

Saltcedar control and water salvage on the Pecos river, Texas, 1999–2003

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Abstract

A large scale ecosystem restoration program was initiated in 1997 on the Pecos River in Western Texas. Saltcedar (*Tamarix* spp.), a non-native invasive tree, had created a near monoculture along the banks of the river by replacing most native vegetation. Local irrigation districts, private landowners, federal and state agencies, and private industry worked together to formulate and implement a restoration plan, with a goal of reducing the effects of saltcedar and restoring the native ecosystem of the river. An initial management phase utilizing state-of-the-art aerial application of herbicide began in 1999 and continued through 2003. Initial mortality of saltcedar averaged about 85–90%. Monitoring efforts were initiated at the onset of the project to include evaluating the effects of saltcedar control on salinity of the river water, efficiency of water delivery down the river as an irrigation water source, and estimates of water salvage. To date, no effect on salinity can be measured and irrigation delivery was suspended in 2002–2003 due to drought conditions. Water salvage estimates show a significant reduction in system water loss after saltcedar treatment. However, a flow increase in the river is not yet evident. Monitoring efforts will continue in subsequent years.

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1. Introduction

The Pecos River Ecosystem Project was proposed in 1997 by the Red Bluff Water and Power Control District to address saltcedar issues along the Pecos River. Initial objectives of the project were to increase efficiency of water delivery in the river to irrigation districts within the Red Bluff District and improve the quality of the water by decreasing the salinity. After 4 years of herbicide application on saltcedar, the project has emerged as the first step to what could be important to the overall statewide plan for water conservation along Texas' rivers by managing saltcedar infestations. Success of the Pecos River Ecosystem Project can be attributed mainly to its cooperative effort and organization. Numerous agencies, organizations, and companies, such as Upper Pecos Soil and Water

Conservation District, Texas Cooperative Extension, Texas Department of Agriculture, USDA Natural Resources Conservation Service, Red Bluff Water and Power Control District, Irrigation Districts in Loving, Reeves, Ward and Pecos Counties, US Environmental Protection Agency, Pecos River Compact Commission, International Boundary and Water Commission, BASF Co., North Star Helicopters, Inc. and local landowners, were involved in the organizational efforts early in the project development.

Saltcedar (*Tamarix* spp.) is an introduced phreatophyte in western North America estimated to occupy well over 600,000 ha of waterways (Robinson, 1965; Kunzmann et al., 1988). It is a vigorous invader of riparian zones and subirrigated pastures. The plant was introduced into the United States as an ornamental in the early 1800s. In the early 1900s, government agencies and private landowners began planting saltcedar to control stream bank erosion along such rivers as the Pecos River in New Mexico and Texas (Everitt, 1998). The plant has spread down river in Texas and occurs along the river south of Interstate 10 to the confluence with the Rio Grande. Mature plants can reach

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heights of 6–9 m and densities of 700–1000 plants/h in this region. More recently saltcedar has become a noxious plant not only along rivers and their tributaries, but also along irrigation ditch banks, low-lying areas that receive extra runoff accumulation, and areas with high water tables. In addition, many Conservation Reserve Program (CRP) hectares in Central Texas are being invaded with saltcedar.

As a prolific seeder over an extended period (April to October), early seedling recruitment is very slow, but once established seedlings grow faster than native plants (Tomanek and Ziegler, 1960). Once mature, the plant becomes well established with deep roots that occupy the capillary zone above the water table with some roots in the zone of saturation (Schopmeyer, 1974). Saltcedar can quickly dominate an area, out-competing native plants for sunlight, moisture, and nutrients. Mature plants can withstand prolonged drought or periods of inundation. The plant also brings salts to the surface by excreting it through the leaves and dropping it onto the soil surface below the canopy. Only extremely xeric or halophytic species of plants can tolerate the understory environment of saltcedar. As a result, the plant commonly forms a near monoculture where it grows (Taylor and McDaniel, 1998).

Probably more important than any other fact about saltcedar is its hydrological implications. An invasion of a flood plain or river bank by saltcedar usually leads to depletion of stream/river flow, lowered water table, an increase in the area inundated by floods, and an increase in sediment production (Blackburn et al., 1982; Smith et al., 1998). The plant has an extremely high rate of evapotranspiration which assists the plant in tolerating saline conditions (Walker and Smith, 1997). Numerous techniques have been used to estimate evapotranspiration rates of saltcedar including Bowen ratio, eddy covariance, micro-meteorological data, evapotranspirometer, non-weighing lysimeter, tanks, sap flow, stem-heat-balance, and ground-water monitoring wells (Hays, 2003). Estimated evapotranspirational water use by saltcedar reported in the literature varies from 0.3 to 3.1 m per year (Hays, 2003). Major factors affecting volume of water transpired by saltcedar include leaf area, plant density and size, depth to water table, water salinity, and soil type (Devitt et al., 1997; Smith et al., 1998). Two specific studies reported that saltcedar transpired 0.3–1.0 cm of water per day or 1.2–3.1 m of water per year (Davenport et al., 1982), and 2.1 m³/m² (Carmen and Brotherson, 1982).

Additionally, monotypic stands of saltcedar have a negative impact on wildlife and livestock. The plant provides little browse and no seed food source for native wildlife species (Taylor and McDaniel, 1998). The wildlife habitat value of saltcedar is limited to screening cover for mammals, nesting sites for some birds, and a pollen source for bees. In most instances, the wildlife habitat value of a saltcedar monoculture is much less than that of its native counterpart that it has replaced (Cohan et al., 1978; Anderson and Ohmart, 1977). Therefore, it is expected

that native plants taking over the riparian zones or revegetation after the saltcedar control will provide biodiversity for the region and establish richer wildlife habitats.

The management of saltcedar infestations has, more than once, resulted in the return of surface water to an area. Two examples documented include the Eagle Borax Spring in Death Valley National Monument (Neil, 1983) and Spring Lake in New Mexico (Duncan, 1997). At Spring Lake in New Mexico, saltcedar was treated with Arsenal™ herbicide. Within 34 months after application, the water table had risen to the soil surface from a depth of greater than 6.0 m below the soil surface. This occurred even though the area had experienced a mild drought.

Fires burn easily through green saltcedar and will almost always top kill the plants. However, due to its ability to re-sprout from the base, seldom does fire kill the plant as the root crown area is usually well protected from the fire. Mechanical control practices have shown only slightly greater success when compared to fire. Mowing or shredding has shown similar results to burning, while root plowing or grubbing have provided some mortality. However, these mechanical methods disturb the soil surface resulting in increased erosion potential along stream banks. Saltcedar plants have a high re-sprouting capability from both the crown and roots of a plant adding to the difficulty of controlling with mechanical means. Due to this, use of the root plow or other heavy equipment as a control method for saltcedar has become less frequent (Hollingsworth, 1973).

The response of saltcedar to chemical control has historically been variable, with little satisfactory control except under specific conditions or repetitive applications. The most satisfactory control was provided by cut stump or basal bark treatments. These treatments tend to be very time consuming and not practical for larger acreage. Additionally, many of the herbicides historically used for saltcedar control are no longer approved or are currently unavailable. Research has been conducted recently with Imazapyr (Arsenal™) herbicide. Results indicate Arsenal™ applied alone or in combination with Glyphosate controlled saltcedar to levels of 90% or greater within 1 year after application when applied in August or September (Duncan and McDaniel, 1998). Their recommendations include 1.12 kg a.i./ha Imazapyr or 0.56 + 0.56 kg a.i./ha of Imazapyr and Glyphosate, respectively.

Saltcedar occupies a near continuous buffer along both banks of the Pecos River from Red Bluff Dam southward for the entire area (approx. 289 river kilometers) of the Red Bluff Irrigation District. This region of Texas is characterized by a semi-arid, desert environment receiving 152.5–203.2 mm of average annual rainfall. One of the important reasons for controlling saltcedar is to conserve water, especially for the semi-arid area experiencing drought most, if not all, of the time. The width of the saltcedar band varies from 7.6 to 152.5 m with an average of 45.8 m on each river bank. Within this stretch of river, saltcedar occupies about

7.5–10 ha per river kilometer. Additionally, the Pecos River in Texas is a meandering stream with a ratio of river kilometers to air kilometers of about 3:1. Another primary concern of the project was to apply the herbicide with minimal contact with off-target vegetation. This situation created a real challenge for aerial application of herbicides. This paper describes the Pecos River saltcedar control program in Texas and its preliminary results.

2. Methods and procedures

The first step undertaken by the planning group was to develop a section 24(C) special use label to use Arsenal™ herbicide on saltcedar within rangeland and aquatic areas in Texas. The label was prepared by the Pesticide Division of the Texas Department of Agriculture and approved for use in 1999. The project was designed with two major phases, a saltcedar treatment phase and debris removal and follow-up management phase. Also of major concern to the project group was the revegetation of the river banks with native plants to complete the ecosystem restoration. Once the label and funding were secured, the project was ready to begin the first phase of herbicide treatments. The Upper Pecos Soil and Water Conservation District Board of Directors were selected to administer the project.

During the initial meetings to begin planning the process of saltcedar removal, several major concerns emerged. First, the treatment method selected should provide a high rate of saltcedar mortality while minimizing the detrimental effects on existing native vegetation. Second, this should be accomplished in the most economical way possible. And finally, soil loss from stream banks should be minimized as much as possible. Another daunting task was to obtain permission from private landowners to treat saltcedar along the river, as much of the land is in private ownership. A ‘spray easement’ was developed and used as a contract between the Project and private landowners, allowing access for treatment and follow-up management for a 10 year period. To date, over 800 easements have been signed by private landowners, with a rejection rate of less than 1%. Bids were solicited from aerial applicators in late summer 1999 with the project ultimately being awarded to North

Star Helicopters from Jasper, Texas. With funding, land-owner permission, and applicator contract in hand by August 1999, initial treatments could begin in September.

The ecohydrological study was conducted after the application of herbicide to assess impacts of saltcedar control in terms of water quality and water quantity. As part of this research program, water quality samples were collected annually at 10 locations and water quality was monitored hourly at two locations. To quantify water flow between surface water and ground water, surface water flow release and diversions were monitored and groundwater level diurnal fluctuations were monitored at both treated and untreated sites. The latter were used to estimate the water losses by evapotranspiration and water salvage potential from the saltcedar control (Fig. 1). Details for each component are described in the following sections.

2.1. Herbicide applications

Applications of 1.12 kg a.i./ha of Arsenal™ herbicide were made by helicopter and applied with a specially designed boom that produced large droplets and high total spray volume. The helicopter had the advantage of being able to fly at slower air speeds compared to fixed-wing aircraft, which made the sharp turns of the river much easier to navigate. The helicopter application also provided for much higher precision of application by utilizing specialized nozzle and boom technology. The herbicide was applied in a total spray volume of 140 L/ha with a 1000–1500 μ droplet. Less than 0.5% of the droplets were ‘driftable’ fines (<200 μ). The boom was also sectioned into 3–4.5 m sections for an overall width of 13.5 m. Combinations of the boom could be turned on to allow for a 4.5, 9, or 13.5 m swath width. This further reduced the amount of herbicide that came in contact with off-target vegetation. Another advantage of the helicopter over fixed-wing aircraft was its ability to land on loader trucks that were positioned near the river and eliminated the need of ferrying to and from a landing strip.

Helicopters were equipped with GPS navigational equipment to aid in application. The use of on-board GPS allowed for near elimination of skips between spray swaths and allowed the pilot to easily return to the point

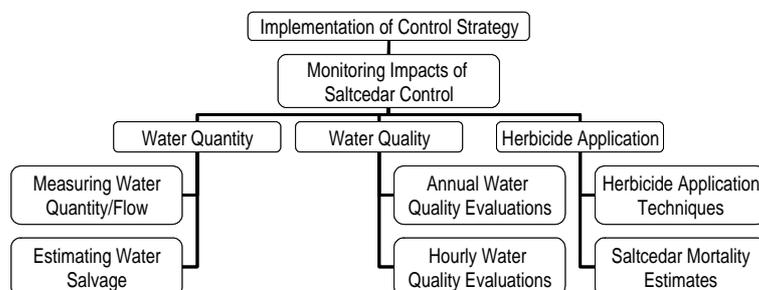


Fig. 1. Flow chart of treatment evaluations and ecohydrological assessment following saltcedar control.

where they finished spraying the previous spray load. The system was also connected to the sprayers flow control system so that rate of flow through the boom was varied to precisely match ground speed, eliminating the need to maintain a constant ground speed. After completion of treatments, GPS log files were downloaded to a computer to produce maps of the treated area and make calculations about the area treated.

Percent mortality of saltcedar plants was estimated after a minimum of 2 years post-treatment. Counts were conducted at multiple locations to determine percent mortality of saltcedar by counting live and dead plants along belt transects on both sides of the river. If any green plant tissue was evident on a plant, it was recorded as live. Plants were counted within a 2.5 m wide belt transect until 100 plants were recorded as live or dead. A minimum of four transects were conducted at each sample location, two on each side of the river.

2.2. Monitoring water quality

Salinity of river water was measured from water samples taken annually at 10 locations from the Red Bluff Reservoir to Girvin (Fig. 2). Electrical conductivity was measured with a conductivity meter from water samples taken in 1999–2003. An unfiltered sample of water is placed in a 50 ml beaker. The conductivity meter is placed in the sample up to the maximum immersion level without touching the bottom of the beaker, then gently stirred around in the solution and the conductivity read when it stabilizes. A control using reagent-water was also utilized as a standard.

Additionally, electrical conductivity measurements were made at two sites near Mentone, Texas with continuous monitoring loggers placed in the river. Measurements are taken each second and an hourly average ($\mu\text{S}/\text{cm}$) recorded. The loggers were placed in PVC pipe secured to the bottom of the river. Logging began in February 2001.

2.3. Measuring water quantity/flow

Water quantity is monitored through release and delivery data from Red Bluff Water and Power Control District. Water released from Red Bluff Reservoir and delivered to seven local irrigation districts along the Pecos River is recorded daily during the irrigation season in acre-ft. Release and delivery data are obtained from weirs located at the point of release from Red Bluff Reservoir and at each irrigation turnout point on the river. Historical release and delivery data have also been provided by the Red Bluff Water and Power Control District, with pre-treatment averaged from 1988 to 1999 to establish a comparative baseline. Flow data are obtained from United States Geological Survey (USGS) Gauging Station 13257 located at Girvin, Texas. This gauging station is located at the southern end of the Red Bluff Water and Power Control District boundary. Water released from Red Bluff Reservoir that is not delivered to upper districts is captured at Imperial Reservoir, located upstream from the USGS gauging station.

2.4. Estimating water salvage

Water loss resulted from evapotranspiration within saltcedar stands and water salvage from saltcedar control

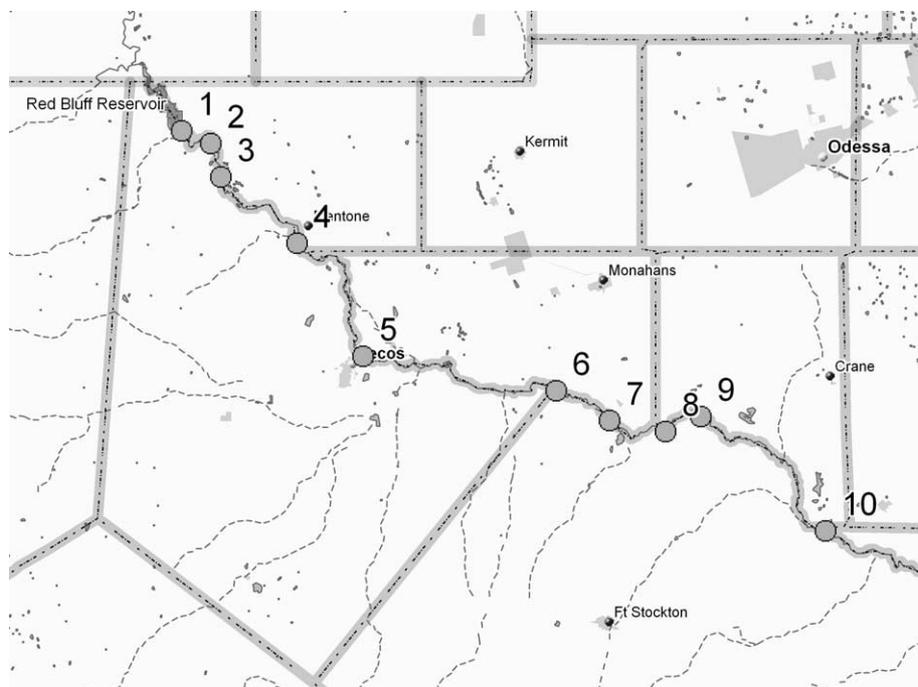


Fig. 2. Water sampling sites from Red Bluff Reservoir to Girvin, Texas along the Pecos River.

is estimated by monitoring groundwater diurnal fluctuations within saltcedar sites. Shallow groundwater monitoring wells were installed at a study site located on the Pecos River near Mentone, Texas to provide data on the fluctuation of the groundwater table. The wells were constructed by hand auguring through the soil profile into the water table until gravel or a thick clay layer was encountered. Well depths ranged from 2.6 to 6.0 m with the deeper wells farthest from the river. Each well consisted of a 7.62 cm hand bored opening in which a 5.08 cm diameter PVC pipe with a 1.22 m long well screen attached was inserted to the bottom of the boring. The slots in the well screen were 0.01 mm. The PVC pipe extended approximately 0.9 m above the soil surface. Blasting sand was used to fill the annular space around the well casing to within 0.3 m of the soil surface. The last 0.3 m of annular space was capped with pre-mix cement to prevent overland flow entering the annular space around the well casing. During the coring process, soil samples were taken for each 0.3 m interval for laboratory analysis to determine soil particle size distribution. River depth monitors were also installed by placing a PVC pipe down the bank of the river to the bottom of the river. Detailed vegetation analysis, described by Hays (2003), was also conducted within the study sites.

Water level loggers (Global Water Instrumentation, Inc. Model WL14X) were used to measure hourly water levels in the wells and the river. The sensor on the WL14X is a submersible pressure transducer that is amplified and temperature and barometric pressure compensated with an accuracy of 0.2%. Logger models used in this study had a reported accuracy of 0.0091 m and were calibrated prior to being placed in the wells. Additionally, wells were cleaned and flushed annually to remove silt and root accumulation. Loggers were programmed to record water level every hour.

A drawdown–recharge method (Fig. 3) of calculation was used to estimate water loss from hourly measurements that produced diurnal fluctuations in the water table. This method assumes little evapotranspiration occurs during the nighttime (21:00–8:00 h) and that the period from the low

point of the water table during daylight hours to the nighttime high can be used to calculate a recharge rate for the drawdown period. This method requires a drawdown and recharge diurnal cycle; hence, days when the water table rapidly rises or falls through out the diurnal cycle were excluded from the calculations. More information on the procedures and calculations used are found in Hays (2003).

A paired plot design was used, with four monitoring wells and a river monitor at each of two plots. Each plot was monitored for an entire growing season (December 1999 to September 2001). The relationship between wells across plots was established through simple linear regression and reported by Hays (2003). In September 2001, one plot was treated with Arsenal herbicide and the saltcedar killed. When sufficient data are available, water loss on untreated plots will be used to predict that on untreated plots, and a comparison made between predicted and actual. To date, this calculation has not been performed due to low water releases for the latest 2 years.

3. Results and discussion

Based on field observation and data analysis over the last 3 years, the following preliminary results were obtained for herbicide application, water quality, water losses by evapotranspiration and water salvage potential by saltcedar control. Additional research is also recommended to have a better understanding of the impacts of saltcedar control and to quantify volume and fate of water salvage by saltcedar control.

3.1. Herbicide applications

The project was funded in 1999 and 2000 by Red Bluff Water and Power Control District and irrigation districts along the Pecos River. Approximately 106 river kilometers or about 544 ha of saltcedar were treated with an actual spray cost of \$253,555.

During 2001, \$1 million was allocated to the Pecos River Ecosystem Project by the State of Texas through the Texas Department of Agriculture. Eight percent (8%) of these funds were used for project administration and monitoring with the remaining 92% used for saltcedar treatments in 2001 and 2002. Third year (2001) applications treated approximately 92 river kilometers or 583 ha of saltcedar at a cost of \$263,000. From 1999 to 2001, 1127 ha of saltcedar were treated at a total cost of \$515,635.

Fourth year applications were completed in September 2002. Approximately 1444 ha were treated including segments of the river between Red Bluff and Grandfalls, TX that were not sprayed during the previous years, from the New Mexico/Texas state line to Red Bluff Reservoir (including areas around the lake) and 8 km of Salt Creek, a major tributary of the Pecos River in Reeves County. About \$660,000 was spent during the 2002 spray season.

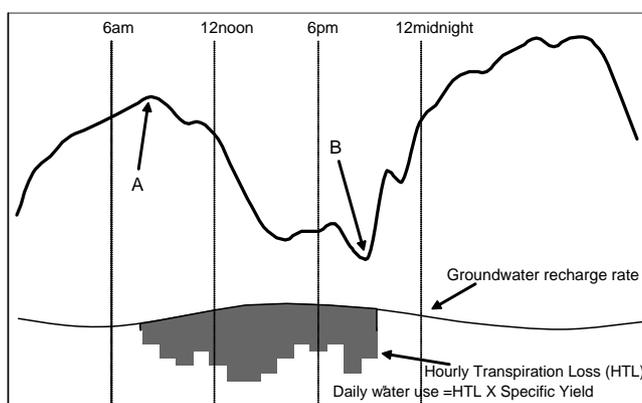


Fig. 3. Conceptual illustration showing diurnal fluctuation in groundwater and representation of drawdown–recharge method for calculation of water loss.

Applications in 2003 were funded through a joint effort of the USDA NRCS Environmental Quality Incentives Program (EQIP) and Texas State Soil and Water Conservation Board Brush Control Program. EQIP is a private landowner based program for cost share of environmental practices. This program provided 75% of the saltcedar treatment costs to the landowner. The Texas State Soil and Water Conservation Board provided the remaining 25% of the cost through the Texas Brush Control Program. During 2003, approximately 1510 ha of saltcedar were treated within the Pecos Basin Watershed in Culberson, Reeves, Ward, Crane, Pecos, Crockett, Terrell, and Val Verde Counties. Of this area treated, approximately 122 km or 1080 ha were along the main river channel. The remaining hectares were treated along tributaries and springs within the basin. Treatment cost during 2003 was \$518.70/ha for a total of \$783,300.

To summarize, from 1999 to 2003, 320 km of the Pecos River and various tributaries and springs within the basin have been treated for saltcedar control in Texas (Fig. 4). Approximately \$1.9 million has been spent to treat 4081 ha. Debris removal and follow-up management continues to be a priority to complete the project and this phase is currently being planned.

Percent mortality estimates were made during the summer of 2002 at six sites along the river treated in 1999 and 2000. Average estimated mortality within a site ranged from a low of 84% to a high of 90.7% after herbicide

applications. Across all sample sites, saltcedar mortality averaged $87.5 \pm 0.1\%$ 2 years after treatment. These results are very close to other studies as discussed in the introduction (Duncan and McDaniel, 1998).

3.2. Water quality

Electrical conductivity was measured in August 1999–2003 for each of 10 sampling locations. August sample sites are presented graphically in Fig. 5. Electrical conductivity (salinity) of Pecos River water doubled from $7300 \mu\text{S}/\text{cm}$ at Red Bluff Reservoir Dam to $15,460 \mu\text{S}/\text{cm}$ at Girvin, Texas during pre-treatment samples taken in August 1999. Samples taken during August 2000 indicate salinity levels were still increasing down river, but not to the extent of pre-treatment levels. By the August 2001 sampling date, approximately 60 river miles of the Pecos River had been chemically treated for saltcedar control. During this sampling period, similar down river increases were not seen, but salinity levels were higher at Red Bluff Dam. This can be attributed to lower lake levels during the 2001 irrigation season and increased salinity measured at the first site below the Red Bluff Lake dam. Samples taken during the 2002 and 2003 growing seasons show a high variability among sites and a general overall increase in salinity. It is speculated that this is due to the fact that no irrigation water was released from Red Bluff Reservoir during the 2002 or 2003

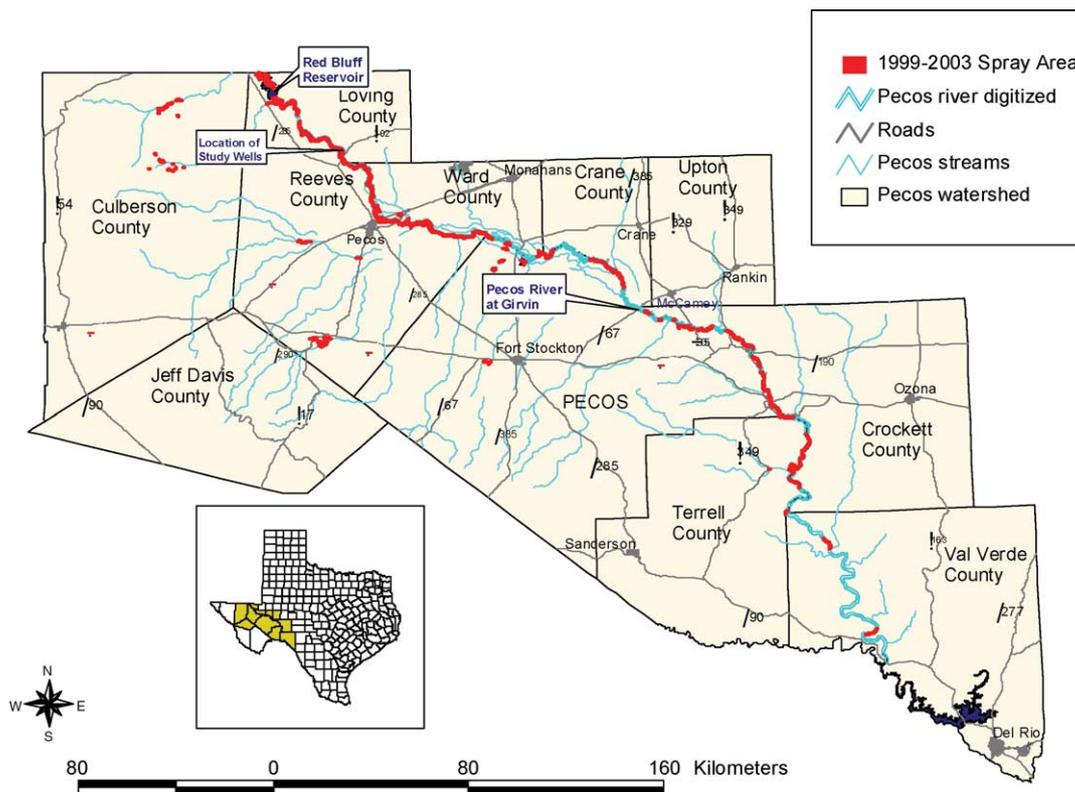


Fig. 4. Areas of the Pecos River Basin treated for saltcedar control during 1999–2003.

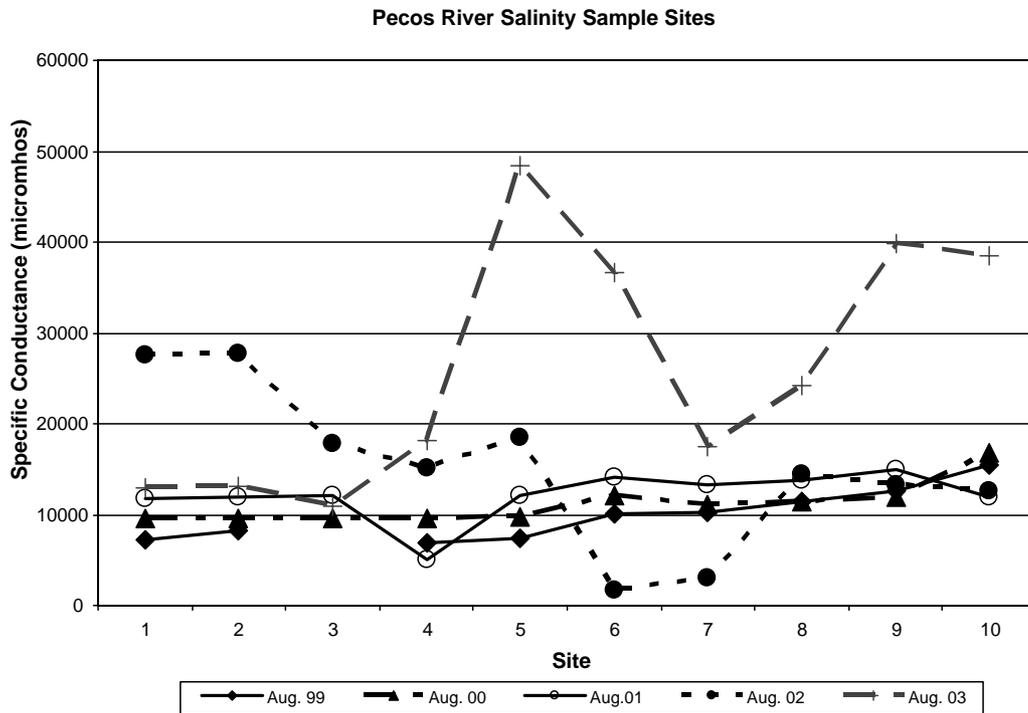


Fig. 5. Electrical conductivity of Pecos River water at 10 sites from Red Bluff Reservoir to Girvin, Texas sampled annually from 1999 to 2003.

growing seasons and base flow was significantly less. Changes in salinity, then, were believed to be influenced most by natural inputs into the river at various locations. As a result, the effects of saltcedar control on water salinity are not conclusive.

Electrical conductivity measurements were also recorded hourly from two sites near Mentone, Texas during 2001–2003. Corresponding measurements of river level are taken at the same locations to explain sudden drops in salinity after rain events swell the river and dilute the salts. Figs. 6–8

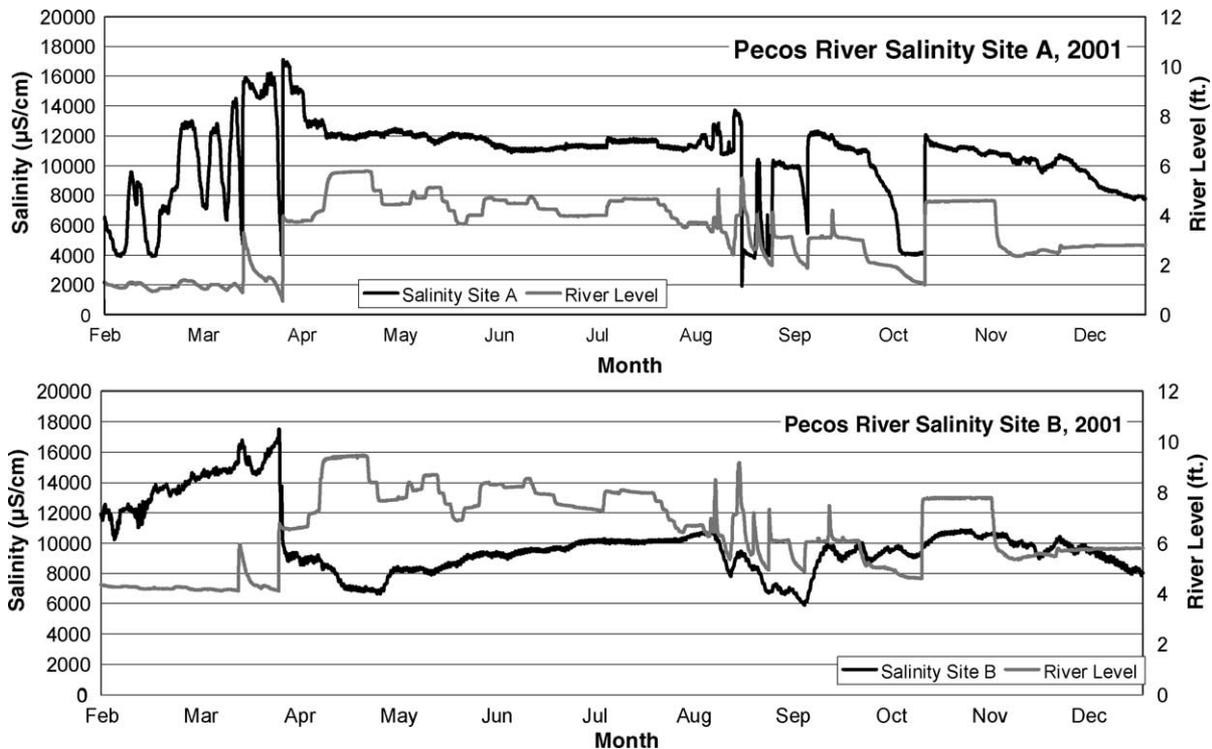


Fig. 6. Electrical conductivity ($\mu\text{S}/\text{cm}$) of Pecos River water and river level (ft) for sites A and B during February to December 2001.

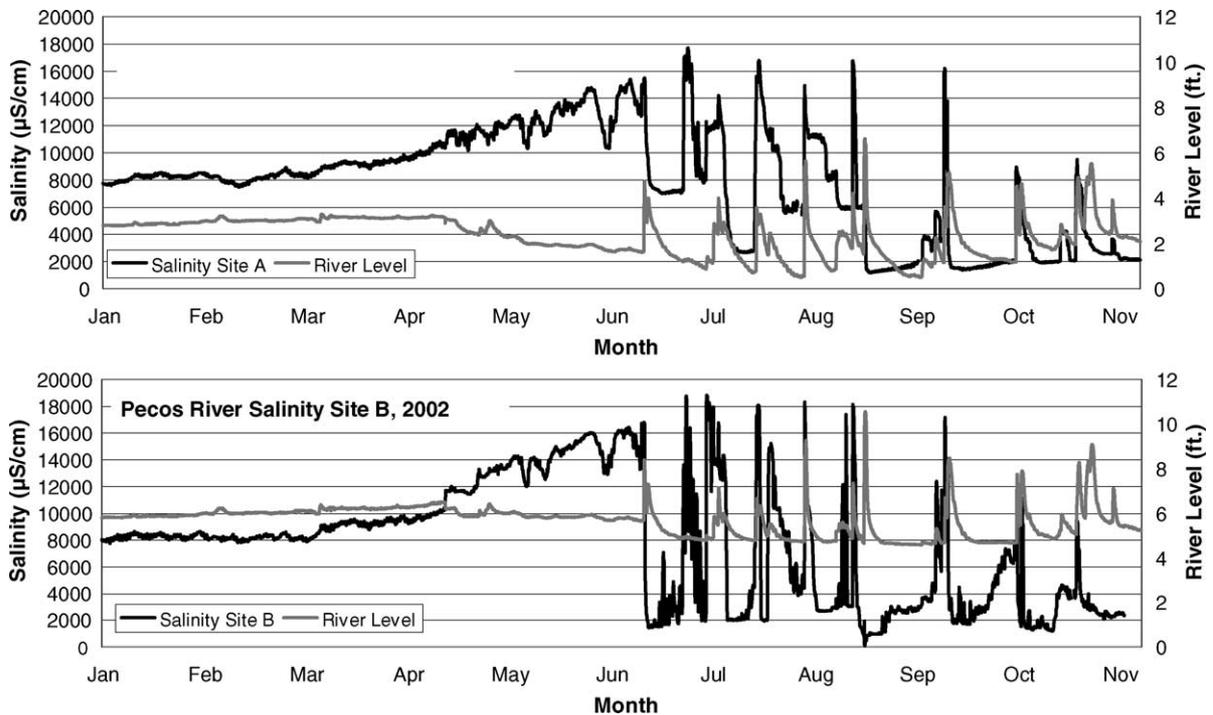


Fig. 7. Electrical conductivity (µS/cm) of Pecos River water and river level (ft) for sites A and B during January to November 2002.

show hourly electrical conductivity and river levels for the two sites during 2001–2003. It should be noted that Red Bluff was releasing water for irrigation during the 2001 growing season but did not release irrigation water during the entire 2002 and 2003 growing seasons. Natural base

flow in the river is extremely low when irrigation releases are not made. A further evaluation of this data is planned, but general observations indicate salinity tends to increase when water is released from Red Bluff Reservoir, and decrease with rainfall events.

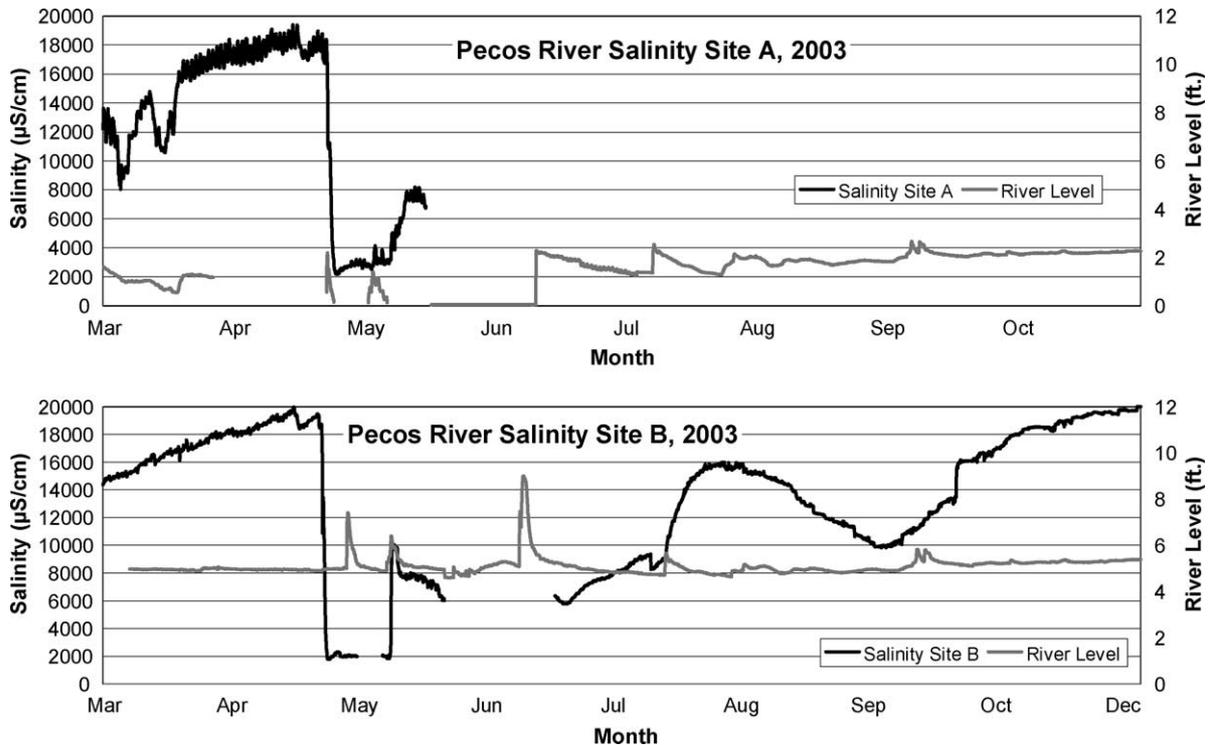


Fig. 8. Electrical conductivity (µS/cm) of Pecos River water and river level (ft) for sites A and B during March to November 2003.

Table 1
Average monthly release, delivery and percent loss for three release and delivery periods for the Pecos River from 1988 to 1999

Delivery period	Average monthly (acre-ft)		
	Release	Delivery	Percent loss
First month	7862	2927	68
Growing season	11,105	6648	39
Late season	3534	2074	43

3.3. Water quantity/flow

One priority was to determine if a relationship existed between water released at Red Bluff Reservoir and the amount of flow measured at Girvin. A coefficient of determination was calculated on flow (cfs) measured at Girvin and the volume of water (cfs) released from Red Bluff Reservoir, where $r_2=0.15$ ($p<0.05$). A low correlation provides evidence that release from Red Bluff Reservoir is at best only weakly related to flow through the USGS station at Girvin (Clayton, 2002).

Once it was determined that losses occurring between release and delivery were not highly correlated to the flow at Girvin, only release and delivery data were analyzed and the Girvin data were not utilized in the analysis. It was observed that during certain time periods within a delivery year, percent loss changed considerably. This pattern precipitated dividing the irrigation delivery year into three categories, initial release and delivery (first month), release and delivery during the growing season, and later release and delivery (later irrigation season). Initial releases did not

occur during the same month each year but varied between March and April. Delivery months were then numbered consecutively from the first month of release each year. The three categories allowed for a characterization of changes in percent loss occurring during the delivery year.

A monthly average was calculated for each of the three delivery categories (Table 1). The first month releases averaged 7862 acre-ft with a delivery of 2927 acre-ft and resulted in an average percent loss of 68%. Monthly releases increased during the growing season to an average of 11,015 acre-ft, but losses decreased to 39%. Average release for the late season was the lowest, 3534 acre-ft, with a loss of 43%. It is obvious that much of the release during the first month is used to ‘re-charge’ the banks that were naturally ‘drained’ during the non-irrigation winter months. This initial loss can account for a significant amount of the water lost during the irrigation delivery year.

An average pattern of release and percent loss was also determined for each month from 1988 to 1999 during the period of a delivery year (Fig. 9). The highest average loss occurred during the first month (67%) of release. Percent loss decreased during the second month of release, and for the next 5 months of release the loss ranged from 32 to 47%. However, when the amount of water released begins to decrease in month 7, the percent loss begins to increase (46%) and by month 9, the loss increased to 64%.

Ultimately, this release and delivery data from pre-treatment years will be compared to post-treatment years to determine if control of saltcedar decreases the loss of water during the irrigation period thereby increasing the delivery

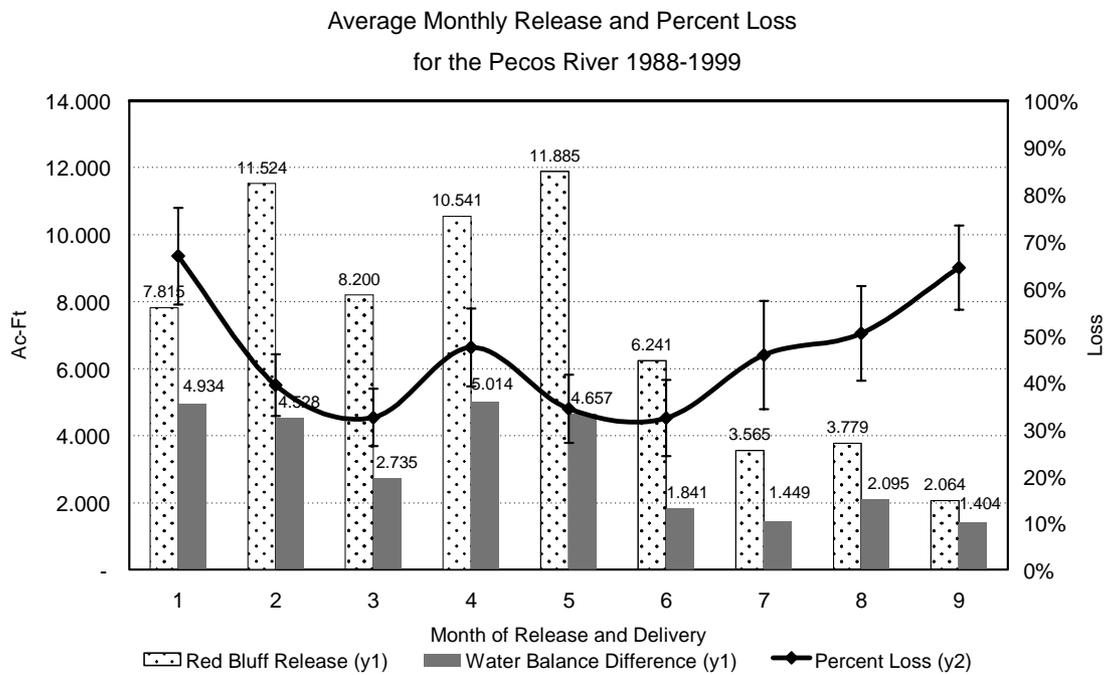


Fig. 9. Average monthly release, delivery and percent loss of Pecos River irrigation water during consecutive delivery months from 1988 to 1999, with standard deviations of percent loss illustrated.

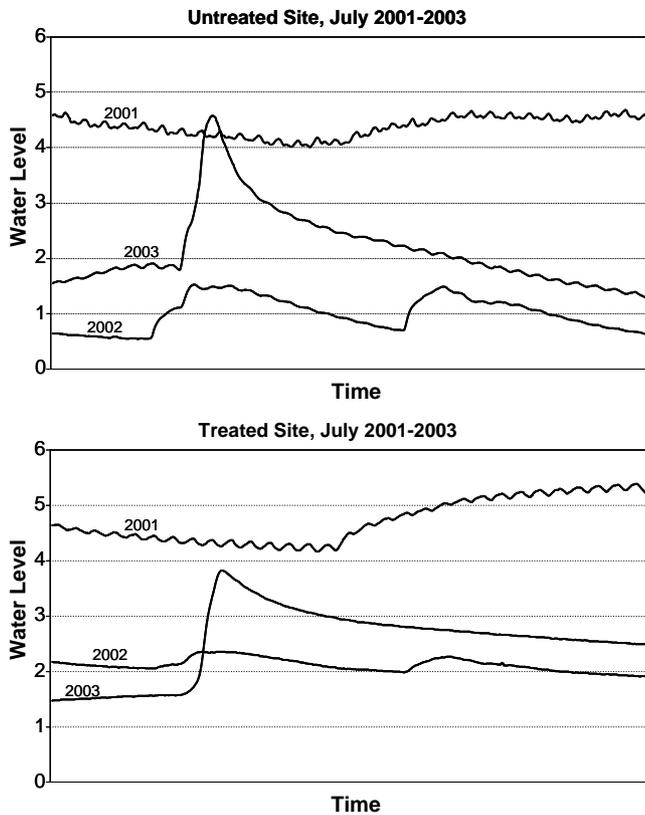


Fig. 10. Shallow groundwater levels at sites A1 (Treated) and B1 (Untreated) during the month of July for the 2001–2003 growing seasons. Saltcedar on the treated site was killed after the 2001 growing season. Note the absence of diurnal fluctuations on the treated site during the 2002 and 2003 growing season.

efficiency. Only a small portion of the Red Bluff District had been treated during 2000–2001 delivery years. During the 2002 and 2003 delivery season, no water was released from Red Bluff Reservoir for delivery to irrigation districts. As irrigation delivery resumes, comparisons of pre-treatment to post-treatment will be made.

3.4. Estimating water salvage

Shallow groundwater wells have been monitored during the 2001–2003 growing seasons. Total water loss is calculated for each of the two plots for each year monitored. During the 2001 growing season, irrigation water was released as normal from Red Bluff Reservoir, but no irrigation water was released during the 2002 and 2003 seasons.

Due to the lack of river flow during the 2002 and 2003 growing seasons, several of the wells were dry during the year; hence only the wells closest to the river are reported at this time. Herbicide treatment was applied to plot A at the end of the 2001 growing season. Nearly 90% control of all vegetation was observed at this plot after the 2002 growing season. Fig. 10 shows the diurnal fluctuations in the groundwater table during July of each of the years for well locations A1 (treated plot) and B1 (untreated plot). Note that at well location B1, the diurnal fluctuations are evident for all 3 years. However, at well location A1, the diurnal fluctuations disappear during the 2002 and 2003 growing season. This is attributed to the fact that the saltcedar was killed on this plot after the 2001 growing season. Total water loss per year was calculated at 1.72 m at well location B1 and 2.96 m at well location A1 for the 2001 growing season (Fig. 11). Water loss at well location B1 remained fairly constant at 1.94 and 2.03 m, respectively, for 2002 and 2003. Water loss at well location A1 was reduced to 0.17 and 0.04 m, respectively, for 2002 and 2003, after saltcedar treatment.

Total water loss was greatly reduced following saltcedar control, although the actual amount of salvage cannot yet be calculated. In addition, native plants have taken over some of the area where the saltcedar has been treated, which will further complicate the estimate of water salvage and its fate. Research will continue to document actual water loss and estimate the amount and

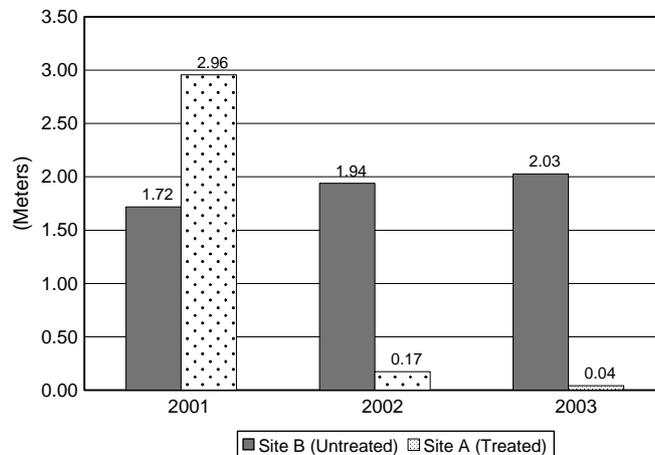


Fig. 11. Total annual groundwater loss from Site A (Treated) and Site B (Untreated) for three growing seasons. Site A saltcedar was treated after 2001 growing season and shows dramatic decrease in water loss. Site B remains untreated through 2003.

fate of salvaged water. Additional, updated information on the project can be obtained from the Internet at the following web site: <http://pecosbasin.tamu.edu>

4. Conclusions

In summary, saltcedar control using the herbicide application described was successful with an average of 85–90% apparent mortality of saltcedar 2 years after treatment. With long-term monitoring, treatment life of the control strategies should be further evaluated and follow-up management alternatives explored.

Preliminary results indicate that there is a great potential for water salvage by saltcedar control even though no fixed values were obtained for amount of water salvage, nor is the fate of the salvaged water identified. It is recommended that additional studies on surface water and shallow ground water interaction be conducted to have a better understanding of the fate of the potentially salvaged water. Additional study is also recommended to explore and validate the methodology for assessment of water salvage.

It is uncertain that saltcedar control improves the water quality in the river. However, it is suggested that monitoring of water quality be continued and additional analysis be conducted on water quality data to characterize the temporal and spatial variations.

This paper presents preliminary results of an ongoing project. Besides the above-mentioned recommendations, the authors also identified several other related issues that should be addressed in future studies. One of the factors that affect assessment of the water salvage is the drought in the region. To overcome such an effect, long-term monitoring is recommended to gain a better understanding of the fate of salvaged water during the wet period. The second factor is re-vegetation or taking-over of the riparian zone by native plants, which could use some of the water salvaged by saltcedar control. Therefore, how much water is needed by native plants should be considered in estimates of long-term water salvage.

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References

- Anderson, B.W., Ohmart, R.D., 1977. Vegetative structure and bird use in the Lower Colorado River Valley. In Importance: preservation and management of riparian habitat; a symposium. USDA Forest Service General Technical Report RM-43.
- Blackburn, W., Knight, R.W., Schuster, J.L., 1982. Saltcedar influence on sedimentation in the Brazos River. *J. Soil Water Conserv.* 37 (5), 298–301.
- Carmen, J.G., Brotherson, J.D., 1982. Comparison of sites infested and not infested with saltcedar (*Tamarix ramosissima*) and Russian olive (*Elaeagnus angustifolia*). *Weed Sci.* 30, 360–364.
- Clayton, L., 2002. Saltcedar management strategies and effects on water quality and quantity of the pecos river. Texas A&M University, Masters Thesis, p. 86.
- Cohan, D.R., Anderson, W., Ohmart, R.D., 1978. Avian population responses to saltcedar along the Lower Colorado River, USDA Forest Service General Technical Report WO-12 1978.
- Davenport, D.C., Martin, P.E., Hagar, R.M., 1982. Evapotranspiration from riparian vegetation: water relations and irrecoverable losses for saltcedar. *J. Soil Water Conserv.* 37, 362–364.
- Devitt, D.A., Sala, A., Mace, K.A., Smith, S.D., 1997. The effect of applied water on the water use of saltcedar in a desert riparian environment. *J. Hydrol.* 192 (1–4), 233–246.
- Duncan, K.W., 1997. A case study in *Tamarix ramosissima* control: Spring Lake, New Mexico, in: Brock, J.H., Wade, M., Pysek, P., Green, D. (Eds.), *Plant invasions: Studies from North America and Europe*. Backhuys Publishers, Leiden, The Netherlands, pp. 115–121.
- Duncan, K.W., McDaniel, K.C., 1998. Saltcedar (*Tamarix* spp.) management with Imazapyr. *Weed Technol.* 12 (2), 334–337.
- Everitt, B.L., 1998. Chronology of the spread of tamarisk in the central Rio Grande. *Wetlands* 18 (4), 658–668.
- Hays, K.B., 2003. Water Use by saltcedar (*Tamarix* sp.) and associated vegetation on the Canadian, Colorado and Pecos Rivers in Texas. Texas A&M University, Masters Thesis, p. 115.
- Hollingsworth, E.B., 1973. Summary report phreatophyte research Los Lunas, New Mexico 1961–1972 1973. USDA-ARS.
- Kunzmann, M.R., Johnson R.R., Bennett, P.S. Technical coordinators. 1988. Tamarisk control in southwestern United States; 1987 September 2–3; Tucson, AZ. Special Report No. 9. Tucson, AZ: National Park Service, Cooperative National Park Resources Studies Unit, School of Renewable Natural Resources: 141 p.
- Neil, W., 1983. The *Tamarisk* invasion of desert riparian areas. *Education Bulletin #83–84*. Publication of the Education Foundation of the Desert Protective Council.
- Robinson, T.W., 1965. Introduction, spread, and areal extent of saltcedar (*Tamarisk*) in the western states, US Geological Survey Professional Paper 491-A 1965. 12 p.
- Schopmeyer, C.S., 1974. *Agricultural Handbook No. 450*. USFS-USDA, Washington D.C.
- Smith, S.D., Devitt, D.A., Sala, A., Cleverly, J.R., Busch, D.E., 1998. Water relations of riparian plants from warm desert regions. *Wetlands* 18 (4), 687–696.
- Taylor, J.P., McDaniel, K.C., 1998. Restoration of saltcedar (*Tamarix* sp.)-infested floodplains on the Bosque del Apache National Wildlife Refuge. *Weed Technol.* 12 (2), 345–352.
- Tomanek, G.W., Ziegler, R.L., 1960. Ecological studies of saltcedar. Unpublished Report. Division of Biological Sciences. Fort Hays State College, Kansas, p. 126.
- Walker, L.R., Smith, S.D., 1997. Impacts of invasive plants on community and ecosystem properties, in: Luken, James O., Thieret, John W. (Eds.), *Assessment and Management of Plant Invasions*. Springer, New York, pp. 69–86.