- Criteria for assessing success
- A long-term monitoring effort

Together, all sections of the plan provide a systematic approach that can be voluntarily implemented to improve the Pecos River watershed in Texas. This WPP is a starting point to finding the answers to water quality and quantity problems in the Pecos River watershed of Texas and will continually evolve as more information is learned.

What's in the Plan

The WPP includes general practices that can be used in a variety of locations across the diverse Pecos River watershed; however, these practices are not needed in all areas of the watershed and can be implemented if the landowner wishes. These management practices include:

Salinity Management

The Pecos River has had elevated salinity for hundreds of years. Sources of this increased salinity include the Chain Lakes and Bottomless Lakes near Carlsbad, New Mexico, and saline groundwater entering the river near Malaga Bend, about 20 miles north of Red Bluff Reservoir. Pilot projects have shown how controlling this source of salinity can improve Red Bluff's water quality. The WPP recommends these efforts be re-established. Other areas of concern that need more study include the area between Coyanosa and Girvin.

Biological Diversity

Biological diversity needs to be improved or restored across the watershed. Specifically, managing brush is a major concern, especially the continued control of saltcedar and upland brush species. Other brush species, such as giant cane and willow baccharis, are also taking over in some places where saltcedar has been treated. This WPP recommends that landowners implement brush control and proper grazing management strategies where they desire across the watershed. Re-establishing native grasses and employing appropriate grazing management strategies will improve the health of the watershed along with grazing potential and profit margins. Proper grazing practices can increase the land's productivity while improving water use and cleanliness. All of these activities will promote an improved biological diversity throughout the watershed.

Keeping previously controlled brush species in check after treatment is a key component to successfully implementing this plan. Saltcedar leaf beetles can be used to control both regrowth and smaller, untreated saltcedar stands, while appropriate grazing management and periodic prescribed burning strategies will also promote healthy grass and suppress the re-establishment of brush. Spot treatment with herbicides can also be used.

Water Quantity

The quantity of water in the Pecos River has always been a concern for watershed residents. The river flows through one of the driest regions of the state, and the area's water demand is continually increasing. Management measures suggested in the plan can influence the amount of water available for use in the watershed if they are implemented. Irrigation methods, timing of water delivery, and vegetation management are several of the management practices recommended to potentially improve the use of the area's water resources.

Golden Algae

Toxic blooms of golden algae were first observed in the Pecos River more than 20 years ago. Since then, the algae has spread across the western half of the United States. Though widely researched, effective treatment methods for rivers and large reservoirs have not been found and questions about the algae and their fish-killing toxins remain unanswered. As a result, no management measures are recommended in this plan to control present populations and prevent future outbreaks. The plan does recommend that boaters and fishermen thoroughly wash their equipment after each use to prevent cross contamination with other water resources.

Dissolved Oxygen

Improving the DO levels in the river between Pecos and Girvin is a primary objective of this WPP since this area was recently included on the *Texas 303(d) List*. Water with a high salt content cannot hold as much DO as less saline waters; therefore, addressing salinity issues is a logical step. Possible management measures include constructing artificial riffles, installing aeration devices, and implementing nutrient management in upland areas.

Sediment

Sediment loading is not a problem in most areas of the river; however, planned debris removal activities will increase the risk of excessive sedimentation until vegetation is re-established. These excessive sediment loads can destroy vital river habitat, block river flow, increase sediment levels in reservoirs and erosion in channels, cause soil loss, and reduce productivity in the landscape. Proper management practices will help decrease the total sediment load in the river and maintain the integrity of the watershed. Establishing healthy ground cover in upland and riverbank areas will have the greatest positive impact on sediment levels and will increase available grazing in the watershed.

Oil and Gas Production

Many landowners are concerned about oil field production and its affect on water quality. The upper portion of the watershed is covered with oil and gas wells that are being drilled, are producing, or have been abandoned. Some landowners have reported leaking wells and/or improper brine disposal on their land or adjacent lands. The date and location of these potential sources of water quality degradation must be reported to the Railroad Commission of Texas (RRC), the regulatory agency for oil and gas production. The State should address the problem, but available funding is limited. As a result, financial assistance will be sought for these efforts.

Nutrients and Chlorophyll-a

The State has developed screening levels to identify potential concerns for elevated nutrient levels in reservoirs, freshwater streams, tidal streams, and estuaries. Several sections of the Pecos River and Red Bluff Reservoir have elevated levels of nutrients when compared to other waterbodies in Texas. Although nutrients are not currently regulated in the state, implementing voluntary management measures to reduce current nutrient levels would be wise and could potentially prevent future problems. Some of the management techniques and educational activities recommended in this plan will help address this issue.

Technical and Financial Assistance

The project coordinator, a local county Texas AgriLife Extension Service agent or a local SWCD official will be able to provide technical assistance in many situations. If additional assistance is needed, groups such as the Natural Resources Conservation Service (NRCS), RRC, specialists with Texas AgriLife Research, or Extension, the Texas Commission on Environmental Quality (TCEQ), the Texas State Soil and Water Conservation Board (TSSWCB), and the Texas Water Development Board (TWDB) can be contacted. Appendix F of this document provides contact information for regional agency personnel who should be able to provide technical assistance when requested.

Education and Outreach

Education and outreach programs, such as those provided by Extension and other agencies, can help landowners voluntarily implement management strategies on private lands. Providing these educational opportunities is an important part of this plan.

Implementation Schedules and Milestones

The WPP's tentative timelines for implementing recommended management strategies provides a general idea of what is feasible now and in the future. Unknown factors, including available funding and changing weather conditions, can affect the timing of these strategies.

Monitoring and Measuring Success

Evaluating ecological factors within the watershed before and during implementation of the plan will show how these management practices have affected the biodiversity of the area. Wildlife and aquatic species surveys also will provide information on the plan's impact in these areas. Water quality monitoring can be accomplished through automated sampling technology and the Clean Rivers Program (CRP) monitoring, vegetation monitoring, and periodic aquatic species surveys.

Participation in Watershed Protection Plan Implementation

This WPP addresses concerns across the watershed but will not apply to all areas of the watershed because some concerns have a limited impact. The Pecos River watershed in Texas covers about 10 million acres and encompasses many ecosystems. Because the area is too vast for each specific area of concern to be addressed in this plan, recommended management measures are general in scope and will only be applied where landowners desire. This plan has no regulatory implications and will not be used to force anyone to do anything. All actions taken as a result of this plan will be strictly voluntary.

Private Property and Water Rights

Maintaining complete control of privately held land and water rights are primary concerns of many landowners across the watershed. This plan proposes a coordinated approach to establish voluntary partnerships and cooperative efforts while increasing the ability to leverage funding to implement these projects. Although this plan is completely voluntary, it will not improve the quality of the watershed unless it is implemented across the watershed.

Impacts from New Mexico

A primary concern voiced by numerous landowners across the watershed is that New Mexico lies upstream of Texas on the Pecos River and is faced with many of the same issues. Everything that takes place in New Mexico can and, in many cases, does have a significant impact on what happens to the river in Texas. For this reason, it is paramount that New Mexico also addresses these same issues simultaneously, if not prior, to Texas. Primary concerns are the impacts of saltcedar and salinity downstream. Saltcedar cannot be effectively combated in Texas without eliminating the seed source in upstream areas, both in Texas and New Mexico. Similarly, salt loads entering Texas from New Mexico are also problematic. Past research has shown the potential decreases in the salt load entering Texas by pumping salt-laden groundwater from the Malaga Bend area and removing it from the river. The main concern for Texas landowners is that money spent in Texas will result in short-term changes if nothing is done in New Mexico to address major sources of the apparent problems.

Pecos River near the city of Pecos

Introduction

The Pecos River is a dwindling western river flowing 418 winding miles through semi-arid West Texas before entering the Rio Grande. As the largest river subwatershed flowing into the Rio Grande, the 10 million-acre Pecos River watershed in Texas plays a significant role, both biologically and hydrologically, in the future of the Rio Grande Basin. The flows of the once great Pecos River have dwindled to a mere trickle due to many causes, some natural and some man-induced.

The Pecos River Watershed in Texas

The river and its watershed have long served as a vital source of life in the Trans-Pecos Region. Archeological evidence collected in the watershed has verified that humans have relied on the watershed as a source of food, water, and shelter for thousands of years. Artifacts collected at the Bonfire Shelter near Langtry, Texas, revealed that the area was used as a bison jump site where bison were effectively stampeded over the cliff. Native Bison remains and tools found at the site are estimated to be about 13,500 years old (Prewitt, 2007). Numerous other Native American tribes and peoples have also been identified as inhabitants of the Pecos River watershed and, undoubtedly, depended on the waters of the river and springs in the watershed to sustain themselves (Jensen, 2006).

European explorers who traveled through the area during their many conquests recorded the earliest accounts of the Trans-Pecos region. Álvar Núñez Cabeza de Vaca led the way with the first expedition through the region in 1530 and was followed by Francisco Vázquez de Coronado (1540), Fray Augustín Rodriguez (1580), and Antonio de Espejo (1583). De Vaca was impressed with the size and flow of the Pecos River and referred to it in his records as the "great river" while Coronado and Espejo recorded seeing Native Americans using irrigation to sustain their crops near present day Pecos, Texas and San Solomon Springs (Jensen, 2006).

Beginning in the mid-1800s, American exploration and settlement began in the region. When they arrived, many settlers brought cattle with them and their herds often drank from numerous flowing springs as well as the Pecos River. During the late 1860s, cowboys used the Goodnight and Loving trails to drive large herds of cattle from West Central Texas through the Pecos Valley to points north and west. When cattle were driven to the Pecos River at Horsehead Crossing, the lack of water east of the Pecos constituted one of the most serious obstacles along the way. Further compounding matters, alkali ponds adjacent to the Pecos River would often kill cattle that drank from them. Despite these problems, settlers established vast cattle ranches on each side of the Pecos River in the 1870s and 1880s (Daggett, 1985; Dearen, 2000; Eagleton, 1971; Hayter, 1986; Newman & Dale, 1993; Williams, 1982).

The lack of available fresh water in the watershed led to the search for dependable groundwater supplies. Settlers drilled the first water wells in Culberson County near Van Horn in 1849 to fulfill this need. They also relied heavily on numerous springs in the area as dependable sources of water, but these springs were not able to support all of the water needs in the area. In 1853, a

U.S. Army surveying party led by John Pope searched in vain for an artesian water source in Culberson County (Dearen, 2000; Williams, 1982). The crew later drilled successful water wells in Loving County near the state line in 1857 (Dunn, 1948).

Salinity in the Pecos has long been a known water quality concern and led to people establishing numerous water wells capable of providing better quality water. In some cases, people have referred to the Pecos as the “dirty river,” the “salty river” or the “pig river” (Daggett, 1985; Dearen, 2000; Williams, 1982). Salinity levels in the Pecos are commonly above 6,000 milligrams per liter (mg/L) at the Texas-New Mexico state line, often exceed 12,000 mg/L near Girvin, and usually decline to about 2,000 mg/L after Independence Creek converges with the river (Miyamoto et al., 2005). Elevated salinity levels in the Pecos have multiple detrimental effects. The salts limit the types of crops that can be grown and irrigated with river waters and can negatively impact the productivity of crops that can tolerate the salinity levels present. Increased salinity is also detrimental to downstream activities and uses. The Pecos River greatly influences the water quality of Amistad International Reservoir, located just below the confluence of the Pecos and the Rio Grande. Miyamoto et al. (2006) indicated that the Pecos River contributes 9.5 percent of the annual inflow into Lake Amistad and 26 percent of the annual salt load. For a month in 1998, salinity of Amistad exceeded 1,000 ppm, the maximum limit for drinking water, and has since fluctuated below that level. This exceedance greatly concerns those who depend on Amistad as a source of drinking water and should be strongly considered when managing salinity across the watershed. To successfully maintain the salinity levels of the reservoir below 1,000 ppm will require management to control salt loading from the Pecos to the Rio Grande. Reducing salinity in the upper segments of the Pecos in Texas will also make river flows more suitable for livestock use and irrigation of croplands.

Despite the overall contributions of salts into the Pecos and the potential impacts that can be seen downstream, some segments of the river have relatively good water quality. Salinity levels in the upper portion of the river can be restrictive for the majority of agricultural production and are definitely not suitable for human consumption. Below I-10, the river is dominated by spring flow and, as a result, is of much better quality than the upstream portions of the river. These inflows result in a significant dilution effect that greatly improves the quality of the water before it enters the Rio Grande.

Encroaching woody plant species have also drastically altered the Pecos River watershed. Historical accounts indicate that grasses were the dominant vegetation in the watershed and any type of woody plant was scarce at best. The establishment of vast cattle ranches and subsequent over grazing have undoubtedly influenced the shift from grassland to woodland in upland and riparian areas. Saltcedar (*Tamarix spp.*) practically took over riparian areas in the watershed and created monocultures along almost every waterway. Originally introduced to the watershed in the early 1900s to control streambank erosion, this plant has taken over and formed dense stands along the river banks and floodplain (Jensen, 2006). In many cases, saltcedar pulls water from shallow water tables near the river, diverting river flow into these water tables. Based on this information, saltcedar removal is seen as a viable option to increase flows in the river by increasing local water table levels. Removing this noxious plant will also help in re-establishing native riparian vegetation. Upland brush and other nongrass species have also changed the face of the watershed. Areas that were once short-grass prairies are now dominated by mesquite, greasewood, creosote bush, prickly pear, and many other species that have a competitive advantage over native grass species. Proper control practices and long-term management can effectively restore these grasslands to a seminative state that is more productive and produces cleaner, more available water in the watershed.

The Upper and Lower Pecos River

Throughout the river's course across West Texas, the Pecos undergoes a drastic transformation that results in a river that looks and is completely different in its upper and lower reaches. In the upper portion of the watershed, the river is largely comprised of irrigation water releases from Red Bluff Reservoir and occasional storm flow and is relatively poor in quality as compared to the lower portion of the river. Implementing the watershed protection plan (WPP) in the upper part of the river is critical for improving the health of the watershed and the quality of water between the state line and I-10. Addressing salinity, increasing DO, implementing brush control through Texas State Soil and Water Conservation Board (TSSWCB)-certified water quality management plans (WQMPs) and identifying and addressing contributions from oil production will be primary activities that can lead to improvements in this area and will eventually lead to improved water quality that supports designated uses and surface water quality standards.

Below Sheffield and I-10, the river begins to transform into a predominantly spring fed river with greatly improved water quantity and quality as compared to the upper portion. The inflow of Independence Creek adds a vital source of fresh water that doubles the flow of the river and reduces the salinity by half or more. Despite this marked increase in water quantity and quality, the need to implement components of the WPP in this lower portion still exists. Brush control and the development and implementation of WQMPs will sustain, if not improve, the quality of the river and improve watershed health while providing economic benefits to the landowners who choose to participate in implementing this plan.

Pecos River Subwatersheds

To effectively manage the many variables that affect water quality, large watersheds are often separated into subwatersheds. Given the complexity and size of the Pecos River watershed in Texas, this approach seems logical and numerous landowners throughout the watershed prefer this approach. The WPP was drafted as the first step in collectively addressing all water quality issues in the Pecos River watershed of Texas and provides a broad picture of overarching management measures recommended for implementation throughout the watershed. Initial implementation efforts will focus on invasive species control and ecosystem restoration along the main riparian corridor of the Pecos River. As the WPP implementation process continues to encompass the entire watershed, it will be necessary to narrow the focus into smaller subwatersheds. This process will allow for more detailed management focused on the specific subwatersheds and their respective needs.

The U.S. Geological Survey (USGS) has delineated watersheds throughout the country based on surface hydrologic features, which are much smaller than the larger river watersheds. In Texas, the Pecos River watershed has been divided into 11 separate cataloguing units (8-digit) that were determined based on major tributaries that flow to the river (Table 1, Figure 1). These cataloguing units, as defined by the USGS, will be used to divide the Pecos watershed into subwatersheds to facilitate focused water quality management. Most of the tributaries within these subwatersheds are dry creek beds throughout most of the year and only contribute measurable flow to the Pecos during heavy rainfall events (Belzer, 2007).

Lower Pecos – Red Bluff

The Lower Pecos–Red Bluff (LPRB) subwatershed reaches from the state line with New Mexico to just above Tunas Creek in Pecos County and includes 4,430 square miles of land and portions of eight counties. Elevation in the LPRB ranges from 2,276 feet in the lowlands to 5,699 feet in the Glass Mountains of Brewster County. There are ten springs located within the watershed including Comanche, Cottonwood, Diamond Y, Horseshoe, Monument, Rustler, Salt, Santa Rosa, Screw Bean and Toy (http://www.esg.montana.edu). Diamond Y Spring Preserve is owned and managed by The Nature Conservancy (TNC) and provides important habitat for two species of rare desert fishes listed as federally endangered species: the Leon Springs pupfish (*Cyprinodon bovines*) and the Pecos Gambusia (*Gambusia nobilis*). Diamond Y is also home to the federally threatened, rare, salt-tolerant Pecos (or puzzle) sunflower (*Helianthus paradoxus*). Two reservoirs are located in this subwatershed: Red Bluff Reservoir on the main stem of the Pecos just below the state line and Imperial Reservoir in northern Pecos County.

Table 1. Pecos River Subwatersheds in Texas

Hydrologic Unit Code (HUC)	Subwatershed Name	Area (mi^2)
13070001	Lower Pecos – Red Bluff *	4,430
13070002	Delaware *	802
13070003	Toyah Creek	990
13070004	Salt Draw	2,066
13070005	Barilla Draw	864
13070006	Coyanosa – Hackberry Draws	1,502
13070007	Landreth – Monument Draws *	4,145
13070008	Lower Pecos	2,956
13070009	Tunas Creek	1,037
13070010	Independence Creek	784
13070011	Howard Draw	1,119

* This HUC is not entirely in Texas

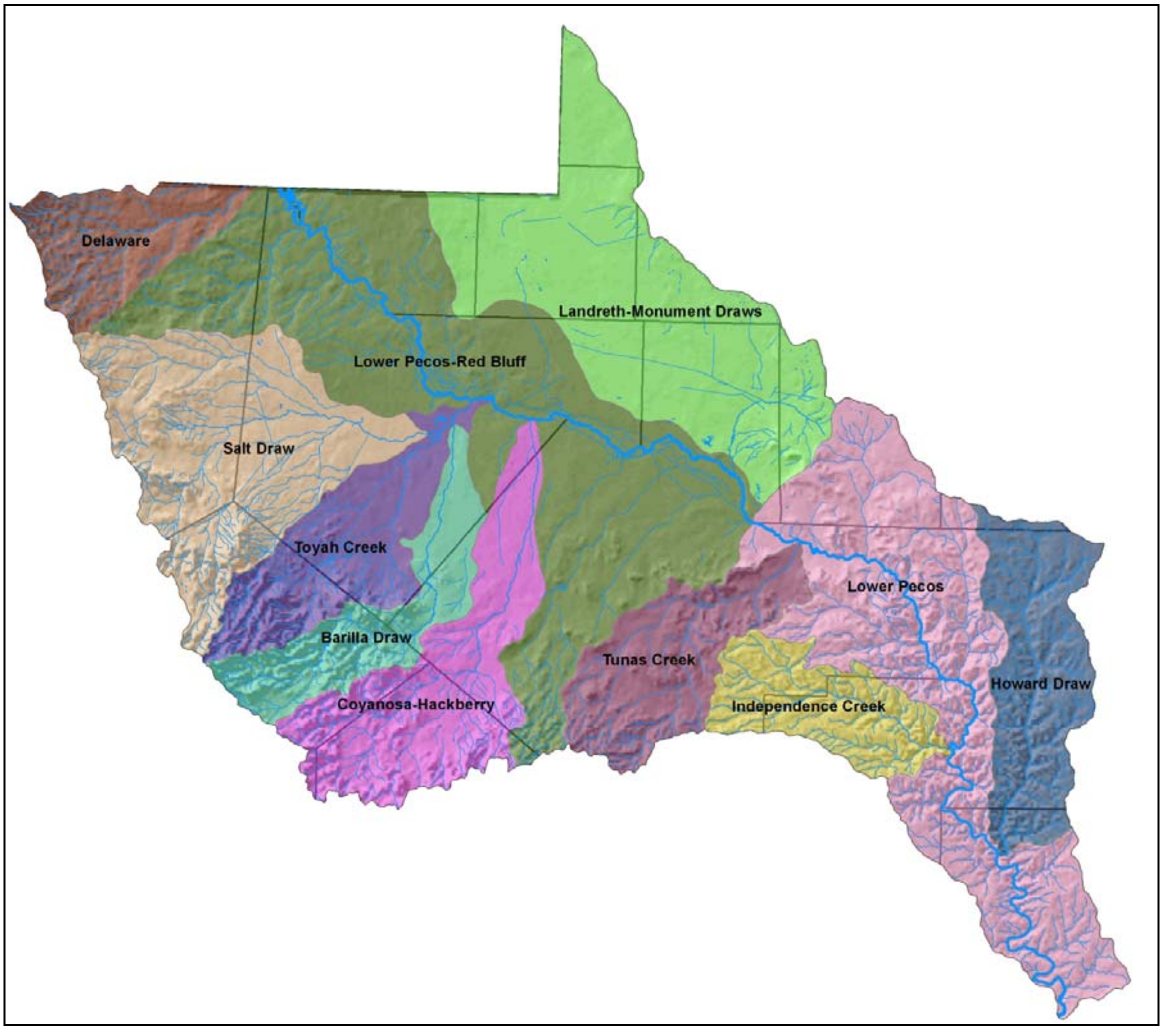


Figure 1. Pecos River subwatersheds (8-digit HUCs) in Texas

The Pecos River flows through the entire LPRB and will naturally be the focus of management activities within this subwatershed. Salt Creek, which travels through Culberson County and drains into the Pecos in Reeves County, will also be a priority for evaluation and targeted best management practices (BMPs). The salt inflow from Salt Creek is estimated at 45,700 tons per year at the annual flow of 3.3 million cubic meters and markedly increases the salinity of Pecos River flows directly below Red Bluff Reservoir (Miyamoto et al., 2005). Detailed monitoring of streamflow and water quality in this tributary will be necessary to assess its current salinity contributions and prescribe management measures. This segment of the Pecos is also listed as impaired by the Texas Commission on Environmental Quality (TCEQ) for having depressed DO levels within the stream and will require management strategies adequately addressing this issue. Riparian and upland brush control in this watershed will aid in maintaining continued freshwater contributions to the Pecos River. Implementing WQMPs in the area will improve overall riparian health and provide an additional step toward maintaining the LPRB diverse ecosystems. In addition, it may be necessary to further fragment the LPRB into smaller subwatersheds due to the large size of this particular cataloguing unit.

Delaware

The Delaware River is a freshwater intermittent stream with its headwaters located in Culberson County, Texas, and its confluence with the Pecos River in Eddy County, New Mexico, just above Red Bluff Reservoir. The Delaware watershed covers 802 square miles and ranges in elevation from 2,851 feet in Eddy County to 8,399 feet in the Guadalupe Mountains (http://www.esg.montana.edu). Guadalupe Mountains National Park is located in the watershed and is home to a unique variety of desert springs, geology, flora, and fauna. Habitats within the park include "succulent and shrub desert in the lowlands and south facing slopes, semi-arid grasslands above 5,000 feet, and mixed coniferous-deciduous woodlands and coniferous forests at the highest elevations" (http://www.nps.gov).

The USGS maintains a real-time streamflow gage on the Delaware near Red Bluff Reservoir and provides access to discharge data from 1938 to present. The lowest mean annual discharge on record occurred in 2000 at 1.32 cubic feet per second (cfs), and the highest occurred in 1938 at 33.9 cfs (http://www.usgs.gov). No known water quality problems are currently associated with the Delaware River and its flows provide significant dilution to the saline Pecos River water entering Red Bluff Reservoir. Riparian and upland brush control in this watershed will aid in maintaining continued freshwater contributions from the Delaware to the Pecos River. In addition, the implementation of WQMPs by private landowners in the area will improve overall riparian health and provide an additional step toward maintaining the unique ecosystems contained within the Delaware watershed. However, because the Delaware River flows into the Pecos River above the state line and Red Bluff Reservoir, implementation of WPP strategies will be a low priority in this cataloguing unit.

Toyah Creek

The Toyah Creek subwatershed covers approximately 990 square miles and passes through Jeff Davis, Pecos and Reeves counties in Texas. Elevation in the watershed ranges from 2,523 feet to 7,734 feet and includes a portion of the Davis Mountains in Jeff Davis County (http://www.esg.montana.edu). San Solomon Spring produces 22 million gallons to 28 million gallons of freshwater per day and feeds the unique desert swimming pool located in Balmorhea State Park. The park also contains the recently recreated Cienega Project, which is a spring-fed wetland ecosystem that provides habitat for endangered fish and other aquatic vegetation, birds, and wildlife (http://www.tpwd.state.tx.us/). Balmorhea Lake, also fed by San Solomon Spring, was impounded in 1917 by Reeves County Water Irrigation District #1 to provide water for local irrigation projects. The lake covers a surface area of 556 acres, has a maximum depth of 25 feet and supports healthy populations of game fish. Phantom Lake and Giffin are other significant springs in the area.

Toyah Creek is an intermittent stream flowing northeasterly from Balmorhea to its confluence with the Pecos River in Reeves County. Although it only contributes surface flow following significant rainfall events, Toyah Creek is possibly increasing the salinity of the Pecos through subsurface flow. Miyamoto et al. (2005) noted that the salinity of the Pecos increases below Salt Draw and Toyah Creek, where both enter into a shallow depression and then seep into the river underground. Belzer (2007) also suggests that due to the high sulfate levels in soil samples taken on Toyah Creek, salts on the surface could be entering the Pecos in notable portions at times when the creek is flowing.

Salt Draw

Salt Draw watershed is located between the Toyah Creek and Delaware subwatersheds in Culberson, Jeff Davis, and Reeves counties and includes 2,066 square miles. Elevation ranges from 2,559 feet in the lowlands to 7,695 feet in the Apache and Delaware Mountain ranges (http://www.esg.montana.edu). No significant surface water resources are located in the subwatershed.

Miyamoto et al. (2005) discusses Salt Draw as being a potential source for measurable salt contribution to the Pecos River. Saline sub-surface flow appears in two places within the Pecos River between the towns of Pecos and Coyanosa, Texas, and it is believed that Salt Draw is one of the sources (Miyamoto et al., 2005). Salt Draw and Toyah Creek merge to form Toyah Lake before entering the Pecos River. Throughout most of the year, both tributaries and Toyah Lake remain dry on the surface, but will flow if sufficient precipitation occurs in the area. During these events, it is quite possible that some surface salts are washed to the Pecos.

Barilla Draw

The Barilla Draw subwatershed is located in Jeff Davis, Pecos, and Reeves counties and covers 864 square miles. The highest elevations within the subwatershed occur in the Davis Mountains in Jeff Davis County, peaking at 7,677 feet, and the lowest elevation is 2,559 feet (http://www.esg.montana.edu). This subwatershed contains unique high-elevation habitat within the Davis Mountains State Park and surrounding mountainous regions. Limpia Creek, a significant spring-fed water resource, originates above Fort Davis, Texas, and drains into Barilla Draw in Pecos County.

Within the Barilla Draw subwatershed, the USGS maintains real-time streamflow gages on Limpia Creek above Fort Davis and Barilla Draw near Saragosa, Texas. The lowest annual mean discharge for Limpia Creek for 1966 to 2007 occurred in 1985 at 0.030 cfs and the highest was in 1984 at 13.4 cfs (http://www.usgs.gov). The lowest annual mean discharges in Barilla Draw for 1976 to 2007 occurred in 1977, 1980, and 2006 with absolutely no flow being recorded for those three years. The highest mean annual flow occurred in 1978 at 23.5 cfs. This illustrates the intermittent nature of the majority of tributaries within the Pecos watershed.

Coyanosa–Hackberry Draws

The Coyanosa–Hackberry subwatershed is located in Brewster, Jeff Davis, Pecos, and Reeves counties in Texas and covers 1,502 square miles. Elevations in the area range from 2,492 feet to 6,976 feet and no significant springs or surface water resources contribute measurable flow to the Pecos River (http://www.esg.montana.edu). Coyanosa and Hackberry Draws are both intermittent creeks that are dry most of the year and may contribute runoff to the Pecos during high rainfall events. As discussed in Belzer (2007), sediment samples taken in Coyanosa Draw reveal that it is an unlikely contributor of pollutants.

This subwatershed includes the town of Alpine, Texas, and Sul Ross State University. Sul Ross houses the Rio Grande Research Center's Sustainable Agricultural Water Conservation Research Project whose goal is "to improve our understanding of the water resources in the Rio Grande Basin and to provide approaches for their sustainable use" (http://www.sulross.edu). Cooperation with this program would provide an ideal partnership to conduct a detailed study of the Coyanosa–Hackberry subwatershed.

Landreth–Monument Draws

The Landreth–Monument Draws subwatershed covers 4,145 square miles and is located in Chaves, Eddy, and Lea counties in New Mexico, and Andrews, Crane, Ector, Loving, Upton, Ward, and Winkler counties in Texas. Elevation in the watershed ranges from 2,316 feet to 4,419 feet and does not include any mountainous regions (http://www.esg.montana.edu). The subwatershed is situated on the east side of the Pecos River and does not contain any significant surface water.

Oil and gas production in the Landreth–Monument watershed is extremely high and an unknown amount of brine water created in the process likely makes its way to the Pecos River. Abandoned and improperly plugged wells provide a direct conduit to underground aquifers and may be a source of groundwater contamination. Many landowners throughout the Pecos watershed have expressed concern over the observed and potential negative effects oil field activities are having on the Pecos River and its watershed. Identifying and addressing these problem areas will be one of the focuses in the Landreth-Monument subwatershed.

Lower Pecos

The Lower Pecos subwatershed covers 2,956 square miles and includes Crane, Crockett, Pecos, Reagan, Terrell, Upton, and Val Verde counties in Texas. Elevations range from 1,166 feet to 3,240 feet and the terrain becomes deep canyon lands carved by the Pecos River in the southern end of the watershed (http://www.esg.montana.edu). The Pecos River is the only perennial surface water resource and its mouth is located at the southern end of the watershed where it converges with the Rio Grande in Amistad National Recreation Area.

The Pecos River and its adjacent riparian zone will be the primary focus within the Lower Pecos subwatershed. Continued saltcedar and upland brush management will be necessary to help sustain groundwater recharge. This segment of the river, above Independence Creek, is also listed by the TCEQ as having depressed DO levels and will need to be managed accordingly. The confluence of Independence Creek with the Pecos, the most significant freshwater contribution to the Pecos River in Texas, is located in the Lower Pecos subwatershed. Maintaining the integrity of this valuable resource will remain critical to Pecos River water quality. Independence Creek is discussed further in its corresponding subwatershed section.

Tunas Creek

The Tunas Creek subwatershed covers 1,037 square miles and is located exclusively in Pecos County, Texas. Elevation in the watershed ranges from 2,240 feet to 4,898 feet (http://www.esg.montana.edu). Tunas Creek is an intermittent stream flowing only during high rainfall events and no significant perennial surface water resources are within the subwatershed. Focused strategies for WQMPs in this subwatershed may include brush control and grazing management along with investigation of oilfield activities influencing water quality.

Independence Creek

Independence Creek subwatershed covers 784 square miles and is located in Pecos and Terrell counties. Elevations in the watershed range from 1,861 feet to 3,599 feet (http://www.esg.montana.edu). Independence Creek is the largest freshwater tributary of the Pecos River in Texas and drastically improves both water quality and quantity in the river. Below the confluence of the Pecos and Independence Creek, the river's flow volume increases by 42 percent and total dissolved solids decrease by 50 percent (http://www.nature.org). This virtually transforms the Pecos, providing the water necessary to support both recreation and healthy populations of aquatic species.

The Chandler family and TNC have permanently protected approximately 20,000 acres along Independence Creek through conservation easements and are committed to maintaining the ecological integrity of this resource. Caroline Spring, located on the Nature Preserve, produces 3,000 gallons to 5,000 gallons of fresh water per minute and contributes approximately 25 percent of Independence Creek's flow (http://www.nature.org).

Howard Draw

The Howard Draw subwatershed covers 1,119 square miles and is located in Reagan, Crockett and Val Verde counties in Texas. Elevation in the watershed ranges from 1,619 feet to 2,913 feet (http://www.esg.montana.edu). Howard Draw is an intermittent stream only flowing in high rainfall events and no significant perennial surface water resources are within the watershed. Focused strategies for WQMPs in this subwatershed may include brush control and grazing management along with investigation of oilfield activities influencing water quality.

Watershed Boundaries

The Pecos River enters Texas just east of the 104^{th} meridian, and continues to flow southeast 418 river miles before emptying into the Rio Grande and the International Amistad Reservoir in Val Verde County. The river creates the eastern boundary of the most mountainous and arid region of Texas, known as the Trans-Pecos. It also forms the boundaries of Loving, Ward, Reeves, Pecos, Crane, Crockett, and Terrell counties. Andrews, Brewster, Culberson, Ector, Jeff Davis, Presidio, Reagan, Upton, and Winkler counties are also included in the Pecos River watershed (Figure 2). The Pecos River watershed in Texas is bound by Texas' Colorado River Basin to the northeast and by the Rio Grande watershed on the south and west.

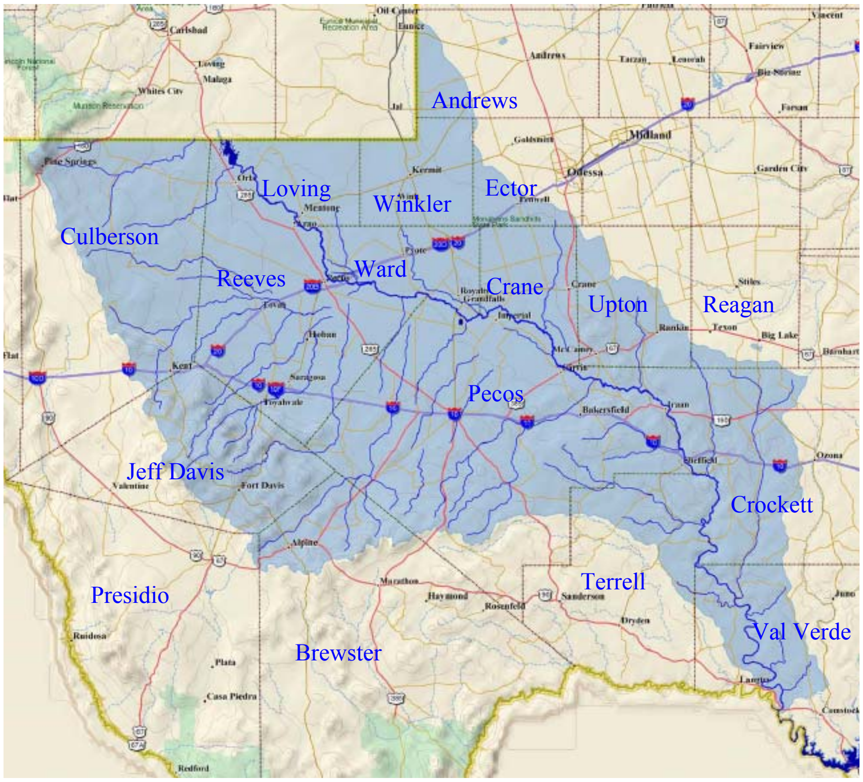


Figure 2. Pecos River watershed of Texas including counties (in blue)

Land Use and Land Cover

National Land Cover Dataset information from 2001 was used to delineate land uses and land coverages for the Pecos River watershed. Primary land uses and land cover were divided into seven major categories. Rangeland is by far the dominant land cover in the watershed and accounts for approximately 68 percent of the land area. Grassland is the second most prominent land cover found in the watershed accounting for about 28 percent of the watershed area. Uses for these land covers include primarily livestock and wildlife grazing. The remainder of the watershed (4 percent) is split between many different land uses and land covers. The largest of these are quarries (2.2 percent), combined forest (1 percent), urban (0.37 percent), agriculture (0.26 percent), water (0.08 percent) and wetlands (0.0087 percent). These seven land uses and land covers account for 99.9 percent of the watershed; the remaining 0.1 percent is dispersed over 43 other land use and land cover categories.

Figure 3. Level IV Ecoregion map of west Texas (adapted from Griffith et al. 2004)

Ecoregions

In Texas, the Pecos River watershed encompasses approximately 10 million acres and a variety of ecological regions (Figure 3). According to Griffith et al. (2004), there are 10 distinct Level IV Ecoregions in the watershed, each with its own characteristics, land uses, and vegetation types. These include the:

- Chihuahuan Desert Slopes (Ecoregion 23a)
- Montane Woodlands (Ecoregion 23b)
- Chihuahuan Basins and Playas (Ecoregion 24a)
- Chihuahuan Desert Grasslands (Ecoregion 24b)
- Low Mountains and Bajadas (Ecoregion 24c)
- Chihuahuan Montane Woodlands (Ecoregion 24d)
- Stockton Plateau (Ecoregion 24e)
- Shinnery Sands (Ecoregion 25j)
- Arid Llano Estacado (Ecoregion 25k)
- Semiarid Edwards Plateau (Ecoregion 30d)

The Chihuahuan Desert Slopes and Montane Woodlands are located on the north western boundary of the watershed in Culberson County. These two ecoregions encompass the Guadalupe Mountains and their isolated ecosystems and vegetation communities. At elevations above 5,500 feet, juniper, pinyon pine, and oak are the dominant vegetation species with isolated areas of Douglas-fir, southwestern white pine, and ponderosa pine present. Elevations from 2,000 feet to 5,500 feet include a chaparral community, grassy plateaus, and riparian areas surrounding springs dominated by velvet ash, chinkapin oak, Texas madrone, bigtooth maple, maidenhair fern, and sawgrass. Succulent desert shrubs tend to dominate the lower slopes with interspersed areas of grasslands mixed throughout and scarce water resources (Griffith et al., 2004). This area is almost, if not entirely, included in the Guadalupe Mountains National Park and is designated as a wilderness area used primarily for recreational purposes (http://www.nps.gov).

The Chihuahuan Basins and Playas make up approximately half of the Pecos River watershed in Texas and have the hottest, most arid climates in Texas with annual rainfall averaging less than 12 inches per year. This region is predominantly below 3,500 feet in elevation and has saline or alkaline soils, salt flats, sand dunes, and windblown sands.

Vegetation in the region has adapted to withstand the low moisture conditions and large temperature variations of the region; some vegetation species include creosotebush, tarbush, fourwing saltbush, blackbrush, gyp grama, and alkali sacatone. Saltcedar and giant cane have invaded riparian areas and completely dominate the riparian corridor in many cases. Grazing and irrigated agriculture exist in this predominantly rangeland region, but is limited due to the scarcity of water. Irrigated crops include cotton, pecans, alfalfa, tomatoes, onions, and chile peppers (Griffith et al., 2004).

Chihuahuan Desert Grasslands occur predominantly on the western edge of the Pecos River watershed and are situated on areas of fine-textured soils with a higher water-holding capacity than surrounding soils. Average annual rainfall in the area is as high as 18 inches. Historically, these areas were almost exclusively grass dominated, but excessive grazing pressure in the late 19^{th} and early 20^{th} centuries has led to the invasion of brush species. Typical grasses found in this region are black, blue and side oats grama, bush muhly, tobosa, beargrass, and galleta; Creosote bush and cholla cactus are scattered throughout (Griffith et al., 2004). Grazing is the typical land use; however, some irrigated agriculture exists where groundwater is available.

The Davis Mountains, the Apache and Delaware Mountains, and the periphery of the Stockton Plateau are disjunct areas of the watershed that are all included in the Low Mountains and Bajadas Ecoregion. This terrain has shallow, rocky soils that support a predominantly desert shrub vegetation community. Typical shrubs include sotol, lechuguilla, yucca, octillo, lotebush, tarbush, and pricklypear with and interspersion of black grama and other grasses. In higher elevations of the region, juniper and pinyon pine are common and gray oak, velvet ash, and little walnut are typically found in the drainages coming down from the highlands (Griffith et al., 2004).

At elevations above 5,000 feet, the Chihuahuan Montane Woodlands characterize the landscape in the Davis, Glass, and Apache Mountains. Increased rainfall at these elevations support woodland ecosystems dominated by oaks, junipers, and pinyon pine. In isolated locations, Ponderosa pine, Douglas fir, southwestern white pine, and whiteleaf oak thrive. A mixed understory of shrubs and herbaceous cover is present in all locations (Griffith et al., 2004).

The Stockton Plateau is similar to its eastern neighbor, the Edwards Plateau. Because of the much drier climate in the Trans Pecos region, the Stockton Plateau supports a more desert-type plant community dominated by mesquite and juniper on the plateau tops with shrub-type oak species on the slopes. Smaller shrubs and grama grasses are interspersed throughout the area (Griffith et al., 2004).

The Shinnery Sands forms the northeastern boundary of the Pecos River watershed. This ecoregion is named for the oak species that helps hold the sands blown from the Pecos River toward the Llano Estacado. Moving sand dunes, sand hills, and flat sandy recharge areas are sparsely covered with sand sagebush and prairie grasses, such as sand dropseed, sand bluestem, and big sandreed. This area has limited use for grazing land due to the sparse vegetation available; however, oil and gas production in the area adds considerable value to the land (Griffith et al., 2004).

To the east of the Shinnery Sands lies the Arid Llano Estacado. This region is typified by a Trans-Pecos type climate that limits the area's productivity. Playas are not as common in this area as they are to the north and west. Precipitation is adequate to support grazing operations and irrigated agriculture is possible where groundwater is sufficient. Oil and gas production is also widespread throughout the area (Griffith et al., 2004).

Precipitation is the factor that makes the Semiarid Edwards Plateau different from the rest of the Edwards Plateau to the east. Geologic formations are not weathered to the extent that those farther east are due to the relative lack of precipitation. Mesquite and juniper species dominate upland areas while live oak thrive in the valleys where soils are deeper. Other arid shrubs are common such as lotebush, lechuguilla, sotol, and redberry juniper. Short grasses are common in the western portion of the area with buffalograss, tobosa, and black grama being the most dominant (Griffith et al., 2004).

Agriculture and Economy

Farming has historically been very important to the economy of communities in the Pecos River watershed in Texas. The Torres Irrigation Company began using the waters of the Pecos River in 1870 to support irrigation in Pecos County in 1870. This effort watered 480 acres that produced 12,000 bushels of corn that year (Williams, 1975). In 1877, the Pecos River Irrigation Company was incorporated to take water from the Pecos River and develop irrigation on 320 acres (Bogener, 2003; Daggett, 1985; Dearen, 2000; Williams, 1982; Bogener, 1993). By 1914, work had started or had been completed on 10 irrigation projects stretching from Arno (near the Texas-New Mexico state line) to Girvin about 150 river miles downstream (Lingle & Linford, 1961). On paper, more than 173,000 acres of irrigable land were included in these 10 projects, but less than 30,000 acres were actually cultivated (Jensen, 2006). Some crops grown in the Pecos watershed of Texas throughout the early 1900s included cantaloupes, alfalfa, vegetables, grapes, orchard crops, and strawberries (Newman & Dale, 1993).

The Texas Water Development Board (TWDB) reported in 2001 that irrigated acreage rose to 233,578 acres in 1958 and peaked at nearly 260,000 acres in 1964 because of widespread groundwater pumping. Irrigated acreage began to decline in the 1970s because of rising costs to pump groundwater from greater depths and because less water was flowing in the Pecos River (Table 2). Currently, irrigated acreage has increased slightly in the region with data from 2000 showing 73,171 acres in the Pecos watershed.

Table 2. Total acreage irrigated in the Pecos Basin of Texas

County	1958	1964	1969	1974	1979	1984	1989	1994	2000
Brewster	234	220	0	148	248	233	120	116	145
Crane	0	0	0	0	0	115	12	12	0
Crockett	805	1,320	1,718	908	909	450	341	345	118
Culberson	9,905	10,480	8,974	8,429	21,105	9,819	9,013	2,806	5,620
Loving	700	273	68	51	40	0	42	583	358
Pecos	117,413	119,313	55,043	51,795	27,291	31,232	25,296	24,369	27,083
Reeves	96,000	118,200	82,035	78,170	36,502	27,061	19,509	27,526	24,063
Terrell	111	207	277	106	194	166	264	196	96
Upton	550	2,810	5,676	6,486	14,002	12,067	10,906	13,573	9,843
Val Verde	2,200	1,300	1,575	1095	870	1022	792	835	953
Ward	5,660	5,447	6,496	5,536	1,788	284	3,204	2,651	4,892
Total	233,578	259,570	161,862	152,724	102,949	82,449	69,499	73,012	73,171

Data compiled from TWDB, 2001.

These data also reveal trends in groundwater and surface water uses for agricultural irrigation since the 1950s (Tables 3 and 4). For example, groundwater pumping for irrigation totaled more than 684,972 acre-feet (AF) in 1958, peaked at 777,785 AF in 1964, and has generally declined ever since. In 2000, groundwater pumping totaled 176,541 AF (TWDB, 2001).

Table 3. Acre-feet of groundwater used for irrigation in the Pecos Basin of Texas

County	1958	1964	1969	1974	1979	1984	1989	1994	2000
Brewster	0	50	0	130	311	427	238	327	430
Crane	0	0	0	0	0	90	7	22	0
Crockett	1,839	3,197	3,167	2,090	1,305	338	412	419	160
Culberson	29,176	24,512	31,861	28,935	46,885	20,051	14,145	5,583	24,765
Loving	0	0	0	0	0	0	0	0	0
Pecos	313,900	339,397	187,157	171,240	90,147	90,022	65,932	70,946	72,412
Reeves	335,168	402,017	310,092	286,856	105,103	63,226	61,345	93,579	63,228
Terrell	0	0	1,050	257	489	242	389	494	0
Upton	698	3,594	5,438	9,015	17,493	15,235	14,394	18,483	12,471
Val Verde	2,369	2,174	2,155	401	220	736	386	363	270
Ward	1,822	2,844	2,918	2,136	577	357	295	529	2,805
Totals	684,972	777,785	543,838	501,060	262,530	190,724	157,543	190,745	176,541

Data compiled from TWDB, 2001.

Irrigation water use from the Pecos River and other surface waters has largely been confined to a few counties. The volume of surface water used for irrigation (ranging from a low of 1,415 AF in 1969 to a high of 35,189 AF in 1958) is only a small percentage (less than 5 percent) of overall agricultural water use in the region (Table 4).

Table 4. Acre-feet of surface water used for irrigation in the Pecos Basin of Texas

County	1958	1964	1969	1974	1979	1984	1989	1994	2000
Brewster	588	665	0	249	316	0	0	0	191
Crane	0	0	0	0	0	0	0	0	0
Crockett	0	0	0	0	0	0	0	0	0
Culberson	0	0	0	0	0	0	0	0	0
Loving	700	273	68	51	40	0	42	583	358
Pecos	0	0	0	0	0	0	7,530	1,160	1,824
Reeves	33,400	12,200	333	317	613	0	3,527	300	10,811
Terrell	501	1,035	200	0	76	0	0	0	80
Upton	0	0	0	0	0	0	0	0	0
Val Verde	0	0	187	1,344	1,130	1,612	1,612	1,279	1,258
Ward	0	0	627	317	333	0	13,705	10,781	10,597
Totals	35,189	14,173	1,415	2,278	2,508	1,612	26,416	14,103	25,119

Data compiled from TWDB, 2001.

Total water use for agricultural irrigation in the region peaked in 1964 at 835,412 AF and declined to a low of 193,163 AF in 1989; however, the most recent data from 2000 showed that agricultural water use totaled 202,221 AF in 2000 (Table 5). Increasing costs to pump groundwater from increasing depths has caused some decline while a general decrease in the number of acres farmed in the watershed has significantly reduced the demand as well.

Table 5. Total acre-feet of water used for irrigation in the Pecos Basin of Texas

County	1958	1964	1969	1974	1979	1984	1989	1994	2000
Brewster	588	715	0	379	627	427	238	327	621
Crane	0	0	0	0	0	90	7	22	0
Crockett	1,964	3,197	3,167	2,090	1,305	338	412	419	160
Culberson	29,176	24,512	31,861	28,935	46,885	20,051	14,145	5,583	24,765
Loving	700	273	68	51	40	0	42	583	358
Pecos	345,266	367,455	201,748	184,669	94,463	90,022	73,462	72,106	74,236
Reeves	368,568	414,217	334,392	319,785	127,470	89,689	74,076	101,723	74,039
Terrell	501	1,035	1,250	257	565	242	389	494	80
Upton	698	3,594	5,438	9,015	17,493	15,235	14,394	18,483	12,471
Val Verde	2,369	2,174	2,342	1,745	1,350	2,348	1,998	1,642	1,528
Ward	14,739	18,240	23,806	22,975	7,549	357	14,000	11,310	13,963
Total	764,569	835,412	604,072	569,901	297,747	218,799	193,163	212,692	202,221

Note: Total irrigation water use totals include land irrigated with both surface and groundwater. These areas where not individually included into Tables 3 and 4; therefore, some totals presented in Table 5 are larger than the sum of totals from Tables 3 and 4 which only record the water use for areas irrigated with only groundwater and only surface water.
Data compiled from TWDB, 2001.

Soils, Geology and Topography

The soils of the Pecos River watershed consist mostly of well-drained Aridisols and Entisols that support sparse desert shrubs. The drainage basin near Red Bluff Reservoir consists of gypsic soils, such as the Reeves and Holloman soil series. The majority of Reeves and Pecos counties consist of either shallow Aridisols (Del Norte, Nikel, and Reakor) or calcareous silty clay loam, such as a Hoban series. The soils in the east bank of the river are predominantly Simona and Sharvana series, both of which are shallow calcareous soils developed over caliche and have moderate permeability. The soils along the Pecos River are alluvial, namely Pecos, Patrole, Toyah, and Gila series that have textures ranging from silty to loamy. Arno series, also alluvial, is the only series along the river that has montmorillonitic clayey textures with low permeability (Miyamoto et al., 2005).

This complexity of soil types, as viewed from the scale of the entire Pecos River watershed, indicates a necessity for detailed analysis and understanding of soils at a much finer scale when specific BMPs are being planned for specific locations. This finer understanding of soil types will especially be applied when developing WQMPs for grazing and crop lands, as described later in the WPP.

The following description of the geology of the Pecos River watershed was taken from a report by the New Mexico Bureau of Geology and Mineral Resources (McLemore & Brandvold, 2001):

> "The geology of the Pecos River drainage basin is complex with rocks ranging in age from Proterozoic to recent. Lithologies are likewise diverse, ranging from metamorphic volcanic rocks to granites to syenites to shales, limestones, and sandstones. Proterozoic rocks crop out along the upper Pecos River and several tributaries north of Pecos, Texas. The oldest rocks are mafic metamorphic and volcaniclastic rocks that comprise the Pecos greenstone belt. The most abundant

> Proterozoic rocks are the plutonic rocks that consist of granite, tonalite-trondjemite, gabbro, diabase, and ultramafic rocks. Overlying sedimentary rocks consist of Mississippian limestone, sandstone, and shale of the Arroyo Penasco Group (Espiritu Santo and Terrero Formations) and unconformably overlie the Proterozoic rocks. Pennsylvanian siltstones, sandstones, shales, thin coals, and limestones overlie the Mississippian and, locally Proterozoic rocks in the Pecos River area. The Pennsylvanian-Permian rocks consist of the Magdalena Group and the Sangre de Cristo Formation. Permian siltstones, limestones, and sandstones overlie the Pennsylvanian-Permian rocks and consist of the Yeso, San Andres, and Bernal Formations. Triassic sandstones crop out in the area south of Pecos and consist of the Santa Rosa Sandstone. Permian evaporates that comprise the Permian Basin section crop out south of Roswell. Quaternary rocks are found throughout the area and consist of Pleistocene to recent alluvial, terrace, and floodplain deposits."

The Pecos River watershed is located in the southwestern edge of the Permian Basin, which extends all the way to western Oklahoma. The Permian Basin was covered by an inland sea approximately 250 to 300 million years ago, and upon evaporation, salts, mostly halite and gypsum precipitated as much as 300 meters (1,000 feet) thick. Salts deposited in this fashion are now found in several salt units that underlie a vast area (Miyamoto et al., 2005) of the Pecos River watershed and are the natural source of salts in the river. Although human influences have likely affected salt loading levels in the river, the source of these salts is natural and cannot be completely removed from the watershed. Managing these sources to reduce their impacts on the river is the only feasible approach to addressing salinity issues in the watershed.

The topography of the Pecos Basin varies greatly. The northern part of the river in New Mexico includes mountain pastures and reaches elevations of 13,000 feet above sea level. In Texas, the elevation shifts from 2,700 feet above sea level at Red Bluff Reservoir to 1,050 feet above sea level at the mouth of the Pecos. The river passes through a deep canyon (walls as high as 200 feet or more in some places) in its lower reaches before merging with the Rio Grande in Val Verde County.

Precipitation and Climate

Average annual rainfall in the Pecos watershed of Texas ranges from 18 inches to 20 inches in the Davis Mountains to only 10 inches at Pecos, Texas (Table 6 and Figure 4). Much of the basin lies in the Chihuahuan Desert where rainfall is sparse and humidity levels are low; this results in the annual potential evapotranspiration greatly exceeding precipitation in most years. For instance, the average annual rainfall for Fort Davis, Texas, is 17 inches while the average potential evapotranspiration is 72 inches per year (Jensen, 2006).

The Pecos watershed in Texas encompasses three distinct climactic regions: Subtropical Arid, Subtropical Steppe, and Mountain. The Guadalupe, Chisos, and Davis Mountains of the Trans-Pecos exhibit low humidity, cool temperatures, less dense air, and orographic precipitation in the higher elevations. The surrounding lowlands in the basin and plateau region of the Trans-Pecos have a Subtropical Arid climate. These areas are marked by warmer dry air and summertime precipitation during wet years. The lower-eastern portion of the Pecos Basin is categorized as Subtropical Steppe, and has a semi-arid to arid climate.

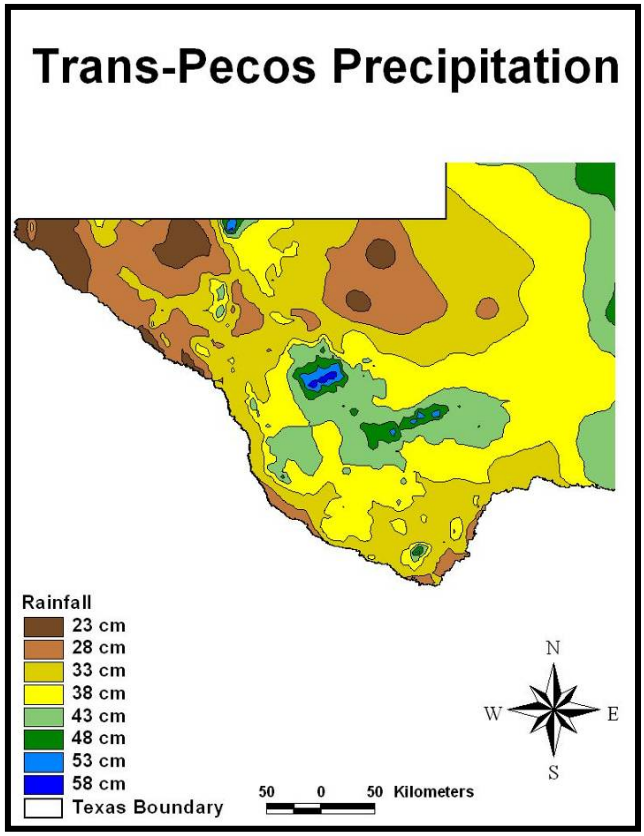


Figure 4. Average annual precipitation from 1961-1990 for the Trans-Pecos region of Texas

Note: 1 cm = 0.39 inches (Flores, 2006)

Table 6. Average annual precipitation across the Pecos watershed

Alpine	16.09 in	Mentone	9.23 in
Balmorhea	13.59 in	Monahans	13.16 in
Crane	14.61 in	Pecos	10.59 in
Ft. Davis	15.81 in	Penwell	13.19 in
Ft. Stockton	13.54 in	Pine Springs	19.15 in
Girvin	12.80 in	Rankin	15.93 in
Imperial	11.03 in	Red Bluff Dam	10.98 in
Kent	12.28 in	Sheffield	14.74 in
McCamey	13.67 in	Wink	12.50 in

Developed using data from the National Weather Service, Midland Office

Surface Water and Groundwater Resources

Surface water is scarce in the Pecos watershed of Texas. The Pecos River is the main source of perennial surface water in the upper end of the watershed and has been known to go dry in some places. Numerous springs in the watershed also provide perennial sources of surface water that bolster the flow of the Pecos. In Texas, Salt Creek provides readily observable surface flow and high salt loading in the Upper Pecos while Independence Creek provides high-quality water to the river in the Lower Pecos. The remaining tributaries in Texas are intermittent and typically only carry flow during high volume rain events (Belzer, 2007a).

Across the basin, surface water and groundwater resources are highly connected and can significantly influence each other. Many areas of the Pecos are known to lose large amounts of streamflow to shallow water tables and aquifers near the river. Although this water is "lost" from the river's flow, it often flows parallel to the river and can re-enter the channel further downstream. The river also has a significant connection to groundwater resources further away from the river. Springs, such as Caroline Springs that supplies about 25 percent of Independence Creek inflow, arise in the watershed and can be significant sources of inflow to the Pecos. According to Gunnar Brune's comprehensive description of the springs of Texas (2002), the Pecos Basin originally contained more than 50 flowing springs. Some of these springs stopped flowing during the "drought of record" that lasted in Texas throughout most of the 1950s. According to local experts (Karges, 2006), as few as eight springs may still flow in Reeves and Loving counties. Some of the springs in the Pecos watershed include:

- Kokernot Spring (Brewster County)
- Live Oak Springs and Cedar Springs (Crockett County)
- Rustler Springs (Culberson County)
- Madera Springs, Phantom Lake Springs, and Seven Springs (Jeff Davis County)
- Comanche Springs, Diamond Y Springs, Leon Springs, Pedro Ureta Springs, Santa Rosa Springs, and San Pedro Springs (Pecos County)
- Giffin Springs, Sandia Springs, San Solomon Springs (Reeves County)
- Red Bluff Springs (Loving County)
- Caroline Springs, Cedar Springs, Geddes Springs, King Springs, Myers Springs, and Vanderbeek Springs (Terrell County)

There are several significant groundwater resources along the Pecos River, including the Pecos Alluvium, Dockum, Capitan Reef, Rustler, Igneous, and Edwards-Trinity Plateau aquifers (Figure 5). The Cenozoic Pecos Alluvium is the principal aquifer in the Texas portion of the river and consists of up to 1,500 feet thick alluvial sediments. This aquifer was once used for irrigating large areas of cropland in the Pecos Valley of Reeves County. During the peak irrigation era of the 1950s, pumping from wells was estimated to have reached as much as 730,000 AF/year. Pumping from this alluvium declined drastically after the 1960s, and water tables have dropped as much as 200 feet according to a TWDB report (Ashworth, 1990). However, recent data shows that water tables west of the Pecos rose as much as 30 feet between 1989 and 1998 while areas east of the river have declined by 40 feet or more (Boghici, 1999). Perched water tables near the Pecos River are usually between 10 feet and 20 feet below the surface, and deepen to 50 feet away from the river. Water table depth fluctuates depending on the flow of the Pecos (TWDB, 2001). TWDB 2006 data reports that the depth-to-groundwater in Pecos and Reeves counties averages 125 feet and ranges from 12 feet to 1,492 feet with the greatest depth occurring where cones of depression have developed as a consequence of groundwater pumping for agriculture and other purposes (Miyamoto et al., 2005). Mills (2005) suggests that groundwater inflows to the Pecos River between Red Bluff and Girvin averaged 30,000 AF/year before large-scale irrigation projects were developed.

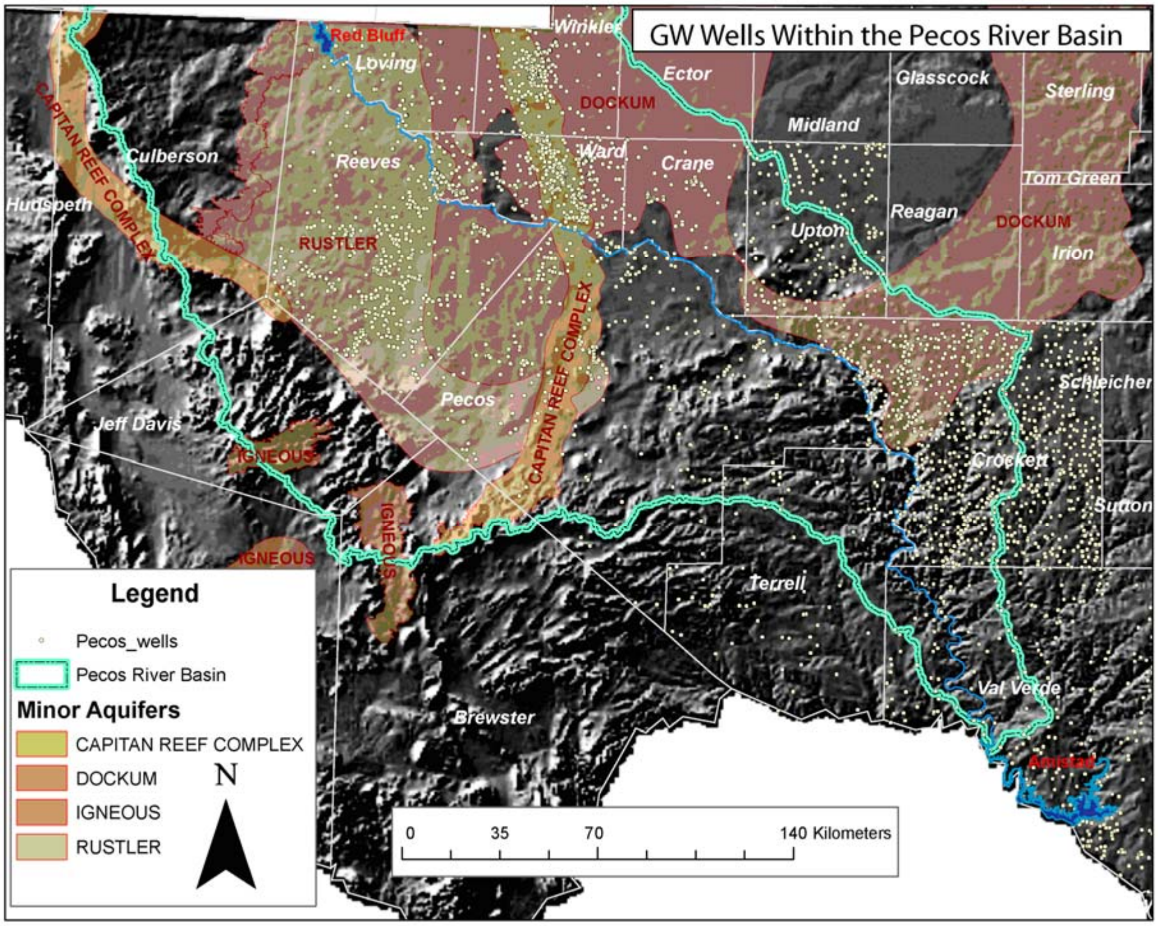


Figure 5. Groundwater wells within the Pecos River Basin (Villalobos, 2007)

Declining groundwater levels in these aquifers have caused the reversal of flow paths in some locations. This reversal results in lower quality water in the river flowing into the aquifers instead of the higher quality aquifer water flowing into the river. Essentially, the river is contaminating nearby aquifers with lower quality water, which only intensifies the need to improve the river's water quality. Pumping paired with rampant saltcedar growth in the watershed has undoubtedly exacerbated this phenomenon. Decreasing the influences of these impacts will have a positive impact on restoring hydrologic function along the river and water quality of the river.

Wildlife and Aquatic Habitat

Plant and animal life in the river and in its adjacent banks have changed significantly since modern settlement began. In an early account, Lieutenant S.G. French of the U.S. Corps of Topographical Engineers described the condition of the Pecos River of Texas in 1849 (cited in Campbell, 1958):

> "It is a narrow deep stream, its waters turbid and bitter, and… [it carries] more impurities than any other river of the south. The only inhabitants of its waters are catfish."

In the 1950s, the Texas Fish and Game Commission (Campbell, 1958) surveyed the aquatic biology at 28 stations on the Pecos River in Texas from Red Bluff Dam to a site near Langtry. Results showed that the gizzard shad and white bass were frequently found in the upper reaches of the Pecos while blue catfish and channel catfish were most common inhabitants of the middle and lower reaches of the river.

In 1996, Texas Parks and Wildlife Department (TPWD) (Linam & Kleinsasser, 1996) and the TCEQ (Larson, 1996) assessed fish and aquatic life in the Pecos River and its tributaries. TPWD gathered data on fish species and water quality at 16 sites on the Pecos River from Red Bluff Reservoir to Amistad Reservoir. TPWD documented only 26 of the more than 40 fish species historically found in the river. The most common species collected included red shiner, hybrid pupfish, rainwater killifish, western mosquitofish, Mexican tetra, and inland silverside. TPWD's study concluded that the volume of flow in the river, salinity from natural and man-made sources, and contaminants from oil production and agricultural activities have the potential to negatively influence the aquatic biology of the river. These conclusions support the need to manage the watershed in a way that promotes improved water quality and quantity, specifically increasing flow and/or decreasing salinity.

Hoagstrom (2003) examined changes in the composition of fish and other aquatic species over time along the reaches of the Pecos River from Orla to Sheffield and downstream to the confluence of the Pecos River with the Rio Grande. Since the arrival of settlers in the 1850s, the diversity and populations of native fish species at these sites has declined by more than 50 percent, while the number of nonnative fish species that prefer saline waters has increased markedly (Hoagstrom, 2003). Humans have influenced the Pecos River by diminishing spring flows, spreading toxic algae blooms, introducing nonnative fish species, and degrading and fragmenting riparian habitats.

Several investigations have examined aquatic biology present in the lower Pecos River near its confluence with Independence Creek in Texas. Larson (1996) studied possible correlations between water quality trends and populations of benthic insects and found that water quality in the main stem of the Pecos River improved significantly downstream of the river's junction with Independence Creek, resulting in healthier populations of river fauna. Again, this suggests that increasing flow and/or decreasing salinity are the primary mechanisms to positively impact aquatic life in the Pecos River. In 2005, Texas State University (Bonner et al., 2005) researchers found that the number of fish species in the lower Pecos River had declined slightly since the 1950s, possibly due to human influences, such as reduction in flows and land use practices, which degrade water quality. Studies by the University of Texas at Austin suggest that 27 species of fish including bass, darters, gar, eels, carp and suckers can be found in the lower Pecos River near Independence Creek (Hubbs, 1991).

The USGS and TCEQ were contracted to conduct aquatic life and habitat inventory surveys along the Pecos as a part of the Pecos River Basin Assessment Program (PRBAP). TCEQ responsibilities included evaluating the upper portion of the river from Orla to Sheffield in December 2006. USGS conducted sampling efforts in the lower portion of the Pecos during June 2006. In each case, the sampling sites received a limited biotic integrity score (Belzer 2007b). This score is based on the Index of Biotic Integrity (IBI), which uses 12 indicator criteria that are ranked from one to five. Therefore, the IBI score for a stream can range from a low of 12 to high of 60. IBI scores ranged from limited to intermediate and the number of fish species present were intermediate for all the sampling sites on the Pecos (Table 7); however, the number of fish species and benthic macroinvertebrates did increase below the river's confluence with Independence Creek, indicating an improvement in overall river quality. Complete scores and a report, "Aquatic Life and Habitat Inventory Assessment," describing these rankings for all sites is available on the project Web site, links for the specific report can be found in Appendix A.

Each site was also evaluated based on its available aquatic habitat. Criteria evaluated in this assessment included available in-stream cover, bottom substrate stability, number of riffles, dimensions of the largest pool, channel flow status, bank stability, channel sinuosity, riparian buffer vegetation, and the aesthetics of the reach. A habitat evaluation sheet in Belzer 2007b provides a more detailed description of the parameters used to rank the streams habitat. The scores for aquatic habitat health for the Pecos ranged from 15 to 22 (Table 7); the highest possible score is 35 but it is rarely achieved in any stream. Benthic macroinvertebrates that include bottom-dwelling invertebrates, such as aquatic insects, mussels and clams, and crayfish, were also sampled as a means of determining overall stream health; these scores are also presented in the table below.

Table 7. Pecos River aquatic life and habitat inventory scores

Pecos River Sampling Locations	TCEQ Sampling Site	# of Fish Species Collected*	IBI Score †	Habitat Score	Benthic Macroinvertebrate Score
Sites Above Independence Creek					
Hwy 652 nr Orla	13265	4	20	15 Intermediate	9 – Limited
FM 1776 nr Coyanosa	13260	4	22	18 Intermediate	19 – Limited

Hwy 67 nr Girvin	13257	5	20	16.5 Intermediate	19 - Limited
CR 307 nr Sheffield	15114	8	18	22 High	18 – Limited
Chandler Ranch	13248	11	16	20 High	22 – High
Sites Including and Below Independence Creek					
Independence Creek	14163	13	20	16 Intermediate	26 – Exceptional
Pandale	13245	13	30	18 Intermediate	28 – Exceptional

* All fish species collected ranked in the intermediate category

† IBI Score ranges and designations for the Chihuahuan Desert Ecoregion are: <18: Limited; 18-20: Intermediate; 21-26: High; >26: Exceptional

Information compiled from Belzer 2007b.

Recreation

Various recreational opportunities are available on the Pecos River in Texas. Most of the land adjacent to the channel in the upper portion of the river is private property, which limits public access to this segment. However, Red Bluff and Imperial Reservoirs offer boating, fishing, and bird-watching opportunities for a small access fee. Streamflow, as well as recreation activity, increases on the lower end of the river below Sheffield due to freshwater inflow from tributaries. The public can enjoy canoeing, kayaking, tubing, fishing, and swimming at various locations along the lower end of the Pecos. River access and camping are available to the public at Amistad National Recreation Area, which is located in Val Verde County and extends upstream into the Pecos River for 14 miles.

Recreational activities not directly related to the river also exist in the Pecos watershed. State parks offer public access to unique natural resources found in the area. Balmorhea State Park, located in the foothills of the Davis Mountains southwest of Balmorhea, Texas, in Reeves County, features camping, picnicking, and a 1.75-acre spring-fed swimming pool suitable for activities such as scuba diving. Camping and fishing are also available at the nearby 500-acre Balmorhea Lake. Davis Mountains State Park is located four miles northwest of Fort Davis, Texas, in Jeff Davis County and offers activities that include camping, sightseeing, nature study, picnicking, hiking, backpacking, day and overnight equestrian use, mountain biking, and interpretive programs. Monahans Sandhills State Park, located near Monahans, Texas, in Ward and Winkler counties contains acres of sand dunes, some up to 70 feet high, which can be "sand surfed" by park visitors. Other available activities include camping, hiking, picnicking, horse riding and camel treks, and bird and wildlife watching (TPWD, 2007b). The Guadalupe Mountains and Fort Davis National Parks and the Amistad National Recreation Area are also located within Pecos River watershed and provide additional recreation opportunities (Figure 6).

Texas State Parks (adapted TPWD Map) National Parks in Texas (adapted NPS.GOV Map)

Figure 6: National and state parks in the Pecos region

Numerous private properties across the watershed also offer recreational activities for a fee. Birding, camping, hiking, and hunting are some of the typical activities that are available on many of these properties.

Waterbody Segments, Designated Uses and Applicable Standards

In Texas, the TCEQ is the agency that is responsible for monitoring water quality and assessing its overall ability to sustain designated uses. To aid in this process, TCEQ has divided the Pecos River and Independence Creek into segments and has further refined those into Assessment Units (AU). Table 8 indicates the segment and AU numbers, names and describes their geographic extent.

Table 8. TCEQ designated river segments and descriptions

TCEQ Designated River Segments in the Pecos River Watershed		
Segment	**Name**	**Segment Description**
*2305**	*International Amistad Reservoir*	From Amistad Dam in Val Verde County to a point 1.8 km (1.1 miles) downstream of the confluence of Ramsey Canyon on the Rio Grande Arm in Val Verde County and to a point 0.7 km (0.4 miles)downstream of the confluence of Painted Canyon on the Pecos Arm in Val Verde County and to a point0.6 km (0.4 miles) downstream of the confluence of Little Satan Creek on the Devils River Arm in Val Verde County, up to the normal pool elevation of 1117 feet (impounds Rio Grande)
2310	*Lower Pecos River*	0.7 km downstream of the confluence of Painted Canyon in Val Verde Co. to a point immediately upstream of the confluence of Independence Creek in Crockett/Terrell Co.
2310A	*Independence Creek*	From the confluence of the Pecos River NE of Sanderson in Terrell Co. to the upstream portion of the stream SE of Fort Stockton in Pecos Co.
2311	*Upper Pecos River*	From a point immediately upstream of the confluence of Independence Creek in Crockett/Terrell Co. to Red Bluff Dam in Loving/Reeves Co.
2312	*Red Bluff Reservoir*	From Red Bluff Dam in Loving/Reeves Co. to New Mexico state line in Loving/Reeves Co., up to normal pool elevation 2,842 feet (impounds Pecos River)

TCEQ Assessment Units		**Assessment Unit Description**
Lower Pecos River	*2310_01*	Upper segment boundary to Big Hackberry Canyon (FM 2083)
	2310_02	From FM 2083 near Pan Dale Rd to the lower segment boundary
Independence Creek	*2310A_01*	Upper end of creek to Surveyor Canyon
	2310A_02	From Surveyor Canyon to the confluence with the Pecos River
Upper Pecos River	*2311_01*	Red Bluff Dam to FM 652
	2311_02	FM 652 to SH 302
	2311_03	SH 302 to Barstow Dam
	2311_04	Barstow Dam to US 80 (Bus I-20)
	2311_05	US 80 (Bus I-20) to FM 1776
	2311_06	FM 1776 to US 67
	2311_07	US 67 to US 290
	2311_08	US 290 to lower segment boundary
Red Bluff Reservoir	*2312_01*	Texas/New Mexico state line to Mid-lake
	2312_02	Mid-lake to Red Bluff Dam

* Amistad Reservoir is the receiving waterbody for the Pecos River

The federal Clean Water Act (CWA) requires that states specify appropriate water uses to be achieved and protected for each of its waterbodies:

> "Appropriate uses are identified by considering the use and value of the water body for public water supply, for protection of fish, shellfish, and wildlife, and for recreational, agricultural, industrial, and navigational purposes. In designating uses for a water body, States…examine the suitability of a water body for the uses based on the physical, chemical, and biological characteristics of the water body, its geographical setting and scenic qualities, and economic considerations. Each water body does not necessarily require a unique set of uses. Instead, the characteristics necessary to support a use can be identified so that water bodies with those characteristics can be grouped together as supporting particular uses" (EPA, 2006).

The TCEQ has defined the designated uses and water quality standards on the three classified segments of the Pecos River in Texas (Segment 2310 – Lower Pecos River; Segment 2311 – Upper Pecos River; Segment 2312 – Red Bluff Reservoir), Independence Creek; unclassified Segment 2310A and the International Amistad Reservoir; Segment 2305 (Table 9).

Table 9. Designated uses and water quality standards

Rio Grande River Basin		Designated Uses			Water Quality Criteria						
Segment No.[1]	Segment Name	Recreation	Aquatic Life	Domestic Water Supply	Cl^{-1} (mg/L)	SO_4^{-2} (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L) (24 hr avg/min)	pH Range (SU)	Indicator Bacteria[2] #/100ml	Temp (°F)
2305[3]	International Amistad Reservoir	CR	H	PS	150	250	800	5 / 3	6.5-9.0	126/200	88
2310	Lower Pecos River	CR	H	PS	1700	1000	4000	5 / 3	6.5 - 9.0	126/200	92
2311	Upper Pecos River	CR	H	---	7000	3500	1500	5 / 3	6.5 - 9.0	126/200	92
2312	Red Bluff Reservoir	CR	H	---	3200	2200	9400	5 / 3	6.5 - 9.0	126/200	90

TCEQ Standards, 2000

[1] Independence Creek, Segment 2310A is considered an unclassified stream and therefore, does not have specified water quality standards; therefore, the unclassified waterbody assessed against the criteria for its parent classified waterbody.

[2] The indicator bacteria for freshwater is *E. coli* and Enterococci for saltwater. Fecal coliform is an alternative indicator. Geometric mean standard/single sample maximum standard.

[3] Amistad Reservoir is the receiving waterbody for the Pecos River

Definitions of use and criteria acronyms:

CR = Contact Recreation, includes activities such as swimming, water skiing, diving, surfing and wading by children; these include a significant risk of ingesting water.

H = High – Habitat Characteristics are highly diverse. Species Assemblage: usual association of regionally expected species. Sensitive Species: present. Diversity: high. Species Richness: high. Trophic Structure: balanced to slightly imbalanced.

PS = Public Water Supply – Segments designated for public water supply are those known to be used as the supply source for public water systems.

According to the 2006 *Texas 303(d) List*, the Upper Pecos River, or Segment 2311, is the only portion of the river that is impaired. Specifically, AUs 2311_05 and 2311_06, which cover the area of the river between US 80 (Bus 20) and US 67 were found to have depressed DO levels (Table 10). As a result, these segments were placed in the "5c" category of impaired streams and will be monitored more extensively to determine if depressed DO is a frequent problem that warrants additional action. A limited data set consisting of eight samples collected between both sites was used in this evaluation; however, seven of these samples did not meet the minimum DO levels for this segment of the river. No other portions of the river are listed as impaired on the 2006 *Texas 303(d) List* (TCEQ, 2007a).

Several AUs in the Pecos River are identified as having concerns due to screening level exceedances for parameters without numeric criteria in the Texas Water Quality Standards. A screening level for a specific parameter is determined by averaging statewide water quality data for the given parameter in similar waterbodies and calculating the 85th percentile for that parameter. Thus, the screening level for that parameter in the specific type of waterbody is then set at the 85th percentile of the statewide average. Table 10 indicates what these screening levels are for freshwater streams and reservoirs, the two scenarios that apply to the Pecos River.

Table 10. Statewide nutrient screening levels

Nutrient Screening Levels Applicable in the Pecos River Watershed

Waterbody Type	Parameter	Screening Level
Freshwater Stream	Nitrate	1.95 mg/L
	Ammonia	0.33 mg/L
	Orthophosphorous	0.37 mg/L
	Total Phosphorous	0.69 mg/L
	Chlorophyll-a	14.1 µg/L
Reservoir	Nitrate	0.37 mg/L
	Ammonia	0.11 mg/L
	Orthophosphorous	0.05 mg/L
	Total Phosphorous	0.20 mg/L
	Chlorophyll-a	26.7 µg/L

The screening levels are described as the 85th percentile of the state-wide average of a specific nutrient in the specified waterbody type

When more than 20% of the collected samples on an individual waterbody exceed the 85th percentile, the waterbody is identified as having a concern for screening criteria

mg/L = milligrams per liter or parts per million
µg/L = micrograms per liter or parts per billion

For a stream, or AU of that stream, to be considered as having a concern for exceeding the screening level, more than 20 percent of collected samples have to be above this screening level. This “concern” does not imply that the particular reach of the river is impaired; instead, there may be cause for concern regarding the quality of water in that reach. Table 11 shows which segments of the river are impaired and which areas of the river are identified as having a concern.

In the immediate future, numeric nutrient criteria will be established for each waterbody in the state and will replace the currently used nutrient screening levels. Based on preliminary draft language proposed by TCEQ, chlorophyll-a will be used as an indicator criterion that measures nutrient loading and its impacts on algal growth. Reservoirs will be the first waterbodies that these criteria are applied to and streams and estuaries will follow in the future. The chlorophyll-a criteria level proposed for Red Bluff Reservoir at TCEQ monitoring station 13267 is 20.3 micrograms per liter (µg/L). Current chlorophyll-a levels as recorded by TCEQ and used in the *2006 Texas Water Quality Inventory*, indicate Red Bluff Reservoir would likely be considered impaired if the draft numeric criteria were applied. Despite this impending listing on the state's 303(d) List, TCEQ lists the sources of this impairment as natural nonpoint source pollution and nonpoint source pollution that is derived outside of the state's jurisdiction. Other areas of the watershed also faced imminent listing as an impaired waterbody once nutrient standards are applied to the remainder of the river because they currently exceed the 85th percentile screening criteria. This looming impairment is even more reason to attempt to address these problems before the listing occurs.

Table 11. Surface water quality impairments and concerns for the Pecos River

Surface Water Quality Impairments and Concerns as Reported in the 2006 Texas Water Quality Inventory				
Assessment Unit	**Constituent of Concern**	**Description of Concern**	**Level of Support**	**Implications**
2311_05	*Dissolved Oxygen*	Dissolved Oxygen levels fell below the 24 hour minimum concentration of 3.0 mg/L	NS	placed on 303 (d) List in 2006
2311_06	*Dissolved Oxygen*		NS	placed on 303 (d) List in 2006
2310	*Golden Algae*	Golden Algae present in the River's waters have led to extensive fish kills; no standard criteria have been set by the state for Golden Algae	CN	none, no standard in place
2311	*Golden Algae*		CN	
2312	*Golden Algae*		CN	
2312_01	*Nitrates*	Over 20% of data collected indicate that nitrate levels are above the state-wide screening level	CS	none at this point, further data evaluation will occur before the site is further assessed
2312_02	*Ammonia*	Over 20% of data collected indicate that nitrate levels are above the state-wide screening level	CS	none at this point, further data evaluation will occur before the site is further assessed
	Nitrates		CS	
	Orthophosphorous		CS	
2311_07	*Chlorophyll-a*	Over 20% of data collected indicate that nitrate levels are above the state-wide screening level	CS	none at this point, further data evaluation will occur before the site is further assessed
NS	indicates that the specific reach does not support its designated uses for the specific parameters listed and is impaired			
CN	indicates that the specific reach is close to being considered non supporting for specific parameters evaluated			
CS	indicates that the specific reach is identified as having a concern for the screening level set for the specific criteria			

As noted above, the Pecos River is currently considered a freshwater stream despite its constantly elevated salinity levels, and, according to TCEQ's *2006 Guidance for Assessing and Reporting Surface Water Quality in Texas*, it has total dissolved solids (TDS), salinity and specific conductance levels that would qualify it to be a 'Tidally Influenced Stream.' In this guidance, 'Tidally Influenced Streams' are those that are found to have TDS levels ≥2,000 mg/L, salinity levels ≥2 parts per thousand or specific conductance readings ≥3,077 µmhos/cm. This distinction is important because of the applicable standards that the waterbody has to meet, which in most cases is a less stringent standard. Although the Pecos River is not influenced by the tides, it does flow through the Permian Basin and the ancient salt deposits that were left behind from the Permian Sea. Measured TDS and specific conductance levels in the Pecos River are continually recorded above the levels that are considered indicative of a tidally influenced stream. As such, it seems pertinent that the Pecos River should be assessed based on the criteria for a 'Tidally Influenced Stream' or another designation, such as a brackish stream or highly saline inland water because the salts in the Pecos are naturally occurring. Currently, through the triennial review of water quality standards, TCEQ is entertaining a category of "highly saline inland waters" to apply the most appropriate bacteria indicator (Enterococci). If this proposed language ultimately includes the Pecos River, then likewise, the Pecos should have the "tidally influenced stream" DO criteria applied. Application of different DO criteria may require the development and approval of a Use Attainability Analysis.

Oil and Gas Production

Oil in Texas was first recorded in 1543 when a survivor of the De Soto expedition saw oil floating on the surface of the water, but it was not until the second half of the 19th century that oil production began. Fueled by the post Civil War market for petroleum products, exploration, and production drastically increased in 1870s and 1880s. Oil and natural gas exploration and production in the Pecos River watershed came on the heels of discoveries in other parts of the state and nation. Not until the 1910s and 1920s did exploration and subsequent production begin in the Permian Basin. Since the discovery of oil and gas in the watershed, populations have greatly increased and the industry has driven local economies.

Today, oil and gas wells cover the watershed. Railroad Commission of Texas (RRC) records indicate that the counties making up the Pecos River watershed contained 52,479 oil and gas wells with 337 of them being orphaned wells as of September 3, 2008. These numbers over estimate the actual number of oil and gas wells in the watershed because total well numbers are lumped by county. Included in this count are regular producing wells, shut-in wells (includes orphaned wells), injection wells, and miscellaneous wells. Production levels for these counties have varied greatly over time with the discovery of new fields and declining production in old fields. Data compiled by the RRC in 2002 and 2006, shown in Table 12, highlight recent annual production levels for the counties included in the Pecos River watershed.

Table. 12: Recent annual oil and gas production across the watershed

Oil and gas production in the counties that make up the Pecos River Watershed

Only counties that reported production are included, not all counties in the watershed are listed
Source: Texas Railroad Commission online data

	2006 Data				2002 Data
County	**Oil (BBL)**	**Casinghead Gas (MCF)**	**Gas Well Gas (MCF)**	**Condensate (BBL)**	**Total Injected Material (BBL)**
Andrews	24,347,354	32,838,714	1,731,957	9,870	347,603,281
Crane	9,413,072	44,244,598	12,548,427	86,213	161,443,362
Crockett	1,668,572	1,584,007	81,659	3,081	58,972,170
Culberson	110,606	165,998	1,110,452	3,118	1,586,900
Ector	18,292,257	27,998,446	12,359,069	4,685	325,277,218
Loving	1,053,702	2,968,704	90,366,541	131,208	13,980,329
Pecos	11,621,389	62,743,794	131,209,901	122,716	131,244,130
Reagan	645,016	3,005,827	102,634	1,078	46,518,770
Reeves	858,584	2,142,962	23,116,396	35,819	11,584,865
Terrell	856	11,114	1,246,580	4,160	349,780
Upton	2,903,629	2,461,256	27,328	186	90,949,153
Val Verde	1,852	5,612	15,925,784	223	15,570
Ward	5,196,940	15,522,984	32,525,177	100,199	55,248,443
Winkler	4,073,030	15,880,941	23,378,385	80,025	86,386,496
Pecos Total	***80,186,859***	***211,574,957***	***345,730,290***	***582,581***	***1,331,160,467***
Texas Total	***346,988,668***	***679,640,996***	***5,674,860,065***	***44,924,656***	***5,367,018,227***

A Changing Watershed

Since settlement began in the mid 1800s, an untold number of changes have occurred within the watershed. Some of these changes have been profound while others have been subtle. What has remained unchanged is that the Pecos River has been and always will be a vital water resource in the Trans-Pecos region of the state. The integrity of the entire Rio Grande Basin below the Pecos also stands to benefit from improvements in the health of the Pecos River watershed. A holistic management plan that addresses problem areas across the watershed is the tool that will be implemented as a means to improve the quality of the watershed and improve its benefits to watershed inhabitants.

Watershed Protection Plan Development Process

In its simplest terms, "a watershed is an area of land that drains to a common waterway such as a lake, a stream, a wetland or an ocean" (EPA 2005). In this case, the Pecos River serves as the common waterway. WPPs function as holistic tools to protect, restore, or improve watersheds and their associated waterbodies.

According to the TSSWCB (2007), a WPP is:

> "a coordinated framework for implementing prioritized and integrated water quality protection and restoration strategies driven by environmental objectives. Through the WPP process, the State of Texas encourages landowners to holistically address all of the sources and causes of impairments and threats to both surface and ground water resources within a watershed. Developed and implemented through diverse, well integrated partnerships, a WPP assures the long-term health of the watershed with strategies for protecting unimpaired waters and restoring impaired waters."

A WPP serves as a mechanism for addressing complex water quality problems across the entire watershed and is used as a tool to better leverage the resources of local governments, state, and federal agencies, and nongovernmental organizations. The planning process integrates activities and prioritizes implementation projects based upon technical merit and benefits to the community, promotes a unified approach to seeking funds for implementation, and creates a coordinated public communication and education program. The overall goal of the WPP is to initiate a landowner-driven process to promote voluntary BMPs throughout the watershed that will improve water quality and overall health of the watershed.

The EPA (2005) breaks down the actual process of watershed planning into six major steps. The following steps provide the general framework for developing an effective WPP. The steps are listed as:

1. Build Partnerships
2. Characterize the watershed to identify problems
3. Set goals and identify solutions
4. Design an implementation program
5. Implement the watershed plan
6. Measure progress and make adjustments

In addition to these six steps, EPA also describes "nine key elements of watershed protection plans" that are considered integral components of all potentially successful WPPs. The nine elements are:

a. Identification of the causes that will need to be controlled to achieve the load reductions described in (b)
b. Estimate of the load reductions expected for the management measures described in (c)
c. Description of management measures that will need to be implemented to achieve the load reductions described in (b)
d. Estimate of technical and financial assistance needed to implement this plan
e. Information/education component that will be used to enhance public understanding of this plan
f. Schedule for implementing management measures described in (c)
g. Description of interim, measurable milestones for determining whether management measures described in (c) are being implemented

h. Set of criteria that can be used to determine whether load reductions described in (b) are being achieved
i. Water quality monitoring component to evaluate effectiveness of implementation measured against the established criteria described in (h)

This WPP addresses issues stated by concerned landowners at meetings conducted in 2006, 2007, and 2008 and outlines management strategies that can be voluntarily implemented throughout the watershed to improve its overall health and quality. These strategies, however, are founded on adaptive management. The management measures included only address well understood watershed issues; if the source of the problem is known then it is addressed with the appropriate and recommended management measures. The overall size of the Pecos watershed in Texas has limited the ability to collect specific nonpoint source (NPS) pollutant data for the entire watershed. Funds available for assessing these sources were used where the greatest information could be obtained and a great deal of useful information was extracted from these efforts, but work that is more precise is needed in various areas. One key area of the watershed that does not have management measures specifically targeted for it by the plan is the reach of river between Coyanosa and Girvin (about 100 miles). Salinity data collected and evaluated showed that this area is responsible for the largest amount of salt entering the river in Texas, but the data was unable to define specific areas where management measures will be effective for controlling salt intrusions into the river (Miyamoto et al., 2005). Situations such as this one cause the WPP to be a working document that can and will be reviewed and updated as more is learned about the watershed, feasible management practices, and the needs/concerns of interested parties in the watershed.

Private Property and Water Rights

Attendants at the meetings held in April 2006 and all subsequent meetings felt and continue to feel strongly about fully retaining their private property rights and potential impacts that WPP implementation efforts may have on them. Private property rights will not be affected by the WPP. This document defines a plan of action that can be adopted and implemented by people across the watershed to improve the overall health of the watershed. The acceptance of this plan and implementation of any recommended practice is 100 percent voluntary and will not be carried out without the cooperation and support of landowners in the watershed; however, if the plan is not implemented it is highly unlikely that any water quality or watershed health improvements will be realized. Landowners will retain 100 percent of their property rights and will not be forced to do anything; everything will be done on a voluntary basis.

Maintaining complete control of privately held water rights is also a major concern of watershed landowners. What little water they do have is very precious and maintaining complete control of those rights is of utmost importance to them. As with private property rights, water right holders will in no way be forced into giving up their water rights through the implementation of this WPP.

Determining Landowner Concerns

Landowners and local citizens have voiced a variety of concerns related to the watershed and its water quality during a series of four public meetings held in April 2006. Seventy-three people were present at the meetings, held in Mentone, Imperial, Sheffield, and Iraan. These meetings were held to seek input from the attendees and determine the most important and pressing watershed issues. As concerns were voiced, they were written down and then attendees were asked to rank all the issues voiced at the meeting from least to greatest importance from 1 to 4 with 4 being the most important. At the conclusion of these public meetings, results were tallied to yield an overall ranking. Table 13 illustrates the results of the ranking process and effectively shows what the major concerns in the watershed are and what the landowners and watershed residents believe should be addressed through WPP implementation.

Table 13. Rankings of concerns voiced at April 2006 meetings

Point totals as ranked by meeting attendees for issues facing the Pecos River in Texas						
	Mentone	Imperial	Sheffield	Iraan	Total	%
Brush Control	3	42	44	29	118	22.7
Private Property Rights	1	10	54	45	110	21.2
Water Quality (salinity)	27	23	15	26	91	17.5
Education	1	23		22	46	8.8
Water Quantity	8		26	8	42	8.1
Funding for projects		13		6	19	3.7
Loss of water rights to New Mexico	15				15	2.9
Water marketing to other areas of the state			11	3	14	2.7
Low population should not equal low priority	12				12	2.3
Let natural processes work			11		11	2.1
Standing dead saltcedar		10			10	1.9
Development - platted subdivisions			7		7	1.3
Government regulation		4		3	7	1.3
Revegetation		6			6	1.2
Recreation	3			2	5	1.0
Wildlife			3		3	0.6
Riparian management				3	3	0.6
Negative impacts of dams		1			1	0.2

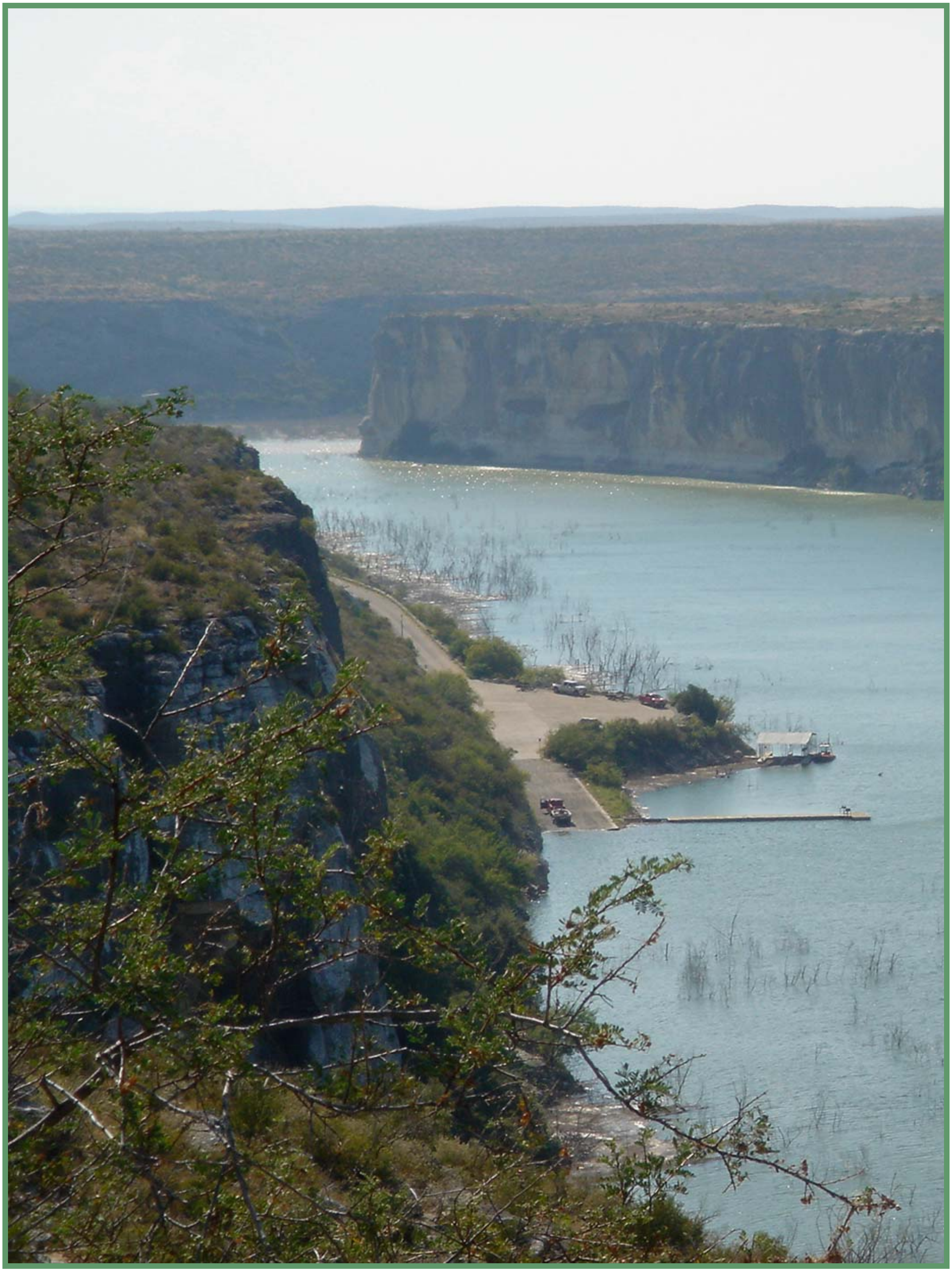
Since these meetings, other concerns about the watershed have also been voiced while many of those listed in Table 13 have been reiterated and expanded upon. Some concerns mentioned, but not included in the table, are the impacts of oil field activities on water quality, concern with the saltcedar leaf beetle, the influence of mining activities in New Mexico on water quality, the need to effectively manage water quality upstream in New Mexico before trying to address water quality concerns in Texas, and the need to establish a working relationship with New Mexico that will allow for collaborative efforts between the states to address salinity issues. A primary concern that was repeatedly voiced and emphasized heavily was the need to secure financial assistance for implementing a variety of management practices including the establishment of cross fencing, development of alternative water sources, prescribed burning in riparian and

upland areas, brush management efforts in upland and riparian areas, alternative shade sources, and rangeland planting. Other concerns continually brought up were the complete retention of private property rights, the need to continue saltcedar control and long-term management, burning the debris left behind from controlling saltcedar, establishing tolerant grasses in place of the burned saltcedar, and any wariness of conditions that may be attached to money received through financial assistance programs.
Overall, this WPP is a holistic management plan that will collectively address the stated concerns while advocating the improvement of the watershed and river. The development and implementation of this plan will by no means restore the Pecos River watershed to its historic conditions, but will be a useful tool that can lead to overall improvement in watershed health and will aid in securing funding from multiple sources to implement the strategies in the plan. Success of this project rests solely in the hands of project participants who must be willing to adopt and implement the voluntary practices and strategies outlined in the WPP.

Brush control, private property rights, and water quality where ranked as the most important issues by meeting attendants; however, many other concerns are equally important and will be addressed as well. The Pecos, like other rivers, is a complex system facing multiple problems that must be managed collectively. Attempting to manage these problems individually increases the risk of exacerbating other concerns and not addressing watershed-wide issues. A watershed scale approach that addresses multiple issues is needed to remedy problems in these complex systems. Salinity, biological diversity, and water quantity are primary concerns in the basin and all must be addressed to effectively manage and improve the resources of the Pecos Basin. The project Web site was also used to conduct an online survey to gauge perceptions of water resources challenges facing the Pecos watershed in Texas. Fifty-seven people responded to the survey; results are listed in detail in Appendix B. This survey and information gleaned from the April 2006 meetings was used to develop a first draft of the WPP.

In September 2007, the first draft of the WPP was released to the public for their review and comment. Following this release, project personnel held public comment meetings in Mentone, Pecos, Imperial, Iraan, and Del Rio where landowners attended and provided their comments and input directly to project personnel. Similar meetings were also held in conjunction with soil and water conservation districts (SWCDs) throughout the watershed during November 2007. Comments and requested changes received during these meetings, via mail or the project Web site were incorporated into the second draft of the WPP released to the public in January 2008.

Another series of public meetings were held in February 2008 to receive comments on the second draft of the plan. These meetings were in Pecos, Imperial, Iraan, Ozona, and Del Rio and again offered an opportunity for landowners to directly speak with project personnel, ask questions, and submit comments. Comments were also received online and through the mail. Comments received were incorporated into this version of the WPP. Additional comments received will also be incorporated into the WPP as time progresses. New ideas and management practices will likely surface and added accordingly.



Pecos River confluence with the Rio Grande

Watershed Concerns and Management

Water quality and the factors that influence the quality and quantity of water in the river have been primary concerns. This section of the WPP focuses on specific concerns and describes their significance. Material presented in this section regarding each concern includes:

- Causes and sources of the concern
- Where critical areas for this concern are located
- An estimate of load reduction
- Management measures needed to address the concern
- Technical and financial assistance needed

Salinity

Salt content in the Pecos has long been a problem for the river's users. The amount of salt transported by the river on a yearly basis is well understood and is often referred to in terms of "salinity" and "salt loading." Salinity is defined as a quantity of dissolved salts present in a given volume of water or the concentration of salts in the water and is measured as a mass per volume (typically mg/L or ppm). Salt loading is a function of salinity and flow in the river over time and is measured as mass per time (expressed as tons/year in the WPP). Despite knowledge about the amount of salt in the river, specific sources of salts entering the stream are not as clear and this requires further investigation to develop sound management measures.

The Pecos River is among the saltiest rivers in North America, with streamflow salinity regularly exceeding 7,000 ppm at the Texas and New Mexico border and 12,000 ppm near Girvin, Texas. High salinity in the river has adversely affected stability and biodiversity of the riparian ecosystems as well as the economic uses of the river and reservoirs. Irrigated agriculture has suffered and continually faces problems associated with highly saline irrigation water. Human consumption is also starting to feel the impacts of increasingly saline waters in the Pecos and other rivers in the southwestern United States. Amistad International Reservoir, located on the Rio Grande below its confluence with the Pecos, is a major source of potable water for numerous Texas and Mexico cities and communities. A recent study shows that the flow of the Pecos accounts for 26 percent of the salts entering the reservoir, yet only 9.5 percent of annual inflow (Miyamoto et al., 2005). Rising salinity levels in the reservoir are slowly approaching the 800 mg/L salinity standard for drinking water; TCEQ's 2006 water quality assessment showed that the mean salinity level of 59 samples collected over the previous five years was 522 mg/L. If salinity in the reservoir continues to rise, then expensive treatment upgrades will be needed to make the water potable. Salinity issues also extend to shallow groundwater along the Pecos that has deteriorated because of salty river water replenishing depleted water tables, through reversal of normal flow paths as discussed earlier in the WPP.

Causes and Sources of Salinity

In general, natural sources of salt throughout the watershed cause the Pecos to be salty. Remnant salt deposits left by the ancient Permian Sea in both New Mexico and Texas are the culprit in this case and, over time, have been exposed by erosion; however, nature itself is not the sole cause of these salts finding their way into the river. Human disturbances have undoubtedly had an impact on the pathways that salt uses to enter the river.

New Mexico Sources

The USGS collected streamflow and salinity data at 11 gaging stations along the main stem of the river from the northern watershed to Girvin, Texas to evaluate salinity (Table 14). This analysis revealed that the main salt loading in New Mexico occurs in three reaches: between Santa Rosa and Puerto de Luna, Acme and Artesia, and Malaga and Pierce Canyon Crossing. The total annual salt loading into these reaches is an estimated 683,000 tons/year. The main ions entering through the first reach are calcium (Ca) and sulfate (SO_4) while sodium (Na) and chlorine (Cl) ions are entering through the second and third reaches (Miyamoto et al., 2005, Miyamoto et al. 2008).

Reference points along the Pecos River

The loading of Ca and SO_4 from the northern watershed is probably occurring through old or developing sinkholes and gypsum dissolution into agricultural drainage water in irrigated areas. The loading process is difficult to control as gypsum is found widely throughout the Pecos Basin. Fortunately, the dissolution of gypsum into streamflow is not nearly as damaging as the dissolution of NaCl for irrigated crop production. The situation worsens in the second reach (Acme to Artesia) where Na and Cl are the dominant ions entering into the flow of the Pecos (Miyamoto et al., 2005, Miyamoto et al. 2008).

The river segment between Acme and Artesia receives approximately 166,000 tons of salts per year from various sources, including the outflow from Chain Lakes and Bottomless Lakes. The salinity of these lakes located east of Roswell, New Mexico, varies from 15,000 ppm to 35,000 ppm and eventually flows into the Pecos (McAda & Morrison, 1993). These lakes appear to be a major source of water and salts; however, there are about 50,000 acres of cropland irrigated with groundwater nearby on the west bank of the Pecos that could contribute some flow to the river (Miyamoto et al., 2005). Furthermore, some suggest that subsurface flow into these lakes is coming from the west, rather than from the north (McAda and Morrison, 1993).

Salt loading into the Pecos between Malaga and Pierce Canyon Crossing is from brine seepage into the riverbed. This area of the Pecos watershed has been the focus of several studies, primarily by USGS (e.g., Hale et al., 1954; Cox and Havens, 1961; Cox and Kunkler, 1962; Havens and Wilkins, 1979) and by the State of New Mexico. Geological study indicates that this brine is an upward leakage of saturated brine from the boundary between the Rustler Formation and the Salado Formation (Miyamoto et al., 2005).

Historical flow and salinity data from this reach show that salinity of the Pecos was around 3,000 ppm at Malaga prior to 1950, and since 1959 has averaged 4,100 ppm with greater fluctuation. Average salinity at Pierce Canyon Crossing, downstream of Malaga Bend, during 1938-1940 was 4,800 ppm, but increased to 7,100 ppm after 1954. Historical records also indicate that large precipitation events occurring near Roswell or Malaga can flush enough salts into the Pecos to elevate salinity of Amistad Reservoir above the 1,000 ppm drinking water standard for TDS (Miyamoto et al., 2006, Miyamoto et al. 2008).

Table 14. Average flow, annual mean salinity and salt load of the Pecos River from USGS data collected from 1959-2002 (adapted from Miyamoto et al., 2005)

Gauging Stations	Annual Average Flow (Acre-feet)	Annual Salinity (ppm)	Salt Load (1,000 ton/yr)	Load Changes (1,000 ton/yr)	* Percentage of the Salt Load As Measured at:	
					Girvin	Langtry
New Mexico Sources						
Santa Rosa	70,532	675	42	+ 42	6	5
P. Luna	136,200	1527	221	+ 179	26	24
Sumner	131,336	1494	218	- 3	Net loss in reach (irrigation)	Net loss in reach (irrigation)
Acme	111,878	1722	228	+ 10	2	1
Artesia	128,903	3171	489	+ 261	38	35
Malaga	68,857	4111	265	- 224	Net loss in reach (irrigation)	Net loss in reach (irrigation)
P. C. Crossing	65,668	7128	437	+ 172	25	23
Red Bluff	68,100	7028	456	+ 19	3	2
Texas Sources						
Girvin	23,511	12849	351	- 105		Net loss in reach (irrigation)
Langtry	189,707	1995	426	+ 75		10

* Percentage of the positive salt loading total above Red Bluff (683,000 tons/year) and that of the total above Langtry (758,000 tons/year).

One source from which salts can be flushed is sinkholes. Sinkholes have developed through dissolution of salts present beneath the western bank of the Pecos River, called the Sacramento Plain. This plateau lies about 1,000 feet above the canyon floor of the Pecos River and is presumably positioned along the ancient shoreline of the Permian Sea. Some believe that the

Pecos River was carved through a series of sinkholes, some holding water and others being dry until the coming of the next flood. One of the sinkholes holding water is Bottomless Lake located near Roswell, New Mexico, between Acme and Artesia, along the Pecos River. This is where the Permian evaporite, halite, appears near ground level, and salt concentrations of the Pecos River increase from 1,700 ppm to 3,200 ppm (Table 14). Farther down the river, brine enters at Malaga Bend, just above Pierce Canyon Crossing, and salt concentrations there rise from 4,000 ppm to 7,000 ppm (Miyamoto et al., 2005, Miyamoto et al. 2008). This type of salt dissolution and salinization of the stream is also reported in the Wichita/Red River Basin and the Arkansas River Basin to the north, both of which travel through the same Permian Basin deposits (Johnson, 1981).

Texas Sources

Although the majority of salt loading into the Pecos River occurs in New Mexico, the Texas portion of the Pecos also experiences significant increases in salinity from saline water intrusion, surface inflow, and water impoundment (75,000 tons/year, as surmised from Table 14). Limited data are available on the specific amounts of salt loading these sources contribute in Texas; however, currently available information is not detailed enough to use as a basis for developing an implementation plan to significantly reduce salt loading from Texas sources. Monitoring work currently underway in the Pecos to Girvin stretch of the river, funded by TCEQ, will provide critical information about the sources of salts entering the river and provide a solid foundation of information that will aid in the future development and selection of management measures to control these sources.

Saline water intrusion appears to be the main cause of high salinity of the river below Coyanosa, Texas (Figure 7, near the gage station at Monahans). The water table in this reach ranges from 10 feet to 70 feet, and is hydrologically connected to the river. There are indications that the source of the saline water intrusion below Coyanosa may actually be the river itself, leaving its banks upstream and returning to the river channel with increased salinity concentration in this area. Isotope readings obtained on March 8 and May 7, 2005 are consistent with this hypothesis. If the shallow groundwater is a separate source, the isotope readings below Girvin should not change greatly when reservoir release is kept at a minimum. Neither the ionic composition, Cl to SO_4 ratios, nor Na to Cl ratios changed greatly below Pecos indicating that this is the case. Bank-flow may account for some portion of the flow (perhaps less than 25 percent) in the area and can present apparent similarities in chemical makeup between streamflow and groundwater intrusion. Nonetheless, these are early indications that the shallow groundwater entering the river below Coyanosa is charged at least in part by seepage from the river (Miyamoto, 2006). Therefore, management to reduce stream “reverse” flow into banks and the alluvial aquifer would be beneficial by reducing the losses of river water to the banks and shallow aquifers, thus resulting in more water moving downstream that has the potential to produce a dilution effect and reduce salinity or increase DO. A preliminary review of TWDB groundwater data seems to support this theory. The current state of knowledge needs to be further refined and, once completed, will provide critical information to aid in the development of feasible management strategies for this area.

Another potential source of salts entering the Pecos is derived from surface inflows from Salt Creek, Salt Draw, and possibly Toyah Creek. These ephemeral streams are not a constant source of salt entering the river, but data have shown that under high-flow conditions they can contribute significant loads of salt to the river. These systems may also contribute salts to the river in the form of subsurface flow.

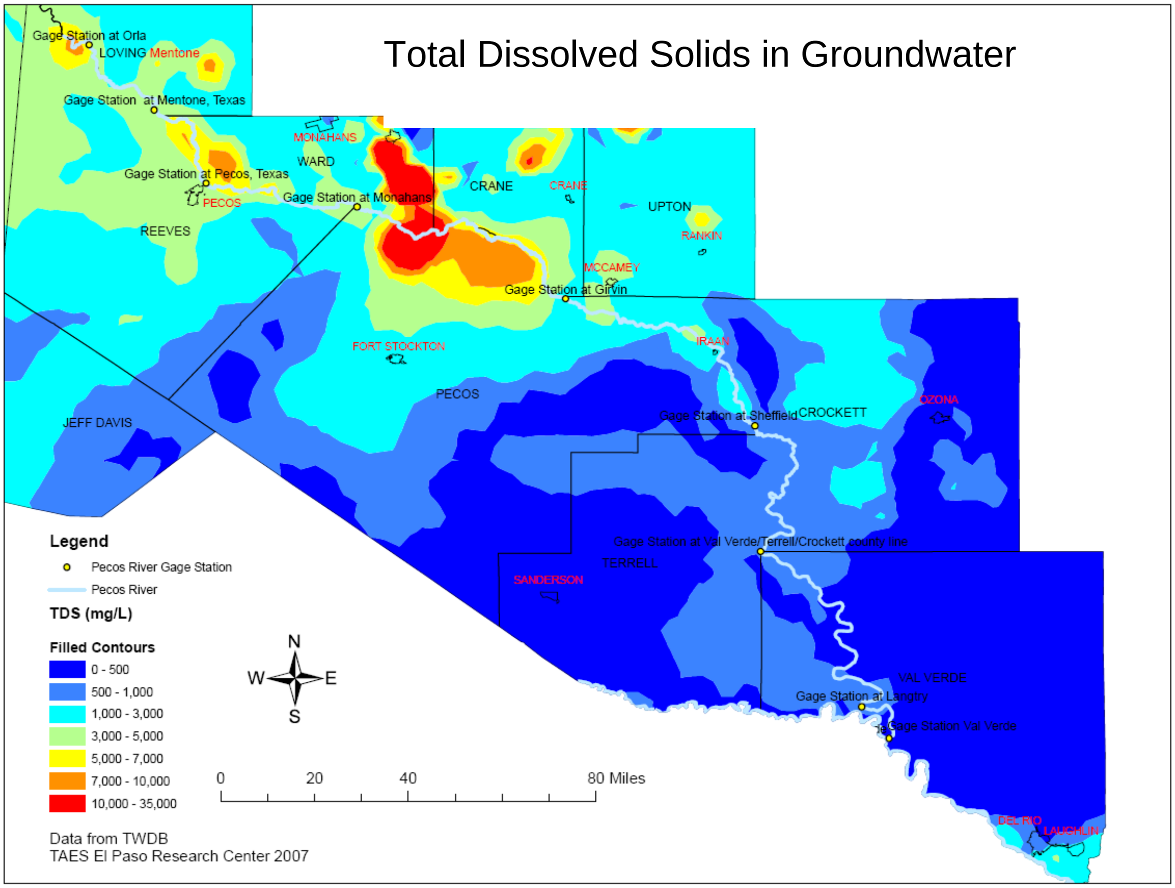


Figure 7. Distribution of groundwater total dissolved solids (TDS) in the Pecos Basin of Texas

Water evaporation and percolation losses from Red Bluff reservoir are also significant factors in increasing salinity concentration of the Pecos River in Texas. The reservoir is shallow, and has a large surface area to depth ratio. The mean depth of Red Bluff at the average storage volume of 81,000 AF is only 19 feet, while the annual water evaporation rate can reach 6.6 feet, or 28 percent of the total inflow. The net evaporative water losses (evaporation minus rainfall) from the reservoir were estimated as 23,511 AF/year. Although the 650 ppm difference in measured salinity between inflow and outflow is comparatively small, the flow-weighted salinity that controls the salt balance can increase to 1,720 ppm. Essentially, flow-weighted salinity is a product of the water's salinity and the flow rate averaged over time to account for the effects of high flow events on the river's salinity.

Estimated percolation losses averaged 33,000 AF/year or 32 percent of the average annual inflow. If the high percolation loss estimates for 1992 and 1995 are ignored, the percolation losses averaged 30,000 AF. This loss decreases further to 28,375 AF/year if the contribution of rainfall on the water surface is also ignored. However, percolation losses tend to increase if the storage volume increases; when reservoir storage was large (150,793 AF), percolation loss reached 48,643 AF/year. The salt unloading through percolation losses for 1999-2001 was an estimated 216,000 tons/year, 21 percent of which may have returned to the river (Miyamoto et al., 2007). The salinity of the percolated water was assumed to be the mean of inflow salinity (flow-weighted) and the outflow salinity.

Critical Areas for Salinity Management

Several major salinity source areas have been identified in the Pecos River that can affect the water quality and cause detrimental effects to the users of the river's water. Saline groundwater entering the river near Malaga Bend is the most critical source of salinity that can be managed. The impacts of this source are known and previously conducted studies and salt mining ventures conducted by the U.S. Department of the Interior – Bureau of Reclamation and private entities have demonstrated that pumping shallow groundwater to prevent it from entering the river has a significant impact on water quality below that point. Previous studies indicate that achieving a load reduction of 25 percent is feasible.

Evaporation pond from a salt harvesting venture at Malaga Bend, NM

In Texas, managing salt sources in the river between Coyanosa and Girvin is the most critical area. The level of information known about this reach of the river prohibits implementation activities from immediately being initiated. Old well casings have been identified as an area of concern and could have significant impacts on the quality of surface water and groundwater.

Red Bluff Reservoir is also a critical area of concern for elevated salinity levels. Irrigation downstream depends on these waters and increasing salinity levels cause decreases in crop production. Highly saline inflows from Malaga Bend coupled with high evaporation losses continually compound salinity levels in the reservoir.

Salinity levels in Lake Amistad have a significant impact on millions of lower Rio Grande Valley residents. Salinity (TDS) levels in the lake are slowly approaching the 800 mg/L drinking water standard and are heavily influenced by salts entering the Pecos River between Coyanosa and Girvin. Data used in the 2006 *Texas Water Quality Inventory* indicated that TDS levels averaged 522 mg/L over the previous five years; however, the long-term trend is increasing as reported by Miyamoto et al., 2006. If levels continue to increase, water utilities downstream will be forced to make sizeable capital investments and upgrade their treatment technology.

Riparian areas of saltcedar infestation also have the ability to impact salinity levels in the Pecos River. Water quality concerns arise from the saltcedar's ability to effectively transport salt from the soil profile or water table to the surface where it remains until it leaches back into the soil or is transported downstream during high flows (Wiesenborn, 1996). Saltcedar can also intensify water quality problems due to its ability to reduce groundwater supplies and streamflow through evapotranspiration. Approximately 3,032 acres of saltcedar remain untreated in the riparian corridor; however, only 2,158 acres are treatable and are the primary target for chemical treatment. Other saltcedar growth in the watershed must not be overlooked; regrowth in areas previously treated with chemicals and small infestations that are not slated for chemical treatment pose a serious threat to the long-term success of controlling saltcedar.

Estimated Salinity Load Reductions

Generally, the volume of flow in a river has been shown to significantly impact the overall effects of salt loading into a stream. This is the case with the Pecos River below Malaga, New Mexico, where limited streamflow mixed with highly saline inflows results in drastic increases in salinity. Historical records indicate that over 202,678 AF of water passed Malaga every year during 1929-1937. Today, the flow has decreased to 65,668 AF/year, thus resulting in reduced dilution and increased salinity. The same scenario applies to the situation at Girvin, Texas, where a significant decrease in streamflow combined with saline water intrusion yields high salinity waters. Long-term average streamflow (1959-2002) at Girvin is about 23,500 AF/year with an average salinity over that same time of 12,849 ppm. Saline groundwater seeping into the river was found to be the primary source of salt entering the river in both of these areas (Miyamoto et al., 2005). To reduce streamflow salinity, it is essential to maintain or, if possible, increase freshwater inflow into the Pecos, and/or to reduce the amount of salty groundwater entering the river by the same ratio that flow has been reduced. In the Girvin area, this can be accomplished by controlling saltcedar between Red Bluff Reservoir and Girvin. Saltcedar in the Pecos River watershed has been conservatively estimated to use 0.5 AF/year to 1.0 AF/year of water for each acre of saltcedar; however, given the potential evaporation of the area the physiology of the tree allows for more evaporative loss than is estimated. Using a water salvage estimate of 1.0 AF/year for the 6,640 acres of saltcedar treated since 2000 and the 1,422 acres of saltcedar above Girvin that will be treated in the near future, an estimated 8,062 AF/year should remain in the river and shallow aquifers adjacent to the river. This amount will result in a 34 percent increase in flow and a 34 percent decrease in salinity (from 12,849 ppm to 8,480 ppm) at Girvin assuming all of this salvaged water remains in the river.

In the case of Red Bluff Reservoir, the inflow decreased from 283,750 AF/year in the 1940s to 64,857 AF/year in 2000, a reduction of 77 percent. If the brine intrusion at Malaga Bend is controlled by pumping and evaporating 645 AF of water per year, salinity of inflow to Red Bluff will be reduced by 25 percent and the salt load would be reduced by 43,000 tons/year.

Table 15. Flow, annual salinity, salt load during normal and low flow years and those reported during controlled flow regimes

	Normal Flow (2000-2001)				Low Flow (2002-2003)			
Gauging Stations	**Flow AF/yr**	**Salinity ppm**	**Load 1000 t/yr**	**Change 1000 t/yr**	**Flow AF/yr**	**Salinity ppm**	**Load 1000 t/yr**	**Change 1000 t/yr**
Red Bluff (Outlet)	106,203	5991	883	-	-	7953	-	-
Orla	72,964	7184	739	-144	7,134	8449	83	-
Mentone	8,107	7895	97	-642	4,378	6024	43	-23
Pecos	4,864	-	-	-	7,215	7616	30	-70
Coyanosa	10,539	9148	130	80	6,972	14586	157	121
Girvin	17,025	13504	319	188	11,674	17493	281	123
	[2]Constant Flow (3/1965)				**[2]No Release (5/1965)**			
Red Bluff	93,232	7190	829	-	1,865	13860	32	-
Orla	89,178	7320	720	-109	243	17292	6	-25
Pecos	55,939	7320	512	-208	0	-	-	-
[1](Salt Draw)	-	-	-	-	(3,729)	(16310)	(75)	(75)
Grandfalls	43,779	7520	499	-13	730	17420	15	15
Girvin	45,400	9500	562	63	8,269	18216	187	172

[1] Saline flow, which appears in two sites between Pecos and Coyanosa, and is believed to originate from the subsurface flow of Salt Draw. Not considered as steady subsurface inflow.
[2] Flow and salinity measured under the controlled flow of 44,589 AF/yr by Grozier et al. (1966).

Data collected by CRP and Grozier et al. 1966.

Maintaining a constant flow level in the river has also shown to decrease the influence of saline groundwater entering the river; however, a constant flow level is probably not feasible because of the limited quantities of water in the area. Analysis of a study conducted by Grozier et al. (1966) indicates that salt loading into the Pecos between Grandfalls and Girvin, Texas can be reduced from 172,000 tons/year to 63,000 tons/year if adequate reservoir releases are maintained. The data shown in Table 15 indicate that saline water intrusion is reduced under elevated flow, e.g., greater than 40,536 AF/year. These data also suggest that salinity concentration levels could be decreased under more constant flow conditions even though the overall salt load may actually increase. Dilution by the increased volume of flow will minimize the effects of salinity in the river; however, an estimate of decreased salinity concentration cannot be determined because it will be dependent upon the concentration of salts in the increased flow of water. In addition to potential decreases in salinity, maintaining a constant or elevated flow in the river can decrease annual losses of water from the river to the banks or to shallow aquifers, thus resulting in even more water being transferred downstream.

Salinity Management Measures

Salinity in the Pecos River watershed presents a multi-leveled problem. Issues that influence the salinity of the river include saline groundwater, saline deposits in geologic formations, salt transported to the surface by saltcedar, decreased streamflow, and other potential sources or compounding factors. In several locations throughout the watershed, specific sources of salts entering the river remain unidentified and should be better defined before implementing BMPs to reduce salt loading into the river.

Malaga Bend

Brine intrusion from natural salt formations at Malaga Bend in New Mexico has historically caused a drastic increase in the salinity of the Pecos River and significantly impacts the quality of water received by irrigators below Red Bluff. Attempts to manage these salts in the past were proven effective but with limited economic success. Control of brine intrusion has the most potential to significantly improve the water quality in the Pecos River in Texas and, therefore, should receive high priority.

The Malaga Bend Salinity Alleviation Project, began in 1963, was initially a cooperative effort of the USGS, the Interstate Stream Commission and Red Bluff WPCD. From July 1963 to July 1968, this operation pumped brine from an existing USGS well in the saline aquifer into natural depressions in the surrounding area at a rate of 450 gpm. The soil in the ‘playa’ lakes was compressed to reduce seepage losses and allow the water to evaporate in order to harvest the remaining salts. River salinity temporarily decreased, but the project was terminated in 1976 due to leaking evaporation lakes that allowed the salty water to return to the river. During this time, 3,575 AF of brine water was pumped, which effectively reduced the salt load in the river by about 175 tons/day. In 2001, the project re-emerged in a slightly different form. Brine Partners, a private salt mining company, built several manmade evaporation ponds and the brine at Malaga Bend was again pumped into these ponds. The State of Texas agreed to allow New Mexico a water delivery credit of up to 645 AF/year if the pumping and salt mining effort could reduce the salinity of the water delivered to Texas by a minimum of 25 percent. This reduction level was met and, if maintained over one year, would result in a 43,000 ton reduction in salt loading between Malaga Bend and Pierce Canyon Crossing. However, in 2003 the ponds were leaking again. The ponds were then lined, and operations resumed in early 2004. This phase of the project is no longer in operation because of financial and permitting problems experienced by Brine Partners. No salinity alleviation is currently taking place at Malaga Bend.

Southwest Salt, another private company, is currently interested in cooperating with Red Bluff WPCD to operate the Malaga Bend Salinity Alleviation Project. The company is proposing to buy the well and some of the property owned by Brine Partners, and to purchase property on the east side of the river to install about 200 acres of solar evaporation ponds. In addition, the Center of Excellence for Hazardous Materials Management (CEHMM), a 501(c)(3) non-profit organization located in Carlsbad, New Mexico, is interested in using some of the brine in cooperation with Southwest Salt. CEHMM would use the brine to research and develop methods for producing biodiesel from the propagation and harvesting of brine algae.

Red Bluff Reservoir

As stated earlier, salinity levels of water released from Red Bluff are typically about 7,000 ppm due to the constant influx of saline water from Malaga Bend and evaporation losses from the reservoir. Controlling the flow of salt from New Mexico will have the greatest impact on the quality of water stored by Red Bluff; however, other management measures may be feasible as well.

Evaporation from reservoirs is a significant factor that is responsible for increasing salinity, especially when the reservoir is shallow or has a large surface to depth ratio, like Red Bluff. Current management practices employed at Red Bluff Reservoir keep lake levels at approximately 30 percent capacity to reduce evaporation and percolation losses. Though this practice helps in reducing excess reservoir loss, significant loss still ensues. Miyamoto et al. (2007) found that typical evaporation losses from the reservoir equaled about 28 percent of the annual average inflow to the reservoir. Under the current water delivery practices, the designated allotment of water seems to be transferred from New Mexico to Red Bluff during and shortly after the irrigation season. This water is then subjected to evaporation and percolation losses for as long as 5 months to 6 months prior to its release to Texas irrigators the next season. Although there may be various contractual constraints, holding water in deeper reservoirs upstream until the beginning of the irrigation season may reduce percolation losses, evaporation losses, and associated increases in salinity that occur when water is stored at Red Bluff. Preliminary estimates indicate that holding water in deeper reservoirs can have a significant impact on lowering salinity only if the holding translates to a substantial reduction in water surface area at Red Bluff. Developing an agreement with New Mexico is a key aspect of this management strategy that will take considerable negotiations and time to establish. A downside to this approach is that lower lake levels at Red Bluff mean less available water in the reservoir. If New Mexico is unable to meet its water delivery obligation to Texas for some reason, Texas irrigators will realize the impacts more quickly than they would if some amount of surplus water was being held in the lake.

Reducing percolation losses at reservoirs is another way to potentially reduce streamflow salinity. If water that normally percolated out of the reservoir can be sent downstream, it will help to dilute the salts present in the river; however, this practice is not feasible at all reservoirs. Seepage control at Red Bluff is unlikely to significantly affect salinity of the reservoir's outflow, as seepage loss is merely a form of outflow thought to return to the river in the form of shallow groundwater. As discussed previously, only 21 percent of the salts lost through percolation are returned to the Pecos via downstream inflow. Therefore, eliminating or drastically decreasing percolation losses may cause more harm to the river than through reduced inflow and will likely lead to increased evaporation losses from the lake. Without further investigation, this management practice is not recommended for implementation.

Coyanosa to Girvin

The reach of the Pecos River between Coyanosa and Girvin is the main source of salinity entering the Pecos in Texas. Due to the limited knowledge about specific sources of the saline water intrusion in this area, management options discussed here are based on possible scenarios. Further study in this area is required before any specific management measures can or will be recommended. Current information does not identify the specific source(s) of salts entering the river in this reach.

Data previously reported in Table 15 suggest that the saline water intrusion in this area can be reduced by increasing the volume of flow, resulting in higher hydrostatic pressure. An alternative to increasing river flow is to implement a large check dam or series of smaller check dams in the appropriate location(s) along a channel. This practice would effectively result in similar outcomes by elevating local water levels due to ponding and would increase the hydrostatic pressure in isolated areas, thus reducing the amount of undesirable groundwater entering the river channel. A potential obstacle is the slope of the land, which drops a mere 60 feet over a 34 mile stretch of river; damming the river on such slight gradients would result in large increases in surface area and subsequent evaporation losses. Water lost to the shallow water tables may re-enter the river further downstream and reduce the effectiveness of a single check dam, but a series of these dams can minimize this effect in areas where groundwater is highly saline. To determine the effectiveness of this approach, a feasibility analysis and more in-depth understanding of the shallow water tables and what the sources of saline contributions are in this reach is required. If it is determined that this approach is feasible, coordination with TPWD and U.S. Army Corps of Engineers (USACE) will be critical.

A groundwater pumping and evaporation operation similar to the one described as a management measure to implement in the Malaga Bend area would also aid in reducing saline water intrusion into the river in this reach.

Saltcedar

Until research on the use and potential locations of check dams is completed, saltcedar control is the most readily achievable option to decrease the salinity of groundwater intrusion between Coyanosa and Girvin. Saltcedar is potentially compounding the impact of the undesirable groundwater by increasing the salt concentration through evapotranspiration. Sheng et al. (2007) have conservatively estimated annual evaporative losses from saltcedar stands to average between 0.5 AF/year and 1.0 AF/year per acre of saltcedar. By controlling saltcedar, the majority of the water lost through evapotranspiration would remain in shallow water tables or the vadose zone and reduce the amount of water lost from the river to the banks and shallow aquifers.

Controlling saltcedar can impact water quality and quantity through two main methods. Saltcedar stands indirectly impact salinity by effectively reducing the amount of dilution that occurs in the river through evapotranspiration. Water removed from shallow water tables is then replaced by river water resulting in less water moving in the channel to dilute salts entering the river. Controlling saltcedar can influence dilution effects by allowing more water to remain in shallow water tables and subsequently in the river channel. Sheng et al. (2007) indicate that the most likely result from saltcedar control will be increased water in shallow water tables instead of increased streamflow. Saltcedar removal also has the ability to reduce salt loading into the Pecos by eliminating salt-laden leaves from falling on the bank or in the stream. The plant transports salt extracted from soil and water to its leaves where it is eventually voided (Wiesenborn, 1996). TCEQ evaluated this approach and included targeted saltcedar control as one of the critical management measures in the *Implementation Plan for Sulfate and Total Dissolved Solids Total Maximum Daily Loads in the E.V. Spence Reservoir*. In accordance with that implementation plan, TSSWCB successfully implemented targeted saltcedar brush control, with state appropriations and federal grants, on 11,391 acres along the riparian corridor above E.V. Spence Reservoir and in the Spence lake basin itself.

Salinity additions contributed by saltcedar leaves typically have the greatest effect on salinity when overbank flows occur and carry salt excreted from and trapped within the fallen leaves downstream. These short-lived increases in salinity do not make a major contribution to the Pecos River, but salt loading can be significantly influenced during flood events. Decay of these leaves also contributes to increased biological oxygen demand (BOD), a driver of depressed DO.

Chemical and biological control of saltcedar have proven to be the most cost-effective methods for controlling saltcedar and will be discussed in detail in the biological diversity section of the WPP along with needed follow-up management and maintenance needs.

Assistance Needed for Salinity Management

Technical and financial assistance needed to effectively implement salinity management measures in the Pecos River watershed will come from a variety of sources. Continued evaluation of salt sources throughout the watershed is needed to develop a better understanding of their impacts. AgriLife Research, TCEQ, TWDB, and USGS are likely candidates for providing assistance. Funding for further studies will be sought from federal agencies such as the Department of the Interior or the USACE or through CWA §319(h) NPS grants.

Malaga Bend

The brine pumping described earlier in the WPP has proven effective, but economic restraints have kept this effort from being pursued further. Substantial private investment will be required to effectively pump, harvest, and market the salts captured from the saline groundwater entering the Pecos at Malaga Bend. A rough estimate of needed funding to support a private salt mining effort was roughly $200 million dollars for initial capital costs. The Southwest Salt and US Salt Companies have both shown interest in pursuing this venture, but to date have not made any major progress towards an operational project.

Federal funding could also be used to pump saline groundwater and evaporate it in a natural salt flat without harvesting. Costs for this effort will vary depending on the cost of the pumps, land acquisition, pipeline easements, and a pipeline to deliver pumped water to the evaporation ponds. Land costs, according to online listings for the area, range from about $500 per acre to several thousand depending on the land. In this case, $500 per acre is probably a reasonable estimate for land in this area and approximately 200 acres or 300 acres would be sufficient for the operation. Cost for the pipeline and easements can be considerable depending on how far the water will need to be transported. To carry 645 AF/year, a minimum of an 8-inch pipeline is needed and would cost approximately $40,000 per mile using 2002 cost figures for a natural gas transmission line. This cost figure includes right of way costs, material, labor, and other costs; however, actual costs will vary according to the specific needs of the project. In addition, an engineering firm will likely need to be hired to conduct a feasibility study of the project.

Red Bluff Reservoir

There should not be any needed technical or financial assistance to modify the release and delivery of water from New Mexico to Red Bluff Reservoir. Rescheduling the timing of water delivered to Texas will require coordinating efforts from the entities managing the waters of the two states. Initially, the Pecos River Compact Commission (PRCC) could work to facilitate this; however, the Red Bluff WPCD would need to support this idea of New Mexico delivering water to Texas late in the winter rather than the fall when the bulk of the delivery typically takes place. Although specific financial assistance will not be needed, considerable time and negotiation will be required.

Coyanosa to Girvin

Technical and financial assistance needed to evaluate the feasibility of check dams in the Pecos River is quite extensive. Initially, the entire river in this reach will need to be assessed for feasible check dam locations based on the gradient of the riverbed. Once suitable locations are identified, each one will need to be evaluated to determine if installing a check dam will effectively reduce saltwater intrusion in that reach of the river. The USACE or TWDB could potentially conduct a study of this sort, but a private consulting firm would likely be a better candidate. Considerable funding will be needed to evaluate and implement this management practice and the practice in general may not be a cost-effective means to address the situation. Permitting issues will also need to be addressed if this course of action is taken.

Technical and financial assistance needs for a groundwater pumping and evaporation project located in this area would be similar to those needed for the effort at Malaga Bend.

Biological Diversity

Biological diversity refers to a wide variety of features in the watershed that can include aquatic, riparian, and upland vegetation; aquatic life species; and wildlife species. Over time, significant changes have been made to these biological components of the watershed and these components stand to be enhanced through improved management measures.

Causes of Biological Diversity Change

Various studies on aquatic life have shown that more than 40 species of fish have historically existed in the river. More recent surveys have found decreasing numbers of these fish present along the river. Increasing demands on river water and declining water quality are the likely cause of these lower numbers.

Vegetation in riparian areas across the Pecos has changed significantly since the first settlers arrived in the region. Early accounts suggest that cottonwood trees lined parts of the Pecos and its tributaries (Wauer, 1973; Wuerthner, 1989) while other areas had no trees or shrubs (Humphrey, 1958) but instead were covered with deep grasses (Echols, 1860).

Brush dominated rangeland near Pecos, Texas

In recent years, saltcedar has become the dominant species in almost all riparian habitats, although recent control efforts have led to the re-establishment of some native species. Giant cane (*Arundo donax)* and willow baccharis (*Baccharis salicina*) are also thriving in some parts of the watershed. Without proper management, these species may take over the riparian corridor much the same way that saltcedar has the last 100 years. The key to controlling these species over a long time is to eliminate their seed sources. To accomplish this, eradication efforts must be carried out in both Texas and New Mexico. A critical need for controlling these invasive species is to conduct follow-up management in treated areas to bolster the establishment of native species and assist in preventing the re-establishment of other invasive or nuisance species. Following treatment in riparian areas, removing the debris through mechanical means or prescribed burns will be an important step in minimizing the negative impacts of dead material left behind and will aid in preparing a suitable seed bed for re-establishing native vegetation along the riparian corridor.

Upland vegetation has also changed drastically since modern settlement. When the first settlers arrived in the Trans-Pecos region, what they found in many parts of the watershed was extensive grasslands void of mesquite, greasewood, saltcedar, or any other tree or shrub species. Watershed residents whose families have lived in the area for several generations have confirmed that shrubs or brush were relatively nonexistent when their families arrived.

Critical Areas for Biological Diversity

Aquatic life surveys conducted for this project indicate that the entire river could improve in the overall number of fish species present, habitat quality, and biological diversity. The upper portion of the river exhibited the least amount of biological diversity in both fish and macroinvertebrate species among the reaches sampled. Elevated salinity and highly variable flows in these reaches are the main factors that limit the diversity of species present. Improving habitat conditions and water quality will be a critical step in bolstering the existing populations and must be done before any other actions are taken to boost populations.

Riparian brush control continues to be a critical task for improving biological diversity. As of March 2008, all but 3,032 acres of saltcedar along the main channel of the river have been sprayed (see maps in Appendix C). Only 2,158 of the remaining acres of saltcedar are treatable with chemical and treating these areas will be critical in controlling future growth of saltcedar along the river. Project personnel can treat only those areas where landowners have granted permission. These same areas will be the focus areas for burning debris and revegetating the riparian corridor. Other key areas that must be addressed to keep future outbreaks in check are 1) saltcedar stands in tributaries and upland areas of the watershed, 2) areas of regrowth in previously treated areas, and 3) saltcedar stands in New Mexico. If these three key areas are not managed properly, they will serve as a seed source that will eventually lead to the establishment of saltcedar stands along the main channel of the Pecos River again. Other riparian species becoming more prevalent in the watershed are giant cane and willow baccharis. These species are typically taking over in some areas along the river where saltcedar was sprayed and other native vegetation was not able to re-establish quickly. These species also need to be addressed or they may become a nuisance similar to saltcedar.

Critical areas where conducting upland brush control and subsequent management practices to prevent future brush invasion should be areas that have the ability to produce significant runoff or significant aquifer recharge. These areas include land in close proximity to the river, a creek, wash, draw, or any other areas where concentrated flow occurs. These areas may also have more compact soils that promote runoff rather than infiltration and are on a steeper slope. Areas known to contribute recharge to underlying aquifers should also be considered as a critical area for restoring upland habitats.

Biological Diversity Management Measures

Biological diversity in the river and riparian areas has seen many changes since the expansion of settlement in the basin. Many activities and management practices (or lack there of) have led to the decreasing numbers of native species and consequent reductions of habitat and species diversity. Even though complete habitat restoration is not possible, a significant management effort can help to improve some of the natural habitat in the watershed and aid in containing the spread of nuisance species.

Saltcedar Control

Continued saltcedar management is perhaps the most feasible management option for restoring some of the watershed's biological diversity. In many cases, saltcedar has completely taken over the riparian corridor by outcompeting native species in this saline environment. Recent control efforts have greatly reduced the amount of saltcedar present in the basin; however, a one-time effort to kill saltcedar will not be effective long term or for complete removal of the species from the watershed. Additional efforts that treat as much remaining saltcedar as possible and a long-term maintenance approach to keep the plant in check are necessary to prevent re-establishment of widespread saltcedar stands. Controlling the currently viable seed sources in the watershed will be critical to limiting future impacts of saltcedar regrowth. Without continued efforts to manage this species across the entire watershed, all monies previously spent to treat saltcedar will be wasted. Future control efforts must be continued in both states until all viable saltcedar stands are kept in check, or saltcedar will undoubtedly take over the riparian corridor again in the future. Continually monitoring and treating regrowth in riparian areas will be critical for identifying areas where additional treatments are needed. Increasing the use of the saltcedar leaf beetle will be an important and cost-effective part of the long-term management plan for the watershed. Re-establishing and managing native vegetation will be beneficial to biological diversity as well. NRCS provides plant recommendations in its Field Office Technical Guide (FOTG) that will be beneficial in choosing plant species that can tolerate conditions near the river. This information, coupled with continued saltcedar management, will be critical in re-establishing a healthy riparian corridor.

A recent survey estimated the area of unsprayed saltcedar along the Pecos River corridor at 3,032 acres (Table 16); however, 874 of these acres are not feasible to treat with helicopter-applied herbicide due to high canyon walls. Figure 8 shows 13,497 acres along the river and in the watershed that have been treated with aerially applied Arsenal® using global positioning system

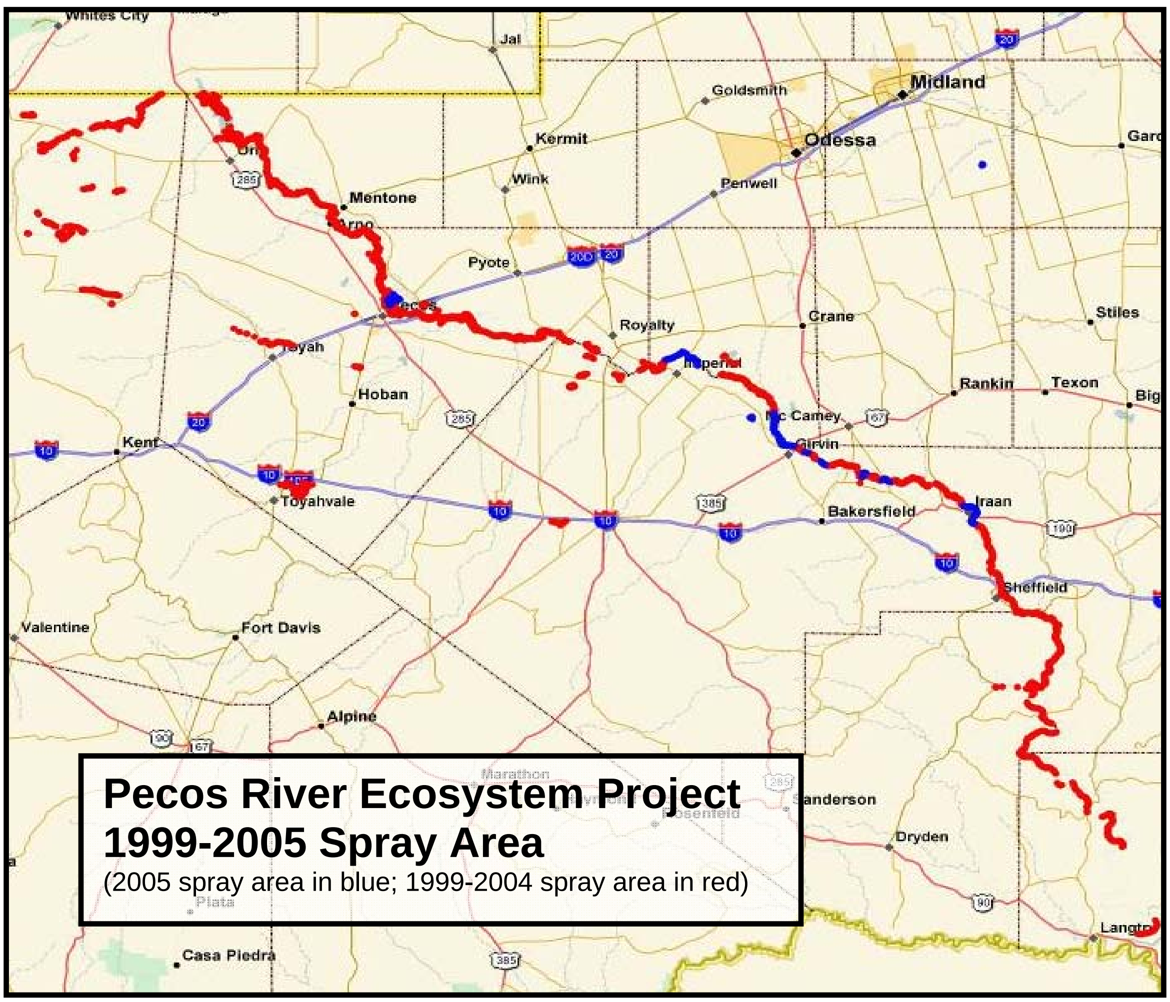


Figure 8. Areas sprayed for saltcedar control on the Pecos River in Texas, 1999-2005

(GPS) guided helicopters to spray saltcedar through the Pecos River Ecosystem Project and Appendix C shows areas along the river that have yet to be sprayed. As of 2005, $2,693,915 in local, state, and federal funding has been spent on saltcedar treatment at an average per acre cost of $199.59. Of the 13,497 acres treated, 10,354 were along the main stem of the Pecos. More maps and information regarding previous saltcedar spraying can be accessed from the project Web site in the "Geographical Information System Coverage" report (Villalobos et al., 2007). Other significant areas of saltcedar growth exist away from the river in isolated pockets and along tributaries to the river and implementing management measures to manage these areas should also be a priority. These stands away from the river represent a seed source that also needs to be controlled to minimize seed production and reduce the chance of new stands being established.

Eventual regrowth will likely occur and a long-term sustainable management plan must be in place to prevent future large-scale infestations. In these situations, treatment options such as aerial spraying will likely not be financially feasible. Other management measures such as biological control or individual plant management by landowners are more suited for these applications. This approach uses the saltcedar leaf beetle (*Diorhabda elongata*) to repeatedly feed on the plant's leaves and eventually lead to the demise of its host through continued defoliation. The saltcedar leaf beetle will not completely eradicate saltcedar in the watershed; instead, it will help keep the species under control. These beetles have been extensively evaluated by USDA Agricultural Research Service (ARS) and have been approved by the USDA Animal and Plant Health Inspection Service (APHIS), U.S. Fish and Wildlife Service, and Texas Department of Agriculture (TDA) for release in Texas. The leaf beetle, a native of Eurasia and

Diorhabda elongata, the Saltcedar leaf beetle (http://entowww.tamu.edu). Actual size of an adult beetle is 5-6 mm in length

Table 16. Estimates and corrected estimates of digitized saltcedar acreage left unsprayed in Ward, Crane, Pecos, Crockett, Terrell, and Val Verde counties after the 2005 spray season

	Ward	Crane	Pecos	Crockett	Terrell	Val Verde	Total
Total Digitized Acres	**67.32**	**562.79**	**3185**	**1551.27**	**515.17**	**427.9**	**6309.52 acres**
Digitized acres after 2004 spraying	34.4	263.9	658.6	532.54	85.97	132.16	1707.57 acres
Digitized acres after 2005 spraying	34.4	163.11	591.7	430.18	85.97	132.16	1437.52 acres
Digitized acres sprayed 2003-2004	32.92	298.89	2526.47	1018.73	429.2	295.74	4601.95 acres
Digitized acres sprayed 2005	0	100.79	66.9	102.36	0	0	270.05 acres
Total digitized acres sprayed	**32.92**	**399.68**	**2593.37**	**1121.09**	**429.2**	**295.74**	**4872 acres**
Actual acres sprayed in 2003-04	42.78	604	1539	1417	506	513	4621.78 acres
Actual acres sprayed in 2005	0	365	102	186	0	0	653 acres
Total acres sprayed	**42.78**	**969**	**1641**	**1603**	**506**	**513**	**5274.78 acres**
Corrected digitized acres after 2005 spraying	**51.4**	**223.4**	**641.9**	**586.4**	**151.2**	**487.6**	**2141.8 acres**
Total estimated acres of saltcedar	1604.77	1192.37	2565.25	2189.38	657.21	1385.90	9597.87 acres
Total acres sprayed through 2005	1333	969	1641	1603	506	513	6565 acres
Corrected est. acres left after 2005	**271.77**	**223.37**	**927.25**	**586.38**	**151.21**	**872.90**	**3032.87 acres**

natural enemy of the plant, represses saltcedar growth by feeding on its leaves and bark. This greatly reduces its water-using potential and will eventually kill the plant after repeated defoliation occurs. Saltcedar is an introduced species and has no close relatives in the United States; therefore, little risk of the beetle feeding on other plants exists (DeLoach et al., 2003; Knutson et al., 2003).

Currently, the Saltcedar Biological Control Program in Texas, through work by AgriLife Extension, has established two populations of the leaf beetle on the Pecos River along with 12 other locations in Texas. The first site, established in early 2006, is located north of the city of Pecos. Beetles were released from their cages in July 2006 and have shown promising results thus far. As of October 2007, this population of beetles has dispersed over half a mile from its cages and has defoliated approximately 94 acres of saltcedar, or 500 individual trees. The second site was established near Imperial and has shown similar success. Beetles at this site were released in July 2006 as well and have spread to the opposite side of the river.

ARS, with funding through CWA §319(h) NPS grants from the TSSWCB, is examining dispersal rates for leaf beetle populations in the Colorado River Basin and developing a computer model for predicting dispersal of the beetle based on observations made.

A key to successfully implementing saltcedar leaf beetles as a means of controlling saltcedar is to establish multiple populations throughout the area that are self-sustaining and spread across the watershed. This will take time and initial results will be limited; but as in all implementation projects, change will not happen over night. This option does present a relatively inexpensive option that should provide a long-term approach to keeping saltcedar in check.

The leaf beetle is not an option that results in quick control of large stands of saltcedar. This approach takes several years for dispersal of the beetle and individual trees to subsequently die and will not result in complete eradication of saltcedar. Therefore, the combination of chemical treatment to get widespread saltcedar infestations under control with biological treatment to ensure long-term control appears to be the best approach for a long-term saltcedar management.

Giant Cane Control

Currently, large-scale efforts to spray giant cane infestations in the southern portion of the river have not been conducted due to limited knowledge about the most effective chemical treatment options. Research is currently being done on Clearcast® and Habitat® Herbicides produced by the BASF Corporation to evaluate their ability to control cane infestations. These are nonselective herbicides that are typically used to kill weeds and any other plants that absorb the chemical through their leaves. Given the nature of the chemicals, precise application is required to limit the extent of vegetation killed. Spot spraying for small stands or precise aerial application from GPS-guided helicopters on larger stands are the most feasible methods of chemical treatment. Treating cane stands in the lower Pecos will be incorporated into additional saltcedar control efforts carried out in the complete riparian restoration effort.

Mechanical control is another option that can be used to combat giant cane, but is only considered partially effective because even small root fragments are able to resprout and lead to a re-established stand. Prescribed burning may also be effective, but has similar problems as mechanical treatment. Test burns have shown that this practice is most effective after the plant has flowered and in combination with other treatment practices such as herbicide use.

The total acreage of giant cane infestations in the Pecos River watershed is not currently known and must be determined before an accurate estimation of needed management measures can be developed. Currently available aerial photography taken in the lower Pecos River may reveal giant cane stands, but project personnel need to assess the photography to establish if it will be adequate for determining areas that need treatment. If this imagery is sufficient, then no additional monies are needed, but if it does not accurately delineate these areas, an assessment of new updated imagery will be required.

Upland Brush Control

Controlling brush species in upland areas will also have a significant impact on helping to improve the watershed. Some landowners have conducted isolated upland brush control activities in the watershed with promising results for improving spring flow and the amount of consumable forage for livestock and wildlife. A large-scale effort to control, manage, and reclaim rangeland and pastures currently infested with brush is needed to address the issue, but because of the high cost of these practices, priority areas must be focused on first.

Mechanical brush control

Costs are a primary concern that landowners have when considering brush control on their property. In this case, chemical treatment is typically the most cost-effective method for controlling a wide variety of brush species but costs are still significant when the treatment is applied over a large area of land. Other effective options for controlling brush are mechanical treatment and prescribed burning. A primary step in conducting a large-scale brush control effort will be to establish a grazing management plan with the help of local NRCS personnel or to establish a WQMP with assistance from local SWCDs. These plans will recommend brush control and proper grazing management practices and enable the landowner to be eligible for financial assistance through those agencies. Adhering to the prescribed grazing practices and preventing overgrazing will also be critical to ensure that brush species do not re-establish themselves after treatment is completed.

Riparian Restoration

Debris removal is another major concern in the watershed. Saltcedar control efforts have left large numbers of dead trees standing in the riparian corridor. Removal of these dead trees will aid in future management efforts in and along the river by allowing for easier access. This process will also reduce BOD from the decaying trees entering the river and traveling downstream. In addition, removing these dead trees also allows floodwaters to move down the river channel with fewer restrictions and decreases the risk of potential damage to bridges and diversion structures downstream. Most importantly, removing debris will aid in the revegetation of native plant species in the riparian corridor.

Prescribed burning has proved to be the most physically and economically feasible method for removing the saltcedar debris in the Pecos watershed and has been successfully demonstrated by the Texas Forest Service (TFS). Test burns conducted at a site near Mentone (see Figure 9) showed the effectiveness of this practice. Currently, burning efforts coordinated by the Upper Pecos SWCD and funded by the 81st Texas Legislature through the TSSWCB and equal amounts of local matching funds are underway. This effort is targeting the area of the river between Red Bluff Reservoir and I-20, roughly 100 river miles; $150,000 in state appropriations has been allocated to this task. Approximately 315 river miles will remain unburned after this initial effort and will need to be burned in the future to eliminate the majority of debris left behind.

Subsequent to debris removal, revegetation of the riparian corridor will be essential for returning these areas to a more natural state, stabilizing streambanks, and providing more suitable habitat and forage for wildlife and livestock. Native grass re-emergence has already been noted in some areas, but seeding may be employed in some areas to expedite the process. Landowners along the river are very much in support of re-establishing quality ground cover along the river and in other areas where debris is burned, but have stated that large-scale reseeding efforts will be relatively impossible due to the rough terrain and inability to get equipment to the river. In those cases, natural re-establishment will be relied upon exclusively. Establishing ground cover after prescribed burns is critical to preventing excessive erosion in these areas. The fourth photo in the series of pictures from the test burn site near Mentone in Figure 9 shows the burn site one year after the burn with species such as Bermudagrass and Russian thistle (tumbleweed) establishing themselves without any reseeding efforts. This and other data evaluated by Extension indicates that conducting prescribed burns three years after chemical treatment results in the highest percent debris removal and increasing the kill rate of any saltcedar regrowth that has occurred following chemical treatment.

Figure 9. Before, during, after, and 1 year-after photos of debris burning tests conducted by the Texas Forest Service at a site near Mentone

To support re-establishment efforts, the NRCS FOTG has plant materials information that will be useful in determining which plant species will be most tolerable and competitive in revegetation efforts. The TFS is conducting ongoing vegetation studies in the Pecos River watershed, and these studies will provide additional information about determining which species are the most tolerant of the environment and the easiest to establish. Soil and water salinity in these areas is a key factor in determining species that will thrive in these areas along the river. Conducting a background survey of soil salinity and shallow groundwater salinity at each site will be beneficial in helping select the most appropriate plant species. Table 17 shows some common shrubs, trees, and grass species that are typical riparian species in the watershed and illustrates their relative growth rates under certain leaching conditions and with water of certain salinity levels.

Table 17. Relative growth rates of riparian species when grown at a leaching fraction greater than 30% using the specified saline solution concentrations

Species	Salinity of Water (mg/L [1])						Ref. [2]
	1,000	5,000	10,000	15,000	20,000	30,000	
Shrubs and Trees	% of optimum growth rate						
Pickleweed *(Allenrolfea occidentalis)*	71	94	81	77	75	72	1
Suaeda *(Suaeda esteroa)*	93	98	99	73	45	13	4
Maritima *(Batis maritima)*	100	91	84	64	51	29	4
Saltgrass *(Distichlis palmeri)*	91	97	99	77	48	20	4
Saltbush *(Atriplex nummularia)*	99	95	82	60	40	17	4
Quailbush *(Atriplex lentiformis)*	72	98	84	65	48	0	2
Saltcedar *(Tamarix ramosissima)*	98	89	78	68	57	35	1
Saltcedar *(Tamarix chinensis)*	95	92	72	53	22	0	2
Mesquite *(Prosopis sp.)*							
Honey Mesquite *(P. pallida)*	97	87	72	55	39	8	3
Honey Mesquite *(P. articulata)*	92	61	38	40	43	48	3
Honey Mesquite *(P. glandulosa)*	93	65	42	32	24	5	3
Arrowweed *(Tessaria sericea)*	60	72	40	24	18	0	2
Arrowweed *(Pluchea sericea)*	95	77	54	31	7	0	1
Sheepwillow *(Baccharis salicifolia)*	91	53	6	0	0	0	1
Goodding willow *(Salix goodingii)*	89	42	0	0	0	0	1
Goodding willow *(Salix goodingii)*	99	13	6	4	3	2	2
Cottonwood *(Populus fremontii)*	86	3	0	0	0	0	1
Grass Species							
Fults alkaligrass *(Puccinellia distans)*	95	99	93	92	87	76	5
Tall wheatgrass *(Thinopyrum ponticum)*	88	91	95	74	46	33	5
Wild rye *(Elymus sp.)*	91	96	66	41	19	0	5
Alkali muhly *(Muhlenbergia asperifolia)*	77	89	93	42	0	0	5
Buffalograss *(Buchloe dactyloides)*	99	61	33	2	0	0	5
Wheatgrass *(Thinopyrum sp.)*	98	53	33	0	0	0	5
Bermudagrass *(Cynodon dactylon)*	99	74	15	0	0	0	5
Blue grama *(Bouteloua gracilis 'Alma')*	99	29	13	0	0	0	5
Black grama *(Bouteloua eriopoda)*	99	0	0	0	0	0	5

[1] Assuming the soil moisture range of 0 to 50% depletion at a leaching fraction no less than 30%
[2] References: 1) Glenn et al., (1998); 2) Jackson et al., (1990); 3) Felker et al., (1981); 4) Miyamoto et al., (1996); 5) Miyamoto and White, (2006).

Adapted from Miyamoto et al., (2007)

Water Quality Management Plans (WQMPs)

A WQMP is a site-specific plan developed through and approved by SWCDs for agricultural or silvicultural lands. These plans include appropriate land treatment practices, production practices, management measures, technologies, or combinations thereof. The purpose of WQMPs is to achieve a level of pollution prevention or abatement that is consistent with state water quality standards, while meeting the landowner's management goals.

The TSSWCB selected requirements for a WQMP based on the criteria outlined in the FOTG, a publication of NRCS. The FOTG represents the best available technology and is tailored to meet the needs of individual SWCDs.

A WQMP covers an entire farm or ranch unit and includes required practices applicable to the planned land use. Conservation cropping sequence, nutrient management, and residue management should be considered for cropland. Proper grazing use is a vital consideration for a good WQMP on rangeland. Various grazing systems will be examined and a sustainable system will be implemented. A WQMP on pastureland/hayland will have water facility considerations. Forestland and wildlife areas are not to be excluded from the WQMP operating unit.

WQMPs also include technical requirements. Nutrient management must be outlined if nutrients are applied and pesticide management must also be considered. An owner/operator will have to know how to properly apply these inputs to their land. If an animal feeding operation is involved (such as a dairy or poultry operation), an animal waste management system will be a component of the WQMP. Waste utilization will be considered when agricultural wastes are applied to the land. WQMPs also have components for irrigation waters and erosion control and are flexible enough to cater to a wide range of operating systems.

The first step in obtaining a WQMP is to visit the local SWCD. NRCS or SWCD staff can take a request for a WQMP, obtain necessary information from the producer, and start the plan development process. There is no charge for development of a WQMP; however, there may be costs for implementing certain practices required in a WQMP, for which financial assistance may be available.

Livestock Impacts

The salinity of river waters and the overall quality of available water supplies is also of great concern for livestock producers. Livestock naturally use the highest quality source of water available, but may be forced to use water that is not good for their productivity or health. In many reaches of the Pecos River, salinity levels are currently high enough to be considered problematic for livestock uses (Table 18). Improvements in water quality and riparian vegetation will encourage increased usage of riparian areas by livestock and wildlife. While this may be seen as a positive step and a good indicator of improving water quality, the increased use of the river by livestock and wildlife may have detrimental effects on other water quality parameters if landowners do not implement appropriate grazing management strategies.

Producers are encouraged to use BMPs to maintain the integrity of restored banks and decrease the possibility of erosion and streambank destabilization from increased use of the river as a source of water for livestock and wildlife. Erosion and degradation as a result of livestock will likely not be a major issue in the Pecos River watershed due to the limited carrying capacity for livestock throughout the watershed, but should be monitored to ensure that no major problem areas arise. Streambanks, whether recovering or established, are sensitive to grazing pressure, especially in arid conditions such as those in the Pecos watershed. Root system establishment does not occur rapidly due to low rainfall rates and can be hindered by trampling from livestock.

Table 18. Salinity guidelines for livestock water supply (NAS, 1974)

Total soluble salts content of waters (mg/l)	Comments
Less than 1,000	These waters have a relatively low level of salinity, and should not present no serious burden.
1,000 to 2,999	These waters should be satisfactory. They may cause temporary and mild diarrhea in livestock unaccustomed to them, but they should not affect their health or performance.
3,000 to 4,999	These waters should be satisfactory, although they may cause temporary diarrhea or be refused at first by animals accustomed to them. Unit for poultry. Often causes watery feces increased mortality and decreased growth, especially in turkeys.
5,000 to 6,999	These waters can be used with reasonable safety. It may be well to avoid using those approaching the higher levels for pregnant or lactating animals. Not acceptable for poultry.
7,000 to 10,000	Considerable risk may exist in using these waters for pregnant or lactating livestock, the young of these species or for any animals subjected to heavy stress or water loss. In general, their use should be avoided, although older livestock may subsist on them for long periods under conditions of low stress.
More than 10,000	The risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

From: NAS, *Nutrients and Toxic Substances in Water for Livestock and Poultry*

Establishing grazing strategies will be beneficial to the Pecos River riparian ecosystem by allowing scheduled rest for riparian areas and providing long-term benefits for producers and landowners such as increased productivity and quality of forage. The U.S. Department of Interior (2006) suggests limiting or discouraging livestock use of these areas in a variety of ways that producers and landowners can consider implementing on a voluntary basis. WQMPs will include suites of these BMPs specific to characteristics of individual properties and landowner preferences.

Attract livestock away from riparian areas:

- Upland water development – Establishment of tanks and troughs in dry pastures can reduce river usage. (may also attract wildlife away from the riparian area)
- Upland seeding – Establishment of palatable forage species on previously abused or depleted uplands.
- Supplementation – Strategic placement of desirable supplements in upland areas. Supplements should be at least ¼ mile from riparian areas (U.S. DOI, 2006)

Limit access to riparian areas:

- Fencing to limit use of critical areas – Livestock will sometimes overuse certain areas and can cause them to degrade over time. Fencing can be established around these critical areas so that cattle can be excluded from these areas as needed to prevent overuse. (This does not mean that you will not be able to use the river for grazing or watering purposes.)

- Natural barriers – Using brush piles or rocks can help ease the traffic load on high use areas. If livestock travel through a highly erodible area on a regular basis, excess erosion may occur. Strategically locating obstructions in these areas can deter animal use and make them find a different path to travel and prevent further damage in the critical area.
- Hardened water access points – Livestock access to the river can be funneled to an area that has been fitted with coarse gravel pads. These pads absorb the impacts of trampling and can help protect the integrity of the streambanks and help to prevent erosion.

Alternative shade can also be implemented as a means to lure livestock and wildlife away from the riparian corridor. This could be a very effective BMP for reducing the time cattle spend near the river or its tributaries, especially during months of high temperatures in the spring and summer. This practice could be paired with supplemental feeding and/or alternative water supplies to increase its effectiveness.

Studies conducted in Virginia, North Carolina, and Oregon have shown significant reductions in stream usage as a result of adding upland water sources. Decreases were seen in the amount of time cattle spent drinking from streams (81 percent), loafing in or near the stream (59 percent), sedimentation of the stream (77 percent), suspended solids loading (96 percent), nitrogen loading (56 percent), phosphorus loading (98 percent), and bank erosion (77 percent) (George, 2005). It is likely that these numbers are not representative of expected results in the Pecos watershed, but they do illustrate that these are effective approaches for reducing the impact of cattle and potentially wildlife in riparian areas. Additional information about alternative water sources and other BMPs that may influence the amount of time livestock and wildlife spend in riparian areas can be found on the Lone Star Healthy Streams project Web site: http://grazinglands-wq.tamu.edu/. The Lone Star Healthy Streams project, funded with CWA §319(h) NPS grants from the TSSWCB to AgriLife Extension, is examining the effects of alternative water sources and shade, as well as different grazing densities (stocking rates), on water quality in Texas.

Windmill providing an alternative water source in the lower Pecos River watershed

Two tools that can be used for improving riparian and upland habitat and that may aid in the reduction of water pollutants listed above are WQMPs and grazing management plans. For rangeland operations, grazing management plans are fundamental components of WQMPs. A grazing management plan focuses on the development of an appropriate grazing schedule and establishing feasible stocking rates to maximize grazing land health, animal health and production, and economic benefits to the landowner. Typical BMPs included in these plans enable controlled use of specified areas covered under the management plan. These can include, but are not limited to, alternative water sources, added cross fencing, supplemental feeding locations, and many others.

Aquatic Life and Habitat

Beneficial improvements in aquatic life and habitat will come from implementing management measures that focus on improving salinity, DO, nutrient levels, and water quantity in the Pecos. Controlling salinity will help to promote increased biological diversity for aquatic fauna and flora in the river. In many locations, salt-tolerant fish species were the dominant or only species present (Hoagstrom, 2001). Increases in nonnative species have also been noted; in some cases, these fishes were introduced as excess bait released by fishermen. One approach to alleviate this problem is to encourage bait sellers to supply species native to the watershed. Ideally, this approach would result in a resurgence of native bait fish populations and allow them to regain dominance over the nonnative species.

Aquatic vegetation has also changed in many areas along the river over the years and will benefit from targeted management. As reported in Hoagstrom (2001), saltcedar hanging into the water was the only habitat present in the river at some locations. Removing the saltcedar will eliminate this cover in these areas and exacerbate the need for re-establishing native vegetation along the riparian area. This process should be approached the same way as other riparian revegetation efforts. Salinity management will also help in the re-establishment of some native or more desirable vegetation species and, over time, these species may re-establish themselves.

In addition to encouraging native baitfish sales, a comprehensive native fish restocking effort could be considered if significant water quality improvements have been realized. Lifelong residents in the Pecos watershed have expressed concern over the decline and disappearance of historically present game fish in some portions of the river. The Inland and Coastal Fisheries Divisions of TPWD oversee many restocking programs in the state and will be consulted to develop a strategy suitable to the Pecos River once water quality has improved. The presence and detrimental effects of golden algae, as discussed later in WPP, and elevated salinity levels can be a sizeable hurdle to restocking efforts. It is strongly advised to wait to restock fish until after management measures have been implemented to control golden algae and salinity levels are brought down to tolerable levels.

Estimated Biological Diversity Changes

Significant changes in riparian vegetation species are anticipated by implementing saltcedar, giant cane, and upland brush control in combination with riparian restoration measures. Chemical treatment of saltcedar and other nuisance riparian brush species and the establishment of long-term saltcedar management followed by debris burning and revegetation in the riparian restoration effort will effectively restore more natural vegetation to the riparian corridor. Saltcedar will probably never be completely eradicated, but through implementing this approach, this invasive species can be kept in check.

Upland brush control efforts are expected to return priority areas of the watershed to more native grasslands that once dominated the watershed. High costs of brush control and the large area of the watershed will prohibit upland brush control efforts across the entire watershed. Priority areas that are close to the river or one of its tributaries, are underlain by shallow aquifers, or are known to be aquifer recharge zones can mostly be treated as long as the landowners desire this practice.

Expected changes in aquatic life and habitat will be highly dependent on improvements in the river's water quality. Management measures suggested for reducing salinity levels in the river and improving DO levels will likely be the primary factors that influence potential improvements in aquatic life and habitat. Unless these management measures are implemented, improvements will not be realized or feasible.

Assistance Needed for Biological Diversity Measures

Improving the biological diversity of the watershed includes numerous management measures that are all interrelated and, if implemented collectively, can lead to a significant change in watershed composition. These practices include control of nuisance plant species in riparian and priority upland areas, removing debris from these control efforts, revegetating those areas with more desirable species, and finally implementing WQMPs. Technical assistance can be derived from a core group of agencies and in some cases financial assistance may be available from these groups as well.

Saltcedar Control

Efforts to control saltcedar have been going on in the Pecos watershed and other areas of the country for numerous years. Cooperative efforts between AgriLife Extension, TSSWCB, and local SWCDs in the basin have successfully sprayed all but about 3,000 acres of saltcedar along the Pecos. These groups will continue to be a vital source of technical assistance and can also assist in securing financial resources to carry out future control efforts.

Biological control is another means of controlling saltcedar that has been evaluated and is currently in use in the watershed and other areas of the state and nation. AgriLife Research and ARS scientists have been in charge of efforts to date and will continue to provide critical technical assistance for implementing and managing saltcedar leaf beetle populations in the future. Earlier work by AgriLife Research and Extension was instrumental in determining which of the five varieties of saltcedar leaf beetle provides the most effective control of current saltcedar stands and regrowth in previously treated areas. ARS and AgriLife Research personnel also evaluated the different varieties of leaf beetle and their impacts on saltcedar and other plants (Hudgeons et al., 2007a and 2007b). Current APHIS evaluations have shown that the saltcedar leaf beetle is a host specific insect, meaning that it only feeds on saltcedar (DeLoach et al., 2003), and has been approved for release anywhere in Texas. The AgriLife Extension entomologist in Fort Stockton can provide needed technical assistance regarding saltcedar leaf beetles.

Potential sources of funding for future saltcedar control and management efforts can come from private, local, state, and federal funds. Other sources of funds that could be used to treat saltcedar are Environmental Quality Incentives Program (EQIP) funding from NRCS, TSSWCB's Water Supply Enhancement Program funds, TSSWCB CWA §319 NPS grants and others. These same sources may also be applicable to implementing biological control methods as well.

Giant Cane Control

Assistance for giant cane control will be similar to that of saltcedar control. The same methods of application and very similar chemical compounds are proving to be the most cost-effective method of treating this invasive species and have similar results to those of saltcedar control. When requested, AgriLife Extension, NRCS, TFS, TPWD, and TSSWCB can all provide information on giant cane and potential control methods. The BASF Corporation can also provide needed information regarding chemical control methods for giant cane and many other plant species. This company developed the herbicide used for saltcedar control and has done extensive research on the best chemical to use for giant cane control.

Giant cane infestation

Financial assistance to control giant cane can come from a variety of sources. Private, local, state, and federal funds can all be used in one combination or another to combat this invasive species. In the past, funds for giant cane control have come from a variety of sources. BASF may also be able to provide some level of matching funds that will help pay for treatment costs.

Upland Brush Control

Needed assistance to help plan for and implement upland brush control activities in priority areas of the watershed is a vital step in addressing upland brush issues. AgriLife Extension personnel have and will continue to evaluate extensively various treatment methods on multiple species of brush. They have publicized the information learned in these studies and this information is available to landowners so they can make an informed decision about which treatment method will work best for their specific scenario. When contemplating the implementation of an upland brush management effort, landowners should consult Extension and/or work with NRCS and SWCDs to select treatment options. In doing this, the landowner will learn more about available options, their expected control effectiveness, costs to implement these strategies, and the expected outcome of implementing the various approaches. Ultimately, the landowners will be responsible for choosing which method of brush control, if any, that they wish to implement on their property. After brush management activities have been implemented, establishing and implementing a grazing management plan through a WQMP will be an important step in properly managing the treated land so brush species do not return in the future. NRCS and SWCDs will assist in developing these plans.

Potential sources of funds for implementing upland brush control again can come from private, local, state, and federal sources. Private or non-federal dollars will likely be required as matching funds if federal programs such as EQIP are used. TSSWCB's Water Supply Enhancement Program may also serve as a source of funding if the areas to be treated meet program guidelines.

Naturally occurring revegetation following chemical saltcedar control

Riparian Restoration

Activities carried out as riparian restoration include burning debris from riparian brush control efforts, voluntary riparian revegetation, and implementing WQMPs to facilitate improved use of resources. The TFS will be the primary resource for technical assistance related to debris burning or other prescribed burning activities. TFS personnel can develop burn plans and conduct burning tasks with landowner permission. TFS can contribute in-kind services as nonfederal matching funds and cover a portion of the costs for these efforts. Burning efforts currently taking place are being funded in part by $150,000 allocated from the 81st Texas Legislature to burn saltcedar debris between Red Bluff Reservoir and Pecos, about 100 river miles. Additional funding through CWA §319(h) NPS grants will be pursued for complementary burning efforts in other portions of the riparian corridor.

For landowners looking for assistance in revegetating their properties after brush control and/or debris burning efforts, primary sources of information will be AgriLife Extension, NRCS, and local SWCD offices. These groups have done work specific to the watershed and will be able to provide critical information about what plant species perform the best in the watershed and can likely help in locating seeds for these plants. Funding programs such as NRCS EQIP and TSSWCB WQMP Program are likely sources of funding for revegetation efforts.

Establishing and implementing WQMPs will also require technical and financial assistance. At the request of the landowner, NRCS and local SWCD technicians will provide technical assistance for developing these plans. Costs associated with placing a technician with a SWCD vary, but are estimated at $51,000 per year. This includes salary and fringe benefits, travel, and supplies. Personnel from these groups will be able to develop site-specific plans that maximize grazing and water quality potential for a specific property. Financial assistance for implementing these programs is available from a variety of programs such as NRCS EQIP and TSSWCB WQMP Program.

Livestock Impacts

Financial and technical assistance to help manage impacts to biological diversity from livestock operations can come from a variety of locations. Primarily, AgriLife Extension, NRCS, and TSSWCB provide information regarding livestock management practices. In addition, Extension offers a variety of educational short courses that provide critical information to producers. Financial assistance will come predominantly from NRCS and TSSWCB in the form of EQIP and WQMP funding. These are voluntary programs with specific guidelines that must be adhered to in order to participate in the programs.

Aquatic Life and Habitat

Assistance for improving aquatic life and habitat will come from many sources. To determine if conditions are favorable for improving aquatic life populations and how habitats have responded, water quality monitoring efforts and aquatic life and habitat surveys will be done. The U.S. International Boundary and Water Commission (USIBWC), TCEQ, and USGS along with several universities have conducted these types of studies in the past and will be able to conduct these tasks again in the future with adequate funding.

If the water quality and habitat monitoring indicate that the river has improved and will be a better habitat for aquatic species, restocking efforts may be feasible. Assuming that this will be the case several years down the road, TPWD and U.S. Fish and Wildlife Service will be likely sources of technical assistance.

Water Quantity

Beyond earlier discussions relating water quantity to salinity dilutions, other concerns related to water quantity are the needed volumes for agricultural purposes and those needed to sustain a healthy aquatic ecosystem in the river. Historic accounts of the Pecos River suggest that the river was up to 100 feet wide and 7 feet to 10 feet deep with a swift current. In 1854, Pope described the river as very tortuous with a current of about 2.5 miles/hr and depths of 5 feet to 20 feet. Today's northern portion of the river is much smaller in width and depth and is generally slow flowing except during floods or large releases of water from Red Bluff.

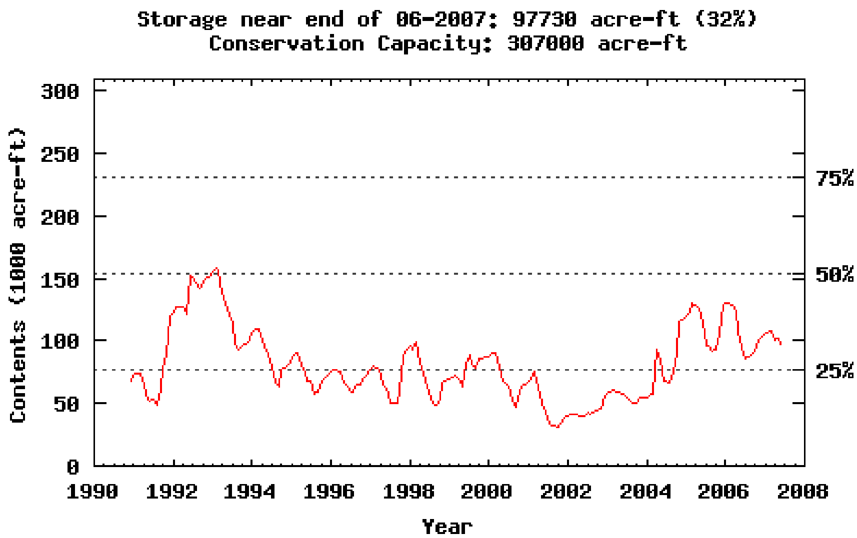


Figure 10. Red Bluff Reservoir storage levels 1990 – 2008 (TWDB Data)

In 1936, Red Bluff Dam was constructed with a storage capacity of 307,000 AF to be used for irrigation and hydroelectric power generation. Recently, storage at Red Bluff has been below 50 percent of total capacity for a variety of reasons: primarily drought and higher evaporative losses when the reservoir storage is increased (Figure 10).

Causes of Water Quantity Concerns

Two factors largely influence the limited water quantity in the Pecos River and its watershed. The first factor is that the watershed encompasses some of the driest portions of the state and yearly evaporation usually exceeds annual precipitation by a large margin. Human influences are the second factor that has caused some concerns about water quantity in the watershed. Human influences include the construction of reservoirs, agricultural irrigation using surface water and groundwater, historic over-utilization of watershed resources, and the introduction of nonnative vegetation to the watershed. The combination of these factors has had a profound impact on the quantity and quality of water available in the watershed today.

Critical Areas for Water Quantity Concerns

Groundwater is the largest source of irrigation water in the basin. At its peak, annual irrigation waters used in the Pecos watershed of Texas exceeded 835,000 AF and, of that 777,000 AF came from groundwater. Large declines in groundwater tables have caused groundwater to travel away from the river in some cases (Hiss, 1980) instead of towards the river. More recent work by Boghici et al. (1999) shows decreasing trends in groundwater use for irrigated agriculture and predicts that this decline will continue due to deteriorating water quality. Analysis of release and delivery data from the Red Bluff WPCD highlights the volume of water lost during transmission from the reservoir to the irrigation districts. Water year data from 1988 to 1999 show that water is delivered for irrigation from March to November with no releases being made in the other months (Clayton, 2002). This delivery period was split into three distinct sections related to the growing season: first month, growing season, and late season. During the first month of reservoir releases, an average of 68 percent of the water released does not make it to the irrigation districts' diversion dams. In the growing season, this number decreases to 39 percent and in the late season, it increases slightly to 43 percent. The majority of this lost water recharges shallow groundwater tables and the river banks, which have been depleted during the three months of the year when no water is released from Red Bluff Reservoir. Because of these losses, the portion of the river between the reservoir and the Imperial area is critical for improving management to minimize these bank losses through saltcedar control and continuous river releases.

Center pivot irrigation using groundwater

The decrease in the river's flow has also affected water quality and salinity in the entire river. Decreasing levels of freshwater entering or remaining in the stream also results in a decrease in the ability of the river to dilute salt contributions, thus waters are not as tolerable for human uses, terrestrial wildlife, aquatic life, and vegetation. Evaporation losses from the stream and reservoirs impact water quality in the watershed by concentrating pollutants. Reservoirs in the area sustain annual evaporation losses similar to recorded pan evaporation rates (about 80 inches) and compound salinity increases. Other water quality parameters negatively affected by the quantity of water flowing in the river are water temperatures and DO, which increase and decrease respectively due in part to decreased flows. In general, these impacts are felt throughout the river, but isolated areas are more impacted than others are. Salinity and DO concerns are greatest in the Pecos to Girvin area due to dwindling river flow and high levels of saline water intrusion. Managing this area of the river to improve quantity will be critical to improving the health of the river and removing it from the 303(d) List.

The quantity of water flowing in the river also has direct impacts on riparian biological and ecological diversity. Variations in flow are responsible for in-stream processes such as transporting sediment, restructuring of habitat, and allowing aquatic life to have access to other areas of the river channel. High flows provide the driving force for significantly changing the structure of the stream bed and associated habitat as well as moving sediment and nutrients within the system. Lower flows also have some positive impact in that they can help control unwanted or invasive vegetation or aquatic species. Extremely low or no flow, however, can have detrimental effects on the stream due to decreasing DO levels or increasing salinity from the lack of dilution. Low DO and/or high salinity levels can lead to fish kills and influence vegetation types present in the stream. Essentially, natural variations in river flow are instrumental in determining the overall assembly of an aquatic ecosystem but these variations have been influenced by human activities throughout the watershed.

Saltcedar can also have detrimental effects on water quantity flowing in the river. These plants are known to tap into shallow groundwater supplies maintained by recharge from the river. Studies have shown direct correlations between saltcedar and daily water table fluctuations, meaning that saltcedar is directly accessing shallow groundwater tables. Sheng et al. (2007) conducted a six-year evaluation of paired plots to determine the amount of potential water salvage expected from saltcedar control. This study compared two sites located within a five-mile-long reach of the Pecos River near Mentone and collected a year's worth of data showing water use at both sites in 2001. Following this initial data collection, Site A was chemically treated with Arsenal® to control saltcedar; an estimated 90 percent of vegetation was controlled at this site. Over the next five years, water use data were collected and compared to estimate the amount of salvageable water from controlling saltcedar. Results from this study indicate annual water salvage from controlling one acre of saltcedar yields a conservative estimated savings of 0.5 AF/year to 1.0 AF/year at this site. They also acknowledge that salvaged water will most likely contribute to aquifer recharge rather than an increase in streamflow and that vegetation regrowth in the area may negate a portion of these savings. Based on this evaluation, treatment of the remaining 2,158 treatable acres of saltcedar in the watershed would result in water savings in the shallow aquifers of 1,079 AF/year to 2,158 AF/year, assuming that saltcedar regrowth was properly managed.

Despite saltcedar's inherent ability to decrease water quantity in the river, it also has negative impacts on the river's ability to transport floodwaters. The vegetation effectively reduces the width of the channel and obstructs flood flows moving through the floodplain (Ruesink, 1983). As a result, excessive sedimentation of the river and floodplain may occur due to lower stream velocities and sediment carrying capacities (Blackburn et al, 1982). Saltcedar debris carried downstream during a flood event could also wreak havoc on infrastructure crossing the river and cause significant economic losses to private parties, irrigation districts, counties, and the state. This further highlights the need to remove this debris through controlled burning.

Upland brush species can also have an impact on the amount of water available for use in the watershed. It is widely known that brush species have root systems that typically enable them to access water sources that grasses are not capable of using. In many cases, brush can directly access shallow groundwater tables, which may contribute to decreased localized spring flow. Over-grazing and fire suppression have led to the shift from grassland to shrubland and large-scale brush management and long-term grazing management improvements will be required to control brush in the watershed and return its rangelands to a more natural state. Due to the significant costs for brush control, efforts will focus on priority areas to yield the most potential water savings for the money spent.

Expected Improvements in Water Quantity

Drastic increases in available water quantity are not expected as a result of implementing management measures recommended in this plan. Subtle changes in the availability of water and how it is naturally used are more realistic and feasible results. As stated above, saltcedar control shows the ability to increase available shallow groundwater supplies and may subsequently lead to slight increases in river flow. Based on the estimated acres of saltcedar remaining in the watershed, Sheng et al. (2007) predict that 1,079 AF/year to 2,158 AF/year can be saved; most likely in the form of shallow aquifer recharge. Adding this to the expected water

Irrigation canal filled with flow impeding vegetation and soil. Obstructions in the canal slow the flow of water and increase the possibility of excess evaporation.

savings from the 13,497 acres of saltcedar previously treated in the watershed; a total water savings of 7,828 AF/year to 15,655 AF/year is expected. One point in the river where this expected savings will be most easily identified is at Girvin. Long-term annual flow at Girvin is 23,511 AF/year. Almost half of the saltcedar treated is located along the river upstream of Girvin. As a result, an anticipated 4,031 AF/year to 8,062 AF/year increase in flow should be recorded at Girvin (17 percent to 34 percent increase).

Other water savings may be realized if management measures that focus on improving irrigation efficiencies are voluntarily implemented; the amount of expected savings will rely on the net improvement of irrigation efficiency between the currently used system and the new system installed. WQMPs on irrigated cropland may be used to estimate water savings.

Maintaining a constant release of water from Red Bluff Reservoir year round may also result in more water in the river; however, a trial release period must be implemented to verify the impacts of this scenario and estimate an amount of expected water savings. This can easily be done by monitoring the volume of water released and comparing it to the water delivered downstream at the irrigation districts' diversion points. Red Bluff WPCD must first agree to this trial release period and evaluation.

Water Quantity Management Measures

Water quantity has always been a concern in the Pecos basin as the river flows through one of the driest regions of the United States. Before extensive settlement, this problem was probably not as profound since the demand on the river's water was much lower. Human activities, such as numerous diversions of water from the river and extensive pumping of groundwater, have undoubtedly influenced the quantity and timing of flow in the river. Drought and evaporation also have a profound impact on the amount of water available in the watershed.

Evaporative losses from reservoirs and irrigation systems account for significant water being removed from the system. Losses from Red Bluff can be as much as 8 feet per year of the reservoir's total depth and can result in a significant amount of water not delivered down river. Holding water to be transferred to Red Bluff in deeper reservoirs upstream, a management measure to help control salinity, discussed earlier in the WPP, may also help keep more water in the river system. Storing the water in deeper reservoirs in cooler climates will help reduce evaporative losses and may yield more water for instream and irrigation uses. Implementing this practice will require a cooperative agreement between Texas and New Mexico.

Barstow Canal, recently re-shaped and cleared of excess vegetation

In addition to evaporative loss in the reservoir, water released downstream to meet irrigation delivery needs is also subjected to significant losses. Much of this water recharges depleted shallow water tables and river banks that contributed water to the river when releases were not made for irrigation. Data presented by Hart et al. (2005) show that during the annual 9-month release period, an average of 51.7 percent of water released from Red Bluff during 1988 to 1999 was lost before being delivered to the irrigation districts. Improved reservoir management could help curtail these losses if different release schedules were followed. During the nonirrigation period of the year, releases from Red Bluff typically cease, which causes shallow groundwater tables fed by the river to be depleted gradually by withdrawals and lack of input. When releases are initiated again in the spring, a large portion of the water recharges these depleted shallow water tables. A continual release pattern with minimal flows being released during nonirrigation periods, combined with riparian area saltcedar control, may be useful in decreasing the significant losses typically experienced during the first month of delivery. Ultimately, this approach could result in less total water being released downstream but more water making it to the irrigators.

Irrigation canals in use can also be responsible for large volumes of water being diverted from its intended use. The majority of canals in the area are not lined with concrete or other impermeable surfaces and may be a significant source of water loss. To determine actual loss from each canal, a water audit can be conducted. A water audit will also help determine if lining a particular canal makes economic sense. Similar efforts conducted under the Rio Grande Basin Initiative have shown annual water savings of 1,827 AF from lining 2.3 miles of canal in one case and a savings of 30,517 AF from lining 71 miles of another canal. Water savings may not be that high in the Pecos irrigation districts, but a water audit can show potential water savings that can be realized by lining canals in the area. Additionally, excess soil and vegetation can cause significant water loss during transmission. If present, they should be cleaned out of the canal to allow waters to travel to their intended use point without excessive restrictions. Less time in the canal translates to less chance for evaporation before arriving at the field.

Inefficient irrigation techniques also contribute to water losses in the form of excess evaporation losses. Irrigation techniques, such as furrow and flood irrigation, have proven to be inefficient when compared to modern technologies, like drip and center pivot irrigation (Table 19). Much of the water applied in flood and furrow irrigation is lost to evaporation before it can be used by the crop. Pivot irrigation is also subject to high evaporation rates if water is applied above the plant canopy, but is typically more efficient than furrow or flood irrigation. Some of the water applied from pivot irrigation systems is applied directly to the leaf of the plant and is easily lost to evaporation. A variation of center pivot irrigation, Low Energy Precision Application irrigation management, applies water below the plant canopy instead of above the canopy like traditional center-pivot irrigation systems. As a result, evaporative losses are minimized, thus yielding more water for the plants, a lower cost to the producer, and less total water needed for delivery. Costs to install the infrastructure for these systems will be the biggest barrier of producers accepting this approach.

Table 19. Typical irrigation efficiencies of various irrigation systems (adapted from Amosson et al. 2001)

Irrigation System	Operating Pressure (psi)	Application Efficiency (%)
Conventional Furrow	10	60
Surge flow Furrow	10	75
Mid-Elevation Spray Application	25	78
Low-Elevation Spray Application	15	88
Low Energy Precision Application	15	95
Subsurface Drip Irrigation	15	97

Subsurface drip irrigation is the most efficient technique that applies water directly into the root zone of the crop, thus eliminating a majority of evaporation losses. Maintenance costs can be high because the drip lines are located 12 inches to 18 inches below the surface of the soil; therefore, if any maintenance on a drip line is required, it has to be excavated before it can be fixed. Adequate filtration of irrigation water is vital to the smooth operation of these systems and must be incorporated to remove debris from the water. Salinity of irrigation waters may also present unwanted maintenance problems and should definitely be considered when determining the types of irrigation systems to implement. Initially, an assessment of current irrigation practices and willingness to convert to more efficient systems is needed to estimate the potential water savings and should be followed by a survey of the irrigators to gauge the demand for irrigation system upgrades. Because of the higher costs of installation, an incentive program will be needed to encourage producers to convert from less efficient irrigation systems to the more efficient drip irrigation. Although costs may be high for installation of a drip system, operating costs associated with pumping water are typically lower due to the smaller amount of water needed to irrigate the same acreage as compared to a pivot or furrow irrigated system.

Flood irrigating a field (Photo courtesy USDA NRCS)

Saltcedar also has a significant influence on water levels in both shallow groundwater tables and water levels in the river. Sheng et al. (2007) presented data comparing water levels at two locations with and without saltcedar. This study also compares the amounts of water used by saltcedar and other vegetation during the growing season at two sites along the Pecos near Mentone, Texas. During the first year, each site was monitored with saltcedar and other vegetation in place and showed significant water losses in the shallow water tables below the sites. At the end of the first year, site A was treated with Arsenal® to control saltcedar. Table 20 shows water lost from each site during the six years of the study. During 2002-2003, a significant drought gripped the area and led to drastic reductions in water use at both sites; then in 2004-2005, significant flooding in the region effectively limited the amount of transpiration that occurred.

Table 20. Paired plot study conducted near Mentone comparing water loss from saltcedar

Year	Site A (Treated) Water Loss (ft.)	Site B (Untreated) Water Loss (ft.)
2001	3.35	4.29
2002	0.61	1.30
2003	0.67	2.35
2004	0.65	1.70
2005	0.91	1.66
2006	1.63	2.21

Overall, results show that an estimated 0.5 AF/year to 1.0 AF/year of water can be salvaged from each acre of treated saltcedar. Despite this predicted salvage, water levels in the river may not be influenced by this increase at all. Instead Sheng et al. (2007) expect that the salvaged water will most likely be visible in shallow groundwater tables, which may be partially used by replacement vegetation. Nonetheless, the question remains of how much water the replacement vegetation will use as compared to the current saltcedar stands. Even if controlling saltcedar and subsequent revegetation does not result in a net gain of water in the river or water tables, this management practice will help with biological diversity and salinity issues. Management techniques for controlling saltcedar have been discussed earlier in the plan.

Upland brush management has also shown to have a significant impact on water quantity in watersheds across the state. This does not mean that more water will flow in the river because of upland brush control, but that increases have been seen in water available for other uses. In the current situation, upland brush has a competitive advantage over the majority of grasses that typically grow in the same areas. Root depth dictates how much water is available for plant use; and, in most cases, roots of woody plant species are capable of reaching much greater depths than those of grasses. Therefore, brush species have the ability to access both shallow and deep water supplies while grasses can typically only access shallow water. Anecdotal evidence suggests that upland brush control has been responsible for returning spring flow and subsequent increases in streamflow. Santa Rosa Springs, a historically perennial spring northwest of Fort Stockton, is one of these cases. In 1999, the landowner decided to treat the saltcedar infestation around the spring in an effort to restore perennial flow and improve water quality. Data collected in 1939 and 1943 indicate that the spring was flowing at about 2,000 gpm with TDS readings of

~2,500 mg/L. Following treatment of saltcedar with Arsenal®, spring flow has returned to a perennial state and water quality is improving. Water quality analysis conducted in December 2006, showed that TDS levels were ~4,500 mg/L and flow was ~1,200 gpm. Although this may not happen in every case, there is no doubt that removing brush can and does result in more water available for use by replacement vegetation. Upland brush management options were discussed earlier in the WPP and should be focused in areas where the most benefit can be gained.

Assistance Needed for Water Quantity Measures

Assistance for implementing measures geared toward increasing water quantity will come from a variety of sources depending on the specific management measure. In general, local county Extension agents and the watershed coordinator will be able to provide general information about management measures and direct those requesting information to other sources as needed. NRCS and SWCDs will also provide technical assistance for on-the-ground implementation of more efficient irrigation systems.

Assistance for modifying water allocation schedules from New Mexico and irrigation water release and delivery practices will come primarily from the Red Bluff WPCD and the PRCC. Significant cooperation with New Mexico and the PRCC will be required to alter the timing of water deliveries to Texas from New Mexico. No financial assistance is anticipated to be needed to conduct this task, as this will only entail a policy change. Altering irrigation water releases from the reservoir downstream to irrigators will require the cooperation and assistance from Red Bluff WPCD and individual irrigators and/or irrigation districts. Further information on potential water savings as a result of a continuous reservoir release schedule as opposed to a block release will be beneficial in proving the utility of this practice. No financial assistance should be required.

AgriLife Extension engineers can provide technical assistance for conducting water audits on irrigation canals and improving the efficiency of the canals. If financial assistance is needed to carry out these audits, it can likely be gained from groups focused on improving irrigation efficiencies. The TWDB is one such group that has financial assistance programs and low-interest loan programs that can be used to fund these efforts. TWDB Agricultural Water Conservation Grants and Loans can be used to conduct demonstrations, educational programs, and research, provide technical assistance, and transfer technology. Funding from these sources can also likely be used to line canals and minimize water losses.

AgriLife Extension, NRCS, and TSSWCB personnel will be primary contacts for information in improving irrigation efficiencies and implementing techniques that achieve this goal. Personnel will be able to locate information on specific irrigation techniques, requirements for installing these systems, capital costs and typical operation and maintenance costs. WQMPs can include improvements in irrigation water use and will provide needed technical assistance for measures recommended. Financial assistance programs through NRCS (EQIP), TSSWCB (WQMP), and TWDB (Ag Water Conservation) are likely sources of funding for implementing improved irrigation techniques.

Sources of technical and financial assistance for implementing saltcedar and upland brush control as a means of increasing available water has been presented previously in the Biological Diversity section. Information presented there will also apply for these practices when implemented to address water quantity.

Golden Algae

Golden algae (*Prymnesium parvum*) was first described in 1937 in England and has been found on all continents except Antarctica. It is most often associated with estuarine or marine waters, but can also exist in inland waters. *P. parvum* was first identified in the United States in 1985 after water samples were analyzed from the Pecos River in Texas (Sager et al. 2007). This naturally occurring algae produces toxins known to kill large numbers of fish and bivalves (mussels and clams) in a single bloom event. The 1985 bloom and several subsequent blooms have caused large-scale fish kills that devastated the aquatic diversity in some reaches of the Pecos. These outbreaks have killed more than 2 million fish in the Pecos alone (Table 21).

Fish killed by golden algae in water stained a golden color by the algae

P. parvum is a microscopic, one-celled mixotroph (an organism that can function as both a plant and animal) that prefers saline waters and usually blooms during the winter months when the water is colder. Researchers have concluded that winter blooms provide the golden algae a competitive advantage over most blue-green algae, which prefer warm water and are generally not as active during the winter. When stressed, *P. parvum* produce and release toxins that have adverse effects on all Texas fish species, bivalves, crayfish, gilled amphibians, and some plankton species. These toxins affect fish by damaging skin and gills, leading to hemorrhaging, circulatory system poisoning, and internal organ damage; however, they are not harmful to livestock, terrestrial wildlife, or people (Sager et al., 2007).

Critical Areas for Golden Algae

Golden algae have affected the entire Pecos River in Texas at one point or another. Salinity in the river provides a habitat conducive for golden algae to thrive. Algae cells are easily transported between lakes and the river and can be present at any point in the river at any given time; however, the algae are not always toxic and thus do not always pose a threat to fish populations. Current research is exploring methods for locating areas where the algae may congregate or form a "seed-bed." If these areas can be located, targeted control methods can be explored and the algae can be more easily managed in the river system. For now, there is not a physically feasible management option that can be exercised in the river.

Table 21. Reported fish kills caused by golden algae blooms in the Pecos Basin of Texas

Beginning	End	Counties	Waterbody	Estimated # of fish killed
04/21/1985	04/27/1985	Loving	Red Bluff Lake	10,125
10/31/1985	11/10/1985	Crockett, Pecos, Terrell, Val Verde	Pecos River	111,459
11/19/1985	11/20/1985	Val Verde	Pecos River	300
11/20/1986	12/12/1986	Pecos, Terrell, Val Verde, Crockett	Pecos River	263,879
11/05/1988	11/16/1988	Reeves, Loving, Ward, Pecos, Crane, Crockett	Red Bluff Lake, Pecos River	1,580,320
12/06/1989	12/06/1989	Reeves	Red Bluff Lake	50
11/03/1993	11/21/1993	Pecos, Terrell, Val Verde, Crockett	Pecos River	33,124
12/05/1995	12/09/1995	Crockett, Terrell	Pecos River	7,598
01/06/2003	02/15/2003	Reeves	Red Bluff Lake	1,156
01/22/2005	1/28/2005	Loving	Red Bluff Lake	200
02/20/2005	02/26/2005	Crockett	Pecos River	1,500
03/27/2007	N/A	Reeves	Pecos River	13,263
			Total	**2,022,974**

Adapted from TPWD data

Estimated Golden Algae Load Reductions

Current knowledge about golden algae is limited at best. Numerous agencies, universities, and groups around the world are studying this organism and trying to develop a better understanding of its life cycle, what factors influence its behavior, and how it can be effectively managed. Successful management of golden algae in small ponds and reservoirs has involved either elimination of the organism or reduction of the impacts of its toxins. Some effective methods used on smaller waterbodies include application of ammonia, ammonium sulfate, or copper sulfate; controlling salinity; and lowering the pH to 6.0-6.5. Despite their effectiveness, these methods can be quite costly and essentially kill all organisms in the treated waterbody; therefore, they are not an option for the Pecos River. Research currently being conducted by Baylor University, Texas A&M University, and University of Texas at Arlington faculty and TPWD personnel has shown correlations between golden algae, limiting nutrient levels present in the waterbody, and the production of its toxic chemicals. Further evaluations are planned and will hopefully lead to the discovery of feasible management measures.

Due to the lack of knowledge regarding golden algae and its management, an estimated load reduction cannot be made at this point. These estimates may be possible after more information about the algae, its life cycle, its behavioral characteristics, and how it can be controlled become available.

Golden Algae Management Measures

Currently, there are no recommendations for managing golden algae in river systems or large reservoirs. The few control methods that exist are best suited for small waterbodies that can be closely monitored and controlled, as well as restocked, at a smaller cost to the consumer. Scientists and researchers across the state and nation are exploring options for managing golden algae in larger reservoir and river systems. Some researchers speculate that management measures to control the algae can be as simple as fertilizing specific areas of the waterbody with phosphorus fertilizer to offset nutrient limitations that may cause the algae to become toxic, but this theory remains unproven. When feasible management measures are discovered, they will be assessed for use in the Pecos and recommended accordingly.

Assistance Needed for Golden Algae Concerns

Scientific expertise will be required to develop feasible management measures to control or prevent the toxic blooms of golden algae. TPWD and university collaborations will provide needed information about the behavior of these organisms and what causes them to produce their toxic chemicals. Upon determining what causes this production, feasible management measures can be developed that can be used to manage golden algae populations throughout the state. Information regarding current research efforts can be found at: http://www.tpwd.state.tx.us/landwater/water/environconcerns/hab/ga/ and at http://lakegranbury.tamu.edu/goldenalgae.php. TPWD will continue to investigate fish kills due to golden algae and other causes to continue determining the impact of golden algae in the Pecos.

Dissolved Oxygen

DO is an important water quality parameter that must be maintained for the health and survival of aquatic ecosystems. Fish and other organisms living in the river are dependent on the amount of DO in the water. Without enough DO, fish cannot survive, and significant fish kills can result. Temperature, turbulence, water depth, and the salinity of water are factors that can influence the amount of DO available in the water column. Photosynthesis by aquatic vegetation produces a large portion of DO present in water; however, this only occurs during daylight hours and oxygen levels typically decline during the nighttime hours. Oxygenation of the water also occurs from contact with air; more turbulent water can absorb more air because of the increased surface area of the water.

Decomposition of organic matter also influences DO levels in water, but in a negative way. The decay process occurs continuously and consumes oxygen as organic matter breaks down. Consequently, large variations in DO levels can occur because of the imbalance between DO production during photosynthesis and DO consumption during decay. Besides influencing photosynthesis, light also plays a role in this imbalance by transferring heat and increasing water temperatures. Warmer waters are not able to hold as much gas (DO) as cooler water and as a result may not contain enough DO to sustain aquatic life.

Salinity levels present in water also influence the amount of oxygen that water can physically absorb. Increasing salinity levels result in a decrease in the amount of oxygen that water can absorb. The high levels of salinity present in some portions of the Pecos are likely an influence on the DO levels present in those segments. The exact cause of depressed DO levels in the Pecos is not known, but the combination of factors (low flow, high temperatures, salinity, nutrient loading, and organic matter decomposition) is the probable driver of the DO deficiency. Management focused on improving these factors is needed to address the low DO levels and other water quality issues.

Critical Areas for Dissolved Oxygen Concerns

All portions of the river are critical for maintaining healthy aquatic ecosystems. TCEQ has designated the Pecos as a perennial stream with high aquatic life use, and to support this designated use, the river must meet water quality standards described in the next section. The 2006 *Texas Water Quality Inventory* revealed that the upper Pecos River between US 67 and US 80 (AUs 2311_05 and 2311_06) did not meet the DO criteria standards because levels declined below the 3.0 mg/L minimum standard. Essentially, this covers the section of the river between the towns of Pecos and Girvin. As a result, these segments of the stream have been identified as impaired on the 303(d) List due to depressed DO levels and are the critical target areas for improving DO levels. The decision to add these segments to the impaired waters list was based on eight 24-hour sampling events. Due to minimal data available, the segments were both listed in the 5c category of impairment, which means that more data will be collected and analyzed before any further action takes place.

Expected Dissolved Oxygen Improvements

DO standards for the Pecos River are set to maintain a 24-hour average DO concentration of 5.0 mg/L and to maintain a minimum of 3.0 mg/L. According to the 2006 *Texas Water Quality Inventory*, impairments exist in AUs 2311_05 and 2311_06 (Pecos to Girvin) because recorded samples did not remain above the 24-hour minimum DO level. Data used to assess these river segments show that DO levels at both sampling sites have been recorded below the 3.0 mg/L minimum several times. TCEQ's continuous water quality monitoring network show that DO levels typically drop below 3.0 mg/L during early morning hours of the warm months of the year when water temperatures are higher (http://ww.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/swqm_realtime_swf.html#data). Properly implemented management practices will be able to elevate DO levels to comply with designated water quality standards.

This WPP recommends the implementation of management practices that will increase the surface area of the water (agitation), decrease the temperature of the water in the summer months, decrease salinity levels, and reduce the amount of decaying material. Coincidentally, the impaired segments for DO are also the segments of the river that show significant increases in salinity and properly located salinity management measures may also have a positive impact on DO levels.

At this point, anticipated improvements in DO levels because of implemented management measures cannot be quantified as no instream dynamic water quality model has been developed. An estimate of nutrient load reduction, BOD reduction, and sediment reduction can be developed from individual WQMPs and, in turn, can be translated into anticipated DO improvements. Individual WQMPs will have varying levels of expected water quality improvements based on the practices recommended for implementation; these estimated improvement levels will be estimated after WQMPs have been developed.

Artificial riffles pose the same problem. An extensive literature review has not produced any anticipated water quality improvements from installing artificial riffles, but the consensus from the scientific community is that they improve water quality and improve aquatic habitat. A pre- and post-implementation evaluation of water quality will be required to quantify the impacts of this practice.

Dissolved Oxygen Management Measures

Management measures needed to improve DO levels in the Pecos will focus on decreasing river salinity, increasing the interaction between water and air, decreasing water temperatures in the river, improving the aquatic vegetation in the river, and reducing the amount of decaying organic matter in the river.

Natural riffles in the Lower Pecos River

Potential BMPs are a series of small check dams or a large check dam to increase the hydrostatic pressure of shallow groundwater tables and slow the intrusion of saline water into the river. These structures can help to improve DO by lowering water temperatures and increasing the turbulence of the flow if properly designed. This can be accomplished by installing an overflow drain pipe that draws cooler water from the bottom of the pool and releases it through a standpipe above the water level in the river. This creates a small fountain that will allow the water to absorb more oxygen than if it simply flowed over a smooth spillway. The emergency spillway of the check dam(s) can also be equipped with obstructions that increase the agitation of the water. Other methods to increase the agitation of the river water can be employed as well. Constructing semipermeable dams that will slightly raise water levels in the river or creating artificial riffles will also help to improve DO levels. Using readily available aggregate resources from the watershed, small, low-cost barriers can be constructed in the main channel of the river from several loads of gravel, rock or other material. These structures may be washed out during high flow events, but can be replaced relatively easily and at a small cost. Similarly, artificial riffles can be constructed using the same materials to agitate the water in a manner similar to natural riffles. Technical assistance will be needed to identify appropriate locations to implement these riffles and to develop a feasible design and material list. Implementing any of these instream measures will require coordination with TCEQ, TPWD, and USACE for proper permitting.

Saltcedar control and subsequent revegetation efforts will also improve DO levels along the river. Potential increases in the quantity of water flowing in the river may be seen from saltcedar control and can have a significant impact on the quality of water in the river. If the water level does increase, this will help to increase DO levels by providing cooler water at the bottom of the stream and by decreasing the level of salt concentrations. Burning the sprayed saltcedar and/or giant cane debris will decrease the amount of dead material that can enter the waterway thus minimizing the amount of material using oxygen in the decay process. Initially, an increase in organic matter (ash) may be introduced to the river in a high flow event, but regrowth of herbaceous species should occur rapidly and minimize this risk. Some of these activities could be incorporated into WQMPs for lands in the riparian corridor.

Assistance Needed for Dissolved Oxygen Management

Significant improvements in DO levels can be made through the implementation of management measures targeted for improving salinity and biological diversity of the river and riparian areas. Biological diversity improvements include saltcedar and giant cane spraying, debris burning, and the riparian revegetation efforts. WQMPs implemented along the river corridor will also be beneficial in improving DO levels through improved land management measures. Local SWCD personnel will provide the needed technical assistance for WQMP development and implementation. Technical assistance for these activities can be obtained from a variety of sources, including AgriLife Research, Extension, NRCS, and TFS. Technical assistance for management measures that improve DO levels by decreasing salinity is discussed in the 'Salinity Management' section of the plan.

Technical assistance needs for planning artificial riffles implementation to improve DO levels will be sought from graduate students studying geology or water resources management with a specific emphasis on stream morphology. An engineering consulting firm, TPWD, TCEQ, or USACE may also be able to provide assistance if students are not available. These agencies will need to be contacted prior to implementation to ensure that proper permits are attained, if needed.

Check dams will require the most technical assistance of all recommended BMPs to address DO levels. An engineering feasibility analysis and dam design will be required prior to implementing any check dams on the river. Additionally, permits will be required and an ecological impact study will likely be needed as well prior to implementation. Coordination with USACE, TCEQ, TPWD, and TWDB will be needed prior to any major consideration of check dams in the Pecos River.

Sediment

Sediment is the greatest source of NPS pollution nationwide (Simon and Darby, 1999). The threshold for soil loss from an area is dependent on many factors, such as land use, soil type, and precipitation, but is typically quantified in terms of percent ground cover. In many temperate environments, the quantity of soil loss increases significantly if ground cover falls below 70 percent to 75 percent (Costin, 1980; Lang, 1979; Butler et al., 2006). However, semi-arid and arid regions typically require less ground cover to prevent substantial soil loss (Dadkhah and Gifford, 1980; Bartley et al., 2006; Gutierrez and Hernandez, 2006). In the semi-arid region of Australia, Bartley et al. (2006) found that at least 30 percent ground cover is needed to reduce total soil loss from pastures. Dadkhah and Gifford (1980) in Utah revealed the need for ground cover greater than 50 percent to minimize sediment loss. Results from a semi-arid region in northern Mexico were similar to those from Utah during the growing season but higher levels of ground cover, above 70 percent, were needed to manage runoff during the dormant season (Gutierrez and Hernandez, 2006). On the Pecos, Clayton (2002) calculated the percentage of bare ground before and after saltcedar herbicide treatments. Pre-treatment plots contained on average between 23.8 percent and 62.0 percent bare ground. Even though post-treatment results were inconclusive due to drought conditions, the percent of bare ground did increase (Clayton, 2002).

Limited ground cover following a debris burn

Saltcedar infestations in the riparian corridor and floodplain have been shown to exacerbate sedimentation in river channels. Blackburn et al. (1982) conducted a long-term assessment of sediment deposition and impacts on river channel morphology on the Brazos River in north central Texas. They evaluated aerial photos taken between 1941 and 1979 to assess the change in river channel width due to sedimentation and saltcedar growth. Their findings indicated that the average width of the river channel decreased from 515 feet to 220 feet, a reduction of about 57 percent. The noticeable effects of this decrease in channel size have been negative impacts on flood stages. An example that Blackburn et al. (1982) used was a 1971 flood with peak flows of 42,695 cfs had a 1.3 foot higher flood stage at Seymour, Texas than a 1926 flood at the same location with peak flows of more than 95,000 cfs. The reason for the increased flood flows is the increased sedimentation of the river paired with saltcedar growth. Researchers noted that on average, sediment depth increased by 9.8 feet during this same period. This equated to 28,512 AF of sediment deposited in the river channel that would have otherwise been transported downstream. Therefore, treating saltcedar in the Pecos River should have impacts on the river's ability to transport both sediment and floodwaters more efficiently.

Immediately following the application of Arsenal® herbicide (Imazapyr) to control saltcedar and other riparian brush species, and after prescribed burns to remove debris, ground cover will be at its lowest and the potential for sediment loss will be at its greatest. However, work conducted by Knight et al. (1983) showed that sediment production rates were the lowest under areas that were chemically treated then subsequently burned as compared to areas that are only burned, only chemically treated, or not treated at all. Burning promotes vegetation growth and as such, the vegetation will begin to re-establish itself shortly there after. Once burning is completed, voluntarily implementing revegetation efforts quickly will minimize the potential for large sediment losses.

Critical Areas for Sediment Management

Historical documents suggest that the Pecos has always transported a significant sediment load and that the stream channel is mobile, meaning that it tends to move back and forth across the floodplain as a result of scouring and deposition of sediment. Critical areas in which sediment loading may be problematic are those devoid of vegetation. Specifically, areas where saltcedar stands near the river were or will be chemically treated pose a significant threat to increased sediment loading before vegetation is re-established. This treatment typically kills all vegetation with 85 percent to 90 percent efficiency, resulting in significant amounts of bare ground. These areas of bare ground are highly prone to sediment erosion and produce significantly higher amounts of sediment than areas with herbaceous or herbaceous and woody cover (Carlson et al., 1990). Therefore, in the case of a flood event in the Pecos, significant amounts of sediment could be transported from the riparian areas that remain bare. Following saltcedar treatment, voluntary prescribed burns to remove debris are planned and will result in significant decreases in ground cover as well; however, this action will promote the rapid re-establishment of vegetation by providing a seedbed conducive to rapid plant growth.

Estimated Sediment Load Reductions

Sediment load reductions are not a main goal of the WPP. Instead, the goal is to prevent increased sediment loading due to saltcedar treatment and burning through revegetation activities. Estimating an expected load reduction in sediment yield from saltcedar control cannot be accurately accomplished because the current sediment load has not been calculated. An extrapolated estimation has been developed by using sediment-loading numbers from work conducted on brush stands in south Texas (not saltcedar). The work conducted by Knight et al. (1983) provides some insight into the potential impacts of brush management along the river. Their work showed sediment production levels of 1.04 tons/acre from areas that were just treated with chemicals to kill brush as compared to sediment load of 0.52 tons/acre for areas chemically treated and subsequently burned. Using these numbers, an annual estimate for current sediment production from the previously treated 10,354 acres of saltcedar along the river is 10,785 tons following chemical treatment only and would be reduced to 5,358 tons if burning is used, yielding a sediment load reduction of 5,427 tons. Similarly, load reductions are expected in areas that still require chemical treatment. Extrapolating from Knight et al. (1983), current sediment production levels for treatable saltcedar stands not yet treated are 0.87 tons/acre, yielding a sediment load of 1,882 tons. Applying chemical treatment followed with burning should reduce sediment production rates to 0.52 tons/acre and decrease the production load to 1,117 tons. This produces an estimated load reduction of 765 tons. In total, if burning and chemical treatment are applied to all treatable acres of saltcedar, the estimated total sediment load reduction from treated areas is 6,192 tons.

Casermeiro et al. (2004) concluded that percent plant cover is inversely related to both runoff and sediment yield; therefore, as plant cover decreases, sediment yield and runoff usually increase. As previously stated, Clayton (2002) found that bare ground accounted for an average of 23 percent to 62 percent under saltcedar stands along the Pecos River. The percentage of bare ground will be close to 100 percent after saltcedar treatment and debris burning, thus posing an increased threat of sediment loss. Prompt revegetation efforts will be critical in minimizing potential sediment loss from the treated areas.

Sediment Management Measures

Revegetation will ideally occur within the year following burning of standing dead saltcedar or will be allowed to occur naturally. TFS has indicated that the optimum time to conduct controlled burns to remove dead saltcedar is during late summer to early winter. This planned burn period follows the rainy season of late spring and early summer, so the risk of large rains immediately following debris burning is lower than during other times of the year. Since burning will be conducted during this time frame, the best time for revegetation efforts will likely be the following spring. This timing will also promote revegetation as long as intense flooding does not occur. Natural revegetation will also begin during the spring months as well with the return of the growing season. NRCS and AgriLife Extension have information on plant materials that can be used to determine what plant species have the best chance for regrowth along the river and its tributaries. This material also contains information about planting times to determine the optimum planting schedule for each specific species.

Other management measures recommended in the WPP not specifically geared toward reducing sediment loading from riparian areas can also be beneficial for this purpose. Primarily, these practices are designed to decrease the time that livestock and wildlife spend in riparian areas and have been recommended by the WPP as means for improving riparian habitat and improving the biodiversity in these areas. As previously discussed, studies have indicated these strategies can reduce sedimentation by 77 percent. These practices include relocating supplemental feeding areas, providing alternative water sources away from the river, providing alternative shade, and constructing hardened access points to the river where animals can water without trampling vegetation or increasing soil compaction. However, stocking rates for livestock are quite low across the watershed, resulting in limited impacts in the riparian corridor.

WQMPs can also be a useful tool for reducing sediment loads entering the Pecos. The goals of implementing this practice are to prevent over-grazing and maximize the growth potential and use of present vegetation. In turn, landowner profits and the quality and quantity of ground cover are often increased by implementing and adhering to grazing management plans or WQMPs. Decreases in sediment loss are frequently quantified as a result of implementing these plans.

Assistance Needed for Sediment Management

Revegetation efforts in areas where saltcedar was treated and burned will be the primary strategy used for controlling sediment loading into the Pecos. These areas are most prone to high sediment loss during rainfall events and over-bank flows, and therefore, revegetation must occur as soon as possible. Sediment yield reductions will not happen immediately after the revegetation process is completed; instead, results will be seen gradually as ground cover along the river improves. Sediment yield decreases may also be seen as grazing management plans and WQMPs are established throughout the watershed. NRCS and AgriLife Extension personnel will be able to provide guidance on what plant species will be the best to plant and the most likely to flourish in the riparian corridors along with appropriate planting times. Extension personnel will be instrumental in communicating this information to the landowners and land managers who want to participate in revegetation efforts.

Costs for controlling sediment along the Pecos River through revegetation efforts will be mainly seed, labor, and equipment. Areas that were treated for saltcedar control and recently burned pose the greatest threat for increased sediment loss and will be targeted first. Funds needed to decrease the amount of sediment entering the river will be focused primarily on purchasing and planting vegetation in the riparian areas and, to a lesser extent, upland areas. Funds to implement measures that reduce the amount of time that livestock and wildlife spend in the river and riparian corridor will also be needed to encourage landowners to implement these practices. Private funding paired with financial assistance programs will be the likely source of funding for revegetation projects. Some of the programs that may have available funds are NRCS EQIP and Wildlife Habitat Incentives Program (WHIP) funds and TSSWCB WQMP Program funds.

Oil and Gas Production

The production of oil and gas also serves as a potential source of pollution to the watershed and river. Watershed residents have expressed concerns about the production of salt-laden water, also known as brine water or produced water. Landowners in the watershed have observed that illegal brine-water dumping on roads and highways, improper disposal of brine water into disposal tanks, and failing or overflowing disposal tanks are problems facing the watershed. The primary concern of landowners is that this improper handling of brine water will and has already adversely affected the quality of surface water and groundwater resources. Other chemicals that may be present in produced water are also a significant concern of watershed residents.

Abandoned wells and improperly plugged wells also pose a serious threat to the health of the watershed. These wells can contaminate water supplies by allowing water or oil to move vertically between subsurface layers. The danger here is the potential cross contamination of groundwater supplies. Abandoned wells can also leak fluids out onto the surface; these pollutants can then be dispersed across the watershed during heavy rainfall events and can eventually flow into the river or its tributaries. Proper plugging of an abandoned well effectively eliminates the possibility of this cross contamination by filling the well with drilling mud, concrete, and other materials commonly used and approved for use in well plugging. Wells not properly plugged also pose a threat similar to abandoned wells. They can cross contaminate groundwater and soils and have the potential to leak produced water and oil and gas onto the surface. Several landowners have acknowledged the existence of abandoned and improperly plugged wells throughout the watershed and are concerned about their potential impacts. Identifying and locating these wells is an integral step in properly managing these potential sources of pollution. Landowners who know of these wells or illegal dumping activities should report them directly to the RRC.

Pump jack in the Pecos watershed

Critical Areas for Oil and Gas Production

Oil and gas production is much more prevalent in the upper portion of the watershed than it is in the lower portion. The number of active wells, dry holes, abandoned wells, and injection wells is significantly greater above I-10 than it is below, thus there is an increase in potential impact from oil and gas production in the upper portion of the watershed. The Grandfalls-Imperial area has been identified as one critical area that should receive immediate attention. Oil production in this area began in 1927 in the Pecos Valley Oil Field and the vast majority of the wells produce some level of the highly corrosive hydrogen sulfide gas. Over the last 80 years, this gas has weakened many of the well casings to the point that they are now cross contaminating water tables in the area. Management efforts by RRC that target abandoned or leaking wells or improperly functioning brine disposal sites will be done in accordance with the priority ranking sheet presented in Appendix E. Actively leaking sites and abandoned wells near the river or that penetrate a major aquifer will be given top priority. The RRC currently maintains a list of known abandoned wells that have been prioritized using their priority determination sheet (Appendix E).

There are currently 36 wells in the watershed scheduled to be plugged using state funds; however, this does not include all wells that need to be plugged. Landowners have indicated that old oil wells that are leaking have been redesignated as irrigation wells so that they do not fall under the RRC's jurisdiction. It is unknown how many of this type of well currently exist, but landowners have indicated that there are numerous wells of this type in the watershed.

Load Reductions for Oil and Gas Production Concerns

Determining an accurate estimation of load reductions from oil field activities is not feasible because a complete list of contributing oil and gas related sources is not available. These include abandoned wells, previously plugged wells that are now leaking and a source of contamination, and the locations of illegally dumped brine water, or failing permitted storage facilities. Identifying and reporting sites that may be a source of contamination to the RRC is an integral step in the process of properly managing oil field contamination and determining the extent of their impacts.

Once these sites are identified, they can then be evaluated to determine if they are contaminating the environment and water resources in the area. The RRC has developed a set of criteria (Appendix E) for developing a priority ranking used to determine which abandoned or inactive wells should be plugged next. The well plugging priority system is a system that takes human health factors, safety, environmental, and wildlife factors that carry a specific weight. Each well is graded based on these factors and assigned a priority of 1 thru 5, with 1 being the highest. Actively leaking wells automatically receive a top priority and wells that receive a 1, 2, or 3 priority are recommended for plugging with Oil Field Cleanup funds (RRC, 2000). Addressing top priority areas will certainly have a significant impact on the health of the Pecos River watershed.

Oil and Gas Production Management Measures

Initial management implementation efforts can be targeted to RRC's current list of wells in the area that are waiting to be plugged, but these efforts are definitely not limited to these wells. Activities to carry out this process will include selecting which wells to target, securing funding to carry out needed management measures, soliciting bids to plug the well, and hiring the company to carry out plugging activities.

Another management measure is to identify these sites and ensure that they have been reported to the RRC and are on record. Reporting these problem areas will ensure that the proper people know of these activities and locations; then appropriate action can be taken. Without knowing where these sites are, nothing can be done to correct or improve the situation at each site. Likewise, reporting them to the RRC will improve the possibilities of receiving funds to address problem areas; however, the RRC is not the only source of funds that can be used to plug wells. In the past, EPA funding has been used to investigate and plug actively leaking wells. Three projects using EPA funding from TCEQ's CWA §319(h) NPS Grant Program awarded to the RRC are the Colorado River upstream of E.V. Spence Reservoir project, the Colorado River downstream of E.V. Spence Reservoir project, and the Petronila Creek Saltwater Minimization project. All these projects focus on identifying the source of salinity contribution from oil and gas wells to the waterbodies. This source of funding is likely applicable to the Pecos River watershed and should be pursued. Prioritizing these sites once they have been identified is also a critical management aspect. Undoubtedly, there are not enough funds available to plug all abandoned or leaking wells, address problem areas for brine water disposal sites and to fix other problem areas; therefore, more than one source of funding should be sought.

After prioritizing the wells, the needed management measure will be to begin plugging the highest priority wells and begin addressing other critical areas. Currently, 36 wells located in Andrews, Crane, Pecos and Reeves counties are scheduled to be plugged using currently available state managed funds (RRC, 2007); many more may warrant plugging. RRC records indicate that 52,479 wells are located in the counties that make up the Pecos River watershed; however, not all of these wells are located within the watershed. Of these, 336 are known to be orphan wells, meaning that they have been abandoned and out of operation for at least 12 months. There are numerous other areas in the watershed that are currently identified as needing management, but the limited funding available dictates which areas receive attention first.

Assistance Needed for Oil and Gas Production Concerns

Technical assistance in dealing with potential pollution from oil and gas production or disposal areas will come from the RRC. It is the state agency responsible for monitoring and regulating the oil and gas industry and its personnel will have the knowledge and expertise to provide needed assistance. The RRC currently stores a wealth of information regarding oil and gas production activities across the state and can provide information regarding a specific well in most cases. Much of the information about individual wells can be found on the RRC Web site at http://www.rrc.state.tx.us using its online tools. Despite this large amount of information, there are old wells throughout the watershed that are not properly identified or recorded and are potential sources of pollution. This also holds true for brine disposal sites that are either permitted but not in compliance, are used illegally, or are old abandoned sites and are a source of concern. In this case, reporting these sites to the RRC is the proper course of action.

RRC staff will also be able to help in evaluating problem areas, assessing their potential impact on the environment and area residents, and in determining what steps need to be taken to address the issues. Once a problem area has been identified to receive management attention, RRC can also assist in locating appropriate people or entities that are approved to conduct well plugging or clean up efforts in the state.

Some potential sources for funding well plugging and/or management in other critical areas used in the production of oil and gas are State funds that are managed by the RRC. The RRC maintains and manages the Oilfield Cleanup Fund (OFCUF), which is supported primarily by fees, fines, and other payments from the oil and gas industry and can be used to plug abandoned wells and address pollution issues at other sites. Complete details on this cost-sharing program can be found online at http://www.rrc.state.tx.us/environmental/plugging/statemanagedcleanup.php. Grant monies are another potential source of funds for addressing oilfield pollution that can be sought. TCEQ’s CWA §319(h) NPS Grant Program has been used in conjunction with the OFCUF to plug wells that posed threats to water quality (RRC, 2000) and will be considered if significant funding is needed to address identified areas of concern. The final report for the

Choke Canyon Reservoir Saltwater Minimization Project conducted by the RRC and funded by TCEQ's CWA §319(h) NPS Grant Program highlights what has been done using grant monies in other areas of the state to address leaking, abandoned, and improperly plugged wells. The report serves as an excellent outline for the type of work that could be done in the Pecos River watershed. This report is available online at http://www.rrc.state.tx.us/environmental/plugging/chokecanyonfinalreport072408.pdf. Financial assistance from landowners or other local entities such as county governments will also be a source of funds that can be applied to alleviate these problems.

Nutrients and Chlorophyll-a

Ammonia, nitrates, orthophosphorous, and chlorophyll-a were recently listed in the *2006 Texas Water Quality Inventory* and *2006 Texas 303(d) List*, which was released June 2007, as concerns in portions of the river for exceeding their respective screening levels. Red Bluff Reservoir was identified as the primary area of concern for these nutrients. Nitrates are a concern in the upper portion of the lake while ammonia, nitrates, and orthophosphorous are concerns in the lower portion of the lake. Chlorophyll-a was recorded as exceeding the screening level 20 percent of the time in AU 2311_07, which extends from US 67 near Girvin to US 290 south of Sheffield. TCEQ (2007b) indicates that the sources of these concerns in their respective areas are NPS pollution. Ammonia and orthophosphorous concerns in Red Bluff Reservoir are considered to be from irrigated crop production located in New Mexico and outside of the State's jurisdiction while nitrate levels are thought to be from natural sources located throughout the watershed in New Mexico. Elevated chlorophyll-a levels between Girvin and Sheffield are also thought to be caused by agricultural NPS pollution and elevated nutrient loads; however, many landowners indicate that the limited amount of agriculture in the area probably is not the source and that the irrigated agriculture that is present near the river does not contribute any irrigation tail water to the river. Localized oil spill clean up efforts are a potential source that was pointed out. Nitrogen and phosphorous fertilizers are commonly used to mitigate small oil spills and may contribute to the problem. These are only possible sources and are not known to actually contribute to loadings.

Critical Areas for Nutrient and Chlorophyll-a Concerns

Concerns for nutrients have been identified in Red Bluff Reservoir and the segment of the Pecos between Girvin and Sheffield. These concerns are based on data collected by TCEQ that exceed the screening levels set by the state. The *2006 Texas Water Quality Inventory* and *2006 Texas 303(d) List* suggest that ammonia, nitrates, and orthophosphorous concerns present in Red Bluff are thought to be caused by natural sources, agricultural NPS, and other NPS in New Mexico. Chlorophyll-a is identified as the concern for the stretch of the river between Girvin and Sheffield and is thought to be from agricultural NPS pollution; however, landowners are not convinced that agriculture is the source of this problem because their observations indicate that there is a relative lack of agriculture in the area and the complete absence of irrigation tail water returning to the river. They have indicated that nitrogen and phosphorous fertilizers are commonly used to clean up minor oil spills associated with drilling and pumping operations and may contribute to the problem.

The Pecos River watershed as a whole likely contributes to the loading of nutrients to the river. Nutrients such as nitrogen and phosphorous, along with many others, are stored in the soil and as they erode, these nutrients are slowly transported along with the sediment across the landscape and eventually make it to the river or reservoirs. Nutrient levels in the soils vary widely based on location, soil type, land use, and precipitation; therefore, a soil test is necessary to determine nutrient levels in any specific location. Atmospheric deposition (rainfall or dry particles) is a source of nutrients that are continually added to the watershed and can contribute to nutrient levels in soil and water. Data collected through the National Atmospheric Deposition Program at Guadalupe Mountains National Park recorded annual nitrates deposition of 4.64 lbs/ac with an annual average concentration of 0.837 mg/L. Although the total lbs/ac is not much compared to what humans typically apply in the form of fertilizers, the concentration is relatively high and is higher than the nitrates screening level for reservoirs (0.37 mg/L) and about half that of the freshwater screening level (1.95 mg/L) and therefore, may be a considerable source of nutrient loading to the watershed.

Estimated Nutrient Load Reductions

No estimates of load reductions have been established for nutrients as a result of management practices recommended in the WPP. These concerns were not studied as a part of developing this plan. It is anticipated that the delivery of educational programs on nutrient management and the implementation of improved grazing management and WQMPs implemented in the upper portions of the watershed will improve recorded chlorophyll-a levels by reducing nutrient inputs in this area. As more specific information is learned about these concerns and their sources, additional BMPs will be included in the WPP.

When planning future management activities to address nutrient loadings, the current nutrient screening levels (Table 22) should be used as maximum target values until specific numeric nutrient criteria are established. Table 22 summarizes nutrient data that have been collected in the Pecos and compares it to the state's screening criteria. Although some of the averages of samples collected are below the screening criteria, these are still considered concerns due to the number of samples that exceeded the screening level. A minimum of 20 percent of the collected samples are allowed to exceed the screening level before it is listed as a concern; in the case of the Pecos and Red Bluff, all of the nutrients evaluated exceeded their respective screening level more than 20 percent of the time.

Table 22. Recent nutrient data and applicable screening levels in the Pecos River

2006 Texas Water Quality Inventory Assessment of Nutrient Levels in the Pecos River					
River Assessment Unit	Nutrient Concern	Number of Samples Collected	Mean of Samples	Number of Exceedances	Screening Criteria
2311_07	Chlorophyll-a	21	12.567 µg/L	8	14.1 µg/L
2312_01	Nitrates	11	0.676 mg/L	8	0.37 mg/L
2312_02	Ammonia	11	0.094 mg/L	5	0.11 mg/L
	Nitrates	11	0.265 mg/L	6	0.37 mg/L
	Orthophosphorous	11	0.102 mg/L	10	0.05 mg/L

Nutrient Management Measures

Managing nutrients across the watershed can be accomplished in a variety of ways. Education will be the primary means used to address the nutrient concerns present in the watershed. AgriLife Extension will be a primary source of information on nutrient management and maintains a wealth of information on the topic on its Web site: http://texasextension.tamu.edu/. Extension also hosts and delivers multiple nutrient management programs that can be held in the watershed. Not only will proper nutrient management aid in reducing excess nutrient levels in the watershed and river, it will also save producers money on fertilizer while maximizing crop yields. Ammonia, nitrates, and orthophosphorous are the three nutrients listed as concerns in the Pecos River watershed and may be the result of excess fertilization on farmland or the use of ammonium nitrate fertilizer in cleaning up minor oil spills associated with drilling or pumping operations.

Algae growth in the Pecos that can be affected by excessive nutrient loading

The watershed can be managed to reduce its influence on nutrient loading as well. WQMPs will likely reduce a property's nutrient contribution by implementing management practices specific to nutrient management and others that promote reduced surface runoff and erosion.

As stated earlier, the primary sources of these pollutants contributing loadings to Red Bluff Reservoir appear to be from sources in New Mexico. Managing these sources is critical to reducing the nutrient levels in Red Bluff Reservoir and the river. Educating landowners and the establishment of nutrient management plans on cropland around the Carlsbad area should be the primary target to impact water quality in Texas.

Assistance Needed for Nutrient and Chlorophyll-a Concerns

Technical assistance to address nutrient concerns in the watershed can be obtained from three main sources. AgriLife Extension, NRCS, and TSSWCB all maintain information on the value and benefits of developing and implementing nutrient management plans. As always, these entities can provide technical assistance on nutrient management and help develop plans to address nutrient loadings.

Conservation Plans and WQMPs are developed by SWCDs, NRCS, and TSSWCB at no cost to the landowner; however, NRCS and TSSWCB incur the costs of employing personnel to develop these plans. Implementing recommendations prescribed in these nutrient management plans will require funding that is highly dependent on the recommended practices. Financial assistance available through those agencies and others will provide the bulk of needed financial assistance.

AgriLife Extension will deliver educational workshops at little or no cost to inform farmers and ranchers about methods they can employ to reduce nutrient loads from their properties. If there is a fee associated with the program, it is usually $20 or less and covers the costs of materials and lunch. These programs are typically supported by other sources of funding, such as CWA §319 NPS grants from the TSSWCB.

Pecos River near Sheffield

Education and Outreach

An essential element in implementation of this WPP is an effective education and outreach campaign. Accomplishing comprehensive improvements in the Pecos River watershed of Texas requires long-term commitments from citizens and landowners. The education and outreach (E/O) component of implementation must focus on keeping the public, landowners, and agency personnel informed of project activities, providing information about appropriate management practices and assisting in identifying and forming partnerships to lead the effort.

Past Education and Outreach Activities

The project to develop this WPP began in 2004 and has included many E/O activities since its inception. The main goal of past activities was to inform landowners and watershed residents about the project, why the WPP is being developed, what it aims to do, and how they can be involved in the process. These goals were accomplished by conducting and participating in public meetings, producing publications and other materials describing the project and its activities, building and maintaining a project Web site, and distributing periodic news releases.

Communication and Education

Disseminating information to landowners has been and will continue to be a vital element of fostering project support and involvement. A number of information distribution techniques have been used in the WPP development process and will continue to be used in the implementation phase.

Mailing information to a list of over 1,000 landowners that continues to grow has served as the most effective means of communicating with people about upcoming meetings and other activities related to the project. Letters or newsletters announcing where or how project documents can be found, when and where project meetings will be held, and other brief updates about project activities are typically included in these mailings.

The project Web site (address below) has been the most widely used means to distribute educational materials, project publications, and all other information materials relating to the development of the WPP. This Web site will be maintained and updated throughout the WPP implementation. The Web site was also used to conduct an online survey of landowners' perceptions of water resources challenges facing the Pecos Basin in Texas. A total of 57 individuals responded to the survey, and the results are listed in detail on the Web site and summarized in Appendix B. Additional online surveys will be used during WPP implementation to gain further input regarding perceptions of the implementation effort and additional guidance that landowners may be able to provide. The Web site will also be modified to include a form where anyone can submit feedback on project documents, meetings, and activities, or can ask questions to project personnel.

http://pecosbasin.tamu.edu/

Publication of project reports and informational materials was also a vital element of the E/O component of the WPP development. The varied formats and avenues of distribution of these publications have informed a wide array of audiences about Pecos River issues and WPP development activities. Current project publications mailed out, distributed at meetings or posted on the project Web site are listed below.

- Pecos Project Brochure — distributed throughout the watershed
- "Historic Issues Facing the Pecos Basin of Texas — A Fact Sheet"
- "New Study to Focus on Pecos River," The Ozona Stockman, The Fort Stockton Pioneer, The Terrell County News Leader, and The Pecos Enterprise, May 2005
- "Pecos River Struggles," *Ranch and Rural Living* magazine, April 2005, pp. 23-24
- "The Struggles of the Pecos River," *TRA Stream Lines*, the official newsletter of the Texas Riparian Association, Winter 2006, Volume 4, Issue 1
- "Saltcedar Control and Water Salvage on the Pecos River, Texas, 1999-2003," *Journal of Environmental Management*; Volume 75, 2005, pp. 399-409
- "The Influence of Human Activities on the Waters of the Pecos Basin of Texas: A Brief Overview," Texas Water Resources Institute Publication SR-2006-03
- "Saving a Dwindling River," *txH_2O,* Spring 2007

Meetings across the watershed have also played an important role in the development of the WPP and will continue during the implementation process. Throughout the development phase, meetings were divided into four categories, listed and described below. These meetings were used as an outlet for landowners, managers, citizens, agency personnel, and anyone else interested in the health of the watershed to learn about the project. Attendees obtained project information, learned what they could expect from the project, and informed project personnel of their concerns and thoughts about the way the WPP should be developed and implemented. Table 23 provides an overview of all meetings held to date, the locations of the meetings, the number of people attending, the dates of the meetings and indicates whether a meeting summary is available on the project Web site.

- Informational Meetings – Inform landowners and natural resource professionals about conditions within the watershed and project activities addressing these issues
- Skill Level Meetings – Provide landowners with land management skills and techniques and to acquaint them with new technologies
- Discovery Meetings – Solicit input from landowners on the development of the WPP
- Public Comment Meetings – Presented the proposed WPP to landowners and opportunity for comments

Table 23. Meetings held pertaining to the development of the Pecos River WPP

Date	Meeting Type	Location	Attendance	Meeting Summary
12/04	Informational	Texas Legislature Staff	3	----
02/05	Informational	Independence Creek Nature Preserve	18	----
02/05	Informational	PRAC Monahans, TX	25	Web site
03/05	Informational	TCEQ CMM Midland, TX	9	----
03/05	Informational	PRAC Monahans, TX	22	Web site
04/05	Informational	RGBI Conference Alpine, TX	----	----
05/05	Informational	PRAC Monahans, TX	14	Web site
05/05	Skill Level	Ozona, TX	15	----
05/05	Skill Level	San Angelo, TX	About 100	----
06/05	Informational	PRAC Monahans, TX	16	Web site
08/05	Discovery	Fort Stockton, TX	44	
10/05	Skill Level	Odessa, TX	5	----
11/05	Informational	Society for Petroleum Engineers Odessa, TX	30	----
12/05	Informational	PRAC Monahans, TX	15	Web site
01/06	Informational	PRAC Monahans, TX	10	Web site
02/06	Informational	CSREES Conference San Antonio, TX	----	----
02/06	Informational	Big Bend Native Plant Society Fort Davis, TX	70	----
03/06	Informational	RGBI Conference Ruidoso, NM	----	----
03/06	Informational	TRA Fort Davis, TX	8	----
04/06	Informational	TCEQ CMM Midland, TX	11	----
04/06	Discovery	Mentone, TX	7	----
04/06	Discovery	Imperial, TX	18	----
04/06	Discovery	Independence Creek Nature Preserve	17	----
04/06	Discovery	Iraan, TX	31	----
04/06	Informational	Crockett SWCD Ozona, TX	6	----
05/06	Informational	Public School McCamey, Rankin, TX	170	----
05/06	Informational	Public School Iraan, TX	120	----
07/06	Informational	University Council on Water Resources Santa Fe, NM	----	----
09/06	Informational	Cactus & Succulent Society Kerr County, TX	21	----
10/06	Informational	Chihuahuan Desert Research Institute Fort Davis, TX	About 430	----
3/07	Informational	“The Pecos River: Past, Present, and Future” Conference San Marcos, TX	About 85	----
8/07	Informational	15th National NPS Monitoring Workshop Austin, TX	About 40	----
10/07	Comment	Mentone, TX	4	----
10/07	Comment	Pecos, TX	15	----
10/07	Comment	Imperial, TX	20	----
10/07	Comment	Iraan, TX	15	----
10/07	Comment	Del Rio, TX	12	----
11/07	Comment	Trans Pecos SWCD Fort Stockton, TX	13	----
11/07	Comment	Upper Pecos SWCD Pecos, TX	14	----
11/07	Comment	Rio Grande – Pecos River SWCD Sanderson, TX	16	----

Date	Meeting Type	Location	Attendance	Meeting Summary
11/07	Comment	Devil's River SWCD Del Rio, TX	9	----
11/07	Comment	Sandhills SWCD Odessa, TX	17	----
11/07	Comment	Crockett SWCD Ozona, TX	18	----
2/08	Comment	Pecos, TX	10	----
2/08	Comment	Imperial, TX	12	----
2/08	Comment	Iraan, TX	6	----
2/08	Comment	Ozona, TX	15	----
2/08	Comment	Del Rio, TX	3	----

Involvement

Successful partnerships were formed during the development phase of the WPP and will continue to be an important part of carrying out the WPP process. A combination of landowner groups, government agencies, non-profit organizations, and other interested parties have cooperated throughout the effort and provided input for the development of the WPP. Implementing the plan will continue to foster and rely on these partnerships for project direction and input. A list of current partners and their respective project roles is in Table 24.

Meeting participants

To augment current partnerships formed through WPP development activities, potential collaborators for the implementation process were identified. Some possibilities are listed below.

- Davis Mountains Trans Pecos-Heritage Association
- National Park Service – Amistad National Recreation Area
- U.S. Department of the Interior – Bureau of Reclamation – Upper Colorado Region
- Texas Water Development Board
- Texas Railroad Commission
- US Army Corps of Engineers
- Loving County Irrigation District #1
- Pecos County Irrigation Districts #2 & #3
- Reeves County Irrigation District #2
- Ward County Irrigation Districts #1, #2 & #3
- Carlsbad Irrigation District

Table 24. Project partnerships and involvement

Group	Involvement Level
EPA	Funding, Advisory
TSSWCB	Funding, Advisory
Texas AgriLife Extension Service *	Direction, I/E, Technical
TWRI *	Direction, I/E
Texas AgriLife Research *	Technical, Advisory
USIBWC	Technical, Advisory
TCEQ	Technical
USGS *	Technical
TFS	Technical
NRCS	Cooperation
Pecos Valley RC&D	I/E
Upper Pecos SWCD #213	Advisory/Cooperation
PRAC (formerly)	Advisory
Pecos River Compact Commission	Advisory
Red Bluff Water & Power Control District	Cooperation
TPWD	Cooperation
Texas Wildlife Association	Cooperation
Crockett SWCD #235	Cooperation
Trans Pecos SWCD #231	Cooperation
Rio Grande-Pecos River SWCD #237	Cooperation
Devil's River SWCD #224	Cooperation
Sandhills SWCD #241	Cooperation
TNC	Cooperation
Pecos County Commissioners' Court	Cooperation
City of Fort Stockton	Cooperation
Pecos River Watershed Restoration, Inc.	Cooperation

* Received past project funds from TSSWCB

Future Education and Outreach Activities

Throughout the process of developing this plan, landowners have expressed the need for more information regarding the WPP and implementation strategies described within the document. Providing needed information is a must for gaining the support of any person or group of persons and will be an integral part of implementing management strategies identified in this plan.

Informational Meetings

Informational meetings will continue as an important tool for informing landowners in the watershed about activities being conducted and what they can do to help improve the health of the watershed. These meetings will also give people in the watershed a chance to discuss activities, provide their comments, and give input on implemented or planned management activities. Informational meetings specifically dedicated to WPP implementation will be held bi-annually and updates on the project will be given periodically at other meetings currently being held in the basin (commodity organizations' meetings, SWCD meetings, irrigation district meetings, etc.). Topics discussed in these meetings will be broad in scope and provide general overviews of past and future activities related to the project.

Topic-specific meetings will be held on an as needed basis and will serve several roles. These meetings will inform residents in a specific area about specific management activities recommended for a certain area or those for which funding has been secured.

Field days will also be planned periodically to allow landowners and managers, farmers, watershed residents, and all other interested parties to get a firsthand look at implemented management practices and learn more about them and their benefits to the watershed and the person or group implementing the practice. Anticipated field days will show salinity management measures, such as pumping and evaporation operations, and grazing management practices, such as rotational grazing, prescribed burning, alternative water and shade sources, and others as appropriate.

Guidance

The formation of one or more steering committees to lead and coordinate project activities will be an essential element of involvement during the implementation phase and beyond. In addition, creation of an upper and lower basin watershed steering committee will give landowners an opportunity to actively participate in the implementation process and will provide a sense of ownership in the project in their portion of the river. It is anticipated that the steering committees will meet two to three times per year to provide leadership on needed implementation strategies.

Workshops, Short Courses and Seminars

Workshops and seminars will also be held throughout the watershed and will focus on more specific topics. These are usually longer, more in-depth and, in many cases, result in continuing education hours that can be applied to various license requirements, such as the TDA's Pesticide Applicator Certification program. AgriLife Extension plays a vital role in delivering programs that fit into this category and will provide more of the programs in the Pecos River watershed.

These skill level workshops will play an important role in educating landowners on stewardship efforts, technologies, and practices, which are focused on improving the health and productivity of the watershed and can be implemented by farmers and landowners. One workshop anticipated is the Texas Watershed Steward Program. This program focuses on educating its attendees about watersheds, their function and importance, potential sources of degradation, and how the implementation of a WPP can address these issues. An added bonus to this program is the potential to earn continuing education hours for school teachers, Certified Crop Advisors, and TDA Pesticide License holders. This program is currently funded with TSSWCB CWA §319 grant funds. The Lone Star Healthy Streams program is another workshop that will be beneficial to residents of the watershed. This program focuses on conveying information about potential management practices that cattlemen can implement to improve water quality while increasing the productivity of their land. This program is also currently funded with TSSWCB CWA §319 grant funds.

More information about these two programs is available at their respective Web sites:

Texas Watershed Steward Program: http://tws.tamu.edu/
Lone Star Healthy Streams: http://grazinglands-wq.tamu.edu/

Many other workshops, short courses, and seminars are given each year throughout the watershed and across the state. Local county Extension agents can provide schedules for upcoming workshops and seminars in the area and can help in scheduling requested courses. Topics for some short courses offered by Extension include pesticide use and management, living with and dealing with feral hogs, crop management, irrigation water management, nutrient management, cattle production, proper grazing management, and many others.

Advertising

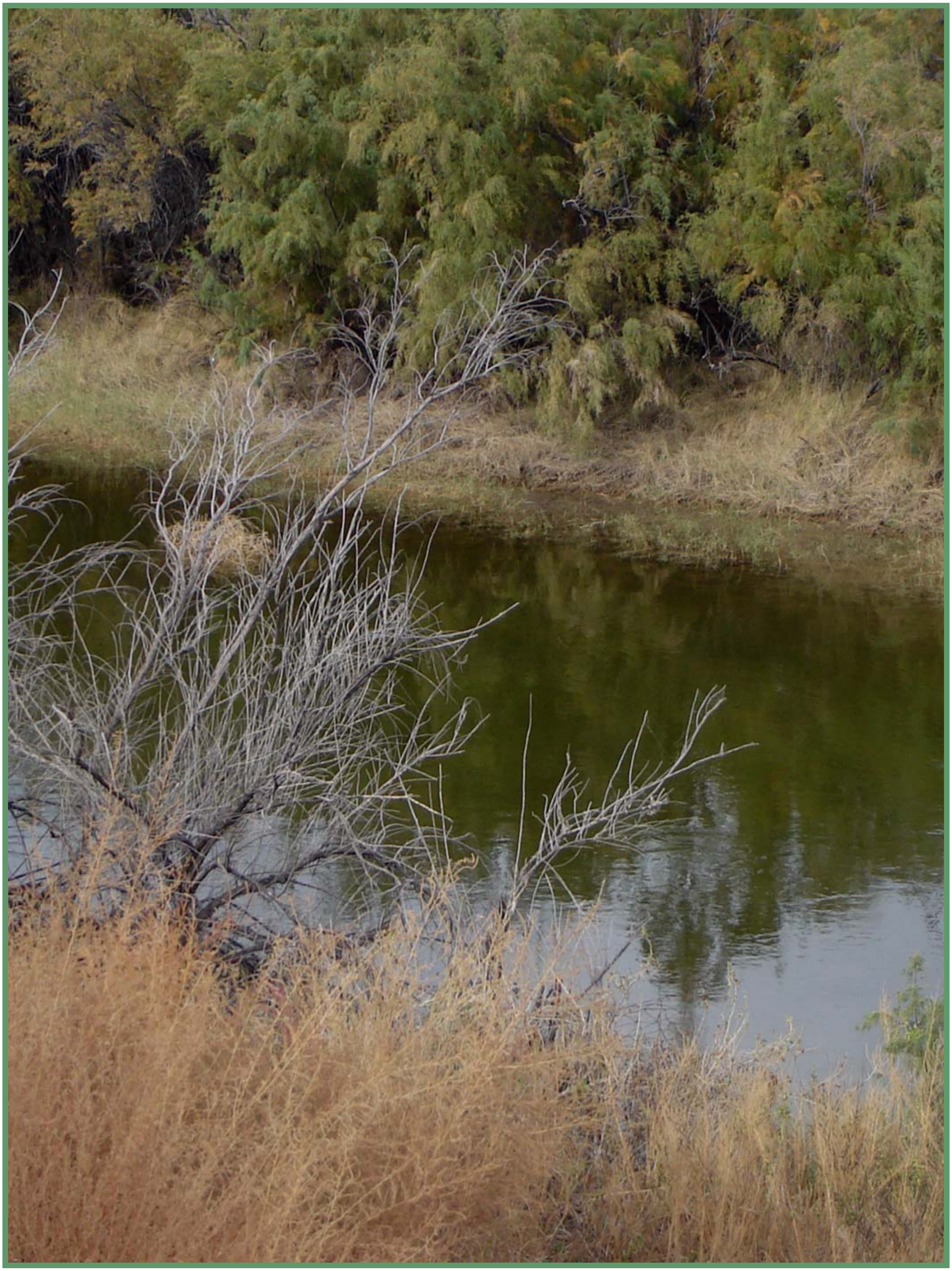
Informing as many people as possible about project meetings, activities, and associated workshops, short courses and seminars is critical for successfully implementing this plan across the basin. Methods that were used in the past and that will continue are direct mailings, posting upcoming events on the project Web site, asking Extension county agents to include the information in their newsletters and columns in local newspapers and developing news releases to run in local newspapers and Ag News, which is a service of Texas A&M AgriLife that can be subscribed to (http://agnews.tamu.edu/listserv/).

In the future along with the methods listed above, public service announcements on local radio stations in the watershed and ads purchased in newspapers that do not print the information as a news release will be used to spread the word about project meetings and activities. These efforts will be undertaken in an effort to reach a larger number of people and get them involved in the WPP implementation process.

All planned meetings, workshops, field days, and any other project activities will be announced on the project Web site, through local media outlets, in newsletters mailed to participants and in agency newsletters distributed throughout the watershed.

Expanding Programs

The need to establish new programs or expand old programs in the watershed will likely arise. In this case, the appropriate steps will be taken to inform needed parties and landowners who can use the new effort. A potential program that could fit into this category is a native bait fish program. This program will entail working with bait sellers in the area and helping them convert from nonnative bait fish species to species native to the Pecos River watershed. This effort will be coordinated with TPWD and local bait shops and will accomplish two things: 1) It will limit the introduction of nonnative fish species to the river and 2) It will help to bolster native fish populations in the river when fishermen discard their excess bait in the waterway.



Living and dead saltcedar along the Pecos River

Implementation Schedule and Estimated Costs

This section of the WPP presents a proposed schedule for implementing management measures and activities described in the WPP. The implementation timeline is an estimate subject to change because a multitude of factors dictate when a project or task will be carried out. Delays in project development, securing funding, acquiring adequate support for the management measure or practice, and permitting or legal constraints are just a few hurdles that can prevent implementation from being conducted on schedule. Ultimately, implementation of voluntary BMPs on private property will be solely at the discretion of the landowner.

The proposed implementation schedule operates within a 10-year period beginning in 2010. Table 25 illustrates targeted implementation timelines for specific management measures and includes an anticipated number of practices implemented and expected costs to implement these practices. Many of the measures listed do not have an estimated cost per unit, number of units to be implemented, or estimated number of practices to be implemented. In these cases, either a specific management practice that addresses the concern has not been identified or the number of practices to be implemented has not been determined.

Table 25. Recommended management practices, potential party overseeing implementation of that practice, estimated cost per unit, estimated units to be implemented, total implementation cost, estimated number of practices and anticipated time of implementation

Management Measure	Technical or Financial Assistance	Estimated per Unit Cost	Estimated Units to be Implemented	Total Cost	Estimated Number of Practices Implemented Year		
					1-3	4-6	7-10
Salinity Control							
Malaga Bend control measures	State of New Mexico/ Private Sector	N/A	1	N/A	1	---	---
Coyanosa to Girvin salt source study	TCEQ/ AgriLife Research	TBD	1	TBD	1	---	---
New Mexico to Texas delivery schedule revision	PRCC/ Red Bluff PWCD/ New Mexico	TBD	TBD	TBD	TBD		
Salinity management feasibility study (Coyanosa to Girvin)	TWDB/ USACE/ AgriLife Research	TBD	1	TBD	---	1	---
Saltcedar and Giant Cane Control							
Saltcedar (chemical)	TSSWCB/ Upper Pecos SWCD/ Crockett SWCD	$220/ acre	2,158 acres	$474,760	1,775 †	383	---
Saltcedar (biological w/ dispersion eval.)	Extension	$5,000/ site	20 sites	$100,000	10 †	10	---
Saltcedar (biological)	Landowner	free	50 sites	free	20	30	---
Giant cane (chemical)	TSSWCB/ Crockett SWCD	$220/ acre	TBD	TBD	TBD	TBD	---
Debris burning /regrowth suppression	Texas Forest Service	$2,000 / river mile	350 miles	$700,000	225 † miles	125 miles	---
Giant cane acreage assessment	Remme Corp.	$30,000 using existing imagery	1	$30,000	1	---	---

Management Measure	Technical or Financial Assistance	Estimated per Unit Cost	Estimated Units to be Implemented	Total Cost	Estimated Number of Practices Implemented Year 1-3	4-6	7-10
Upland Brush Control							
Chemical	Extension/ NRCS/ SWCD	$30 - $45/ acre	TBD	TBD	TBD	TBD	TBD
Mechanical	Extension/ NRCS/ SWCD	$60 - $250/ acre	TBD	TBD	TBD	TBD	TBD
Biological Diversity/Land Management in Riparian Zone							
WQMPs	Upper Pecos and Crockett SWCDs	Up to $15,000/ plan	120 plans	$1,800,000	20 †	40	60
WQMP technician	Upper Pecos and Crockett SWCDs	$51,000/ yr ea.	2 technicians for 10 yrs	$1,020,000	2 †	2	2
Riparian revegetation (planted)	Extension/ Landowner/ NRCS/ SWCD	$13-$29/ acre	~3,750 ac	$48,750 - $108,750	25%	25%	50%
Riparian revegetation (natural)	Landowner	$0/ acre	~11,250 ac	N/A	All areas will be naturally revegetated		
Dissolved Oxygen							
River assessment to ID suitable locations for artificial riffles	TCEQ/ TPWD/ University	$100,000	1	$100,000	1	---	---
Artificial riffles	Extension/ TCEQ/ TPWD/ USACE	$5,000/ riffle	as many as feasible	TBD	---	TBD	TBD
Sediment Control							
Riparian revegetation (planted)	Extension/ Landowner/ NRCS/ SWCD	$13-$29/ acre	~3,750 ac	N/A fund provided in Biological Diversity	25%	25%	50%

Management Measure	Technical or Financial Assistance	Estimated per Unit Cost	Estimated Units to be Implemented	Total Cost	Estimated Number of Practices Implemented Year 1-3	4-6	7-10
Riparian revegetation (natural)	Landowner	$0/ acre	~11,250 ac	N/A	All areas will be naturally revegetated		
Oil and Gas Production							
Well plugging	RRC/ Landowners	$4,500 - $400,000/ well	As many as needed	TBD	TBD	TBD	TBD
Nutrient Concerns							
Nutrient management plans in NM	NM Extension/ NRCS	N/A	N/A	N/A	---	---	---
Nutrient management plans in TX (WQMPs) on land away from river	SWCD	$15,000	50	$750,000	20	40	60
Water Quantity							
Irrigation canal water audits	Extension/ Irrigation Districts	TBD	TBD	TBD	TBD	TBD	TBD
New Mexico to Texas delivery schedule revision	PRCC/ Red Bluff PWCD/ New Mexico	TBD	TBD	TBD	Begin Immediately		
Red Bluff release schedule	Red Bluff PWCD/ Irrigation Districts	TBD	TBD	TBD	Begin Immediately		
Irrigation delivery timing	PRCC/ Red Bluff PWCD/ New Mexico	TBD	TBD	TBD	TBD		
Efficient irrigation systems	Irrigation Districts/ Landowners	TBD	TBD	TBD	TBD		
Monitoring Program							
CWQM new stations (installation)	TCEQ/ USGS	$25,000 - $30,000	1	$25,000 - $30,000	---	1	---

Management Measure	Technical or Financial Assistance	Estimated per Unit Cost	Estimated Units to be Implemented	Total Cost	Estimated Number of Practices Implemented		
					Year		
					1-3	4-6	7-10
CWQM new stations (maintenance)	TCEQ/ USGS	$15,000/ yr	annually	$105,000 / 7 yrs	---	1	
Aquatic life and habitat survey	USGS/ TCEQ/ TPWD	$60,000/ survey	1 survey in yr 7	$60,000 / 10 yrs	---	---	1
Continued level of CRP SWQM	TCEQ/ TNC/ USGS	$15,000/ unit	5	$750,000	15 ††	15 ††	20 ††
Education and Outreach							
Correspondence	Extension/ TWRI	$1,000/ mailing	4 mailings/ yr	$40,000	12 †	12	16
Texas Watershed Steward Program	Extension	NA	2	NA	2 ††	---	---
Lone Star Healthy Streams Program (Livestock Grazing Management)	Extension	NA	1	NA	2	2	2
Nutrient Management Workshop	Extension	NA	3	NA	2	2	2
Biannual meetings	TWRI	$750 ea	20	$15,000	6 †	6	8
Watershed Coordinator	TWRI	$45,000/ yr	10	$450,000	3 †	3	4
Web site maintenance	Extension/ TWRI	$2,950/ yr	10	$29,500	3 †	3	4

† Funds currently being sought through a CWA §319 Grant from TSSWCB

†† Funding currently in place, no additional funds needed at this time

Bridge over Amistad Reservoir

Implementation Milestones

Adaptive management is a process in which decisions are made as part of an ongoing science-based process. Adaptive management involves testing, monitoring, and evaluating applied strategies, and incorporating new knowledge into management approaches based on scientific findings and the needs of society. Results are used to modify management policy, strategies, and practices (USGS, 2000).

The WPP has set interim goals as a means to track progress and ensure that the plan is being implemented in a timely fashion. These goals are divided into short-term, mid-term and long-term goals that will build upon each other to eventually accomplish the overall goals of the WPP. These milestones are set forth as a target to reach during a certain period. If these targets are not reached, the reasoning behind not reaching these targets should be determined. If it is merely delayed implementation, no action is needed; however, if the implemented management measures are not having the anticipated impact then adaptations to the management scheme must be undertaken. It is assumed that year one translates into the 2010 calendar year, 2011 will be year two and so on. Some flexibility will be required in meeting these milestones due to differences in calendar years, fiscal years, funding cycles, and other unforeseen delays such as weather conditions. Nonetheless, efforts will be made to implement these milestones on schedule if possible.

Short-term Milestones (1 to 3 years)

Salinity Control

- Begin additional studies between Coyanosa and Girvin to identify specific salinity sources in this reach of the river
- Begin implementing salinity management measures at Malaga Bend
- Begin work with the PRCC, Red Bluff PWCD, and New Mexico to modify the water delivery schedule between states so that water is stored longer in deeper upstream reservoirs

Saltcedar and Giant Cane Control

- Begin spraying the remaining treatable acres (2,158) of previously untreated saltcedar and giant cane infestations along the main channel and tributaries of the river with landowner permission. A target of 1,775 acres has been set for the first 3 years
- Establish and release saltcedar leaf beetles at 10 initial sites across the watershed where landowner permission has been granted
- Work with area landowners to establish additional saltcedar leaf beetle colonies
- Begin burning standing dead saltcedar with landowner permission. Approximately 225 river miles are expected to be burned in the first 3 years of implementation

Biological Diversity / Livestock Management in Riparian Zone

- Work with landowners to further educate them about the benefits of establishing grazing management plans and/or WQMPs on their land

- Work with landowners along riparian areas to implement management practices that reduce the amount of time livestock and wildlife spend in or near waterways; many of these measures will be included in a WQMP
- Begin burning dead saltcedar (See Saltcedar and Giant Cane Control)
- Establish a voluntary riparian revegetation program that focuses on areas where debris from spraying efforts was burned

Dissolved Oxygen Management

- Work with area universities to conduct river assessment to determine feasible locations for constructing artificial riffles

Sediment Control

- Establish a voluntary riparian revegetation program that focuses on areas where debris from spraying efforts was burned
- Begin burning dead saltcedar (See Saltcedar and Giant Cane Control)

Oil and Gas Production

- Work with RRC and area landowners to identify and plug leaking or abandoned wells

Nutrient Management

- Work with landowners to develop cropland WQMPs specific to their property
- Conduct nutrient management workshops (See *Education and Outreach*)

Water Quantity Management

- Work with Red Bluff WPCD management to attempt to create a reservoir release schedule that maintains a constant flow regime
- Work with Red Bluff WPCD, PRCC, and New Mexico to store water delivered to Texas in upstream reservoirs longer to reduce evaporation losses
- Work with local irrigation districts to conduct water audits on their canal systems

Monitoring Program

- Work to set up partnerships and secure funding sources for the implementation of new continuous water quality monitoring (CWQM) stations along the river, and establish the first site at Girvin
- Maintain at least the current level of surface water quality monitoring being conducted through CRP

Education and Outreach

- Establish steering committees and/or watershed councils for the upper and lower Pecos River watershed to guide the implementation process
- Conduct workshops or field days to educate landowners and managers, watershed citizens, government officials, and others about management techniques that will improve watershed health and water quality (Texas Watershed Stewards, Lone Star Healthy Streams, Nutrient Management, etc.)

- Continually update the project Web site to include meeting/event notices and the most recent materials project materials
- Include project updates in various newsletters across the watershed
- Conduct semiannual educational meetings to inform participants about implementation activities, goals achieved, upcoming milestones, and improvements made in watershed quality and to receive feedback from attendees
- Train local government personnel, landowners, and land managers on the proper methods and timing of spot spraying saltcedar and/or giant cane regrowth

Mid-term Milestones (4 to 6 years)

Salinity Control

- Continue implementing salinity management measures at Malaga Bend
- Continue to work with the PRCC, Red Bluff PWCD, and New Mexico to modify the water delivery schedule between states so that water is stored longer in deeper upstream reservoirs
- Begin salinity management feasibility studies between Coyanosa and Girvin based on completed salinity source assessment conducted in the same area
- Evaluate defoliation progress at and around saltcedar leaf beetle release sites and release beetles at new sites as needed

Saltcedar and Giant Cane Control

- Complete spraying of all remaining targeted areas (about 383 acres) of saltcedar infestation where landowners have given permission to do so
- Complete burning of standing dead saltcedar to remove debris and suppress regrowth where permitted by landowners
- Implement 10 additional saltcedar leaf beetle sites along the river and track their dispersion
- Continue to work with area landowners to establish additional saltcedar leaf beetle colonies
- Establish and implement a saltcedar, giant cane and restored vegetation monitoring and treatment program
- Work with area landowners to conduct localized treatment of saltcedar and giant cane regrowth when discovered

Biological Diversity / Livestock Management in Riparian Zone / Upland Brush Control

- Continue voluntary riparian revegetation efforts
- Continue to work with landowners to further educate them about the benefits of establishing grazing management plans and/or WQMPs on their land
- Continue to work with landowners along riparian areas to implement WQMP
- Continue burning standing dead saltcedar (See *Saltcedar and Giant Cane Control*)
- Implement a riparian revegetation monitoring program (See *Saltcedar and Giant Cane Control*)

Dissolved Oxygen Management

- Install two artificial riffles per year until feasible sites all have artificial riffles in place, after completing the river assessment

Sediment Control

- Continue voluntary riparian revegetation efforts

Oil and Gas Production

- Continue to work with RRC and area landowners to identify and plug leaking or abandoned wells

Nutrient Management

- Continue to work with landowners to develop cropland WQMPs specific to their property
- Conduct nutrient management workshops (See *Education and Outreach*)

Water Quantity Management

- Continue working with Red Bluff WPCD management to attempt to create a reservoir release schedule that maintains a constant flow regime
- Continue working with Red Bluff WPCD, PRCC, and New Mexico to store water delivered to Texas in upstream reservoirs longer to reduce evaporation losses
- Continue to work with local irrigation districts to conduct water audits on their canal systems
- Work with irrigation districts and landowners to implement more efficient irrigation systems

Monitoring Program

- Implement a real-time water quality monitoring station above Red Bluff Reservoir
- Establish and implement a saltcedar, giant cane, and restored vegetation monitoring and treatment program

Education and Outreach

- Continue to educate landowners about the benefits of establishing and implementing grazing management and/or WQMPs.
- Conduct several field tours on properties that have implemented practices recommended by these plans so producers can see their benefits first hand
- Establish a monitoring network of technical professionals and landowners to assess the effectiveness and integrity of artificial riffles after high flow events
- Conduct semiannual educational meetings to inform participants about implementation activities, goals achieved, upcoming milestones, and improvements made in watershed quality and to receive feedback from attendees
- Include project updates in various newsletters across the watershed
- Conduct workshops or field days to educate landowners and managers, watershed citizens, government officials, and others about new management techniques that will improve watershed health and water quality

- Continually update the project Web site to include meeting/event notices and the most recent project materials

Long-term Milestones (7 to 10+ years)

Salinity Control

- Begin implementing salinity management practices in the Coyanosa to Girvin reach of the river based on the findings of the salinity management feasibility study conducted in that area
- Continue implementing salinity management measures at Malaga Bend

Saltcedar and Giant Cane Control

- Continue to evaluate the progress of saltcedar leaf beetle dispersed from initial release sites and redistribute beetles to new sites in the watershed
- Continue to educate persons interested in learning how to treat localized areas of saltcedar regrowth and promote the utility of this practice
- Continue to work with area landowners to establish additional saltcedar leaf beetle colonies

Biological Diversity / Livestock Management in Riparian Zone / Upland Brush Control

- Begin work to develop a fish repopulation program
- Continue to develop and implement the fish repopulation program after aquatic and riparian habitat have been re-established, water quality improvement measures have been put in place, and sufficient water quality improvement have been realized

Dissolved Oxygen Management

- Continue to install artificial riffles if needed and continue the riffle monitoring program

Sediment Control

- Continue voluntary riparian revegetation efforts

Oil and Gas Production

- Continue to work with RRC and area landowners to identify and plug leaking or abandoned wells

Nutrient Management

- Continue to work with landowners to develop cropland WQMPs specific to their property
- Conduct nutrient management workshops (See *Education and Outreach*)

Water Quantity Management

- Continue to work with local irrigation districts to conduct water audits on their canal systems
- Continue to work with irrigation districts and landowners to implement more efficient irrigation systems

Monitoring Program

- Continue the saltcedar, giant cane, and restored vegetation monitoring and treatment program
- Implement two real-time water quality monitoring stations, one at Orla and one upstream of the US 90 bridge
- Conduct an aquatic life and habitat survey to document the changes, if any, since the WPP implementation began

Education and Outreach

- Continue to educate landowners about grazing management and WQMPs. Host more field tours of properties that have implemented these plans
- Conduct semiannual educational meetings to inform participants about implementation activities, goals achieved, upcoming milestones, and improvements made in watershed quality and to receive feedback from attendees
- Include project updates in various newsletters across the watershed
- Conduct workshops or field days to educate landowners and managers, watershed citizens, government officials, and others about new management techniques that will improve watershed health and water quality
- Continually update the project Web site to include meeting/event notices and the most recent materials project materials

Irrigated cotton production in the Pecos River Watershed

Criteria for Assessing Success

The overall goal of the WPP for the Pecos River in Texas is to improve the health of the river and watershed and to have it removed from the state's list of impaired waters. Specific tasks have been identified as pieces of the overall plan that focus on addressing issues of concern in the watershed. Table 26 presents broad watershed issues addressed by the WPP and lists indicators that will be used to determine whether implementing the WPP has effectively achieved its watershed improvement goals. The table also lists target values for specific water quality standards, water quantity levels, improvements in biological diversity, and education and outreach accomplishments that will serve as markers for achieving the goals of this WPP.

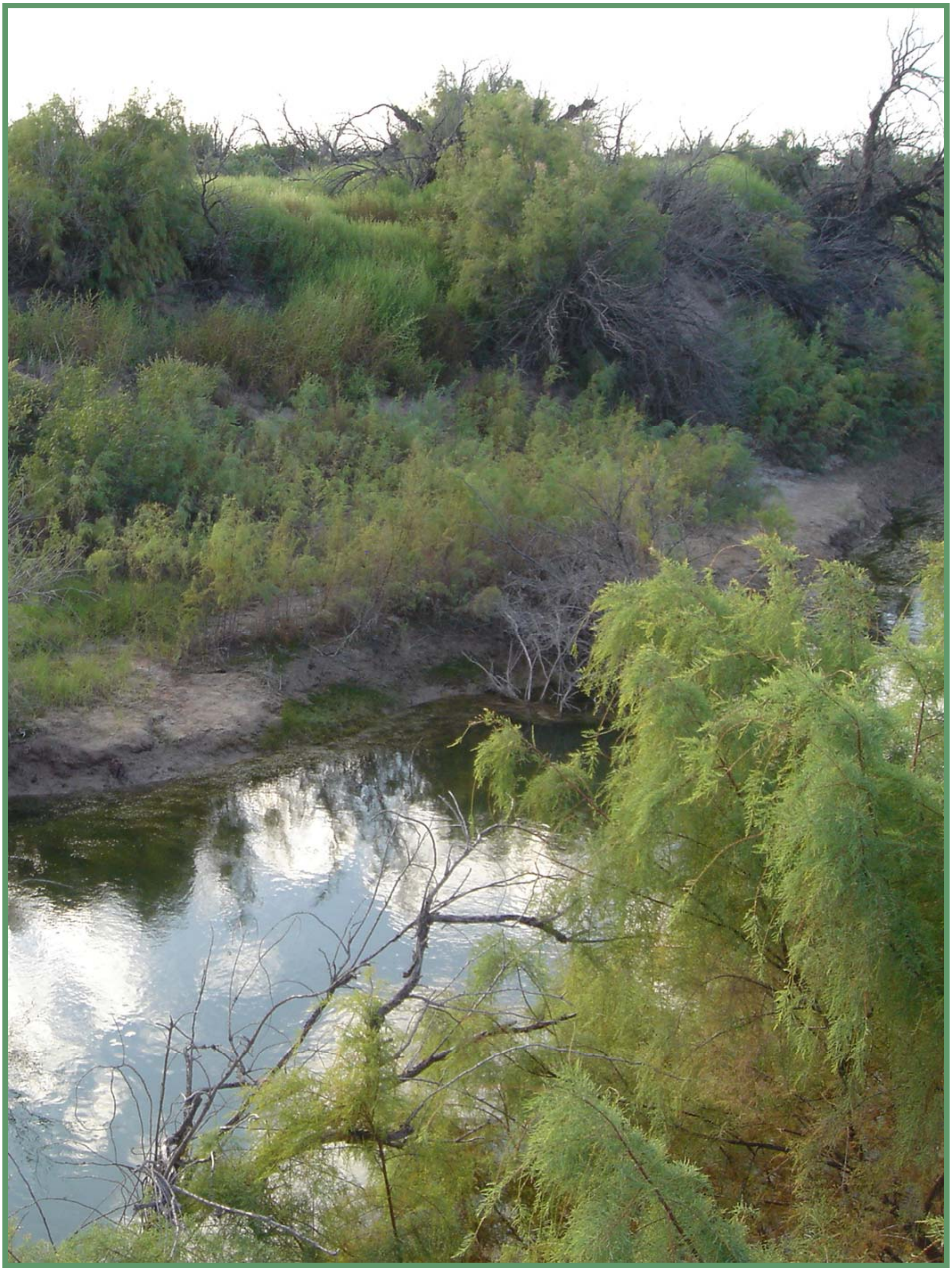
Implementing recommended management practices and reaching designated milestones is a strategy focused to achieve improvements across the watershed. The success of these implemented management measures will be judged based on the targeted values listed in Table 26. Immediate changes in water quality, water quantity, and biological diversity will not be seen; instead, changes will be seen gradually as more management practices are implemented across the watershed. Target values have been set as achievable goals that will improve watershed health to the intended level without being too restrictive or difficult to attain.

Table 26. Implementation Success Indicators

Issue	Indicator	Current Value	Target Value
River salinity improvements	Red Bluff Reservoir inflow salinity	Long-term average of ~7,000 mg/L TDS	5 yr average of 5,000 mg/L TDS or less
	Recorded salinity at Girvin	Long-term average of ~12,800 mg/L TDS	5 yr average of 10,000 mg/L TDS or less
	Amistad Reservoir potable water intake salinity in segment 2305	Long-term average of ~725 mg/L TDS	Maintain below 1,000 mg/L TDS
	Plug leaking or abandoned oil and gas wells	336 wells currently orphaned as of 9/2008	Plug as many problem wells as financially possible
Biological diversity improvements	Remaining saltcedar stands sprayed	3,032 acres along the river (not all acres are treatable due to high canyon walls)	Complete all aerial spraying where feasible and permission is granted by year 5, estimated at ~ 2,158 ac
	Treat giant cane stands along the river	TBD	TBD
	Debris left from spraying effort burned	None burned to date, approximately 6,000 ac scheduled to burn before September 2009	Burn debris where landowner permission is granted by year, estimated at ~15,000 ac

Issue	Indicator	Current Value	Target Value
Biological diversity improvements (Continued)	Riparian acres revegetated following debris burning (planted or volunteer)	None yet as no burning has taken place yet	Implement revegetation practices on previously burned riparian areas with landowner permission, estimated at ~15,000 ac
	Re-populate aquatic communities		Restore or improve populations of some historical species present and healthy by 2022, depending on water quality improvements
	Grazing management plans or WQMPs established and implemented on lands in watershed		Implement 20 WQMPs by 2010, 60 by 2013, and 120 by 2017 (cumulative)
	Increased aquatic life and habitat scores for the 7 reaches previously sampled	See Table 6 for current scores	2 point IBI, habitat and benthic score increases in all reaches by year 10 (see Table 7)
Dissolved oxygen impairment	DO 24-hr average (5.0 mg/L) and minimum single sample (3.0 mg/L) standard	DO regularly exceeds the 3.0 mg/L standard at Pecos and Coyanosa	Increase DO levels so that designated uses and water quality standards are supported for the entire river by year 10
Water quantity	Increase average annual flow at Girvin by 25%	Long-term average of 23,511AF/yr	Increase annual average flow to 29,388 by year 10
	Reduce irrigation water delivery losses	Average irrigation losses from Red Bluff to Irrigation Districts is ~52%	By year 10, reduce transmission losses to 30%
	Conduct water audits on irrigation district canals to determine water losses; then implement control measures to minimize these losses		Complete water audits by year 5 Reduce measured water loss by 25% by year 10
Education and outreach effectiveness	Conduct surveys across the watershed to determine effectiveness of campaign		Conduct surveys at the end of years 2, 5, and 10 to determine level of participant knowledge regarding watershed issues
	Lone Star Healthy Streams Presentations on grazing management		4 workshops conducted in the watershed by year 6
	Texas Watershed Stewards watershed management workshop		2 workshops conducted in the watershed by year 3
	Nutrient management workshop delivery		3 workshops delivered within the first 10 years of implementation

Issue	Indicator	Current Value	Target Value
	Other workshops delivered as appropriate		Workshops include irrigation, wildlife mgmt, and others
Biological saltcedar control	Established saltcedar leaf beetle populations (Extension and landowners)	2 populations have been established at Imperial and Pecos	70 beetle populations across the watershed that are thriving and defoliating saltcedar
Oil and gas production concern management	Plugging wells that are a concern and addressing illegal brine disposal		Address all top priority problem areas in the watershed
Nutrient concerns	Develop WQMPs that include nutrient management guidelines		Cumulative total of 120 WQMPs developed by year 10
Upland brush control	Areas identified as degraded ecosystems thru an appropriate property assessment		Treat 25% of identified degraded areas
Golden algae	# of dead fish	See Table 21	Reduce # of fish kills



Saltcedar regrowth following chemical treatments

Monitoring

Continued and increased monitoring throughout the watershed will be used to evaluate changes in water quality, water quantity, and biological diversity as a result of implementing the WPP. Currently, there is a network of monitoring in place that covers the watershed and is used to evaluate water quality and quantity in the watershed. This currently active network includes continuously and routinely monitored sites (water quality) operated by TCEQ, real-time water depth and flow volumes operated by USGS, and periodic assessments of aquatic biology and habitat conducted by TCEQ, TPWD, USGS, and others. Increasing the extent of this network will be beneficial to evaluating the impacts of implementing the WPP, but will be quite costly.

Water Quality

The Texas CRP is a state fee-funded program for water quality monitoring, assessment, and public outreach. CRP is a collaboration of 15 partner agencies and the TCEQ. CRP provides the opportunity to approach water quality issues within a watershed or river basin locally and regionally through coordinated efforts among diverse organizations. For the Pecos River watershed, USIBWC is the partner agency that administers CRP. The 'Coordinated Monitoring Schedule' (http://cms.lcra.org) indicates that there are 10 active sites (Figure 11, Table 27) that are routinely monitored through CRP; however, four of these sites are also equipped with a real-time CWQM station (as discussed below). All 10 of these sites are monitored for field parameters (DO, pH, conductivity, and temperature), bacteria levels, and conventional parameters such as nutrients. Flow measurements are also taken at monitoring stations in the river and organic water and sediment samples are collected at the Red Bluff Reservoir stations.

Additionally, the TCEQ continuously monitors water quality parameters in real-time in selected watersheds throughout Texas. "Real-time" means that the data collected in the field is reported almost simultaneously to the TCEQ, so the agency knows almost immediately about changes in surface water quality in critical watersheds. The CWQM network in the Pecos River watershed consists of five stations; four of these are on the main stem of the Pecos and the other is on Independence Creek (Table 27). Each of these stations records data on temperature, pH, DO, and conductivity of the water.

The water quality monitoring program used to evaluate the effects of this WPP will be the coordinated monitoring conducted under the auspices of CRP in the Pecos River watershed combined with the CWQM Network in the Pecos River watershed. Efforts will be made through the activities of implementing this WPP to bolster the current monitoring network. Initially, the addition of another CWQM station near Girvin will be sought to provide critical information about the quality of the water at one of the most highly saline locations in Texas. This addition would make it much easier to document water quality and quantity improvements at that point in the river. Funding for three other CWQM sites to be located upstream of Red Bluff Reservoir in New Mexico, near Orla and upstream of the US 90 bridge near Pandale will also be sought.

Table 27. Currently active water quality sampling sites in the watershed

Segment	Location	Frequency/ Yr	Parameters Monitored	Station Number
2312	Red Bluff Reservoir – ½ mi. south of TX/NM border	Semiannual	pH, temp, DO, conductivity, nutrients, bacteria, organics in water and sediment, metals in sediment	13269
2312	Red Bluff Reservoir – above dam north of Orla, TX	Semiannual	pH, temp, DO, conductivity, nutrients, bacteria, organics in water and sediment, metals in sediment	13267
2311	Pecos River @ FM 652 bridge NE of Orla, TX	Quarterly	pH, temp, DO, conductivity, flow	13265
2311	Pecos River near Pecos, TX	Continuous	pH, temp, DO, conductivity	13261/C710
2311	Pecos River @ FM 1776 near Coyanosa, TX	Quarterly/ Continuous	pH, temp, DO, conductivity, quarterly: nutrients, bacteria, flow, metals	13260/C709
2311	Pecos River @ US 67 NE of Girvin, TX	Quarterly	pH, temp, DO, conductivity, flow, nutrients, bacteria, metals	13257
2311	Pecos River near Sheffield, TX above US 290	Quarterly/ Continuous	pH, temp, DO, conductivity, flow quarterly	13249/C735
2310A	Independence Creek near Chandler Ranch	Quarterly/ Continuous	pH, temp, DO, conductivity, quarterly: nutrients, bacteria, flow	13109/C764
2310	Pecos River 2.3 mi. upstream of Crockett, Terrell, Val Verde Co. line convergence	Quarterly/ Continuous	pH, temp, DO, conductivity, quarterly: nutrients, bacteria, flow	18801/C729
2310	Pecos River 0.7 mi. downstream of US 90	Semiannual	pH, temp, DO, conductivity, flow, nutrients, bacteria	16379

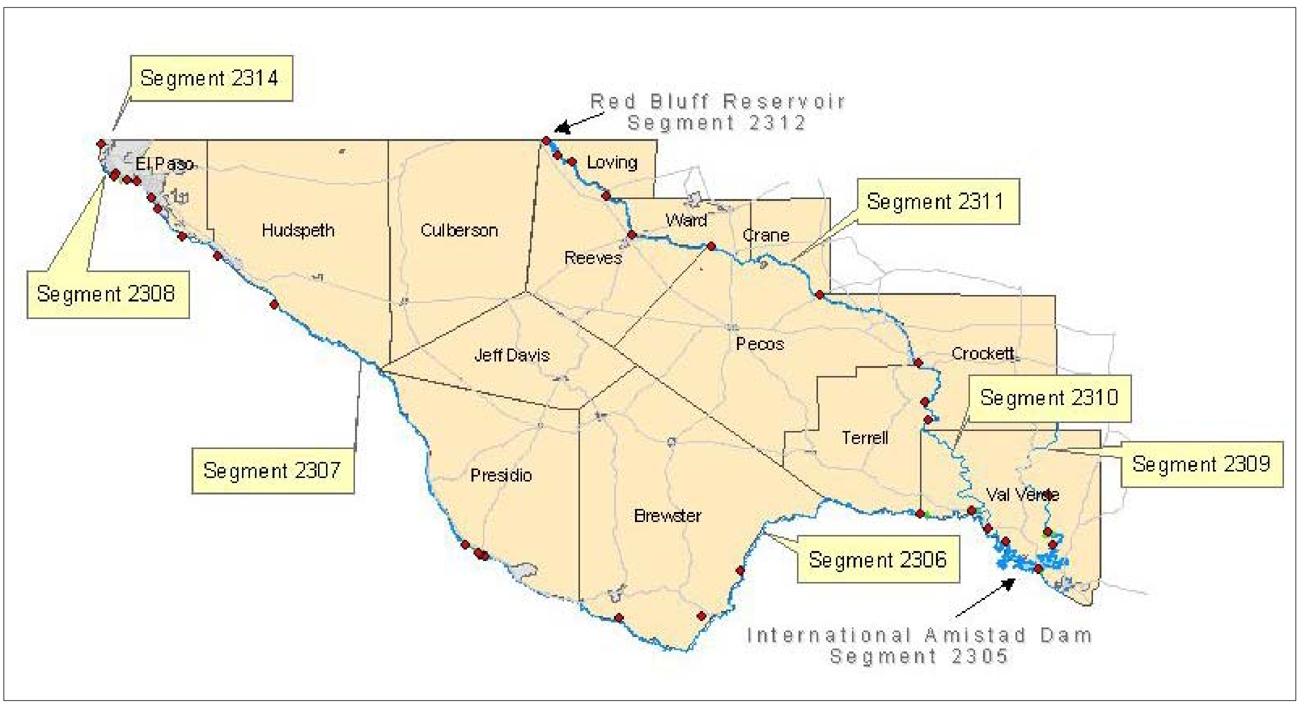


Figure 11. CRP sampling sites in the Pecos River and Rio Grande watersheds

Biological Diversity

Evaluating the effectiveness of habitat management and restoration is an essential element of WPP implementation. Saltcedar control efforts to date have proven to be successful, but the potential for regrowth will always be present unless the seed source in Texas and New Mexico is kept under control. Therefore, a monitoring program will need to be in place to identify and address problem areas in a timely fashion. The same need applies to areas where giant cane is known to be a problem. Conjointly, any stream bank revegetation efforts will need to be evaluated periodically to monitor the health of the re-established vegetation and to ensure that saltcedar and giant cane are kept under control. In 2005, AgriLife Extension established a number of riparian transects located adjacent to segment 2311 of the river and has gathered baseline data pertaining to saltcedar populations and riparian vegetation. In the future, these transects will be used to evaluate changes in the riparian vegetative community as a result of restoration efforts. Technical and financial assistance will be needed to conduct these periodic transect evaluations.

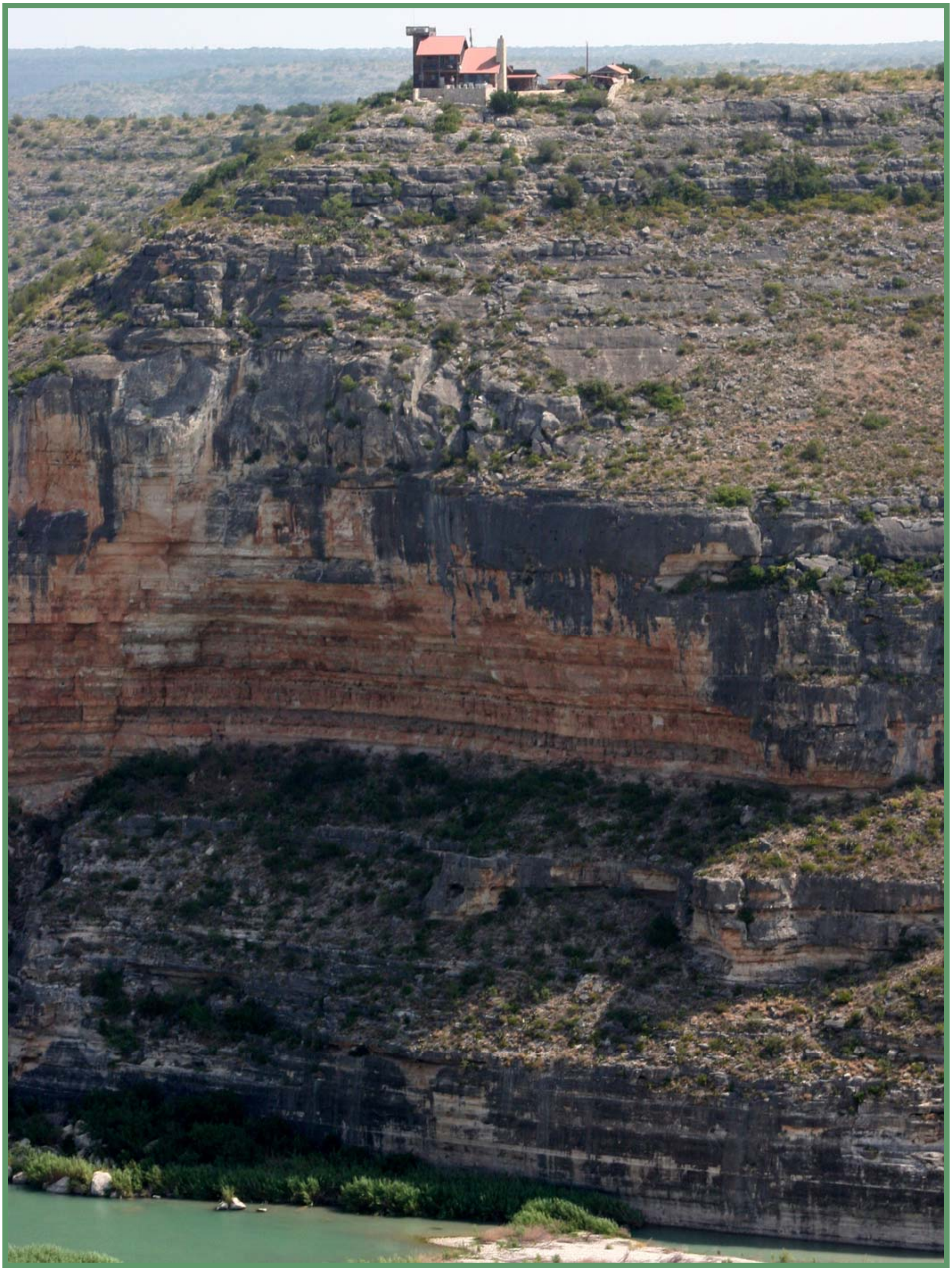
Follow-up monitoring will be needed at the seven sites where TCEQ and USGS conducted the most recent survey (2006) of aquatic life and habitat as a part of developing this plan (TSSWCB Project #04-11). They evaluated each site on the main channel of the river and gathered baseline data on benthic organisms, fish, and physical habitat from which to assess future changes resulting from management. Changes in aquatic organism populations and aquatic habitat generally progress at a slow pace and will require long-term evaluation. The implementation schedule presented in an earlier section of the WPP recommends that aquatic species restocking not take place until after other management measures have been implemented across the watershed and have had an opportunity to improve water quality in the river. As a result, it is recommended that aquatic life and habitat surveys be conducted at 3-5 year intervals to monitor the health of the watershed and the river's inhabitants. TCEQ and USGS will conduct future assessments as well; but financial assistance will be needed. Results from these surveys and other monitoring data will serve as indicator of overall watershed health.

Water Quantity

Increasing the flow in the Pecos is another objective of WPP implementation; therefore, the continuation of surface flow monitoring is important for providing data that will be analyzed for changes in flow trends. There are currently eight gaging stations in the Pecos River watershed in Texas with five of them being on the main stem of the river (Table 28). These stations continually monitor gage height, and half of them monitor flow volumes on 15-minute intervals, and can also be viewed in real-time via the Internet. Data from these stations has been evaluated for 1996-2006 to provide pre- and post-saltcedar treatment and pre-WPP implementation baseline flow figures. Baseflow will be computed in this manner on a yearly basis throughout the implementation phase and into the long-term monitoring effort.

Table 28. USGS gaging stations in the Pecos River watershed

USGS Station Number	Location	Stage Recorded?	Flow Recorded?
08412500	Pecos River near Orla	Yes	Yes
08420500	Pecos River at Pecos	Yes	No
08427000	Griffin Springs at Toyahvale	Yes	Yes
08433000	Barrilla Draw near Saragosa	Yes	Yes
08437710	Pecos River at FM 1776 near Grandfalls	Yes	No
08446500	Pecos River near Girvin	Yes	Yes
08447020	Independence Creek near Sheffield	Yes	Yes
08447300	Pecos River at Brotherton Ranch near Pandale	Yes	No



Pecos River in Val Verde County

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Appendices

Appendix A: **Pecos River Basin Assessment Project Reports**

Appendix B: **Online Survey Results**

Appendix C: **County maps showing areas needing saltcedar treatment**

Appendix D: **Potential Funding Sources**

Appendix E: **Texas Railroad Commission Well Plugging Priority Sheet**

Appendix F: **Contact Information for Regional Agency Personnel**

Appendix A: Pecos River Basin Assessment Project Reports

These reports constitute TSSWCB project 04-11 subtask deliverables and are considered critical appendices to the WPP itself.

Aquatic Life and Habitat Inventory Assessment

Citation: Belzer W. 2007b. *Aquatic life and habitat inventory assessment.* Texas Water Resources Institute. TR-305.

Link: http://twri.tamu.edu/reports/2007/tr305.pdf

Geographical Information System Coverage for Characterization of the Pecos River Basin.

Citation: Villalobos J, Sheng Z, Hart C. 2007. *Geographical Information System Coverage for Characterization of the Pecos River Basin.* Texas Water Resources Institute. TR-300.

Link: http://twri.tamu.edu/reports/2007/tr300.pdf

Identifying and Characterizing the Volume and Quantity of Tributaries and Springs.

Citation: Belzer W, Hart C. 2007a. *Identifying and characterizing the volume and quality of tributaries and springs.* Texas Water Resources Institute. TR-302.

Link: http://twri.tamu.edu/reports/2007/tr302.pdf

Influence of Tributaries on Salinity of Amistad International Reservoir.

Citation: Miyamoto S, Yuan F, Anand S. 2006. *Influence of Tributaries on Salinity of Amistad International Reservoir.* Texas Water Resources Institute. TR-292.

Link: http://twri.tamu.edu/reports/2006/tr292.pdf

Reconnaissance Survey of Salt Sources and Loading Into the Pecos River.

Citation: Miyamoto S, Yuan F, Anand S. 2005. *Reconnaissance Survey of Salt Sources and Loading Into the Pecos River.* Texas Water Resources Institute. TR-291.

Link: http://twri.tamu.edu/reports/2006/tr291.pdf

The Fate of the Water Salvaged through Saltcedar Control in the Pecos River: Surface Water and Groundwater Interaction.

Citation: Sheng Z, McDonald AK, Hart C, Hatler W, Villalobos J. 2007. *The Fate of the Water Salvaged through Saltcedar Control in the Pecos River: Surface Water and Groundwater Interaction.* Texas Water Resources Institute. TR-304.

Link: http://twri.tamu.edu/reports/2007/tr304.pdf

The Influence of Human Activities on the Water of the Pecos Basin of Texas: A Brief Overview.

Citation: Jensen R, Hatler W, Mecke M, Hart C. 2006. *The Influence of Human Activities on the Water of the Pecos Basin of Texas: A Brief Overview*. Special Report-2006-03. Texas Water Resources Institute publication.

Link: http://twri.tamu.edu/reports/2006/sr2006-03.pdf

Use of Satellite Remote Sensing in Monitoring Saltcedar Control along the Lower Pecos River, USA

Citation: Nagihara S, Hart CR. 2007. *Use of Satellite Remote Sensing in Monitoring Saltcedar Control along the Lower Pecos River, USA.* Texas Water Resources Institute. TR-306.

Link: http://twri.tamu.edu/reports/2007/tr306.pdf

Water Balance, Salt Loading, and Salinity Control Options of Red Bluff Reservoir, Texas

Citation: Miyamoto S, Yuan F, Anand S. 2007. *Water Balance, Salt Loading, and Salinity Control Options of Red Bluff Reservoir, Texas.* Texas Water Resources Institute. TR-298.

Link: http://twri.tamu.edu/reports/2007/tr298.pdf

Appendix B: Online Survey Results

- What county within the Pecos River Basin do you own or operate land, or visit for recreational or other purposes?

Crane	9	(17%)
Crockett	6	(11.3%)
Culberson	3	(5.7%)
Loving	7	(13.2%)
Pecos	16	(30.2%)
Reeves	6	(11.3%)
Terrell	6	(11.3%)
Upton	1	(1.9%)
Ward	16	(30.2%)
Val Verde	9	(17%)
None	1	(1.9%)

Percentages out of 53 total surveys.

- How would you describe your association with the Pecos River Basin?

Farmer	8	(15.1%)
Rancher	21	(39.6%)
Recreational user	13	(24.5%)
Landowner	39	(73.6%)
Live in City/Urban area within Pecos River basin	5	(9.4%)
Work for Federal/State Agency	8	(15.1%)
County Official	2	(3.8%)
Other (Aquaculture)	1	(1.9%)

Percentages out of 53 total surveys.

- To what extent are West Texas farming practices affecting the stream flows of the Pecos River? (1 Little Effect, 5 Great Effect)

1 - Little Effect	7	(13.2%)
2	6	(11.3%)
3	6	(11.3%)
4	15	(28.3%)
5 - Great Effect	12	(22.6%)
6 - No Opinion	7	(13.2%)
Average (3.413)		

Percentages out of 53 queried responses.

- To what extent are West Texas farming practices affecting water quality within the Pecos River basin? (1 Little Effect, 5 Great Effect)

Response	Count	Percentage
1 - Little Effect	13	(24.5%)
2	8	(15.1%)
3	4	(7.5%)
4	13	(24.5%)
5 - Great Effect	9	(17%)
6 - No Opinion	6	(11.3%)
Average (2.9362)		

Percentages out of 53 queried responses.

- To what extent are West Texas rangeland conditions affecting the stream flows of the Pecos River? (1 Little Effect, 5 Great Effect)

Response	Count	Percentage
1 - Little Effect	11	(20.8%)
2	5	(9.4%)
3	8	(15.1%)
4	13	(24.5%)
5 - Great Effect	10	(18.9%)
6 - No Opinion	6	(11.3%)
Average (3.1277)		

Percentages out of 53 queried responses.

- To what extent are West Texas rangeland conditions affecting water quality within the Pecos River basin? (1 Little Effect, 5 Great Effect)

Response	Count	Percentage
1 - Little Effect	14	(26.4%)
2	5	(9.4%)
3	10	(18.9%)
4	9	(17%)
5 - Great Effect	10	(18.9%)
6 - No Opinion	5	(9.4%)
Average (2.9167)		

Percentages out of 53 queried responses.

- To what extent are non-native invasive species such as saltcedar affecting the stream flows of the Pecos River? (1 Little Effect, 5 Great Effect)

1 - Little Effect	2	(3.8%)
2	1	(1.9%)
3	3	(5.7%)
4	3	(5.7%)
5 - Great Effect	43	(81.1%)
6 - No Opinion	1	(1.9%)
Average (4.6154)		

Percentages out of 53 queried responses.

- To what extent are non-native invasive species such as saltcedar affecting water quality within the Pecos River basin? (1 Little Effect, 5 Great Effect)

1 - Little Effect	1	(1.9%)
2	2	(3.8%)
3	3	(5.7%)
4	6	(11.3%)
5 - Great Effect	38	(71.7%)
6 - No Opinion	3	(5.7%)
Average (4.56)		

Percentages out of 53 queried responses.

- Does the general public benefit from the use of Public funds to control saltcedar along the Pecos River? (1 No Benefit, 5 Much Benefit)

1 - No Benefit	2	(3.8%)
2	2	(3.8%)
3	4	(7.5%)
4	5	(9.4%)
5 - Much Benefit	39	(73.6%)
6 - No Opinion	1	(1.9%)
Average (4.4808)		

Percentages out of 53 queried responses.

- Rank the following in order of being the most likely source of salt accumulating in Amistad Reservior.

Natural salt deposits		
1 - Most Likely	27	(50.9%)
2	4	(7.5%)
3	6	(11.3%)
4	5	(9.4%)
5 - Least Likely	11	(20.8%)
Average (2.4151)		

Effluent from municipalities		
1 - Most Likely	2	(3.8%)
2	6	(11.3%)
3	9	(17%)
4	17	(32.1%)
5 - Least Likely	19	(35.8%)
Average (3.8491)		

Production agriculture		
1 - Most Likely	2	(3.8%)
2	10	(18.9%)
3	17	(32.1%)
4	11	(20.8%)
5 - Least Likely	13	(24.5%)
Average (3.434)		

Oil field activities		
1 - Most Likely	3	(5.7%)
2	13	(24.5%)
3	16	(30.2%)
4	16	(30.2%)
5 - Least Likely	5	(9.4%)
Average (3.1321)		

Tamarix spp. (Saltcedar)		
1 - Most Likely	19	(35.8%)
2	20	(37.7%)
3	5	(9.4%)
4	4	(7.5%)
5 - Least Likely	5	(9.4%)
Average (2.1698)		

• Rank the following uses of Pecos River water based on your perception of its value.

Livestock		
1 - Highest Value	9	(17%)
2	12	(22.6%)
3	7	(13.2%)
4	9	(17%)
5	11	(20.8%)
6 - Lowest Value	5	(9.4%)
Average (3.3019)		

Municipal uses		
1 - Highest Value	1	(1.9%)
2	5	(9.4%)
3	5	(9.4%)
4	7	(13.2%)
5	14	(26.4%)
6 - Lowest Value	21	(39.6%)
Average (4.717)		

Ecological preservation		
1 - Highest Value	20	(37.7%)
2	6	(11.3%)
3	8	(15.1%)
4	10	(18.9%)
5	4	(7.5%)
6 - Lowest Value	5	(9.4%)
Average (2.7547)		

Farming/Irrigation		
1 - Highest Value	16	(30.2%)
2	12	(22.6%)
3	10	(18.9%)
4	8	(15.1%)
5	3	(5.7%)
6 - Lowest Value	4	(7.5%)
Average (2.6604)		

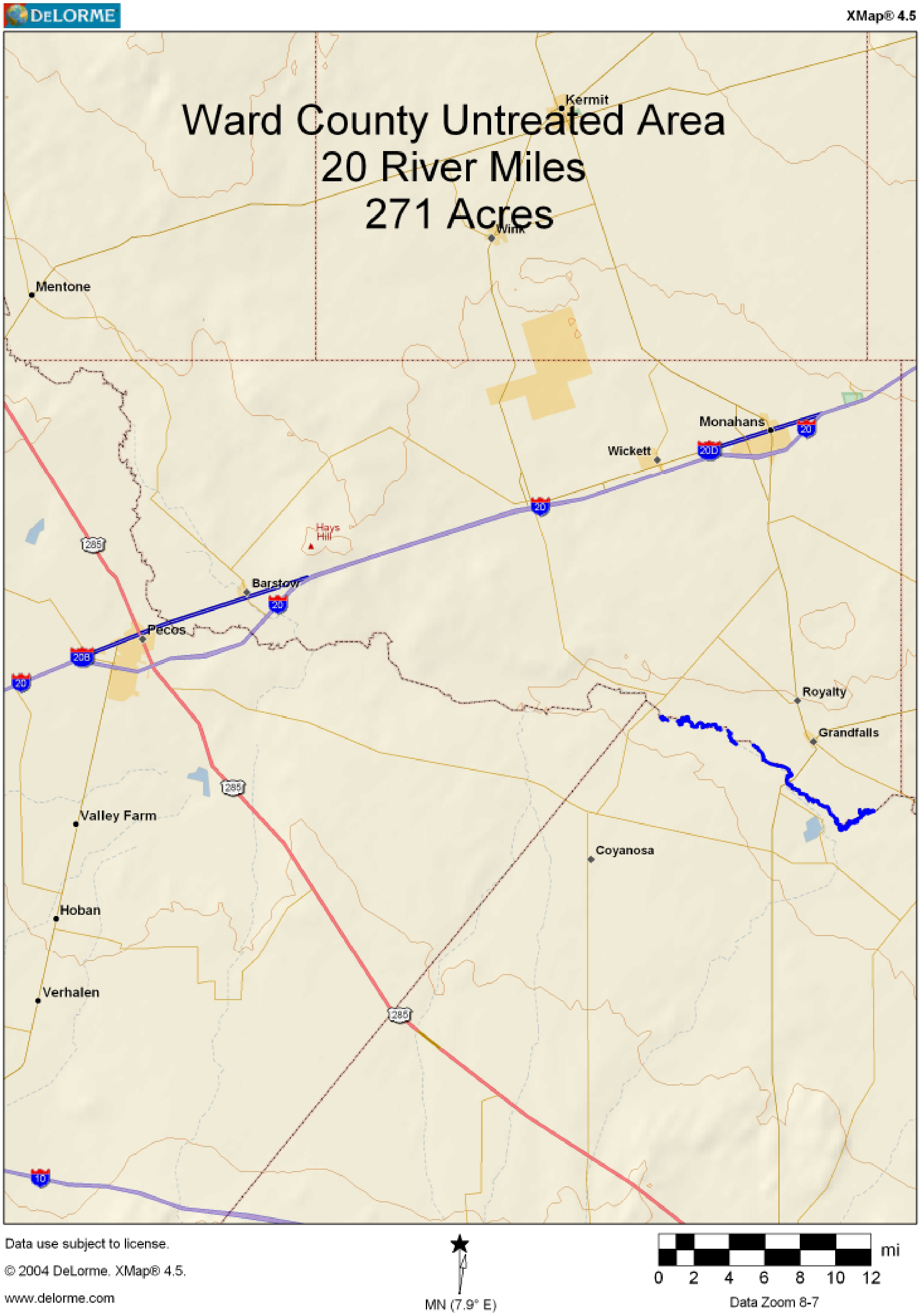
Recreational uses		
1 - Highest Value	5	(9.4%)
2	5	(9.4%)
3	16	(30.2%)

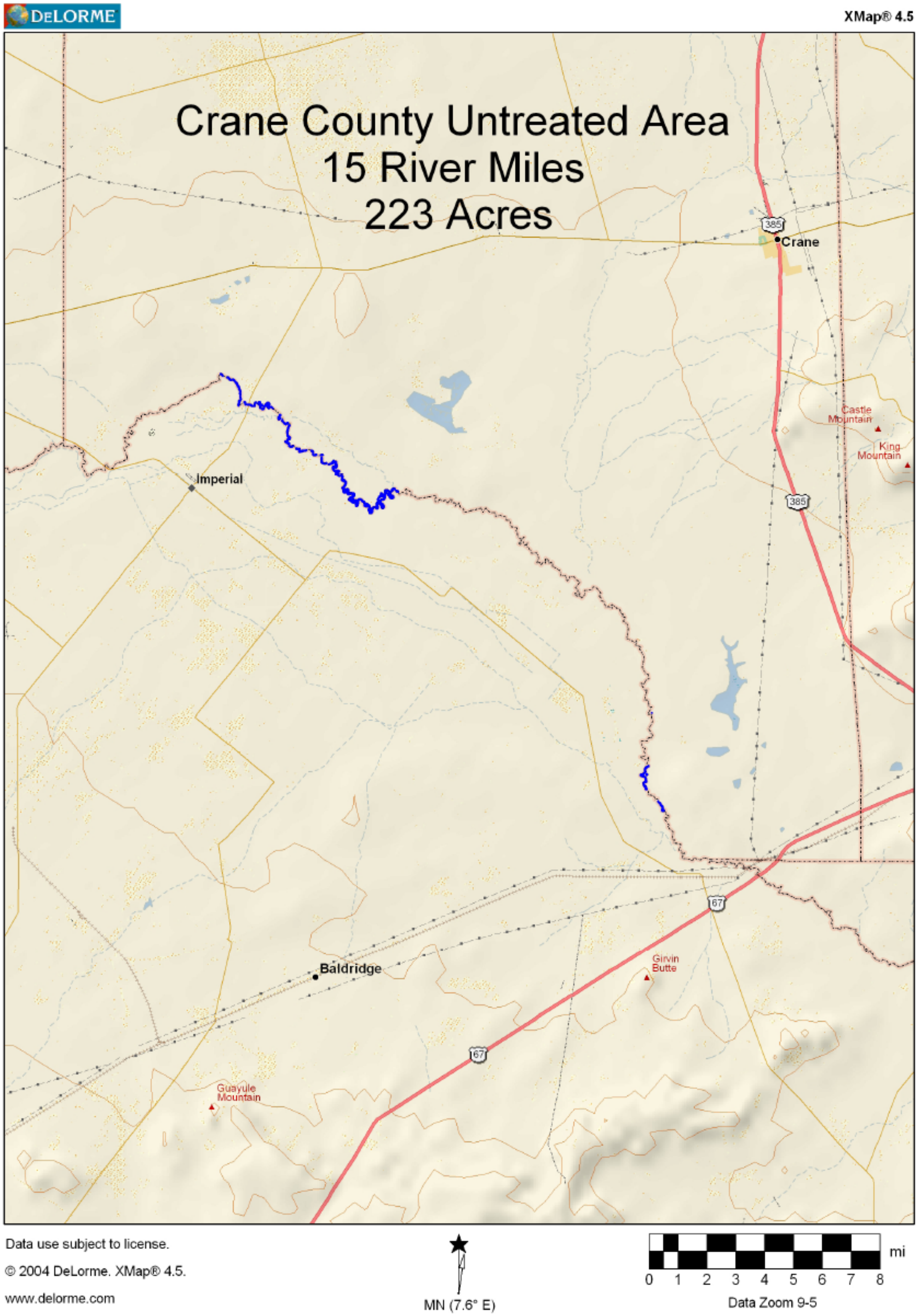
4	10	(18.9%)
5	9	(17%)
6 - Lowest Value	8	(15.1%)
Average (3.6981)		

Aesthetics/Quality of life

1 - Highest Value	2	(3.8%)
2	13	(24.5%)
3	7	(13.2%)
4	9	(17%)
5	12	(22.6%)
6 - Lowest Value	10	(18.9%)
Average (3.8679)		

Appendix C:
County Maps Showing Areas Needing Saltcedar Treatment

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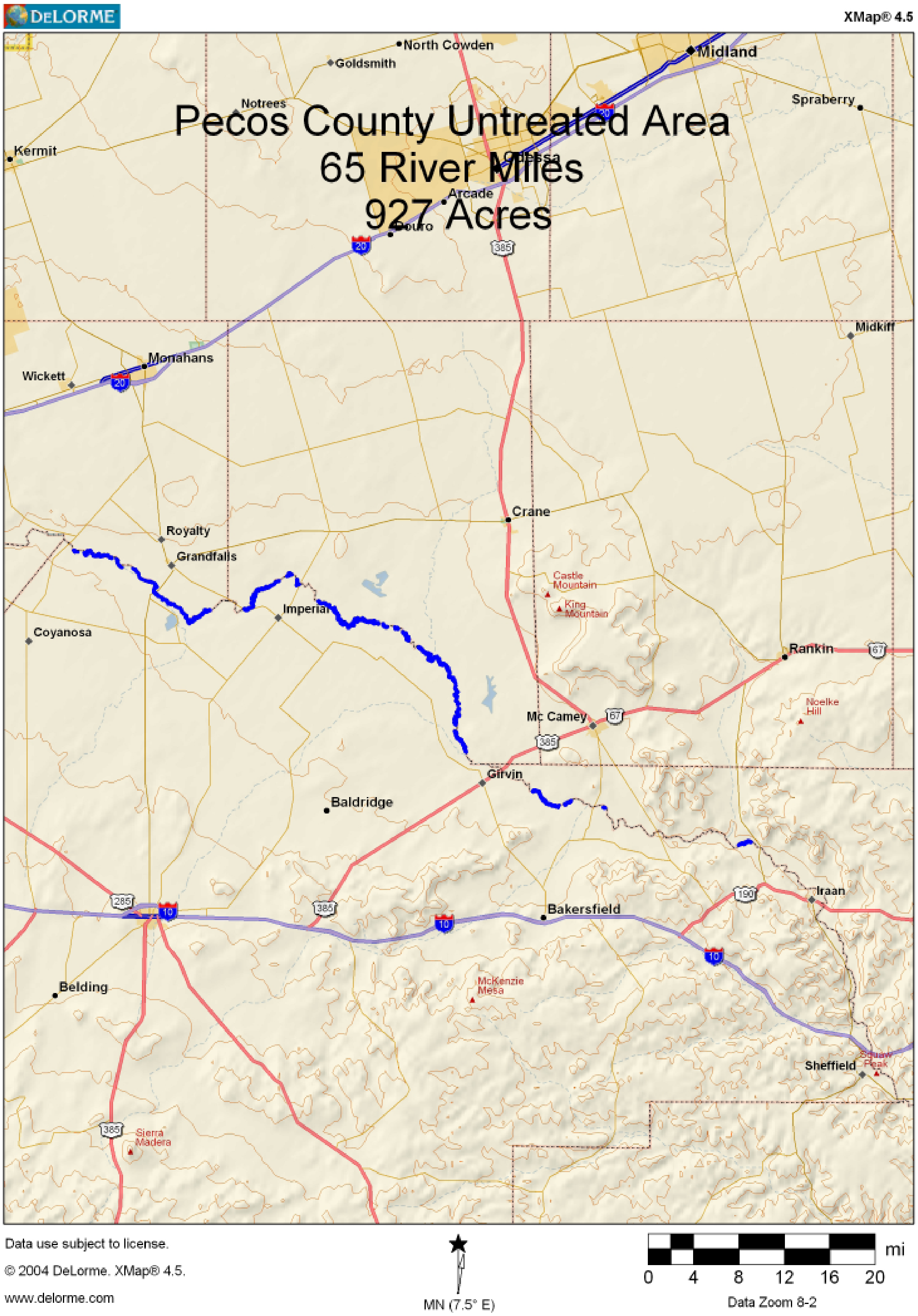
XMap® 4.5
Crane County Untreated Area
15 River Miles
223 Acres
Crane
385
Imperial
Castle Mountain
King Mountain
67
Baldridge
Girvin Butte
Guayule Mountain
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
MN (7.6° E)
0 1 2 3 4 5 6 7 8 mi
Data Zoom 9-5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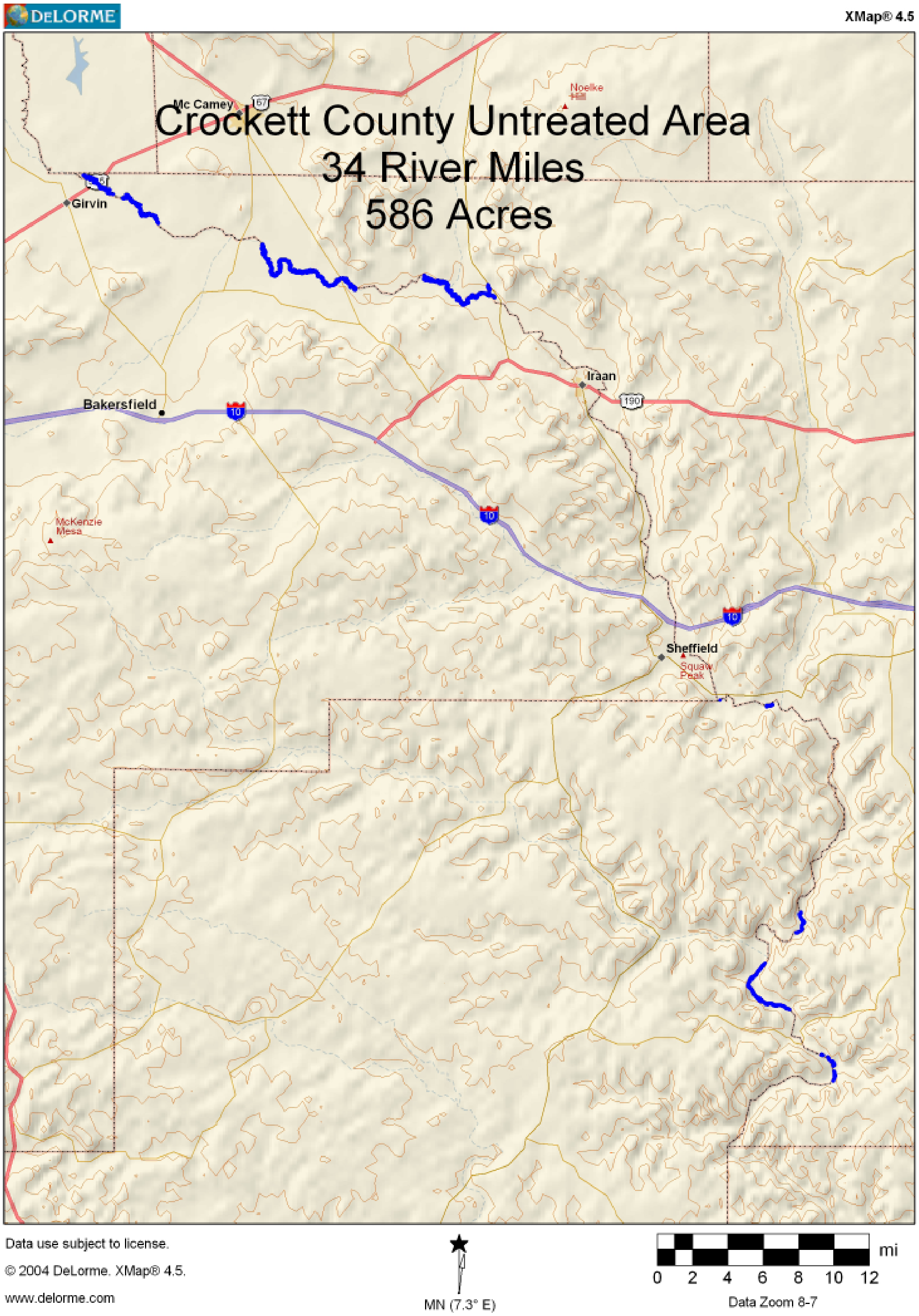
XMap® 4.5
Pecos County Untreated Area
65 River Miles
927 Acres
North Cowden
Goldsmith
Midland
Notrees
Spraberry
Kermit
Odessa
Arcade
Douro
Midkiff
Monahans
Wickett
Crane
Royalty
Grandfalls
Castle Mountain
King Mountain
Imperial
Coyanosa
Rankin
Noelke Hill
Mc Camey
Girvin
Baldridge
Iraan
Bakersfield
Belding
McKenzie Mesa
Sheffield
Square Peak
Sierra Madera
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
MN (7.5° E)
0 4 8 12 16 20
mi
Data Zoom 8-2


DeLORME
XMap® 4.5
Crockett County Untreated Area
34 River Miles
586 Acres
Mc Camey
Noelke
Girvin
Iraan
Bakersfield
McKenzie Mesa
Sheffield
Squaw Peak
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
MN (7.3° E)
mi
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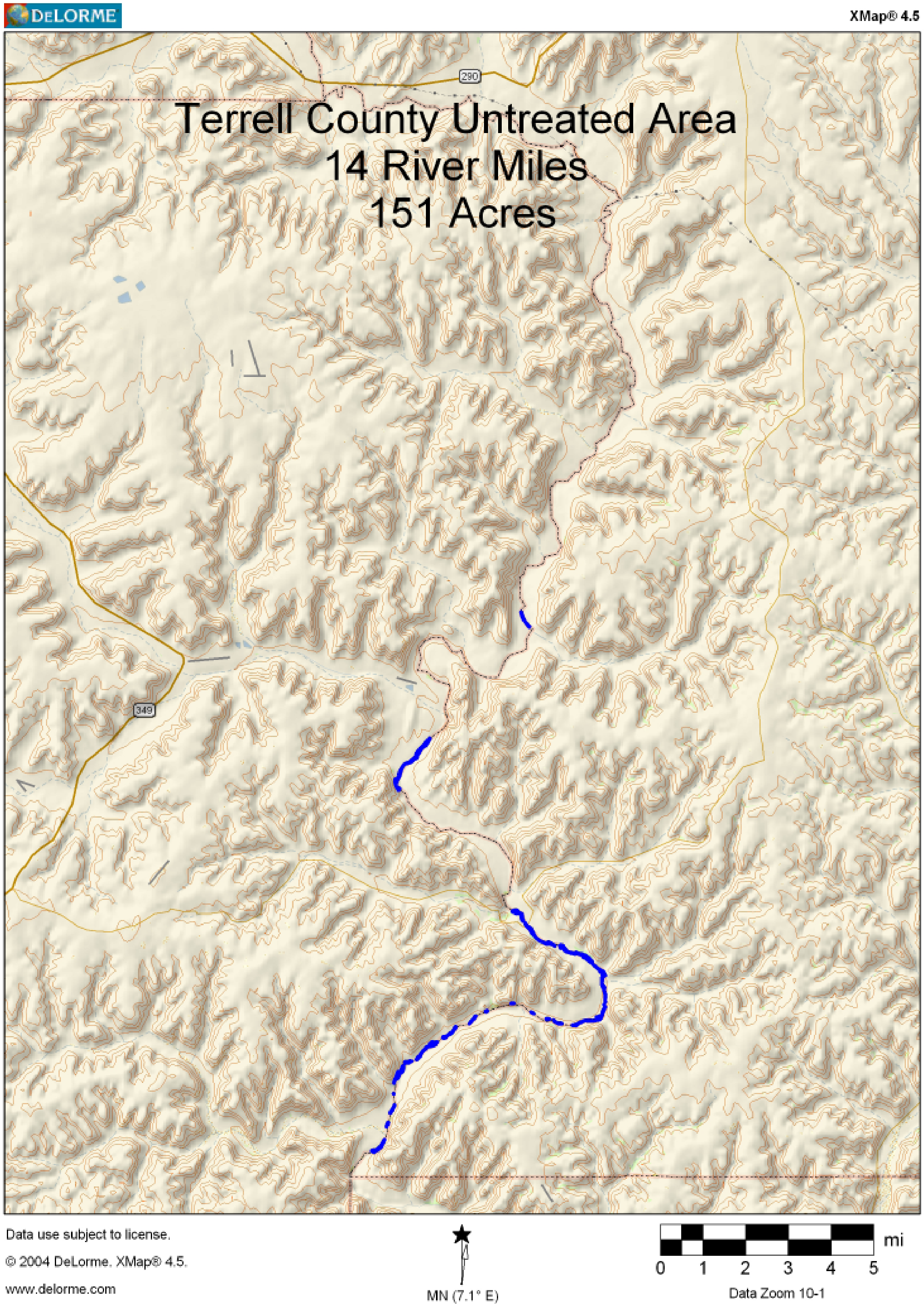
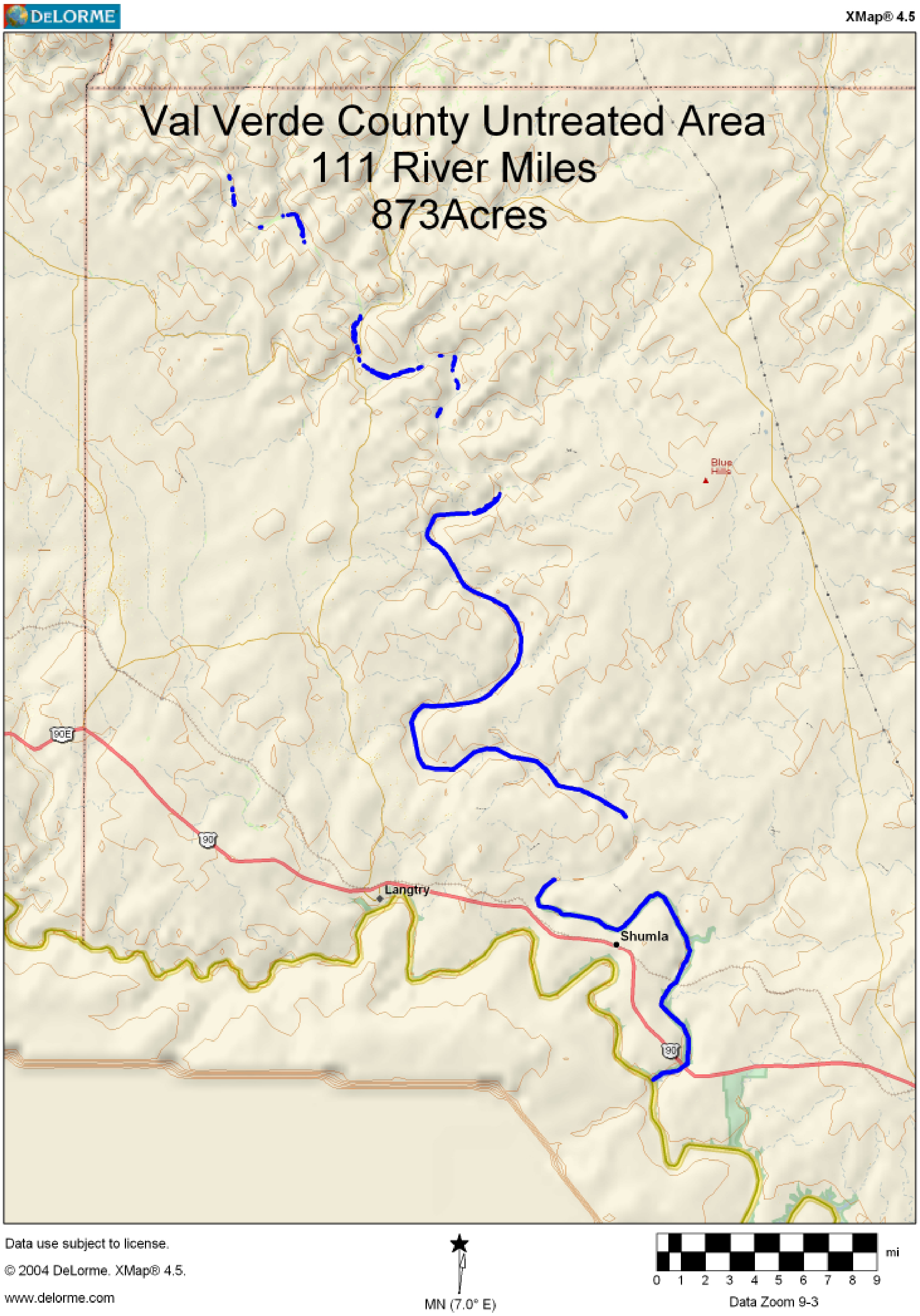
Data Zoom 8-7


DELORME
XMap® 4.5
290
Terrell County Untreated Area
14 River Miles
151 Acres
349
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
MN (7.1° E)
0 1 2 3 4 5
mi
Data Zoom 10-1


DeLORME
XMap® 4.5
Val Verde County Untreated Area
111 River Miles
873Acres
Blue Hills
90E
90
Langtry
Shumla
90
Data use subject to license.
© 2004 DeLorme. XMap® 4.5.
www.delorme.com
MN (7.0° E)
0 1 2 3 4 5 6 7 8 9
mi
Data Zoom 9-3

Appendix D: Potential Funding Sources

Federal Funding Sources

Aquatic Ecosystem Restoration

Entity: U.S. Army Corps of Engineers
Work under this authority may carry out aquatic ecosystem restoration projects that will improve the quality of the environment, are in the public interest, and are cost-effective.

Estimated FY 2008 Funding: $29.5 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=104

Conservation Reserve Program

Entity: USDA-Farm Service Agency
The Conservation Reserve Program is a voluntary program for agricultural landowners. Through CRP, you can receive annual rental payments and financial assistance to establish long-term, resource conserving covers on eligible farmland.

Estimated FY 2008 Funding: $1.9 billion
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=18

Conservation Security Program

Entity: USDA-Natural Resources Conservation Service
The Conservation Security Program (CSP) is a voluntary conservation program that supports ongoing stewardship of private lands by providing payment for maintaining and enhancing natural resources. CSP identifies and rewards those farmers and ranchers who are meeting the highest standards of conservation and environmental management on their operations.

Estimated FY 2008 Funding: $313.2 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=72

Drinking Water State Revolving Fund

Entity: U.S. Environmental Protection Agency
EPA awards grants to states to capitalize their Drinking Water State Revolving Fund (DWSRF) programs. States use a portion of their capitalization grants to set up a revolving fund from which loans are provided to eligible public water utilities (publicly and privately

owned) to finance the costs of infrastructure projects. States rank projects and offer loans to utilities based on a priority ranking system. Priority is given to eligible projects that (1) address the most serious risk to human health; (2) are necessary to ensure compliance with the requirements of the Safe Drinking Water Act; and (3) assist systems most in need, on a per household basis, according to state-determined affordability criteria. States may also use up to 31 percent of their capitalization grants to fund set-aside activities that help to prevent contamination problems of surface water and groundwater drinking water supplies, as well as enhance water system management, through source water protection, capacity development, and operator certification programs.

In Texas, these funds are administered by the Texas Water Development Board.

Estimated FY 2008 Funding: $829 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=6

Environmental Quality Incentives Program

Entity: USDA-Natural Resources Conservation Service
The Environmental Quality Incentives Program (EQIP) was established to provide a voluntary conservation program for farmers and ranchers to address significant natural resource needs and objectives. EQIP offers contracts with a minimum term that ends one year after the implementation of the last scheduled practices and a maximum term of ten years. These contracts provide incentive payments and financial assistance to implement conservation practices. Persons who are engaged in livestock or agricultural production on eligible land may participate in the EQIP program. EQIP activities are carried out according to a plan of operations developed in conjunction with the producer that identifies the appropriate conservation practice or practices to address the resource concerns. The practices are subject to NRCS technical standards adapted for local conditions. The local conservation district approves the plan. The activities and operations of this program are contingent on provisions set forth in the 2008 Farm Bill and are dependent upon future Congressional appropriation and subject to change.

Estimated FY 2008 Funding: $758 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=27

Five-Star Restoration Program

Entity: U.S. Environmental Protection Agency
The EPA supports the Five-Star Restoration Program by providing funds to the National Fish and Wildlife Foundation and its partners, the National Association of Counties, NOAA's Community-based Restoration Program and the Wildlife Habitat Council. These groups then make subgrants to support community-based wetland and riparian restoration projects. Competitive projects will have a strong on-the-ground habitat restoration component that provides long-term ecological, educational, and/or socioeconomic benefits

to the people and their community. Preference will be given to projects that are part of a larger watershed or community stewardship effort and include a description of long-term management activities. Projects must involve contributions from multiple and diverse partners, including citizen volunteer organizations, corporations, private landowners, local conservation organizations, youth groups, charitable foundations, and other federal, state, and tribal agencies and local governments. Each project would ideally involve at least five partners who are expected to contribute funding, land, technical assistance, workforce support, or other in-kind services that are equivalent to the federal contribution.

Estimated FY 2008 Funding: $400,000
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=29

Landowner Incentive Program

Entity: U.S. Fish and Wildlife Service
The Landowner Incentive Program (LIP) grant program provides competitive matching grants to states, territories, and the District of Columbia to establish or supplement landowner incentive programs. These programs provide technical and financial assistance to private landowners for projects that protect and restore habitats of listed species or species determined to be at-risk. LIP projects will likely involve activities such as the restoration of marginal farmlands to wetlands, the removal of exotic plants to restore natural prairies, a change in grazing practices and fencing to enhance important riparian habitats, instream structural improvements to benefit aquatic species, road closures to protect habitats and reduce harassment of wildlife, and acquisition of conservation easements. Although not directly eligible for these grants, third parties such as nonprofit organizations may benefit from these funds by working directly with their states to see if either grants or partnering opportunities are available.

Estimated FY 2008 Funding: not funded
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=78

National Integrated Water Quality Program (NIWQP)

Entity: USDA-Cooperative State Research, Education & Extension Service
The National Integrated Water Quality Program (NIWQP) provides funding for research, education, and extension projects aimed at improving water quality in agricultural and rural watersheds. The NIWQP has identified eight "themes" that are being promoted in research, education, and extension. The eight themes are (1) animal manure and waste management (2) drinking water and human health (3) environmental restoration (4) nutrient and pesticide management (5) pollution assessment and prevention (6) watershed management (7) water conservation and agricultural water management (8) water policy and economics. Awards are made in four program areas - National Facilitation Projects, Regional Coordination Projects, Extension Education Projects, and Integrated Research, Education and Extension Projects. Please note that funding is only available to universities.

Estimated FY 2008 Funding: $12.6 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=61

Nonpoint Source Implementation Grants (319 Program)

Entity: U.S. Environmental Protection Agency
Through its CWA §319(h) Nonpoint Source Grant Program, EPA provides formula grants to the states and tribes to implement nonpoint source projects and programs in accordance with section 319 of the CWA. Nonpoint source pollution reduction projects can be used to protect source water areas and the general quality of water resources in a watershed. Examples of previously funded projects include installation of best management practices (BMPs) for animal waste; design and implementation of BMP systems for stream, lake, and estuary watersheds; basinwide landowner education programs; and lake projects previously funded under the CWA section 314 Clean Lakes Program.

These funds are administered by TCEQ and TSSWCB in Texas. See the State Funding Sources section later in this Appendix.

Estimated FY 2008 Funding: $200.9 million; Approximately $9 million for Texas
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=44

North American Wetlands Conservation Act Grants Program

Entity: U.S. Fish and Wildlife Service
The U.S. Fish and Wildlife Service's Division of Bird Habitat Conservation administers this matching grants program to carry out wetlands and associated uplands conservation projects in the United States, Canada, and Mexico. Grant requests must be matched by a partnership with nonfederal funds at a minimum 1:1 ratio. Conservation activities supported by the Act in the United States and Canada include habitat protection, restoration, and enhancement. Mexican partnerships may also develop training, educational and management programs and conduct sustainable-use studies. Project proposals must meet certain biological criteria established under the Act. Visit the program Web site for more information. (Click on the hyperlinked program name to see the listing for "Primary Internet.")

Estimated FY 2008 Funding: $84.4 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=45

Partners for Fish and Wildlife Program

Entity: U.S. Fish and Wildlife Service
The Partners for Fish and Wildlife Program provides technical and financial assistance to private landowners to restore fish and wildlife habitats on their lands. Since 1987, the program has partnered with more than 37,700 landowners to restore 765,400 acres of wetlands; over 1.9 million acres of grasslands and other upland habitats; and 6,560 miles of in-stream and streamside habitat. In addition, the program has reopened stream habitat for fish and other aquatic species by removing barriers to passage.

Estimated FY 2008 Funding: $42.6 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=46

Pesticide Environmental Stewardship Grants

Entity: U.S. Environmental Protection Agency
EPA's Pesticide Environmental Stewardship Program (PESP) offers grants to support the reduction of risks from pesticides in agricultural and non-agricultural settings and to implement pollution prevention measures. All organizations with a commitment to pesticide risk reduction are eligible to join PESP as members, either as Partners or as Supporters. For more information about membership requirements and available grants, click on the program name and refer to the link listed under "Primary Internet."

Estimated FY 2008 Funding: $1 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=47

Pollution Prevention Grant Program

Entity: U.S. Environmental Protection Agency
This grant program provides project grants to states and tribes to implement pollution prevention projects. The grant program is focused on institutionalizing multimedia (air, water, land) pollution prevention as an environmental management priority, establishing prevention goals, providing direct technical assistance to businesses, conducting outreach, and collecting and analyzing data. The program includes new P2 measurement requirements in compliance with EPA policy, and now requires applicants to work towards reducing pollution, conserving energy and water, and saving dollars through P2 efforts; as identified in EPA's Strategic Plan under Goal 5: Compliance and Environmental Stewardship: Objective 5.2: Improve Environmental Performance Through Pollution Prevention and Innovation.

Estimated FY 2008 Funding: $4.1 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=49

Project Modifications for Improvement of the Environment

Entity: U.S. Army Corps of Engineers
Work under this authority provides for modifications in the structures and operations of water resources projects constructed by the U.S. Army Corps of Engineers to improve the quality of the environment. Additionally, the Corps may undertake restoration projects at locations where an existing Corps project has contributed to the degradation. The primary goal of these projects is ecosystem restoration with an emphasis on projects benefiting fish and wildlife. The project must be consistent with the authorized purposes of the project being modified, environmentally acceptable, and complete within itself.

Estimated FY 2008 Funding: $29.7 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=109

Science to Achieve Results

Entity: U.S. Environmental Protection Agency
The Science to Achieve Results (STAR) program is designed to improve the quality of science used in EPA's decision-making process. STAR funds are provided for research in the following ten areas: (3) Ecosystem Protection/Water Quality: Ecology and oceanography of hazardous algal blooms (EcoHAB); Ecosystem services. (9) Pollution Prevention/Sustainability: Collaborative Science and Technology Network for Sustainability.

Estimated FY 2008 Funding: $60 million
Link: http://cfpub.epa.gov/fedfund/search2.cfm?prog_num=52

State Wildlife Grant Program

Entity: U.S. Fish and Wildlife Service
The U.S. Fish and Wildlife Service's State Wildlife Grant (SWG) program provides grants to states, territories, and the District of Columbia for wildlife conservation. The SWG program provides funds to help develop and implement programs that benefit wildlife and their habitat, including species that are not hunted or fished. Although not directly eligible for these grants, third parties such as nonprofit organizations may benefit from these funds by working directly with their states to see if either grants or partnering opportunities are available.

Estimated FY 2008 Funding: $61.5 million
Link: http://cfpub.epa.gov/fedfund/search2.cfm?prog_num=80

Targeted Watershed Grants Program

Entity: U.S. Environmental Protection Agency
EPA is asking the nation's governors, tribal leaders, and leading watershed organizations to apply for the next round of funding to support collaborative partnerships to protect and restore the nation's water resources. The EPA will select up to 12 watershed organizations to receive grants to implement watershed-based, on-the-ground implementation projects and up to five training and educational organizations to receive grants or cooperative agreements to help build capacity of the many grass roots watershed organizations across the country. Both grants will focus on strong landowner support and producing improved environmental change. In a third part of the program, the Agency will also award Targeted Watershed funds to support nutrient management projects in the Chesapeake Bay Watershed.

Estimated FY 2008 Funding: not funded
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=95

Water 2025 Challenge Grant Program

Entity: U.S. Department of the Interior – Bureau of Reclamation
The goal of Water 2025 is to prevent crises and conflict over water in the western United States. The Challenge Grant Program is administered by the Bureau of Reclamation and is designed to contribute to this goal by providing 50 percent funding for projects that will conserve water, increase water use efficiency, or enhance water management, using advanced technology, improvements to existing facilities, and water banks and markets.

Estimated FY 2008 Funding: $4 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=102

Wildlife Habitat Incentives Program

Entity: USDA-Natural Resources Conservation Service
The Wildlife Habitat Incentives Program (WHIP) is a voluntary program for people who want to develop and improve wildlife habitat on private lands. It provides both technical assistance and cost sharing to help establish and improve fish and wildlife habitat. Participants work with USDA NRCS to prepare a wildlife habitat development plan in consultation with a local conservation district. The plan describes the landowner's goals for improving wildlife habitat, includes a list of practices and a schedule for installing them, and details the steps necessary to maintain the habitat for the life of the agreement.

Estimated FY 2007 Funding: $41 million
Link: http://cfpub.epa.gov/fedfund/program.cfm?prog_num=68

USGS Coop Funds

Entity: U.S. Geological Survey
The USGS Cooperative Water Program is an ongoing partnership between the USGS and non-federal agencies. The program jointly funds water resources projects in every state, Puerto Rico, and several other U.S. trust territories. USGS uses nationally consistent procedures and quality-assurance protocols in conducting cooperative projects. These standards ensure that all data from the Cooperative Water Program are directly comparable from one region to another and available from USGS databases for use by citizens, public officials, industry, and scientists nationwide. Agencies, or "Cooperators," that participate in the Cooperative Water Program are primarily state, tribal, county, and municipal agencies with water resources management and policy responsibilities. Although the Program originated as a 50:50 fund-matching arrangement, Cooperator funds have grown faster than USGS funds in recent years.

Estimated FY 2008 Funding: ~$75 million
Link: http://pubs.usgs.gov/fs/2004/3068/

State Funding Sources

Agricultural Water Conservation Grants Program

Entity: Texas Water Development Board
The Agricultural Water Conservation Grants Program offers grants to political subdivisions for technical assistance, demonstration, technology transfer, research and education, and metering projects that conserve water. Grant Request for Proposals are published on an annual basis, generally in the fall of each year. Grant topics vary from year to year to address current issues and topics in agricultural water conservation.

Link: http://www.twdb.state.tx.us/assistance/conservation/grants.asp

CWA §106 State Water Pollution Control Grants

Entity: Texas Commission on Environmental Quality
Section 106 of the Clean Water Act authorizes EPA to provide federal assistance to states and interstate agencies to establish and implement ongoing water pollution control programs. Prevention and control measures supported by State Water Quality Management programs include permitting, pollution control activities, surveillance, monitoring, and enforcement; advice and assistance to local agencies; and the provision of training and public information. Increasingly, EPA and states are working together to develop basin-wide approaches to water quality management. The Water Pollution Control Program is helping to foster a watershed protection approach at the state level by looking at states' water quality problems holistically, and targeting the use of limited finances available for

effective program management. At present, the program is seeking ways to streamline the grants process to ease the administrative burden on states.

Link: http://www.epa.gov/OWM/cwfinance/pollutioncontrol.htm

CWA §319(h) Nonpoint Source Grant Program

Entity: Texas Commission on Environmental Quality
Texas State Soil and Water Conservation Board

In compliance with Section 319(h) of the Clean Water Act, the U.S. Environmental Protection Agency provides funding to the Texas Commission on Environmental Quality and the Texas State Soil and Water Conservation Board to implement activities that result in progress in achieving Congress' goal of controlling and abating nonpoint source pollution. NPS pollution originates from different sources that cannot be traced to any single point, such as a pipe. It is normally associated with agricultural and silvicultural runoff, urban stormwater, and runoff from construction sites.

Estimated FY 2008 Funding: ~$9.2 million
Link: http://www.tceq.state.tx.us/nav/funding/federal_grants.html#nps
http://www.tsswcb.state.tx.us/managementprogram

Clean Rivers Program

Entity: Texas Commission on Environmental Quality

The Texas Clean Rivers Program (CRP) is a state fee-funded program for surface water quality monitoring, assessment, and public outreach. The program provides the opportunity to identify and evaluate water quality issues within each Texas river basin at the local and regional level. Allocations are made to 15 partner agencies (mostly river authorities) across the state for routine monitoring efforts, special studies, and outreach efforts.

Link: http://www.tceq.state.tx.us/about/funding/clean_rivers.html

Clean Water State Revolving Fund Loan Program

Entity: Texas Water Development Board

The Clean Water State Revolving Fund (CWSRF) provides loans at interest rates lower than the market to political subdivisions with the authority to own and operate a wastewater system. The CWSRF also includes Federal (Tier III) and Disadvantaged Communities funds that provide even lower interest rates for those meeting the respective criteria.

Link: http://www.twdb.state.tx.us/assistance/financial/fin_infrastructure/cwsrffund.asp

Drinking Water State Revolving Fund Loan Program

Entity: Texas Water Development Board
The Drinking Water State Revolving Fund (DWSRF) provides loans at interest rates lower than the market offers to finance projects for public drinking water systems that facilitate compliance with primary drinking water regulations or otherwise significantly further the health protection objectives of the federal Safe Drinking Water Act (SDWA). Projects must also be consistent with the 2002 State Water Plan.

Link: http://www.twdb.state.tx.us/assistance/financial/fin_infrastructure/dwsrf.asp

Flood Protection Planning Program

Entity: Texas Water Development Board
The TWDB offers grants to political subdivisions of the State of Texas for evaluation of structural and nonstructural solutions to flooding problems and considers flood protection needs of the entire watershed. Upstream and/or downstream effects of proposed solutions must be considered in the planning. The financing of the program is from the TWDB's Research and Planning Fund. The proposed planning must be regional in nature by inclusion of an entire watershed.

Link: http://www.twdb.state.tx.us/wrpi/flood/flood.htm

Oil Field Cleanup Fund

Entity: Railroad Commission of Texas
The Site Remediation Section utilizes the State Managed Cleanup Fund in coordination with the RRC District Offices to cleanup pollution of abandoned oil and gas sites. Funding for the program comes from regulatory fees, permit fees, and bond fees paid by the oil and gas industry. An abandoned site becomes a candidate for state cleanup when the responsible party fails or refuses to take action, or is unknown, deceased, or bankrupt. Cleanup prioritization is based on public health, safety, and the protection of the environment.

Link: http://www.rrc.state.tx.us/divisions/og/site_rem/StatefundedCleanupProgram.html

Supplemental Environmental Projects (SEP)

Entity: Texas Commission on Environmental Quality
The SEP program is administered by TCEQ and directs fines, fees, and penalties for environmental violations toward environmentally beneficial uses. Through this program, a respondent in an enforcement matter can choose to invest penalty dollars in improving the environment, rather than paying into the Texas General Revenue Fund. Program dollars

may be directed to septic system repair and wildlife habitat restoration or improvement among other things. Program dollars may be directed to entities for single, one-time projects that require special approval from TCEQ or directed to entities (such as Resource Conservation and Development Councils, http://www.texasrcd.org/) with pre-approved "umbrella" projects statewide.

Link: http://www.tceq.state.tx.us/legal/sep/

Water Supply Enhancement Program

Entity: Texas State Soil and Water Conservation Board
The program consists of a comprehensive strategy for managing brush in areas where brush is contributing to a substantial water conservation problem and designates areas of critical need in the state in which to implement the brush control program. State appropriations are directed to priority watersheds identified in the State Brush Control Plan.

Estimated FY 2008 Funding: ~$2.5 million
Link: http://www.tsswcb.state.tx.us/brushcontrol

Water Quality Management Plan Program

Entity: Texas State Soil and Water Conservation Board
A water quality management plan (WQMP) is a site-specific plan developed through and approved by soil and water conservation districts for agricultural or silvicultural lands. The plan includes appropriate land treatment practices, production practices, management measures, technologies, or combinations thereof. The purpose of WQMPs is to achieve a level of pollution prevention or abatement determined by the TSSWCB, in consultation with local soil and water conservation districts, to be consistent with state water quality standards. State appropriations and federal grants are directed to cost-share programs that provide financial assistance for implementing specific BMPs prescribed in WQMPs. Program funds are generally split between 1) specific allocations to SWCDs in priority areas and 2) a statewide pool for producers/WQMPs not in priority SWCDs but with critical resource protection needs.

Estimated FY 2008 Funding: ~$4.3 million
Link: http://www.tsswcb.state.tx.us/wqmp

Appendix E:
Railroad Commission of Texas Well Plugging Priority Sheet

Well Plugging Priority Determination System

FACTOR	WEIGHT
1. Well Penetrates a Major Aquifer:	5
2. Major Aquifer Outcrop in Vicinity of the Well:	5
3. Well Penetrates a Minor Aquifer:	3
4. Minor Aquifer Outcrop in Vicinity of the Well:	3
5. Well Penetrates High Volume/High Pressure SW-bearing Formation:	5
6. Well Penetrates Other SW-bearing Formation:	3
7. Within 100' of River, Creek, or Lake:	5
8. Within ¾ Mile of River, Creek, or Lake:	3
9. Within 1 Mile of River, Creek, or Lake:	2
10. Known Sensitive Wildlife Area:	5
11. Leaking Oil, Gas, and/or Saltwater:	Priority 1
12. Complaint-related:	1
13. Injection or Disposal Well:	4
14. Drilled Prior to 1965:	1 - 3
15. County Population = 100,000, or greater:	3
16. County Population < 100,000, but > 10,000:	2
17. County Population = 10,000, or less:	1
18. Well in H_2S Field:	4
19. Non-existent Operator or Operator's P-5 Inactive/Delinquent > 2 Years:	2
20. Unique Environmental, Safety, or Economic Concern:	1 - 10

Total Weight: ___________

Priority: ___________

Priority 1 = Leaking Well (surface or subsurface)
Priority 2 = Total Weight = 25, or greater
Priority 3 = Total Weight = 15 – 24
Priority 4 = Total Weight = 14, or less

Appendix F:
Contact Information for Regional Agency Personnel

Name	Location	Address	Phone Number
Texas AgriLife Extension Service			
District 6 Office	Fort Stockton, TX	Hwy. 285 & Airport Dr.	(432) 336-8585
Andrews County Office	Andrews, TX	851 E. Broadway St.	(432) 524-1421
Brewster/Jeff Davis County Office	Alpine, TX	201 W. Avenue E	(432) 837-6207
Crane County Office	Crane, TX	900 W. 6th St.	(432) 558-3522
Crockett County Office	Ozona, TX	1301 Avenue AA	(325) 392-2722
Culberson County Office	Van Horn, TX	300 La Caverna Rd.	(432) 283-8440
Ector County Office	Odessa, TX	1010 E. 8th St.	(432) 498-4071
Loving/Reeves County Office	Pecos, TX	700 Daggett	(432) 447-9041
Pecos County Office	Fort Stockton, TX	100 E. Division	(432) 336-2541
Presidio County Office	Marfa, TX	320 N. Highland	(432) 729-4746
Reagan County Office	Big Lake, TX	County Park Rd	(325) 884-2335
Terrell County Office	Sanderson, TX	105 Hackberry St.	(432) 345-2291
Upton County Office	Rankin, TX	1000 N. Hwy. 329	(432) 693-2313
Val Verde County Office	Del Rio, TX	300 E. 17th St.	(830) 774-7591
Ward County Office	Monahans, TX	3600 S. Stockton, Suite J	(432) 943-2682
Winkler County Office	Kermit, TX	307 S. Poplar	(432) 586-2593
Texas Water Resources Institute			
Main Office	College Station, TX	1500 Research Pkwy, Ste A240	(979) 845-1851
Water Specialist	Fort Stockton, TX	Hwy. 285 & Airport Dr.	(432) 336-8585
Texas State Soil and Water Conservation Board			
State Headquarters	Temple, TX	4311 S 31st St, Ste 125	(254) 773-2250
Regional Office	Hale Center, TX	1201 Ave E	(806)-839-1030
Water Supply Enhancement Program	San Angelo, TX	622 S Oakes St, Ste H-2	(325)-481-0335
Soil and Water Conservation Districts			
Andrews SWCD	Andrews, TX	103 NE. Ave. L, Suite B	(432) 523-4760
Big Bend SWCD	Alpine, TX	807 N. 5th St.	(432) 837-5864

Name	Location	Address	Phone Number
Crockett SWCD	Ozona, TX	201 11th St.	(325) 392-2301
Devil's River SWCD	Del Rio, TX	302 E. 17th St.	(830) 775-3813
High Point SWCD	Van Horn, TX	100 E. Broadway	(432) 283-2277
Highland SWCD	Marfa, TX	110 E. El Paso	(432) 729-4532
Middle Concho SWCD	Big Lake, TX	606 2nd St., Suite B	(325) 884-2182
Midland SWCD	Midland, TX	3300 N. A St., Bldg. 4, Suite 220	(432) 684-8722
Rio Grande – Pecos River SWCD	Sanderson, TX	823 W. Oak	(432) 345-2595
Sandhills SWCD	Odessa, TX	2464 I-20 West	(432) 332-9541
Toyah – Limpia SWCD	Balmorhea, TX	303 S. Dallas	(432) 375-2277
Trans Pecos SWCD	Fort Stockton, TX	2306 W. Dickinson Blvd, Suite 3	(432) 336-5206
Upper Pecos SWCD	Pecos, TX	1415 W. 3rd St.	(432) 445-3196

USDA Natural Resources Conservation Service

Alpine Service Center	Alpine, TX	1805 Hwy. 118 N.	(432) 837-8247
Andrews Service Center	Andrews, TX	103 NE Avenue L	(432) 523-4760
Big Lake Service Center	Big Lake, TX	606 E. 2nd St.	(325) 884-3753
Del Rio Service Center	Del Rio, TX	302 E. 17th St.	(830) 775-3813
Fort Stockton Service Center	Fort Stockton, TX	2306 W. Dickinson Blvd, Suite 1	(432) 336-5206
Marfa Service Center	Marfa, TX	106 E. El Paso	(432) 729-4532
Odessa Service Center	Odessa, TX	2450 I-20 West	(432) 332-9541
Ozona Service Center	Ozona, TX	201 11th St.	(325) 392-3702
Pecos Service Center	Pecos, TX	1417 W. 3rd St.	(432) 445-3196
Sanderson Service Center	Sanderson, TX	823 W. Oak	(432) 345-2595
Van Horn Service Center	Van Horn, TX	100 E. Broadway	(432) 283-2277
San Angelo Zone Office	San Angelo, TX	3878 W. Houston Harte	(325) 944-0147

Texas Forest Service

Fort Stockton Office	Fort Stockton, TX	P.O. Box 9010	(432) 336-7290

Texas Parks and Wildlife

Midland Regional Office, Field Enforcement	Midland, TX	4500 W. Illinois, Suite 307	(432) 520-4649
Kills and Spills Team	San Marcos, TX	505 Staples	(512) 353-3474
Inland Fisheries District Office	San Angelo, TX	3407-A S. Chadbourne	(325) 651-5556

Name	Location	Address	Phone Number
Texas Commission on Environmental Quality			
Midland Regional Office	Midland, TX	3300 N. A St., Bldg. 4, Suite 107	(432) 570-1359
Railroad Commission of Texas			
Midland Regional Office	Midland, TX	10 Desta Dr.	(877) 228-5740
United States Geological Survey			
West Texas Program Office	San Angelo, TX	944 Arroyo Dr.	(325) 944-4600
International Boundary and Water Commission – U.S. Section			
Texas Clean Rivers	El Paso, TX	4171 North Mesa, Suite C-100	(915) 832-4701