ABSTRACT

Saltcedar Management Strategies and Effects on Water
Quality and Quantity of the Pecos River. (May 2002)

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Aerial herbicide treatments initiated in August 1999 on the Pecos River near Orla, Texas, were evaluated for saltcedar density, vegetation cover and soil salinity pre-treatment and one and two years post-treatment. Saltcedar density was used to determine the effectiveness of treatments. All treatments with the exception of Treatment 2 resulted in significant saltcedar mortality compared to the control (Treatment 1). Treatment 6 was determined to be the best treatment for control of saltcedar in this study. Treatment 6 provided the highest mortality of all treatments (93.8±2.2%) and lowest variability. Herbicide treatment showed no significant effect on vegetation cover. Vegetation changes that occurred were due to drought conditions. No effect on soil salinity was found following treatment of saltcedar. Average electrical conductivity of the saturated paste extract (mmhos/cm) increased from pre-treatment to one and two years post-treatment periods for 0 to 5 cm depth, but cannot be attributed to control of saltcedar.

Water quality was characterized by current and historical electrical conductivity (EC) data. Electrical conductivity from Red Bluff to Girvin doubled in concentration for current and historical data. A trend toward decreasing EC in the Pecos River appears to be occurring. However, at this time the decrease cannot be attributed to control of saltcedar.

Water quantity was characterized by historical release and delivery data from the Red Bluff Power Control District. Losses occurring during release and delivery from Red Bluff to irrigation districts are influenced by evaporation by riparian vegetation and from the river and accuracy of release and delivery. Water levels and delivery appear to be influenced by seasonal release from Red Bluff and by the level of a shallow water table underneath the river. The highest average percent loss (67%) occurs during the first month of release for the average delivery year. This indicates that during the irrigation off-season the water table drops and during the first month of release, recharge occurs. Average percent loss decreases to 39% during the growing season, indicating that the water table is recharged. Late season average percent loss increases to 43% following low releases that allow the water table to retreat.

ACKNOWLEDGEMENTS

I would like to thank Dr. Charlie Hart, co-chair of my committee, for the opportunity to work on this project, for all the guidance and encouragement he has given and for never letting me give up. I am very grateful also to Dr. Bob Knight, co-chair of my committee, for the work with data analysis and interpretation. Dr. Larry White has been there for me to bend his ear and has offered support in organizing my thoughts to get something on paper. I would also like to thank Dr. Tom Hallmark for help with interpretations of soil data and teaching a course on soil salinity so I could have an understanding of the subject for my thesis.

Financial support for this project was provided by BASF, Monsanto, Helena Chemical Company, Upper Pecos SWCD and USDA-NRCS EQIP program. Additional funding and my assistantship were provided by the Sid Kyle Rangeland Research and Education program.

Thanks goes to everyone at the Pecos Research Station for the use of the facilities and help with lab work. A big thanks also goes to Donna Prochaska and everyone else at the Soil Characterization Lab for help with lab work. A long summer of research in Fort Stockton would have been even longer without the hard work and friendships of Robbie, Katie and Charlie.

I would like to thank Mark, Heidi, Jeff, Buffy, Summer and Brian for their encouragement, motivation, understanding and friendship. I would never have had the courage to start this endeavor if not for the financial support and love provided by my Mom, Dad and Pop. Thanks so much!

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CHAPTER I

INTRODUCTION

Saltcedar is a woody phreatophyte found along the drainage ways of many rivers in the United States (Frasier and Johnsen 1991). It is considered the most evenly and widely distributed phreatophyte in Texas (Ruesink 1983, Busby and Schuster 1973). Saltcedar was introduced to the United States for use in streambank stabilization by private landowners and government agencies. The most recent estimate made by Duncan and McDaniel (1998) claims that saltcedar occupies nearly 120,000 ha along the Pecos River.

The presence of saltcedar in a river system has raised concerns on its effect on water quality. Saltcedar can to adapt and grow in saline environments, where it has the ability to take up salts from surrounding soil and water and void them aboveground (Wiesenborn 1996). Most native riparian vegetation lacks natural adaptations to saline soils; as a result they can be negatively impacted by the deposition of salt by saltcedar.

Saltcedar also poses a problem in a river system by being an extravagant water user. It is thought to be able to reduce stream flow, lower water table depth and evapotranspire large amounts of water (Carman and Brotherson 1982). Saltcedar can evapotranspire as much as 20 to 25 million ac-ft of water annually in the southwestern United States (Ziegler 1960). Significant reductions in annual water loss from clearing

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Citation and style follow the Journal of Range Management.

riparian areas of saltcedar in the southwestern United States have ranged from 0.65 to 2.3 ft/yr (Sala et al. 1996). Blaney (1933) estimated water savings of 20,268 ac-ft/yr by eradicating saltcedar from the Pecos River from Acme to Artesia, New Mexico.

A variety of brush management practices has been developed to reduce saltcedar populations. The use of herbicides has shown the most success. A study conducted by Duncan and McDaniel (1998) showed the most effective herbicide treatment to date. In this study herbicides were applied with an airplane delivering imazapyr at 1.1 kg a.i./ha or imazapyr + glyphosate at 0.56 + 0.56 kg a.i./ha. The treatments were applied on wide bands of saltcedar surround a spring fed lake.

The objective of this study was to determine mortality of saltcedar and other vegetation species using the same rates of herbicide reported by Duncan and McDaniel (1998) applied with both an airplane and helicopter to the river system of the Pecos River. Also, the study would characterize water quality and quantity from the Pecos River, to determine if removing saltcedar improves water quality and quantity in the river. Hypothesis and major objectives of the study were:

<u>Hypothesis:</u> Herbicide treatments applied by helicopter would be more effective than treatments applied by airplane on a river system. Water quality and quantity would be improved by control of saltcedar.

<u>Objective 1:</u> Evaluate selected aerial herbicide application techniques on saltcedar along the Pecos River.

Objective 2: Develop a sampling protocol for measurement of water quality and quantity of the Pecos River for continued monitoring and characterize the effects of saltcedar control strategies on the quality and quantity of water available in the Pecos River.

CHAPTER II

LITERATURE REVIEW

Phreatophytes are a major water issue in arid and semi-arid environments in the western United States. Phreatophytes have been defined as “plants that habitually grow where they can send their roots down to the water table, or the capillary fringe immediately overlying the water table and then are able to obtain a perennial and secure water supply” (Ziegler 1960). In simple terms, a phreatophyte is a plant that acts like a well, pumping water directly from the groundwater (Horton 1972). Saltcedar (*Tamarix spp.*) is a woody phreatophyte found along the drainage ways of many river systems in the United States (Frasier and Johnsen 1991) and is considered the most evenly and widely distributed phreatophyte in Texas (Ruesink 1983, Busby and Schuster 1973). It was estimated in the 1970’s that 243,000 ha of saltcedar grow in West Texas (Busby and Schuster 1973). Frasier and Johnsen (1991) classified saltcedar as one of the ten worst noxious weeds in the United States. Saltcedar vigorously consumes water, invades lowlands and riparian areas where it competitively replaces native grasses, forbs, shrubs and trees. The resulting vegetative communities are less valuable to livestock and wildlife (Stevens and Walker 1996).

Introduction and Invasion of Saltcedar

Saltcedar is believed to be native of southern Europe, northern Africa and eastern Asia (Frasier and Johnsen 1991). It was introduced to the United States from the Middle East (Frasier and Johnsen 1991) and was first advertised in horticultural catalogs for ornamental sales in the 1820's (Duncan and McDaniel 1997). In the early 1900's, private landowners and government agencies purposely planted saltcedar for streambank erosion protection and windbreaks. In 1925, saltcedar was planted in the upper reaches of the Pecos River near Silver City, New Mexico, in an attempt to slow overland water flow and to reduce soil erosion. By 1925, saltcedar covered 5,000 ha; by 1946, 10,600 ha; by 1955, 16,500 ha; and by 1960, about 20,000 ha. Saltcedar is estimated to occupy near 120,000 ha along the Pecos River (Duncan and McDaniel 1998). Saltcedar now grows along drainage ways of many major rivers throughout the lower half of the United States at elevations of 1830 m or lower and is found across the midsection of the United States from the central valleys of California to the southeastern coastal plains (Frasier and Johnsen 1991). Since its introduction, saltcedar occupies almost a million hectares of riparian areas throughout the western United States (Duncan 1997, Clarke and Nelson 1996, Horton 1972).

The high potential of saltcedar to invade a river system is the combination of many biotic and abiotic factors. A major factor is its ability to produce massive amounts of small, easily dispersed seeds over long periods of time (Sala et al. 1996). A single saltcedar plant can produce as many as 500,000 seeds in a growing season that extends from April to October. Seed dispersed by wind and/or water can germinate within 24 hours, when deposited on moist soil. Seeds remain viable up to five weeks under normal conditions (Duncan and McDaniel 1998). Saltcedar also has the ability to germinate and survive in highly saline soils and tolerate long periods of both desiccation and inundation (Sala et al. 1996). The plant has the ability to take up salts from the soil and groundwater and void them above ground. This is accomplish by excreting salts from glands on the leaf surface that act as a funnel, transporting salts from below ground to the leaf surface (Wiesenborn 1996).

Saltcedar also has high root growth rates following seedling establishment (Sala et al. 1996). Initially seedling growth is very slow, but once established, the primary root grows steadily downward with little branching until it reaches the water table. Secondary branching of the root becomes profuse upon contact with groundwater (Duncan 1997). Roots of saltcedar have been known to penetrate more than 27 m (Gatewood et al. 1950).

Saltcedar also has the advantage of reproducing vegetatively (Sala et al. 1996) from its extensive root system (Larmer 1998). Nearly all saltcedar stems and root cuttings can sprout at all times of the year, provided they are kept warm and wet. These vegetative sprouts can grow up to four meters in a year (Duncan and McDaniel 1998). The facultative phreatophytic nature of mature saltcedar individuals is a major advantage over other native plants. When mature, saltcedar roots occupy both the capillary zone above the water table and the zone of saturation (Duncan 1997).

Abiotic factors that encourage the invasion of saltcedar are mainly of anthropogenic origin, resulting from cumulative impacts of water management programs, i.e., dams, river diversions, flow regulation regimes and irrigation projects (Sala et al.1996). Historically, riparian vegetation supported a mosaic of cottonwood-willow woodlands, brush lands, marshes and meadows in various stages of succession resulting from the periodic movement of a river or stream across the floodplain (Taylor and McDaniel 1998).

Completion of large scale water management programs on most river systems has caused irreversible changes in these native riparian zones. The natural river hydrology has been altered to only allow periodic flooding events. Changes in annual river flow patterns curtail the natural regeneration of native trees and shrubs which released seed to coincide with late spring flooding events (Taylor and McDaniel 1998). Water management programs also caused confinement and narrowing of stream systems (Taylor and McDaniel 1998). Changes in the river system with irrigation and flood control systems also caused a change in the riparian vegetation by lowering the water table (Horton 1972). Native vegetation is dependent on the water table for establishment and growth. The lowering of the water table ultimately results in a reduction of wetland and meadow habitats (Taylor and McDaniel 1998). The absence of naturally occurring events has allowed exotic species, such as saltcedar, to flourish and now dominate river floodplains (Taylor and McDaniel 1998).

Once saltcedar becomes established, the dense cover can have a major impact on the hydrologic balance of an area. The vegetation increases areas inundated by floods by choking or reducing the width of the normal channel, obstructing flood waters and reducing peak flows (Ruesink 1983). During a flood, the damming and ponding effects of dense saltcedar reduce stream velocity and consequently its power to carry sediment, which causes an increase in sedimentation (Blackburn et al. 1982).

Effects of Saltcedar on Water Quality

A major concern with the presence of saltcedar in river systems is its effect on water quality. Water quality concerns come from the plant's ability to take up salts from surrounding soil and water and void them above ground (Wiesenborn 1996). Saltcedar thus acts as a transport mechanism for salts from the soil and groundwater to the leaf surface through leaf glands. Salt gland exudate containing 41,000 ppm of total solids has been measured on plants rooted in groundwater containing 2,000 ppm total solids. Because saltcedar is deciduous, all of the salts exuded eventually reach the soil surface. Salinity levels beneath the plant can increase as leaf fall accumulates until rainfall or floods carry the salts through the soil and back to the groundwater or into the river or stream (Wiesenborn 1996). This process causes soils of saltcedar infested sites to become more saline, with the principal cation being sodium. Concentrations of all soluble salts averaged 5200 ppm (mg salt/kg soil) in the upper 20 cm of the soil surface supporting saltcedar (Carman and Brotherson 1982). Saltcedar can occur on soils with soluble salt concentrations of 700 ppm to as high as 15,000 ppm (Carman and Brotherson 1982). Lacking a similar adaptation to saline soils, many native riparian plants are affected by the salts transported by saltcedar to the soil surface (Wiesenborn 1996). Native plants are unable to tolerate high salinity and consequently plant diversity diminishes, resulting in a monoculture of saltcedar.

Water Use by Saltcedar

The annual rate of water consumed by saltcedar is greater than that of other phreatophytes (Ziegler 1960, Carman and Brotherson 1982). Saltcedar is considered an extravagant water user due to its ability to reduce river and stream flow, lower water table depth and evapotranspire considerable amounts of water (Carman and Brotherson 1982). The water lost from saltcedar is through the process of evapotranspiration (ET) into the air, which is irrecoverable. Saltcedar has the highest transpiration rate of any North American phreatophyte and can depress a water table by as much as 3.9 to 6.9 ft/yr (Brotherson et al. 1984). Total seasonal ET is the product of area, rate and time of duration from the evapotranspiring surface (Davenport et al. 1982).

Numerous studies have been conducted that show the amount of water lost from saltcedar is related to stand density, depth to the water table and climatic conditions (Devitt et al. 1997). In California ET by saltcedar in July varied from 0.08 in/day in sparse stands to 0.63 in/day in dense stands (Davenport et al. 1982). In New Mexico ET in June varied from 0.12 to 0.43 in/day, depending on weather and plant density (Davenport et al. 1982). In both of these study areas, ET declined when saltcedar plants were subjected to stress brought on by low soil water availability and/or high evaporative demand (Davenport et al. 1982). In Arizona, summertime ET rates were measured at 0.67 to 0.83 in/day (Van Hylckman 1974). A study conducted in California of a moderate density stand of saltcedar, showed an ET rate of 0.26 in/day, is about the same (96%) as that of native grass. However, when measurements were conducted on very dense stands, the ET rate was 2.4 times that of native grasses (Davenport et al. 1982).

Saltcedar may evapotranspire as much as 20 to 25 million ac-ft of water annually in the southwestern United States (Ziegler 1960). This raises concerns that saltcedar invasion significantly reduces river flow and water table depth. This has resulted in programs to evaluate effects of saltcedar removal. Results have shown significant reductions in the annual water loss by clearing saltcedar from riparian areas in the arid southwestern United States, ranging from 0.65 to 2.30 ft/yr (Sala et al. 1996). Gatewood et al. (1950) estimated that eradication of saltcedar in the Lower Safford Valley along the Gila River, Arizona, would result in a reduction in consumptive use of 28,375 ac-ft/yr. Blaney (1933) made an estimate of water salvage by saltcedar eradication along the Pecos River from Acme to Artesia, New Mexico to be about 20,268 ac-ft/yr. A study conducted along the Gila River in Graham County, Arizona, showed that 1,720 untreated acres lost an average of 21 ac-ft/day for a six-month period. The study area was then cleared and ET declined to 13 ac-ft/day. This equaled a water savings of 8 ac-ft/day within the 1,720 ac. The study area only had 45% phreatophyte canopy, so the savings would be 1.8 ac-ft/ac of phreatophyte vegetation cleared (Horton 1972).

The most recent study where saltcedar was removed to reduce water loss was conducted on Spring Lake near Artesia, New Mexico. Saltcedar was treated with a herbicide application of imazapyr in August 1989. The water table at Spring Lake rose from a depth of greater than 6.0 m below the soil surface to the soil surface within 34 months of application (Duncan 1997). Water returned to the soil surface of Spring Lake in June 1992, almost three years following herbicide application (Duncan 1997).

Brush Management Practices

Brush management practices have been developed to reduce saltcedar populations and minimize their effects on riparian systems. Management efforts in the past have included root plowing and raking, mowing, prescribed burning and cut stump treatments (Frasier and Johnsen 1991, Duncan and McDaniel 1997). Mechanical control using heavy equipment involves removal of aboveground stems, followed by removal of underground root crown portions of the plant. Removal of the aerial vegetation includes gathering, stacking and burning, while the removal of the underground portion includes root plowing, stacking and burning (Duncan and McDaniel 1998). These methods have provided short term benefits only. Resprouting from roots and/or stems typically results in increases in stem density after mechanical treatments or fire (Duncan and McDaniel 1997).

Herbicides have been applied to foliage, stems, bases of stumps and root zones with varying success. Timing of application is important, and best results from foliar applications of glyphosate [N-(phosphonomethyl)glycine] and imazapyr [2-[4,5-dihydro-4-methyl-4-(l-methylethyl)-5-oxo-(1H-imidazol-2-yl]-3-pyridinecarboxylic acid] are obtained when the herbicides are applied in late spring to early fall, particularly when adequate soil moisture is available for good growing conditions (Jackson 1996, Taylor and McDaniel 1998, Duncan and McDaniel 1998). Mild weather and high relative humidity, for an extended period of time before spraying, leads to a reduction in the thickness of the saltcedar cuticles allowing for better herbicide penetration (Taylor and McDaniel 1998). Results from fixed-wing aerial applications indicate that saltcedar mortality of 95-99% can be obtained with imazapyr applied at 1.1 kg a.i./ha or imazapyr + glyphosate applied at 0.56 + 0.56 kg a.i./ha. Helicopter application of imazapyr or imazapyr + glyphosate can also provide at least 90% control of saltcedar (Duncan and McDaniel 1997). Herbicide effectiveness may be reduced as saltcedar height and stem numbers increase (Duncan and McDaniel 1998). Normally a follow up treatment at least two years after the initial treatment is required to control root sprouts (Taylor and McDaniel 1998).

CHAPTER III

METHODS

Study Area

Two studies were initiated in August 1999 on the Pecos River from Red Bluff Reservoir to Girvin, Texas. One study was established near Orla, Texas (Fig. 1). At this location the evaluation of aerial herbicide applications applied along 10 km (6 mi) of the river was performed. The second study was established between Red Bluff Reservoir and Girvin (Fig. 2), where saltcedar's influence on water quality and quantity was evaluated over 344 km (214 mi) of the river.

The study area is located within the Chihuahuan Desert ecosystem. The Chihuahuan Desert ecosystem includes southern New Mexico and southwestern Texas, as well as over 80% of Mexican states of Chihuahua, Coahuila, Nuevo Leon, Durango, Zacatecas, San Luis Potosí, Tamaulipas, and extreme northern Guanajuato (Macmahon and Wagner 1985). The Chihuahuan Desert receives its moisture largely (65-80%) during summer from the Gulf of Mexico. Precipitation occurs primarily as convection storms, where rainfall tends to arrive in events of short duration and high intensity (Macmahon and Wagner 1985). Mean annual precipitation ranges from 20.3 to 45.7 cm (8.0 to 18.0 in), with dry periods occurring in January through May (Hatch et al. 1990).

Upland soils are mostly clay loams, clays and sands over loamy to clayey, calcareous, gypsic or saline subsoils (Hatch et al. 1990). Vegetation ranges from desert grassland to desert shrubs. Principal vegetation types are *Larrea tridentata*, *Flourensia*

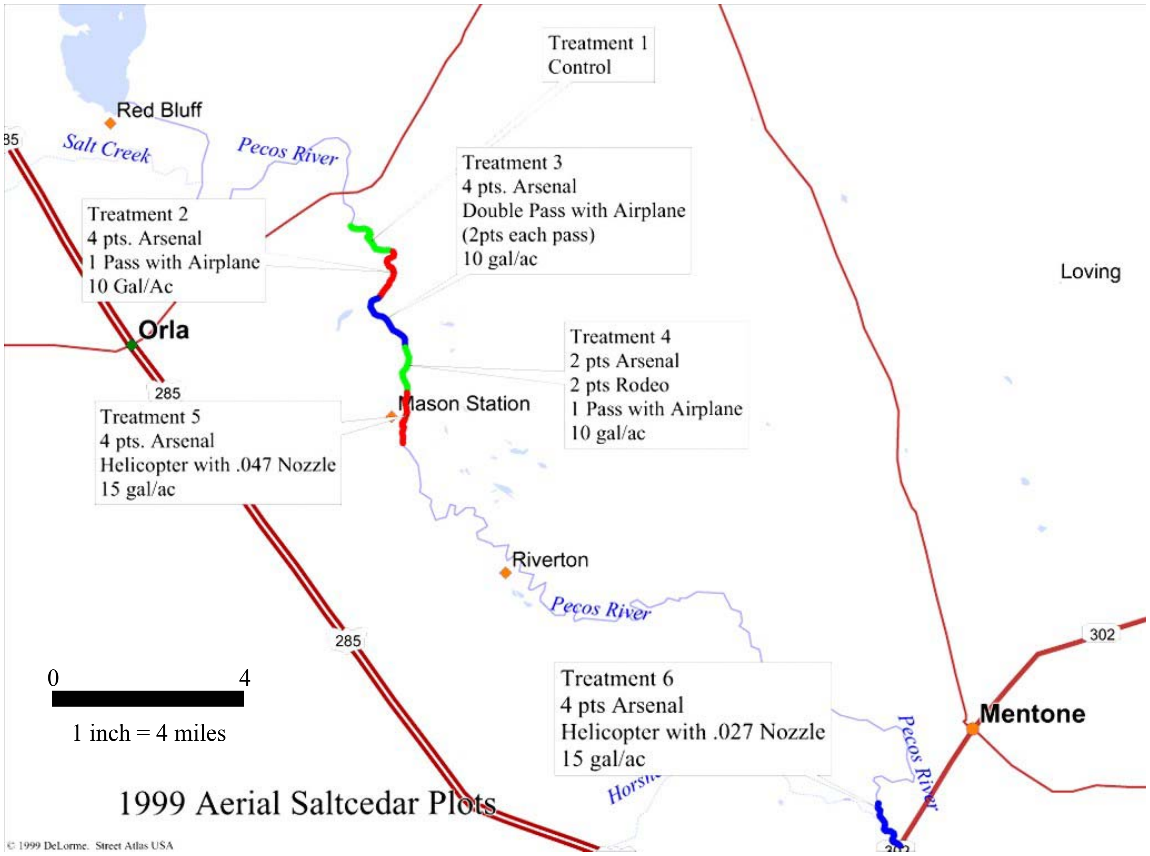

Fig. 1. Aerial herbicide study area located near Orla, Texas (DeLorme, Inc. 2001). The six aerial herbicide treatment locations are shown.

cernua, *Acacia greggii*, *Mimosa biuncifera*, yucca and juniper savannahs, and tobosa flats. *Sporobolus airoides* and species of saltbush (*Atriplex spp.*) occur on saline soils. On the desert grasslands, *Bouteloua eriopoda* and *Hilaria mutica* have most recently been replaced by *Scleropogon brevifolius* and *Dasyochloa pulchella*. More productive sites have numerous species of *Bouteloua*, *Muhlenbergia*, *Sporobolus* and *Aristida* grasses (Hatch et al. 1990).

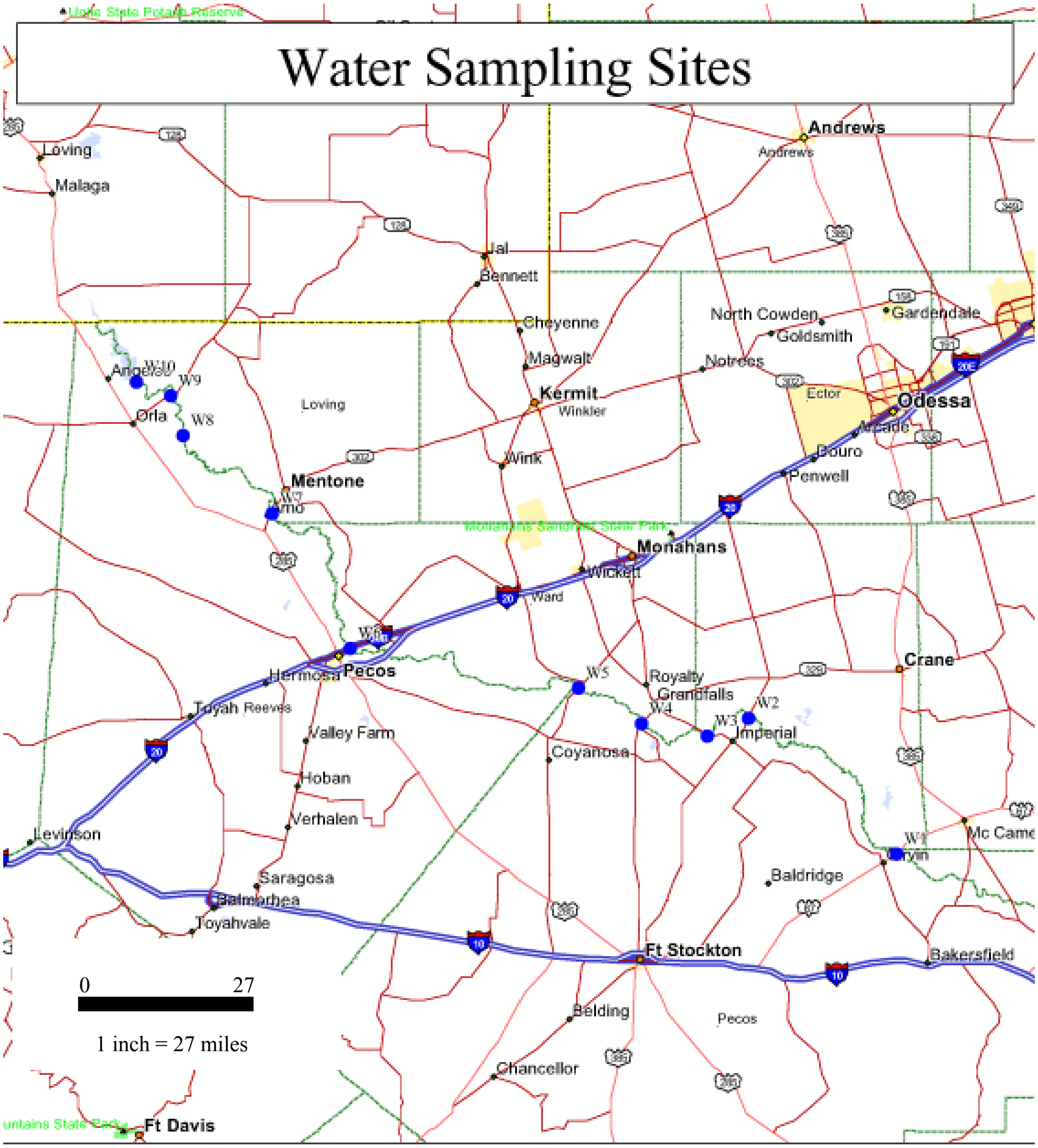

Fig. 2. Water quality sampling sites located along the Pecos River between Red Bluff Reservoir and Girvin, Texas (DeLorme, Inc. 2001).

Aerial Herbicide Treatments

Six treatments were established and replicated twice along a 10 km section of the Pecos River near Orla. The six treatments were applied to 1.6 km (1 mi) plots along the river. Two aerial herbicide treatments were applied on September 18, 1999 from 8:55 am to 10:00 am. These treatments were applied with a helicopter using a 13.7 m (45 ft) boom/swath width delivering a total spray volume of 140 l/ha. The helicopter spray boom was divided into three 4.6 m (15 ft) sections, controlled by the pilot. Flight speed of the helicopter was approximately 48 km/hr (30 mph). The herbicides for each of the two treatments were mixed by the applicator (Northstar Helicopters), and standard procedures were used to calibrate the equipment. The wind speed during the time the treatments were applied was 0 to 5 mph and the wind direction was from the north. Air temperature and relative humidity were 24º C and 61%, respectively at the time of application. Three additional aerial herbicide treatments were applied on October 10, 1999 from 8:00 am to 10:30 am with an airplane using a 19.8 m (65 ft) fixed swath width delivering a total spray volume of 93.5 l/ha. The flight speed of the airplane was approximately 120 mph (193 km/h). The herbicides for each of the three treatments were mixed by the applicator (Ag Aero) and standard procedures were used to calibrate the equipment. The wind was from the west to southwest with a speed of 5 to 15 mph at the time the treatments were applied. Air temperature and relative humidity were measured at 24º C and 40%, respectively. The size of the droplet delivered by the airplane was variable, ranging from 50 to 300 μ. The six treatments applied in 1999 were as follows:

- **Treatment 1** → Control, no treatment applied.
- **Treatment 2** → 0.56 kg a.i./ha of imazapyr plus 0.38 l/ha surfactant delivered with one pass by airplane.

- **Treatment 3** → 0.56 kg a.i./ha of imazapyr plus 0.38 l/ha surfactant delivered with two passes, with a half rate with each pass (0.28 kg a.i./ha with each pass).
- **Treatment 4** → 0.56 kg a.i/ha of glyphosate, 0.28 kg a.i./ha of imazapyr and 0.38 l/ha surfactant delivered in a single pass by airplane.
- **Treatment 5** → 0.56 kg a.i./ha of imazapyr and 0.38 l/ha surfactant delivered with one pass by helicopter equipped with Accuflo 0.047 mm nozzle that delivered 1500 µ droplets.
- **Treatment 6** → 0.56 kg a.i./ha of imazapyr and 0.38 l/ha surfactant delivered with one pass by helicopter equipped with Accuflo 0.027 mm nozzle that delivered 1000 µ droplets.

A 90% non-ionic commercial surfactant (Induce®) was used with each herbicide treatment. The treatment design allowed statistical evaluation of four main components:

1. Overall treatment comparison.
2. One pass verses two passes with the airplane.
3. Two tank mix comparisons with the airplane.
4. Two droplet sizes with the helicopter.

Density and Mortality of Saltcedar

Density of saltcedar (number of trees/ha) along each permanent transect was determined through the use of 30 m (100 ft) belt transects (Cook and Stubbendieck 1986). Two permanent transects were established within in each 1.6 km (1 mi) plot. Density of saltcedar was determined by counting the numbers of trees within the belt transect from the permanent 30 m (100 ft) transect line to the rivers edge. The width of the bank was then measured from the edge of the saltcedar canopy to the waters edge of the river. Information was used to estimate number of trees/ha to determine the effectiveness of the herbicide applications. Density measurements were taken for each transect at pre-treatment and one and two years post-treatment during the month of August. During both post-treatment years numbers of live and dead trees were counted. Saltcedar plants with any evident regrowth were considered live trees. The density of saltcedar for each transect was determined with the use of the following formula:

$$\text{trees/ha} = \frac{43560\text{ft}^2/\text{ac}}{100\text{ ft} * \text{river bank width (ft)}} * (\text{\# of trees}) * \frac{1\text{ ac}}{2.47\text{ ha}}$$

Vegetation Cover

Within each plot, two 30 m (100 ft) permanent transects were established just outside of the saltcedar canopy in order to determine any off-target spraying from herbicide application. At each transect, percent cover estimates (Cook and Stubbendieck, 1986) of canopy cover by species were taken every 3 m (10 ft) with the use of a 1 m^2 frame. The percentages for each observation were averaged for each species found along the permanent transect, giving an average cover for each transect. Vegetation cover measurements were taken for each transect at pre-treatment and one and two years post-treatment during the month of August.

Soil Salinity

Composite soil samples were taken under the saltcedar canopy at depths of 0 to 5, 5 to 15 and 15 to 30 cm, within each 30 m (100 ft) belt transect. Composite samples were taken along the 30 m (100 ft) belt formed by the transect line, with five samples taken every 6 m (20 ft). The five samples were not taken at the same location during the three years of the study. Composite soil samples were taken for each transect pre-treatment, one and two years post-treatment.

All soil samples were analyzed for electrical conductivity of the saturated soil paste extract (ECe) and sodium absorption ratio (SAR) of the saturated paste extract (Richards 1954, Soil Survey Staff 1972). Once the extract was obtained, the ECe (mmhos/cm) was determined with the use of an electrical conductivity (EC) meter (ElectroMark Analyzer). SAR was determined from Ca and Mg concentrations using atomic absorption spectroscopy and Na concentrations using flame emission (SpectraAA55, Varian Instruments).

Water Quality

Water quality of the Pecos River was characterized by use of two data sources. The current water quality of the river was determined by water samples taken at ten locations from Red Bluff Reservoir to Girvin (Fig. 2). Water samples at each site were taken with the use of a plastic bucket, with a nylon rope attached to the handle. Each sample was taken from the top of a bridge crossing the river. The bucket was dropped from the top of the bridge into the middle of the river channel. The bucket was allowed to catch water from the surface of the river, pulled back up to the top of the bridge, poured into a clean plastic container and kept cool. Total dissolved solids (TDS) (Greenberg et al. 1992), total suspended solids (TSS) (Greenberg et al. 1992), and EC (mmhos/cm) were measured for each sample. Measurements were conducted within seven days of initial sampling date. The second source involved three sites that are monitored by the Texas Natural Resources Conservation Commission (TNRCC) Clean Rivers Program (CRP) (http://www.ibwc.state.gov/CRP/monstats.htm). The three sites used in the study were 13257, 13260 and 13265. CRP involves sampling with a portable water quality tester and sampling kit, which measures TDS, TSS, EC, pH, dissolved oxygen, water depth, water temperature and instantaneous flow rate in cubic feet per second (cfs). These three sites correspond to three of the ten current water sampling sites. Two of the three sites have been monitored since 1972. Use of this historical data will allow for characterization of the effects of saltcedar on the water quality of the river over time.

Water Quantity

Characterization of the water balance from release to delivery along the Pecos River was determined with the use of historical and current flow data provided by the Red Bluff Water Power Control District, local water irrigation districts and the United States Geological Survey (USGS) Gauging Station 08446500 (http://tx.waterdata.usgs.gov/nwis/current?type=flow) located at US Highway 67 northeast of Girvin.

The irrigation districts and the USGS site have records of water released and delivered along the Pecos River from Red Bluff Reservoir to Girvin. The difference between released and delivered water provides a measure of loss occurring to the irrigation district. All loss expressed in this study is based on measurements taken by the Red Bluff Power and Control District, and the word “loss” refers to loss to the irrigation district. Red Bluff Power and Control District controls the release of water from Red Bluff Reservoir and delivery of water to seven local irrigation districts. All water released from Red Bluff Reservoir that is not captured by an irrigation district is delivered and stored in Imperial Reservoir. There are five irrigation districts above Imperial Reservoir. The other two irrigation districts receive water directly from Imperial Reservoir. Losses occurring to the irrigation district were determined by obtaining measurements of total water released from Red Bluff, total water delivered to the five irrigation districts above Imperial and total water delivered to Imperial for each month of a delivery period. The difference between release and delivery was calculated and the difference between release and delivery was then divided by release and multiplied by 100, to obtain a percent loss for that time period. Evaluations were also made to determine if the flow data from the Girvin USGS station or rainfall patterns showed a relationship to the release/delivery information.

Statistical Analysis

A standard analysis of variance model (used SAS Version 8 analysis software) was used to statistically identify the effects of herbicide treatments, before application of herbicides, as well as one and two years post herbicide application. Duncan's multiple range test (Steel and Torrie 1960) was utilized for mean separation when applicable. A coefficent of determination (Steel and Torrie 1960) was also used to evaluate the correlative relationship between flow at USGS station at Girvin to the release at Red Bluff Reservoir. Significance levels were determined at the 95% probability level.

CHAPTER IV

RESULTS AND DISCUSSION

Aerial Herbicide Treatments

Saltcedar Apparent Mortality

Saltcedar mortality from six aerial herbicide treatments was evaluated one and two years post-treatment (Table 1). While average mortality across treatments was not significantly different between years ($p<0.05$), second year estimates from 2001 (47.8%) averaged higher than first year estimates from 2000 (45.2%). Studies conducted in New Mexico showed that it takes two years to see full results of treatment after saltcedar is sprayed with imazapyr (Duncan and McDaniel 1997). When herbicide treatments are applied in July through September, the majority of the trees will die the first winter. However, by the second year 15% of the trees that survived the first year will die (Dale 1997). Therefore, <u>mortality estimates discussed hereafter will be two year mortality results only</u>.

Control plots (Treatment 1) showed no natural mortality, two year mortality from herbicide treatments ranged from a low of 29.4%±31.3 on the single pass airplane with imazapyr treatment (Treatment 2), to a high of 93.8%±2.2 on the helicopter, small nozzle treatment (Treatment 6). All herbicide treatments with the exception of the airplane, single pass with imazapyr treatment provided significant ($p<0.05$) saltcedar mortality over control plots. The helicopter small nozzle treatment provided significantly higher mortality over all airplane treatments and gave the lowest amount of variability among transects.

Table 1. Percent mortality of saltcedar for all treatments during 2000 and 2001, following herbicide application in 1999.

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
2000	0±0 [2] c (a) [3]	34.5±10.6 b (a)	30.0±14.2 b (a)	41.2±10.9 b (a)	78.6±8.8 a (a)	86.6±3.6 a (b)	45.2±32.3 (a)
2001	0±0 d (a)	29.4±31.3 cd (a)	47.0±10.9 bc (a)	40.3±30.7 c (a)	76.2±22.1 ab (a)	93.8±2.2a (a)	47.8±63.1 (a)
Trt Avg.	0±0 c	32.0±21.8 b	38.5±14.8 b	40.7±21.3 b	77.4±15.6 a	90.2±4.8 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 μ droplet and Trt 6 – helicopter, 1000 μ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

The study was designed to test three main comparisons between treatments, and each will be discussed separately. The first comparison evaluated single and double passes of the airplane for efficacy. Treatments 2 and 3 were statistically compared to Treatment 1 (control) to determine if the double pass with the airplane provided greater control than the single pass with the airplane. Both treatments applied imazapyr with a surfactant. Although the total quantity of herbicide applied per acre was equivalent, the double pass treatment applied half the rate with each pass. The double pass yielded higher mean mortality (Treatment 3, 47.0%±10.9) than the single pass treatment (Treatment 2, 29.4%±31.3), although the difference was not significant ($p<0.05$) (Table 2). The standard deviation was three times higher for Treatment 2 versus Treatment 3, 31.3% and 10.9% respectively. Statistically, the double pass was significantly different than the control, while the single pass was not. The data suggests, that higher mortality

Table 2. Percent mortality of saltcedar for Treatment 2 and 3 during 2000 and 2001, following herbicide application in 1999.

	Treatments[1]			
Year	Trt 1	Trt 2	Trt 3	Year Avg.
2000	0±0[2] b (a)[3]	30.0±14.2 a (a)	34.5±10.6 a (a)	21.5±18.5 (a)
2001	0±0 b (a)	29.4±31.3 ab (a)	47.0±10.9 a (a)	25.5±26.6 (a)
Trt Avg.	0±0 b	32.0±21.8 a	38.5±14.8 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

may be obtained from a double pass application with the airplane, but there is a high risk of variability and uncertainty.

A second comparison evaluated the use of imazapyr applied alone (Treatment 2) or in combination with glyphosate (Treatment 4) (Table 3). Treatments 2 and 4 were statistically compared to Treatment 1 (control) to determine if the tank mix (imazapyr + Glysophate) provided greater control than imazapyr only. Both treatments were applied by airplane with a single pass. While the imazapyr + glyphosate treatment (Treatment 4) provided higher mean control (40.3%±30.7) compared to the imazapyr alone (Treatment 2, 29.4%±31.3), the difference was not significant ($p<0.05$). Both treatments were highly variable.

A third comparison evaluated application of imazapyr from a helicopter with two

Table 3. Percent mortality of saltcedar for Treatment 2 and 4 during 2000 and 2001, following herbicide application in 1999.

	Treatments [1]			
Year	Trt 1	Trt 2	Trt 4	Year Avg.
2000	0±0 [2] b (a) [3]	34.5±10.6 a (a)	41.2±10.9 a (a)	25.2±20.4 (a)
2001	0±0 a (a)	29.4±31.3 a (a)	40.3±30.7 a (a)	23.3±29.0 (a)
Trt Avg.	0±0 b	32.0±21.8 a	40.7±21.3 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 4 – airplane, one pass with imazapyr.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

different nozzle sizes delivering droplets of 1500 μ (Treatment 5) and 1000 μ (Treatment 6) (Table 4). Treatments 5 and 6 were compared statistically to determine if the smaller droplet provided significantly greater mortality of saltcedar than the larger droplet. Both treatments applied imazapyr herbicide with surfactant. The 1000 μ droplet provided higher mean control (93.8%±2.2) with less variability than the 1500 μ droplet (76.2%±22.1), although the difference was not significant ($p<0.05$). Due to the high variability associated with effectiveness of Treatment 5, statistical differences were not identified.

Vegetation Cover

Vegetation cover was estimated by species for the six treatments at pre-treatment (1999) and one and two years post-treatment (2000 and 2001, respectively). Due to high

Table 4. Percent mortality of saltcedar for Treatment 5 and 6 during 2000 and 2001, following herbicide application in 1999.

	Treatments [1]			
Year	Trt 1	Trt 5	Trt 6	Year Avg.
2000	0±0 [2] b (a) [3]	78.6±8.8 a (a)	86.6±3.6 a (a)	55.1±41.1 (a)
2001	0±0 b (a)	76.2±22.1 a (a)	93.8±2.2 a (a)	56.7±44.1 (a)
Trt Avg.	0±0 c	77.4±15.6 b	90.2±4.8 a	

[1] Trt 1 – control, Trt 5 – helicopter, 1500 µ droplet and Trt 6 – helicopter, 1000 µ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

variability and inconsistency between sampling units and transects, the percent canopy cover by species was grouped into categories of bareground, annual plants and perennial plants for statistical comparisons.

The first comparison evaluated the effects of herbicide treatments on percent bareground. Percent bareground averaged across treatments was significantly different between years ($p<0.05$) with both one and two years post-treatment significantly higher (65.5%±18.7 and 66.4%±24.6, respectively) than pre-treatment (42.9%±19.1) (Table 5). However, comparison of percent bareground within one and two years post-treatment showed no significant difference ($p<0.05$) among treatments. The difference in years can be contributed to drought conditions throughout the study period. While some treatment effects on bareground is evident, however conclusive proof could not be shown due to an overshadowing effect of drought conditions.

Table 5. Percent bareground before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	57.7±10.2 [2] a (a) [3]	49.4±22.9 a (b)	36.7±18.9 ab (a)	19.5±17.2 b (a)	42.0±3.6 ab (b)	52.4±16.1 a (a)	42.9±19.1 (b)
2000	64.1±8.3 a (a)	74.6±12.8 a (ab)	66.5±20.3 a (a)	56.9±26.5 a (a)	67.1±10.1 a (a)	63.6±4.2 a (a)	65.5±18.7 (a)
2001	67.3±14.5 a (a)	80.6±17.2 a (a)	66.0±23.7 a (a)	55.6±23.7 a (a)	66.1±18.2 a (a)	63.0±8.0 a (a)	66.4±24.6 (a)
Trt Avg.	63.0±11.1 a	68.2±21.6 a	56.4±24.0 ab	44.0±27.5 b	58.4±16.4 ab	59.7±11.0 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 µ droplet and Trt 6 – helicopter, 1000 µ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

The second comparison evaluated the effects of the six treatments on percent annual plant canopy cover. Mean percent cover of annual plants was significantly different between years ($p<0.05$) with pre-treatment being significantly higher (24.7%±18.7) than one and two years post-treatment (3.3%±5.7 and 2.3%±5.9, respectively) (Table 6). This again can be attributed to drought conditions present in the area during the study period. Estimates from 2000 showed that percent annual plant cover of the control plots (Treatment 1) were significantly higher than all treatments except for Treatment 6. This indicates that four of the five herbicide treatments did have a negative effect on percent annual plant cover the first year after application. However, estimates from 2001 showed no significant difference among treatments as mean percent annual plant cover decreased from 2000 to 2001 across all treatments. The decrease, while not statistically different, was sufficient to mask treatment effects shown by the

Table 6. Percent vegetation cover of annual plants before treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Treatments[1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	24.9±10.4[2] ab (a)[3]	31.7±25.2 ab (a)	18.8±15.1 ab (a)	36.3±26.3 a (a)	31.0±11.9 ab (a)	5.5±5.7 b (a)	24.7±18.7 (a)
2000	9.8±8.4 a (b)	1.0±1.2 b (b)	0.3±0.5 b (b)	0.5±0.6 b (b)	1.8±2.6 b (b)	6.4±8.3 ab (a)	3.3±5.7 (b)
2001	4.5±5.9 a (b)	0.0±0.0 a (b)	0.0±0.0 a (b)	0.9±1.2 a (b)	1.8±2.9 a (b)	6.6±13.3 a (a)	2.3±5.9 (b)
Trt Avg.	13.0±11.8 a	10.9±20.3 a	6.3±12.1 a	12.5±22.5 a	11.5±15.8 a	6.2±8.7 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 µ droplet and Trt 6 – helicopter, 1000 µ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

one year post-treatment data. The decrease in percent annual plant cover from one and two years post-treatment can be attributed to drought conditions.

A third comparison evaluated the effects of herbicide treatments on percent perennial plant canopy cover. Mean percent cover of perennial plants was significantly different ($p<0.05$) between pre-treatment being (20.2%±24.6) and two years post-treatment (6.6%±12.4) (Table 7). Percent perennial plant cover was not significantly different between the six treatments within years. As a result, the decrease in percent cover of perennial plants between years is attributed to drought effects.

Soil Salinity

Composite soil samples were taken at three depths under the saltcedar canopies for the six herbicide treatments, pre-treatment (1999) and one and two years post-

Table 7. Percent vegetation cover of perennial plants before treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	8.6±4.0 a [2] (a) [3]	8.2±10.3 a (a)	37.1±34.9 a (a)	40.1±38.8 a (a)	17.9±17.0 a (a)	9.4±8.0 a (a)	20.2±24.6 (a)
2000	8.5±7.5 a (a)	3.8±2.5 a (a)	17.9±19.6 a (a)	22.4±30.5 a (a)	5.8±8.5 a (a)	6.3±5.9 a (a)	10.8±15.6 (ab)
2001	2.3±4.5 a (a)	0.3±0.5 a (a)	14.6±16.1 a (a)	15.4±23.9 a (a)	3.5±3.9 a (a)	3.6±3.5 a (a)	6.6±12.4 (b)
Trt Avg.	6.4±5.9 c	4.1±6.6 c	23.2±24.8 ab	26.0±30.6 a	9.0±12.1 bc	6.4±6.0 c	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 µ droplet and Trt 6 – helicopter, 1000 µ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

treatment (2000 and 2001, respectively). Samples were analyzed in the laboratory for electrical conductivity of the saturated paste extract (ECe) (Richards 1954, Soil Survey Staff 1972) and statistically compared by the three depths.

The first comparison evaluated the effects of herbicide treatments on ECe of the soil surface (0 to 5 cm). Electrical conductivity of saturated paste extract (mmhos/cm) averaged across treatments was significantly different between years ($p<0.05$), with both one and two years post-treatment significantly higher (13.8±12.0 and 13.6±12.6 mmhos/cm, respectively) than pre-treatment (6.1±4.9 mmhos/cm) (Table 8). However, ECe compared within years showed no significant difference ($p<0.05$) among treatments. As a result, the increase in ECe from pre-treatment to one and two years post-treatment cannot be attributed to treatments applied to saltcedar. However, several of the treatments showed higher soil surface salinity levels when compared to control

Table 8. Electrical conductivity (mmhos/cm) of soil (0 to 5 cm depth) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	7.6±8.9 [2] a (a) [3]	4.0±3.0 a (a)	4.6±1.6 a (b)	7.4±3.5 a (a)	4.6±2.6 a (a)	8.7±7.0 a (a)	6.1±4.9 (b)
2000	12.8±16.4 a (a)	8.8±5.7 a (a)	26.6±18.5 a (a)	17.5±6.8 a (a)	9.0±3.5 a (a)	8.4±8.0 a (a)	13.8±12.0 (a)
2001	12.1±4.5 a (a)	17.4±15.8 a (a)	13.5±2.0 a (ab)	20.2±28.1 a (a)	9.7±5.1 a (a)	8.8±1.8 a (a)	13.6±12.6 (a)
Trt Avg.	10.8±10.3 a	10.0±10.6 a	14.9±13.6 a	15.0±16.3 a	7.8±4.2 a	8.6±5.6 a	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 μ droplet and Trt 6 – helicopter, 1000 μ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

plots, but due to high variability, these were not statistical significant.

A second comparison evaluated the effects of herbicide treatments on ECe of the second soil sample depth (5 to 15 cm). Electrical conductivity of the saturated paste extract averaged across treatments was significantly different between years ($p<0.05$), with one year post-treatment significantly higher (9.4±6.8 mmhos/cm) than pre-treatment (6.3±3.8 mmhos/cm) (Table 9). The mean ECe of two years post-treatment (8.4±4.1 mmhos/cm) was higher than pre-treatment, though the difference was not significant ($p<0.05$). Electrical conductivity of the saturated paste extract compared within years showed no significant difference ($p<0.05$) among treatments.

The third comparison evaluated the effects of herbicide treatments on ECe of the third soil sample depth (15 to 30 cm). Both one and two years post- treatment provided higher mean ECe levels (8.2±5.5 and 7.0±2.9 mmhos/cm, respectively) than

Table 9. Electrical conductivity (mmhos/cm) of soil (5 to 15 cm depth) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	7.7±6.9 [2] a (a) [3]	5.6±4.0 a (a)	6.3±0.9 a (b)	7.0±3.8 a (a)	5.5±3.3 a (a)	5.8±3.8 a (a)	6.3±3.8 (b)
2000	10.3±11.0 a (a)	6.8±4.6 a (a)	15.5±8.9 a (a)	11.8±3.9 a (a)	6.3±2.0 a (a)	5.9±4.4 a (a)	9.4±6.8 (a)
2001	8.2±5.4 a (a)	11.3±7.2 a (a)	11.4±2.3 a (ab)	7.3±1.9 a (a)	6.0±1.7 a (a)	6.4±1.0 a (a)	8.4±4.1 (ab)
Trt Avg.	8.7±7.4 ab	7.9±5.5 ab	11.0±6.2 a	8.7±3.8 ab	5.9±2.2 b	6.0±3.1 b	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 µ droplet and Trt 6 – helicopter, 1000 µ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

pre-treatment (6.7±4.5 mmhos/cm), but the difference was not significant ($p<0.05$) (Table 10). Electrical conductivity of the saturated paste extract compared within years showed no significant difference ($p<0.05$) among treatments.

Water Quality

Water quality were characterized using both current and historical electrical conductivity (EC) data for the 344 km (214 mi) stretch of the Pecos River from Red Bluff Reservoir to Girvin. The current water quality data were evaluated both pre-treatment and one year post-treatment during the months of August and December. Historical TNRCC EC data were averaged for each site among years when data were available for the months of August and December. The months of August and December were used because typically August is a time of heavy irrigation release, and

Table 10. Electrical conductivity (mmhos/cm) of soil (15 to 30 cm depth) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

	Treatments [1]						
Year	Trt 1	Trt 2	Trt 3	Trt 4	Trt 5	Trt 6	Year Avg.
1999	9.7±9.9 [2] a (a) [3]	6.0±3.7 a (a)	7.0±0.5 a (a)	6.5±3.4 a (a)	6.3±3.0 a (a)	4.6±1.6 a (a)	6.7±4.5 (a)
2000	7.8±6.0 a (a)	7.9±5.5 a (a)	13.7±8.7 a (a)	9.7±3.3 a (a)	5.2±1.8 a (a)	5.0±3.3 a (a)	8.2±5.5 (a)
2001	7.1±4.7 a (a)	8.7±3.8 a (a)	9.1±1.2 a (a)	6.8±1.9 a (a)	5.0±1.2 a (a)	5.3±1.2 a (a)	7.0±2.9 (a)
Trt Avg.	8.2±6.6 ab	7.5±4.2 ab	9.9±5.5 a	7.7±3.1 ab	5.5±2.0 b	4.9±2.0 b	

[1] Trt 1 – control, Trt 2 – airplane, one pass with imazapyr, Trt 3 – airplane, two passes with imazapyr, Trt 4 – airplane, one pass with imazapyr and glyphosate, Trt 5 – helicopter, 1500 μ droplet and Trt 6 – helicopter, 1000 μ droplet.

[2] Values following ± are standard deviations from the mean.

[3] Means followed by the same letter within each row are not significantly different between treatments at the 95% level. Means followed by the same letter within each column in parenthesis are not significantly different by years at the 95% level.

no irrigation water is released during December.

Electrical conductivity levels in August 1999 (pre-treatment) from Red Bluff Reservoir to Girvin ranged from 6.6 to 12.7 mmhos/cm, respectively (Fig. 3). This information showed that the salt level increased as water in the river moved downstream, the level “doubled” in concentration from Red Bluff to Girvin. However, the EC remains relatively constant between site 10 (Red Bluff) to site 6. The larger increase in EC occurs from site 5 to site 1 (Girvin). Electrical conductivity levels one year post-treatment (August 2000) ranged from 6.4 to 10.5 mmhos/cm from Red Bluff Reservoir to Girvin, respectively. The salinity in the river was still increasing as it moved downstream in 2000, however the increase was not as dramatic in 1999.

Historical EC data for the three sites available in the study area also showed, similar increases downstream: the site located near Red Bluff Reservoir averaged

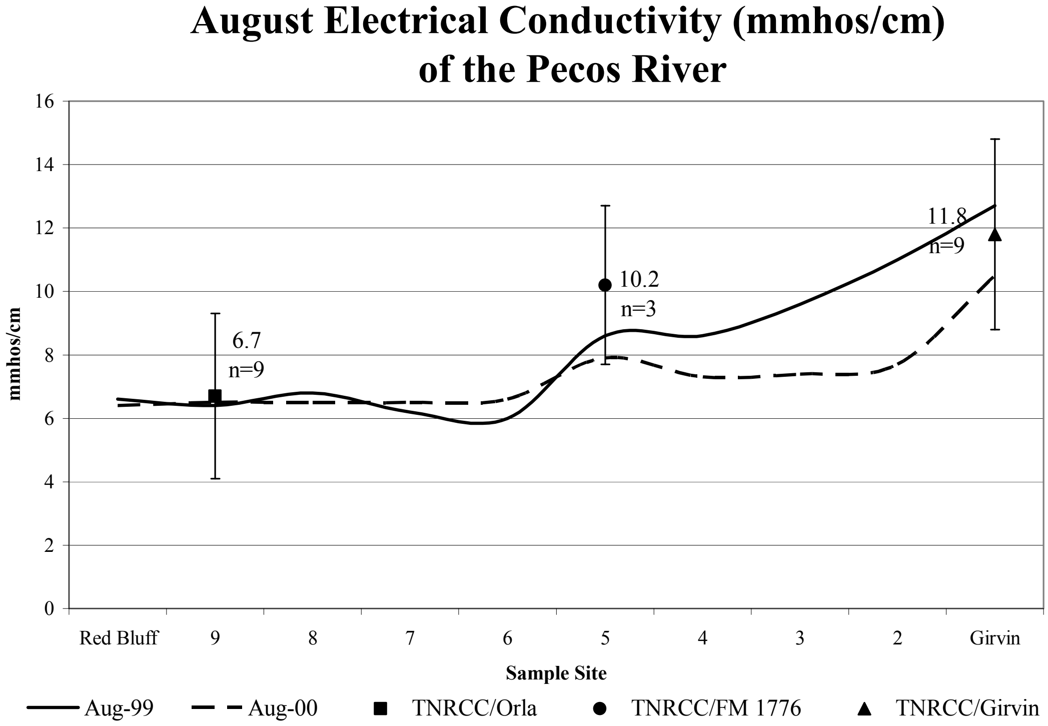

Fig. 3. Electrical conductivity (EC) (mmhos/cm) levels of the Pecos River from Red Bluff Reservoir to Girvin, TX during August. Aug-99 and Aug-00 data indicates EC levels present pre-treatment and one year post-treatment. TNRCC/Orla, TNRCC/FM 1776 and TNRCC/Girvin data points indicates average historical EC levels present in the river from 1972 through 1998 and the variability associated with that average.

6.7±2.5 mmhos/cm (n = 9) and the site located at Girvin averaged 11.8±3.0 mmhos/cm (n = 10). Historically the salinity level also appears to remain consistent with levels observed with the ten current sampling sites.

Electrical conductivity levels in December 1999 (pre-treatment) ranged from 6.7 to 12.3 mmhos/cm, from Red Bluff Reservoir to Girvin, respectively (Fig. 4). Electrical conductivity levels in December 2000 (one year post-treatment) showed the water in the river increased as it moved downstream and the concentration seemed to “double” from

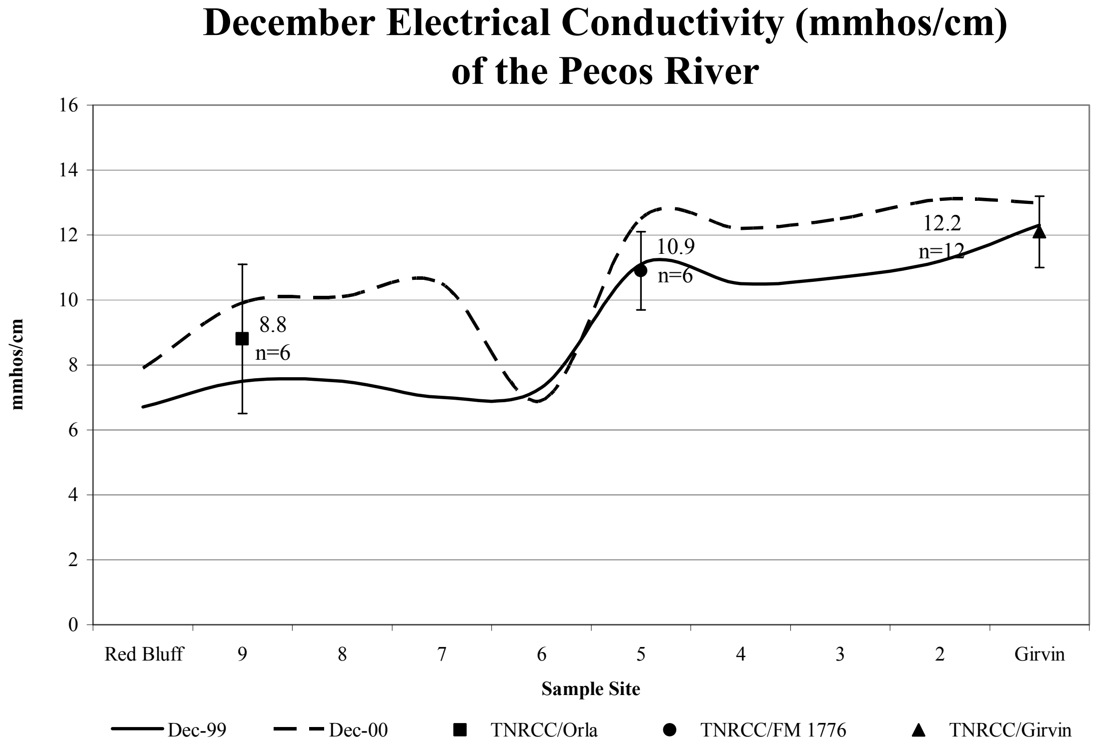

Fig. 4. Electrical conductivity (EC) (mmhos/cm) levels of the Pecos River from Red Bluff Reservoir to Girvin, TX during December. Dec-99 and Dec-00 data indicates EC levels present pre-treatment and one year post-treatment. TNRCC/Orla, TNRCC/FM 1776 and TNRCC/Girvin data points indicates average historical EC levels present in the river from 1972 through 1998 and the variability associated with that average.

Red Bluff to Girvin with the majority of the increase occurring from site 5 to site 1.

Historical data for the month of December also follows the same pattern of increase downstream, as seen with historical data from the month of August, as well as maintaining similar salinity levels to current sampling sites. The TNRCC site located near Red Bluff Reservoir averaged 8.8±2.3 mmhos/cm (n = 6) and the site located at Girvin averaged 12.1±1.1 mmhos/cm (n = 12).

Water Quantity

Water quantity was characterized by determining the water balance from release of water from Red Bluff Reservoir to delivery of water to seven local irrigation districts along the Pecos River. Historical release and delivery data used were provided by the Red Bluff Water Power Control District from 1988 through 1999, along with flow data obtained from United States Geological Survey (USGS) Gauging Station 13257 located at Girvin (Fig. 5). During the course of this study, it was determined that water released from Red Bluff Reservoir not delivered to a local district, is captured at Imperial Reservoir, which is located upstream from the USGS gauging station. Therefore, any significant amount of water released from Red Bluff down the river not delivered to local irrigation districts, will not reach the USGS gauging station at Girvin. A coefficient of determination was performed on flow (ac-ft) measured at Girvin and the volume of water (ac-ft) released from Red Bluff Reservoir, where $r^2 = 0.15$ ($p<0.05$). The low correlation provides evidence that release is not related to flow through the USGA station at Girvin.

Once it was determined that loss occurring from release and delivery were not related to Girvin, a water balance was determined for the study area. During characterization of the water balance, it was observed that during certain time periods within a delivery year, percent loss changes considerably. This pattern resulted in dividing the irrigation delivery year into three categories, first month of release and delivery, release and delivery during the growing season and release and delivery during late season. The three categories allowed for singling out changes in percent loss and

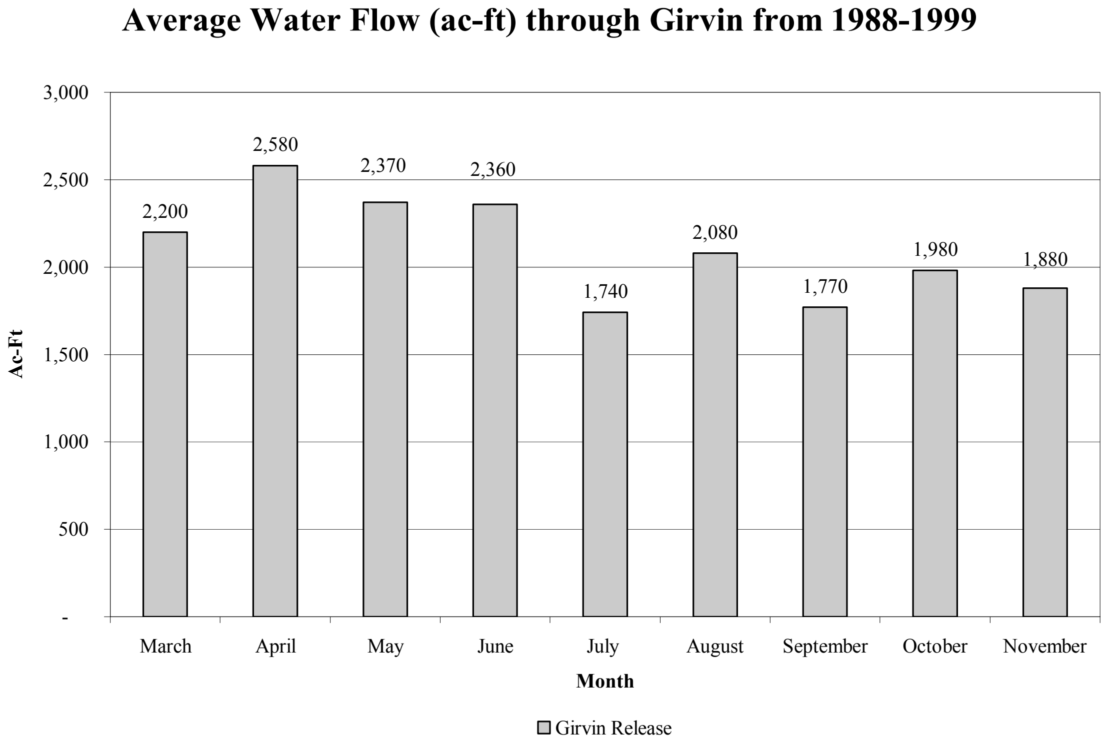

Fig. 5. Mean water flow (ac-ft) through Girvin from 1988-1999. Water flow rates obtained from USGS gauging station 13257 located at US Highway 67 northeast of Girvin. Releases were not made for December through February.

provided a description of when percent losses changed during the delivery year. A monthly average was calculated for each of the three delivery categories (Table 11). The first month of release (7,862 ac-ft) with a delivery of 2,927 ac-ft resulted in an average percent of 68%. Releases increased during the growing season to 11,015 ac-ft, but losses decreased to 39%. Average release for late season showed to be the lowest, 3,534 ac-ft, and had a loss of 43%.

An average pattern of release and percent loss was also determined for each month from 1988 through 1999 during the period of a delivery year (Fig. 6). The highest average loss occurred during the first month (67%) of release. Percent loss

Table 11. Average release, delivery and percent loss for three release and delivery periods for the Pecos River from 1988-1999.

	Average		
Delivery Period	Release	Delivery	Percent Loss
First Month	7,862	2,927	68%
Growing Season	11,015	6,648	39%
Late Season	3,534	2,074	43%

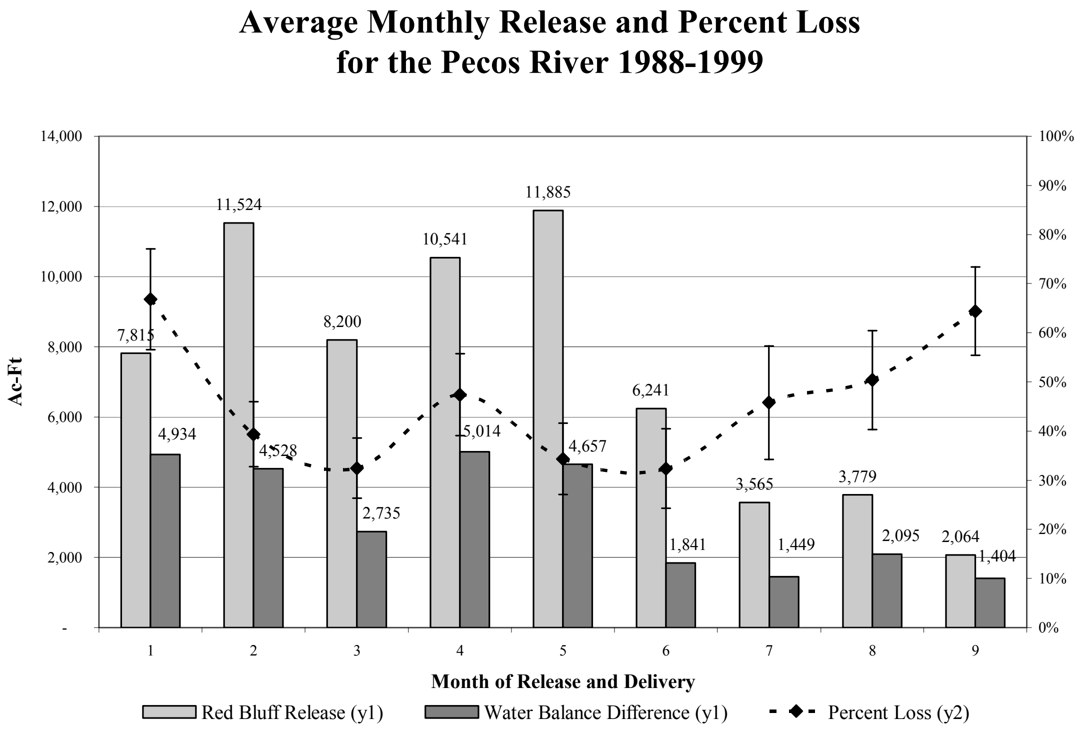

Fig. 6. Average monthly release and percent loss for the Pecos River during irrigation delivery periods from 1988 through 1999. Lines vertical to percent loss for each month is the standard deviation from the mean.

decreased during the second month of release, and for the next five months of release the loss ranged from 32% to 47%. However, when the amount of water released begins to decrease in month seven, the percent loss begins to increase (46%) and by month nine, the loss increased to 64%.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Aerial Herbicide Treatments

Saltcedar Apparent Mortality

All herbicide treatments with the exception of the airplane, single pass with imazapyr treatment (Treatment 2) provided significant saltcedar mortality over control plots. Both the double pass airplane treatment (Treatment 3) and the single pass tank mix (imazapyr + glysophate) airplane treatment (Treatment 4) had higher mean mortality than the single pass with imazapyr airplane treatment. However, there was no significant difference found between the three airplane treatments. The helicopter 1000 micron droplet treatment (Treatment 6) provided the highest mean mortality of all the treatments and was significantly higher than all other treatments, except the helicopter 1500 micron droplet treatment (Treatment 5). The helicopter 1000 micron droplet treatment also provided the lowest variability of all treatments. As a result, the helicopter 1000 micron droplet has been determined to be the best control treatment for saltcedar on this river system.

The higher rate of mortality of the helicopter treatments over the airplane is believed to be influenced by several factors. First, the physical characteristics of the Pecos River made it very difficult for the airplane to deliver the herbicide mix accurately. The Pecos River is sinuous with a narrow band of saltcedar with an average width of 16.5 m, from the waters edge to the edge of the main flooding zone. It was observed that the physical nature of the river caused off target spraying to occur with the airplane. When the airplane banked on curves of the river, less herbicide was delivered on the outside of the curve and/or non-target vegetation would receive the treatment, not saltcedar. The helicopter treatments did not have this problem, because of its lower flight speed (30 mph, 48 km/hr) compared to that of the airplane (120 mph, 193 km/hr). Furthermore, because only a narrow band of saltcedar 16.5 m (54 ft) was present on the river, only one to two passes with the airplane was necessary to cover the saltcedar canopy. Airplane applications normally require some overlap in treatment to guarantee that a full rate is delivered. Even though the same rate of chemical was delivered with both airplane and helicopter treatments, actually less chemical was applied with the airplane because of the restraints of the river characteristics. Off target spraying with the airplane may have been further increased due to weather conditions at the time of application. The wind speed at the time of application was 5 to 15 mph, which could have caused yet another decrease in the accuracy of this application technique.

Another reason for the higher mortality rate of helicopter treatments over airplane treatments was the difference in total spray volume delivered. Helicopter treatments delivered one-third more spray volume than the airplane treatments. The helicopter treatments also had a considerably larger droplet size compared to that of the airplane treatments. The higher spray volume and larger droplets caused more mortality due to the characteristics of the saltcedar stand on the Pecos River. The saltcedar on the river is a mature, dense stand (averaging 81 trees/ha). The higher volume and larger droplet size probably allowed a greater amount of herbicide to cover/penetrate the saltcedar canopy.

Another reason for the difference in mortality found between helicopter and airplane treatments could be due to the difference in application time. Helicopter treatments were applied on September 18, 1999 and airplane treatments were not applied until October 10, 1999. Spraying should be accomplished when saltcedar is in late flower (Duncan 1997). Duncan and McDaniel (1998) state, that airplane applications applied in New Mexico had levels of control of 90% or greater, when applied in August and September. Airplane applications were applied almost a month had passed after the helicopter treatments. Also, the application was applied near the end of late flowering of saltcedar.

Vegetation Cover

A major objective of the project was to determine if off-target vegetation damage occurred from herbicide treatments. Results showed no significant effect on bareground, annual plants or perennial plants from any of the treatments. The mean percent cover of the three categories did change significantly from pre-treatment to after herbicide treatments were applied, but control plots had similar responses. As a result, the changes in percent cover were interpreted to be due to drought conditions that occurred during the time of the study. The average rainfall for the study area was 23.04 cm (9.07 in) in 1999, 22.35 cm (8.80 in) in 2000, compared to a long-term average annual rainfall of 30.68 cm (11.92 in). Annual rainfall were even less in 2001 at 14.81 cm (5.83 in), averaged from January to October across the study site. Annual plants appeared to show a treatment effect due to the decrease in mean percent cover from pre-treatment to one year post-treatment (2000), but this effect was overshadowed in 2001 due to drought as evident in similar decreases on the control plots. In summary this study could not statistically show any negative effects of herbicide applications on off-target vegetation due to overshadowing effects of drought conditions.

Soil Salinity

No effect on soil salinity was found following saltcedar mortality, verified by a lack of significant differences among herbicide treatments sampled for ECe at three soil depths. The mean ECe increased from pre-treatment to both one and two years post-treatment for 0 to 5 cm depth. The second soil sampling depth (5 to 15 cm) had an increase in mean ECe from pre-treatment to one year post-treatment, but two years post-treatment was not significantly different. The same trend with ECe levels occurred with the means of the control plots, for both the 0 to 5 cm (soil surface) and 5 to 15 cm. As a result, the increase from pre- to post-treatment cannot be attributed to herbicide treatments applied to the saltcedar. There was high variability associated with all sampling units, perhaps a result of variability existing within the landscape itself. The high variability could also be associated with sampling technique. A more accurate and consistent soil sampling procedure may be needed if further study is to be done on the soil characteristics of the study site.

Water Quality

Electrical conductivity levels of water in the Pecos River increase downstream and salts appear to “double” in concentration as water moves from Red Bluff Reservoir to Girvin. The majority of the increase in EC does occur between site 5 to site 1. Historical TNRCC EC data also remains consistent with the ten current sampling sites. Electrical conductivity levels do not appear to be influenced by the amount of water and timing of release from Red Bluff Reservoir. This was indicated by data from both the historical TNRCC sites and the current water sampling locations. During times of release or times of no release the concentrations remain relatively similar.

A trend of decreasing EC in Pecos River water appears to be developing. At this time, the decrease in EC cannot be attributed to treatment of saltcedar. The last water quality sample for this study was taken in December 2000 and at this time only 54.1 km (33.6 mi) of the 344 km (214 mi) section of the river between Red Bluff Reservoir and Girvin had been treated. Monitoring of the EC in the river to determine if the decreasing trend in EC observed can be attributed to treatment of saltcedar needs to be continued.

Water Quantity

There is a shallow water table underneath the Pecos River; however, at this time the size is unknown. Data used in this study shows that releases from Red Bluff Reservoir influenced the level of water in this water table. The influence of release on the shallow water table is indicated by first looking at the historical average of the first month of release. Minimal water has been released from Red Bluff during the irrigation off-season period. During this time, the shallow water table is allowed to drain. Once water is released the first month, part of that water appears to recharge the water table, indicated by the highest percent monthly loss (67%) for the average delivery year. However, during the second month of release, the average percent loss decreases. This further indicates that the percent loss is influenced by the water table, due to the fact that after the first month release, the water table has recharged and less water is being lost to it, thereby reducing percent loss during times of constant release. When release begins to drop off in month six, consequently percent loss begins to increase again in month seven. The percent loss from there on to the end of the delivery year continues to increase as release decreases.

There are many unknown factors that can influence the amount of water flowing in the river and the percent water lost during the irrigation delivery period of the Pecos River. Currently, there is no adequate measure of rainfall received for this watershed. The majority of the weather stations located in this region are located in municipalities, which are not near the river or near the watershed that drains into the river. Also, evaporation rates from the river are unknown, as well as transpiration rates of saltcedar along the river banks. All these factors can play a role in influencing both the release of water and the percent of water lost from the river channel.

Delivery efficiency could be greatly improved by maintaining constant and consistent flow in the river during the irrigation delivery period. Losses during the first month of release and delivery are inevitable. However, after this initial loss occurs from recharging the shallow water table, a steady rate of release should be maintained throughout the season. If this is accomplished, water will not have to be used to continually recharge, and equilibrium between the shallow water table and river channel can be obtained, subsequently causing less loss of water from release to delivery.

LITERATURE CITED

Blackburn, W.H., R.W. Knight and J. L. Schuster. 1982. Saltcedar influence on sedimentation in the Brazos River. J. Soil Water Cons. 37: 298-301.

Blaney, H.F. 1933. Water losses under natural conditions in wet areas in southern California, consumptive use by native plants growing in moist areas in southern California: California Dep. of Public Works, Water Resources. Div. Bull. 44. San Francisco, Cal.

Brotherson, J.D., J.G. Carman and L.A. Szyska. 1984. Stem-diameter age relationships of *Tamarix Ramosissima* in Central Utah. J. Range Manage. 37(4):362-364.

Busby, F.E. and J.L. Schuster. 1973. Woody phreatophytes along the Brazos River and selected tributaries above Possum Kingdom Lake. Tex. Water Dev. Board Rep. 168. Austin, Tex.

Carman, J.G. and J.D. Brotherson. 1982. Comparisons of sites infested and not infested with saltcedar (*Tamarix pentandra*) and russian olive (*Elaeagnus angustifolia*). Weed Sci. 30: 360-364.

Clarke, K. and R.M. Nelson. 1996. Saltcedar eradication and native revegetation of a desert riparian area: the pilot study of the Hidden Valley dairy saltcedar eradication project. M.S. Thesis, Univ. of Nev., Las Vegas. Las Vegas, Nev.

Cook, C.W. and J. Stubbendieck (ed.). 1986. Range research: basic problems and techniques. Soc. for Range Manage., Denver, Colo.

Dale, Don. 1997. The rebirth of Spring Lake. Texas Farmer-Stockman. April 1997. p. 12-15.

Davenport, D.C., P.E. Martin and R.M. Hagan. 1982. Evapotranspiration from riparian vegetation: water relations and irrecoverable losses for saltcedar. J. Soil Water Cons. 37(4):233-236.

DeLorme, Inc. 2001. Street Atlas USA Version 2.0. Yarmouth, Me.

Devitt, D.A., A. Sala, K.A. Mace, and S.D. Smith. 1997. The effect of applied water on the water use of saltcedar in a desert riparian environment. J. Hydrol. 192: 233-246.

Duncan, K.W. 1997. A case study in *Tamarix Ramosissma* control: Spring Lake, New Mexico, p. 115-121. *In:* J.H. Brock, M.Wade, P. Pysek, and D. Green (ed.), Plant invasions: studies from North Ameica and Europe. Backhuys Publishers, Leidens, The Netherlands.

Duncan, K.W. and K.C. McDaniel. 1997. Saltcedar management, p. 51-52. *In*: Abstr. 50th annual meeting Society for Range Management. Rapid City, S. Dak.

Duncan, K.W. and K.C. McDaniel. 1998. Saltcedar (*Tamarix spp.*) management with imazapyr. Weed Tech. 12: 337-344.

Frasier, G.W. and T.N. Johnsen. 1991. Saltcedar (Tamarisk): classification, distribution, ecology, and control, p. 377-386. *In:* Lynn F. James (ed.), Noxious range weeds. Westview Press, Boulder, Colo.

Gatewood, J.S., T.W. Robinson, B.R. Colby, J.D. Hem and L.C. Halpenny. 1950. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. USGS Water Supply Paper 1103. Washington, D.C.

Greenberg, A.E., L.S. Clesceri, A.D. Eaton (ed.). 1992. Standard methods for the examination of water and wastewater. American Public Health Assoc., Washington, D.C.

Hatch, S.L., K.N. Gandhi and L.E. Brown. 1990. Checklist of the vascular plants of Texas. Tex. Ag. Exp. Sta. Bull. MP-1655. College Station, Tex.

Horton, J.S. 1972. Management problems in phreatophyte and riparian zones. J. Soil Water Cons. 27 (2): 58-61.

Jackson, N. E. 1996. Chemical control of saltcedar (*Tamarix ramosissima*). Saltcedar Management Workshop. http://bluegoss.arw.r9.fws.gov. July 5, 1999.

Larmer, P. 1998. Tackling tamarisk: is the exotic shrub an ecological menace or merely the best our degraded rivers can muster? *High Country News* 30 (10).

Macmahon, J.A. and F.H. Wagner. 1985. The Mohave, Sonoran and Chihuahuan Deserts of North America, p. 105-202. *In:* M. Evernari, I. Noy-Meir, and D.W. Goodall (ed.), Hot deserts and arid shrublands. Elsevier Science Publishing Company Inc., New York, N.Y.

Richards, L.A. (ed.). 1954. Diagnosis and improvement of saline and alkali soils. USDA. Handbook 60, U.S. Government Printing Office, Washington, D.C.

Ruesink, L.E. 1983. Wanted: water rustlers. Texas Water Resources. 9:3.

Sala, A., S.D. Smith and D.A. Devitt 1996. Water use by *Tamarix ramosissima* and associated phreatophytes in a Mojave Desert floodplain. Ecol. Appl. 6: 888-898.

Soil Survey Staff. 1972. Soil survey laboratory methods and procedures for collection soil samples. Soil Survey Investigations Rep. No. 1. USDA, SCA. U.S. Government Printing Office, Washington, D.C.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York, N.Y. 481p.

Stevens, R. and S.C. Walker. 1996. Saltcedar control. Rangelands 20: 888-898.

Taylor, J. P. and K.C. McDaniel 1998. Riparian management on the Bosque del Apache National Wildlife Refuge. New Mexico J. Sci. 38: 219-232.

Taylor, J.P. and K.C. McDaniel 1998. Restoration of saltcedar (*Tamarix* sp.) - infested floodplains of the Bosque del Apache National Wildlife Refuge. Weed Tech. 12:345-352.

Van Hylckman, T.E.A. 1974. Water use by saltcedar as measured by the water budget method. USGS Professional Paper 491-F. Washington, D.C.

Wiesenborn, W.D. 1996. Saltcedar impacts on salinity, water, fire frequency, and flooding. Saltcedar Management Workshop. http://bluegoose.arw.r9.fws.gov. July 5, 1999.

Ziegler, R.L. 1960. Ecological studies of saltcedar. M.S. Thesis, Fort Hays Kansas State College, Hays, Kan.

APPENDIX A – Saltcedar Density Counts

Table A1. Pre-treatment (1999) saltcedar density (trees/ha) for all six treatment.

Treatment	Replication	Transect	# Live Trees/Transect	River Width (ft)	Transect Length (ft)	Trees/ha
1	1	1	13	50	100	46
1	1	2	76	92	100	146
1	2	1	14	65	100	38
1	2	2	27	70	100	68
2	1	1	25	44	100	100
2	1	2	26	45	100	102
2	2	1	24	74	100	57
2	2	2	22	69	100	56
3	1	1	10	31	100	57
3	1	2	23	41	100	99
3	2	1	15	58	100	46
3	2	2	15	36	100	73
4	1	1	22	57	100	68
4	1	2	22	43	100	90
4	2	1	9	56	100	28
4	2	2	16	59	100	47
5	1	1	44	62	100	125
5	1	2	28	38	100	130
5	2	1	19	57	100	59
5	2	2	17	34	100	88
6	1	1	27	61	100	78
6	1	2	23	65	100	62
6	2	1	24	42	100	101
6	2	2	45	46	100	173

Table A2. One year post-treatment (2000) saltcedar density (trees/ha) for all six treatment.

Treatment	Replication	Transect	# Live Trees/Transect	River Width (ft)	Transect Length (ft)	Trees/ha
1	1	1	13	50	100	46
1	1	2	76	92	100	146
1	2	1	14	65	100	38
1	2	2	27	70	100	68
2	1	1	19	44	100	76
2	1	2	14	45	100	55
2	2	1	22	74	100	52
2	2	2	16	69	100	41
3	1	1	9	31	100	51
3	1	2	13	41	100	56
3	2	1	10	58	100	30
3	2	2	10	36	100	49
4	1	1	10	57	100	31
4	1	2	12	43	100	49
4	2	1	6	56	100	19
4	2	2	11	59	100	33
5	1	1	5	62	100	14
5	1	2	7	38	100	32
5	2	1	6	57	100	19
5	2	2	3	34	100	16
6	1	1	4	61	100	12
6	1	2	4	65	100	11
6	2	1	3	42	100	13
6	2	2	4	46	100	15

Table A3. Two year post-treatment (2001) saltcedar density (trees/ha) for all six treatment.

Treatment	Replication	Transect	# Live Trees/Transect	River Width (ft)	Transect Length (ft)	Trees/ha
1	1	1	13	50	100	46
1	1	2	76	92	100	146
1	2	1	14	65	100	38
1	2	2	27	70	100	68
2	1	1	18	44	100	72
2	1	2	7	45	100	27
2	2	1	20	74	100	48
2	2	2	22	69	100	56
3	1	1	4	31	100	23
3	1	2	12	41	100	52
3	2	1	8	58	100	24
3	2	2	10	36	100	49
4	1	1	16	57	100	50
4	1	2	11	43	100	45
4	2	1	2	56	100	6
4	2	2	15	59	100	45
5	1	1	1	62	100	3
5	1	2	8	38	100	37
5	2	1	10	57	100	31
5	2	2	2	34	100	10
6	1	1	2	61	100	6
6	1	2	2	65	100	5
6	2	1	1	42	100	4
6	2	2	2	46	100	8

APPENDIX B – Vegetation Characteristics

Table B1: Average percent vegetation composition for Treatment 1, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	58	64	67
Litter	4	11	20
Annual Plants			
Amaranthus blitoides	4	3	0
Amphiachyris dracunculoides	0	0	0
Bouteloua barbata	6	1	0
Eragrostis cilianensis	0	0	0
Kallstroemia hirsutissima	4	0	0
Lepidium montanum	8	6	5
Salsola iberica	4	0	0
Perennial Plants			
Atriplex canescens	3	6	6
Chloris crinita	3	6	0
Gutierrezia sarothrea	0	0	0
Helinathus ciliaris	2	0	0
Isocoma wrightii	0	0	0
Prosopis glandulosa	2	1	1
Setaria geniculata	1	0	0
Solanum elaeagnifolium	0	1	0
Sporobolus airoides	2	1	2
Sporobolus cryptandrus	1	0	0

Table B2: Average percent vegetation composition for Treatment 2, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	49	75	81
Litter	5	16	10
Annual Plants			
Amaranthus blitoides	3	0	0
Amphiachyris dracunculoides	0	0	0
Bouteloua barbata	8	1	0
Eragrostis cilianensis	0	0	0
Kallstroemia hirsutissima	0	0	0
Lepidium montanum	18	0	0
Salsola iberica	3	0	0
Perennial Plants			
Atriplex canescens	6	5	9
Chloris crinita	2	3	0
Helinathus ciliaris	1	0	0
Prosopis glandulosa	0	1	1
Setaria geniculata	1	0	0
Solanum elaeagnifolium	3	0	0
Sporobolus airoides	0	0	0
Sporobolus cryptandrus	5	0	0
Tamarix spp.	0	0	0

Table B3: Average percent vegetation cover for Treatment 3, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	37	67	66
Litter	6	13	17
Annual Plants			
Amaranthus blitoides	6	0	0
Amphiachyris dracunculoides	0	0	0
Bouteloua barbata	10	0	0
Gutierrezia sarothrea	1	0	0
Kallstroemia hirsutissima	1	0	0
Lepidium montanum	1	0	0
Perennial Plants			
Atriplex canescens	0	1	0
Chloris crinita	6	5	2
Helinathus ciliaris	2	0	0
Isocoma wrightii	28	13	12
Prosopis glandulosa	2	1	2
Setaria geniculata	1	0	0
Solanum elaeagnifolium	1	0	0
Sporobolus airoides	0	0	1
Sporobolus cryptandrus	0	0	0

Table B4: Average percent vegetation composition for Treatment 4, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	20	57	56
Litter	3	17	21
Annual Plants			
Amaranthus blitoides	4	0	0
Amphiachyris dracunculoides	0	0	0
Bouteloua barbata	21	0	0
Conyza canadensis	0	0	0
Conyza coulteri	1	0	0
Kallstroemia hirsutissima	2	0	0
Lepidium montanum	9	1	1
Salsola iberica	0	0	0
Perennial Plants			
Atriplex canescens	0	2	5
Chloris crinita	11	2	1
Gutierrezia sarothrea	0	0	0
Helinathus ciliaris	4	0	0
Isocoma wrightii	20	20	14
Prosopis glandulosa	1	1	2
Setaria geniculata	1	0	0
Solanum eleagnifolium	1	0	0
Sporobolus cryptandrus	3	1	0

Table B5: Average percent vegetation composition for Treatment 5, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	42	67	66
Litter	3	25	22
Annual Plants			
Amaranthus blitoides	1	0	0
Amphiachyris dracunculoides	0	0	0
Bouteloua barbata	10	0	0
Conyza coulteri	0	0	0
Eragrostis cilianensis	0	0	0
Kallistroemia hirsutissima	4	0	0
Lepidium montanum	14	1	2
Machaeranthera tanacetifolia	2	0	0
Salsola iberica	2	0	0
Perennial Plants			
Atriplex canescens	5	1	4
Chloris crinita	4	1	0
Guiterrezia sarothrea	0	0	0
Helinathus ciliaris	4	0	0
Isocoma wrightii	5	4	3
Kochia americana	0	0	0
Prosopis glandulosa	0	0	0
Setaria geniculata	2	0	0
Solanum elaeagnifolium	1	0	0
Sporobolus airoides	0	0	0
Sporobolus cryptandrus	1	0	0
Tamarix spp.	0	0	3

Table B6: Table B5: Average percent vegetation composition for Treatment 6, pre-treatment (1999) and one and two year post-treatment (2000 and 2001, respectively).

	Average Percent Composition		
Cover Type	1999	2000	2001
Bare Ground	52	64	63
Litter	33	24	27
Annual Plants			
Amaranthus blitoides	2	3	0
Lepidium montanum	1	2	7
Salsola iberica	2	1	0
Perennial Plants			
Atriplex canescens	0	0	0
Bouteloua curtipendula	0	0	0
Chloris crinita	9	5	2
Helinathus ciliaris	0	1	0
Isocoma wrightii	1	0	1
Panicum obtusum	0	0	0
Prosopis glandulosa	0	0	0
Setaria geniculata	0	0	0
Solanum elaeagnifolium	0	0	0
Sporobolus airoides	0	0	0

APPENDIX C – Soil Electrical Conductivity

Table C1. Electrical conductivity (mmhos/cm) of soil (0 to 5 cm) before treatments (1999) and one and two years post-treatment (2000 and 2001, respectively).

			Electrical Conductivity		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	2.9	37.0	8.7
1	1	2	21.0	9.0	17.5
1	2	1	3.5	2.0	8.1
1	2	2	3.0	3.3	14.0
2	1	1	1.2	14.0	32.0
2	1	2	2.9	6.0	30.0
2	2	1	3.6	2.0	5.1
2	2	2	8.3	13.0	2.4
3	1	1	2.6	39.0	12.0
3	1	2	6.4	17.0	15.5
3	2	1	5.2	45.0	11.5
3	2	2	4.0	2.5	15.0
4	1	1	2.7	20.0	3.6
4	1	2	10.7	25.0	10.0
4	2	1	6.7	16.0	2.3
4	2	2	9.3	8.9	62.0
5	1	1	2.6	11.0	11.0
5	1	2	2.6	4.2	9.1
5	2	1	8.0	12.0	15.5
5	2	2	5.3	8.9	3.3
6	1	1	11.9	7.0	6.3
6	1	2	17.0	20.0	8.7
6	2	1	3.4	3.3	10.5
6	2	2	2.3	3.1	9.2

Table C2. Electrical conductivity (mmhos/cm) of soil (5 to 15 cm) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

			Electrical Conductivity		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	8.7	26.0	5.5
1	1	2	17.0	9.6	16.0
1	2	1	2.7	1.5	4.0
1	2	2	2.2	3.9	7.3
2	1	1	10.2	12.0	20.5
2	1	2	2.0	2.4	13.5
2	2	1	2.5	3.6	5.5
2	2	2	7.6	9.4	5.5
3	1	1	5.9	27.0	11.0
3	1	2	7.0	12.0	9.0
3	2	1	7.0	17.0	11.0
3	2	2	5.2	5.9	14.5
4	1	1	1.6	16.0	5.4
4	1	2	10.0	14.0	8.2
4	2	1	6.8	9.4	6.0
4	2	2	9.5	7.7	9.5
5	1	1	4.9	7.1	8.0
5	1	2	2.2	3.3	6.4
5	2	1	10.0	7.3	5.7
5	2	2	5.0	7.5	3.8
6	1	1	7.0	8.0	6.7
6	1	2	10.6	11.0	6.0
6	2	1	2.6	2.1	5.2
6	2	2	2.8	2.3	7.6

Table C3. Electrical conductivity (mmhos/cm) of soil (15 to 30 cm) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

			Electrical Conductivity		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	7.7	15.0	5.0
1	1	2	24.0	10.0	14.0
1	2	1	5.5	1.7	3.7
1	2	2	1.5	4.6	5.5
2	1	1	9.5	15.0	13.5
2	1	2	1.5	1.9	10.0
2	2	1	4.0	6.2	5.7
2	2	2	8.9	8.4	5.5
3	1	1	7.1	26.0	8.8
3	1	2	7.5	10.0	7.5
3	2	1	7.0	13.0	10.0
3	2	2	6.4	5.7	9.9
4	1	1	1.7	13.0	4.7
4	1	2	9.2	7.1	7.8
4	2	1	6.6	12.0	5.8
4	2	2	8.6	6.6	9.0
5	1	1	5.0	4.4	5.9
5	1	2	3.6	3.0	5.5
5	2	1	10.5	6.2	5.4
5	2	2	6.0	7.0	3.2
6	1	1	5.0	6.3	4.6
6	1	2	6.6	9.0	5.9
6	2	1	3.6	2.4	4.0
6	2	2	3.0	2.1	6.7

APPENDIX D – Sodium Absorption Ratio

Table D1. Sodium Absorption Ration (SAR) of soil (0 to 5 cm)before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

			SAR		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	6	37	10
1	1	2	18	10	19
1	2	1	6	4	11
1	2	2	2	5	14
2	1	1	2	13	21
2	1	2	6	3	14
2	2	1	3	4	4
2	2	2	5	9	3
3	1	1	2	24	12
3	1	2	3	13	11
3	2	1	5	37	9
3	2	2	4	5	10
4	1	1	4	17	5
4	1	2	9	16	6
4	2	1	4	13	3
4	2	2	5	5	52
5	1	1	3	7	9
5	1	2	4	5	5
5	2	1	4	8	6
5	2	2	2	7	3
6	1	1	9	6	5
6	1	2	12	16	8
6	2	1	5	4	8
6	2	2	5	3	7

Table D2. Sodium Absorption Ration (SAR) of soil (5 to 15 cm) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

			SAR		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	6	28	4
1	1	2	13	11	19
1	2	1	4	4	7
1	2	2	4	5	8
2	1	1	8	15	22
2	1	2	3	3	11
2	2	1	3	7	6
2	2	2	5	8	5
3	1	1	4	20	15
3	1	2	4	10	12
3	2	1	4	18	8
3	2	2	2	6	15
4	1	1	2	15	9
4	1	2	9	10	6
4	2	1	4	8	6
4	2	2	5	5	14
5	1	1	3	5	6
5	1	2	4	5	5
5	2	1	8	7	6
5	2	2	3	6	4
6	1	1	3	8	10
6	1	2	11	13	10
6	2	1	5	4	6
6	2	2	6	4	9

Table D3. Sodium Absorption Ration (SAR) of soil (15 to 30 cm) before treatment (1999) and one and two years post-treatment (2000 and 2001, respectively).

			SAR		
Treatment	Replication	Transect	1999	2000	2001
1	1	1	4	17	4
1	1	2	18	11	15
1	2	1	3	3	6
1	2	2	3	4	7
2	1	1	9	17	20
2	1	2	1	3	9
2	2	1	3	7	7
2	2	2	6	8	5
3	1	1	4	20	11
3	1	2	6	9	9
3	2	1	4	11	8
3	2	2	4	5	12
4	1	1	2	13	9
4	1	2	9	9	6
4	2	1	6	10	7
4	2	2	8	5	13
5	1	1	1	4	6
5	1	2	5	5	6
5	2	1	11	7	6
5	2	2	3	6	3
6	1	1	6	7	10
6	1	2	12	12	12
6	2	1	6	4	7
6	2	2	6	5	8

APPENDIX E – Water Electrical Conductivity

Table E1. Electrical conductivity (mmhos/cm) for the ten water sampling sites during 1999 and 2000.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1999	August	1	12.7
1999	August	2	11.0
1999	August	3	9.6
1999	August	4	8.6
1999	August	5	8.6
1999	August	6	6.0
1999	August	7	6.2
1999	August	8	6.8
1999	August	9	6.4
1999	August	10	6.6
1999	December	1	12.3
1999	December	2	11.2
1999	December	3	10.7
1999	December	4	10.5
1999	December	5	11.1
1999	December	6	7.3
1999	December	7	7.0
1999	December	8	7.5
1999	December	9	7.5
1999	December	10	6.7
2000	August	1	10.5
2000	August	2	7.7
2000	August	3	7.4
2000	August	4	7.3
2000	August	5	7.9
2000	August	6	6.6
2000	August	7	6.5
2000	August	8	6.5
2000	August	9	6.5
2000	August	10	6.4
2000	December	1	13.0
2000	December	2	13.1
2000	December	3	12.5
2000	December	4	12.2
2000	December	5	12.5
2000	December	6	6.9
2000	December	7	10.5
2000	December	8	10.1
2000	December	9	9.9
2000	December	10	7.9

Table E2. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 1 (Girvin) during the month of August.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1973	August	1	7.8
1974	August	1	16.6
1986	August	1	9.7
1987	August	1	7.0
1989	August	1	13.8
1992	August	1	12.9
1993	August	1	12.8
1994	August	1	11.6
1996	August	1	14.0

Table E3. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 1 (Girvin) during the month of December.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1972	December	1	11.5
1973	December	1	12.2
1974	December	1	10.9
1982	December	1	12.5
1992	December	1	13.2
1993	December	1	11.3
1994	December	1	12.0
1995	December	1	12.0
1996	December	1	14.1
1997	December	1	14.0
1998	December	1	11.3
1999	December	1	11.2

Table E4. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 5 (FM 1776) during the month of August.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1991	August	5	12.9
1993	August	5	9.9
1996	August	5	7.9

Table E5. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 5 (FM 1776) during the month of December.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1992	December	5	10.2
1994	December	5	12.4
1995	December	5	12.5
1996	December	5	10.8
1997	December	5	9.7
1998	December	5	10.0

Table E6. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 9 (Orla) during the month of August.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1985	August	9	10.9
1987	August	9	3.6
1989	August	9	6.4
1991	August	9	10.9
1992	August	9	5.7
1993	August	9	6.9
1998	August	9	5.5
1999	August	9	4.7
2000	August	9	5.8

Table E7. Historical TNRCC electrical conductivity (mmhos/cm) data for Sample Area 9 (Orla) during the month of December.

Year	Month	Sample Area	Electrical Conductivity (mmhos/cm)
1972	December	9	8.3
1973	December	9	7.0
1974	December	9	12.8
1992	December	9	7.0
1993	December	9	10.2
1994	December	9	7.6

APPENDIX F – Monthly Release and Delivery Data

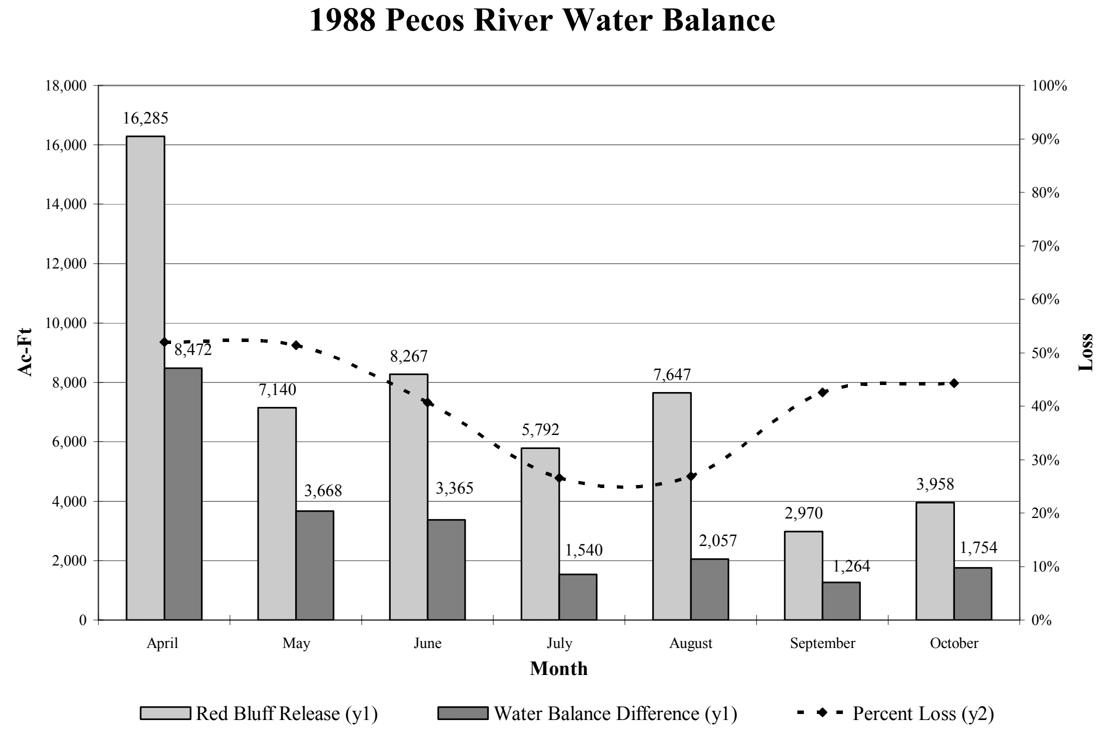

Fig. F1. Water balance by monthly release and percent loss during the irrigation delivery period of 1989.

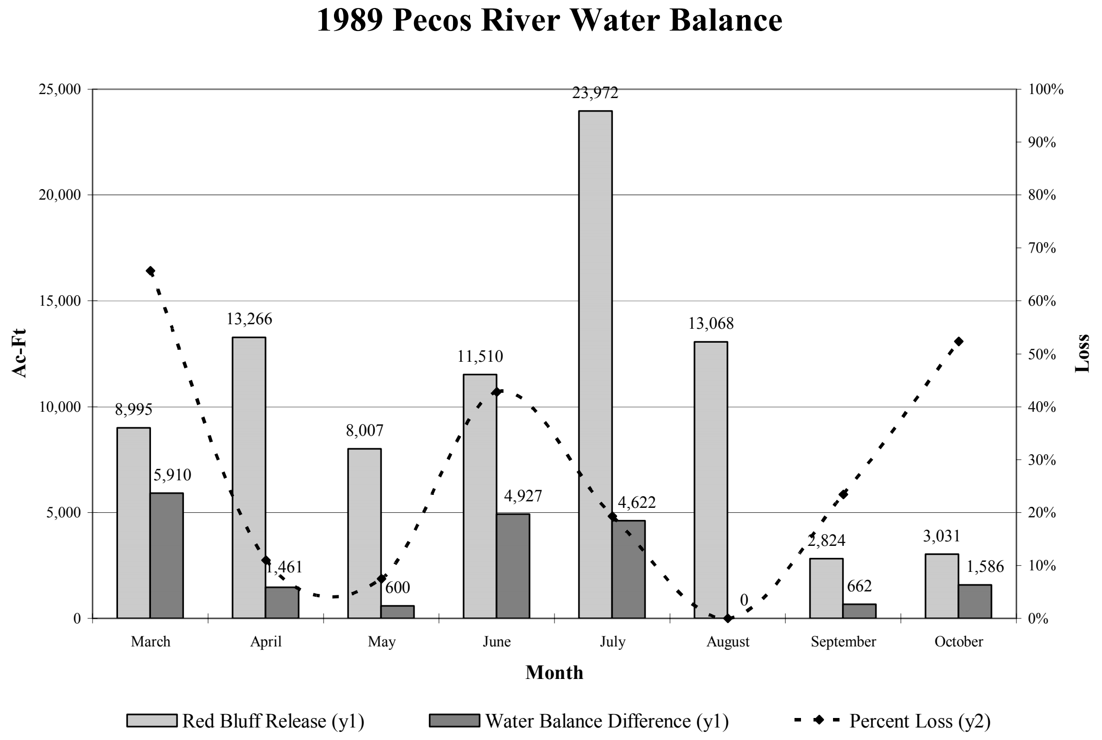

Fig. F2. Water balance by monthly release and percent loss during the irrigation delivery period of 1989.

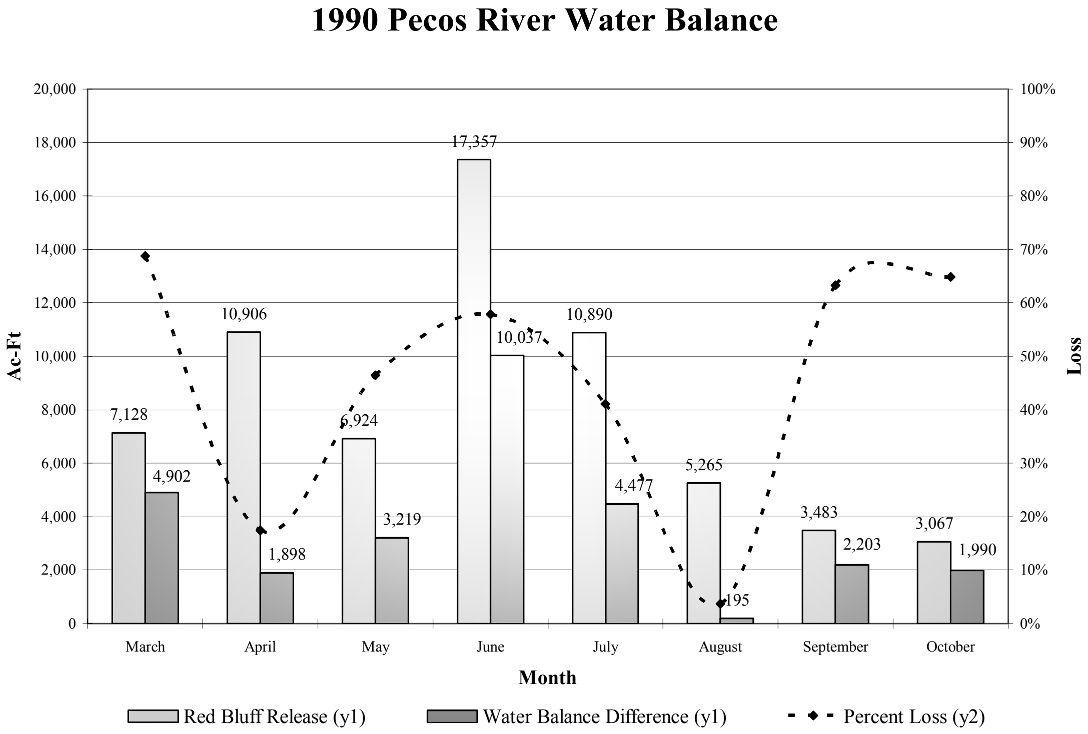

Fig. F3. Water balance by monthly release and percent loss during the irrigation delivery period of 1990.

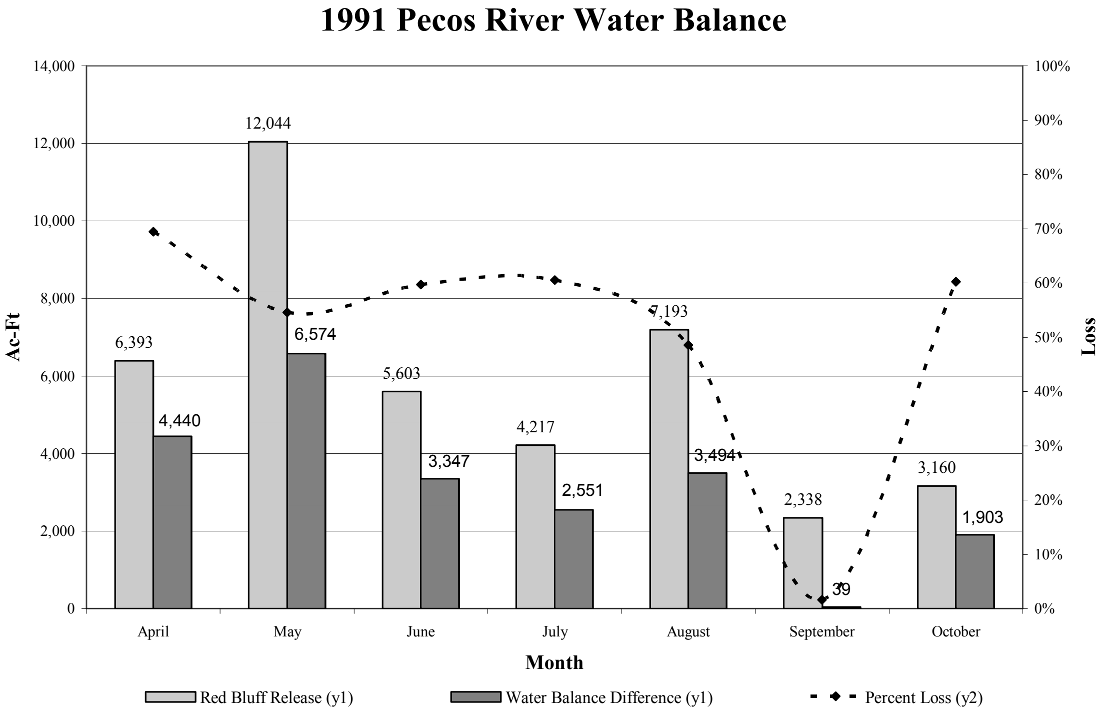

Fig. F4. Water balance by monthly release and percent loss during the irrigation delivery period of 1991.

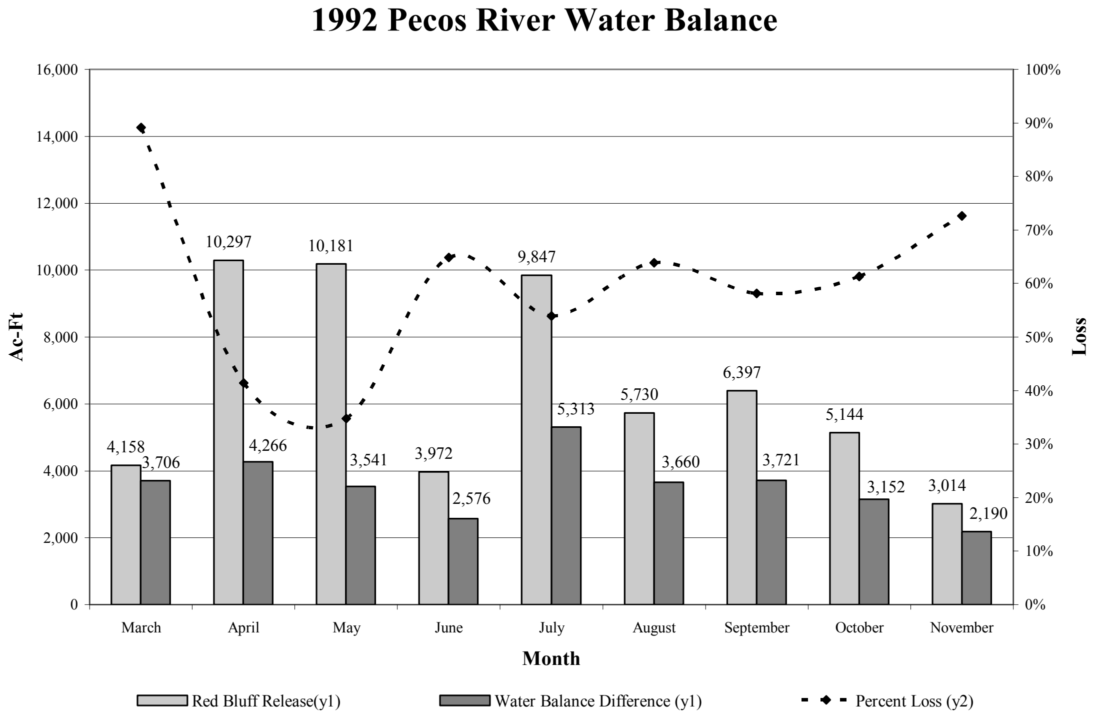

Fig. F5. Water balance by monthly release and percent loss during the irrigation delivery period of 1992.

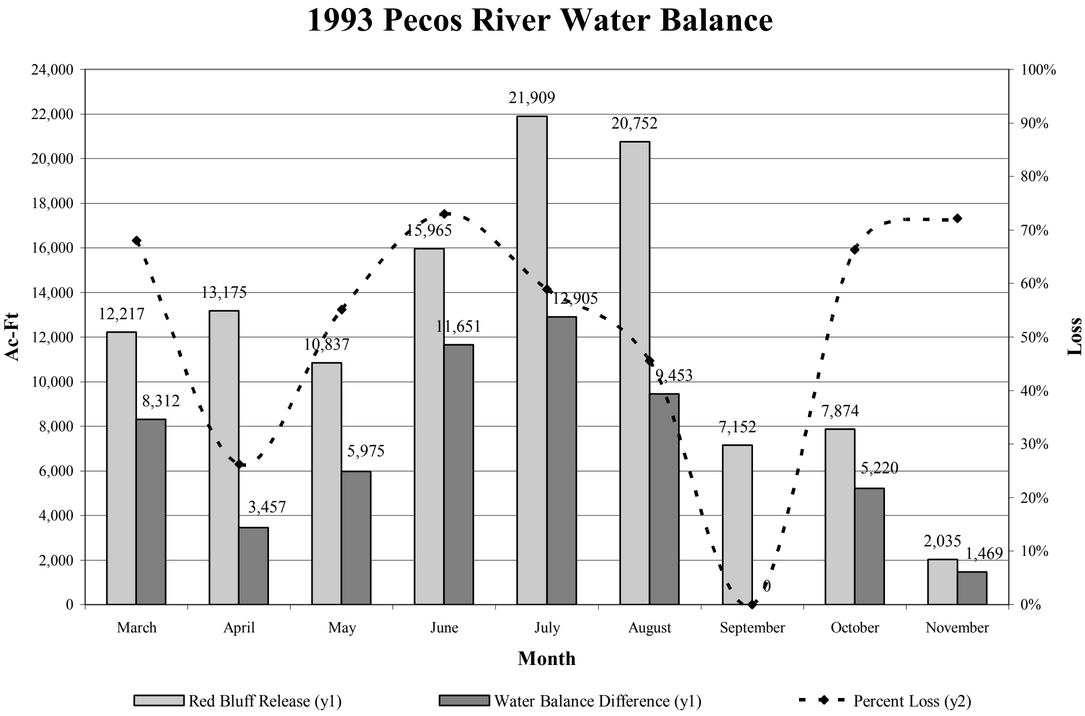

Fig. F6. Water balance by monthly release and percent loss during the irrigation delivery period of 1993.

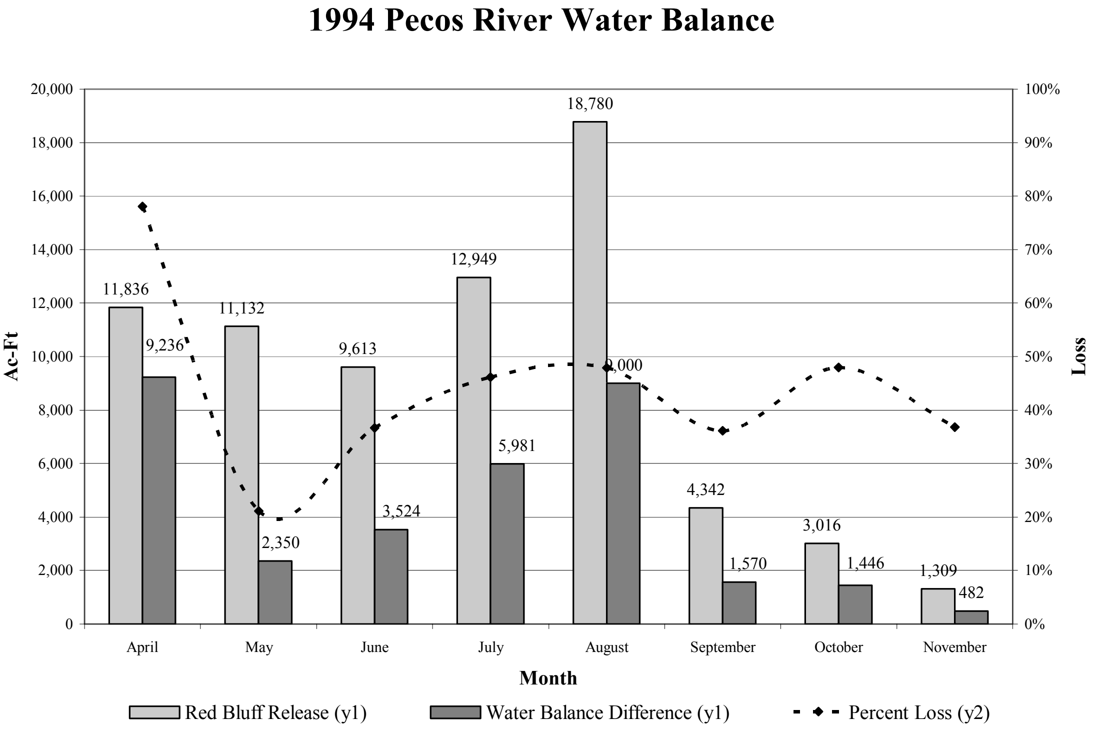

Fig. F7. Water balance by monthly release and percent loss during the irrigation delivery period of 1994.

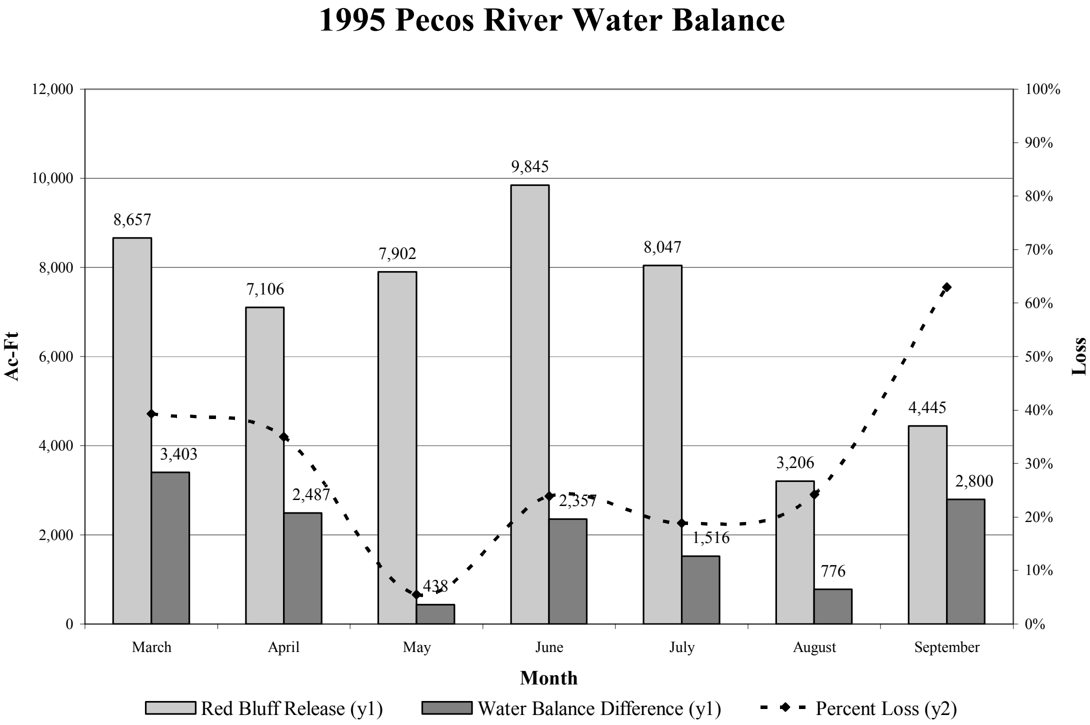

Fig. F8. Water balance by monthly release and percent loss during the irrigation delivery period of 1995.

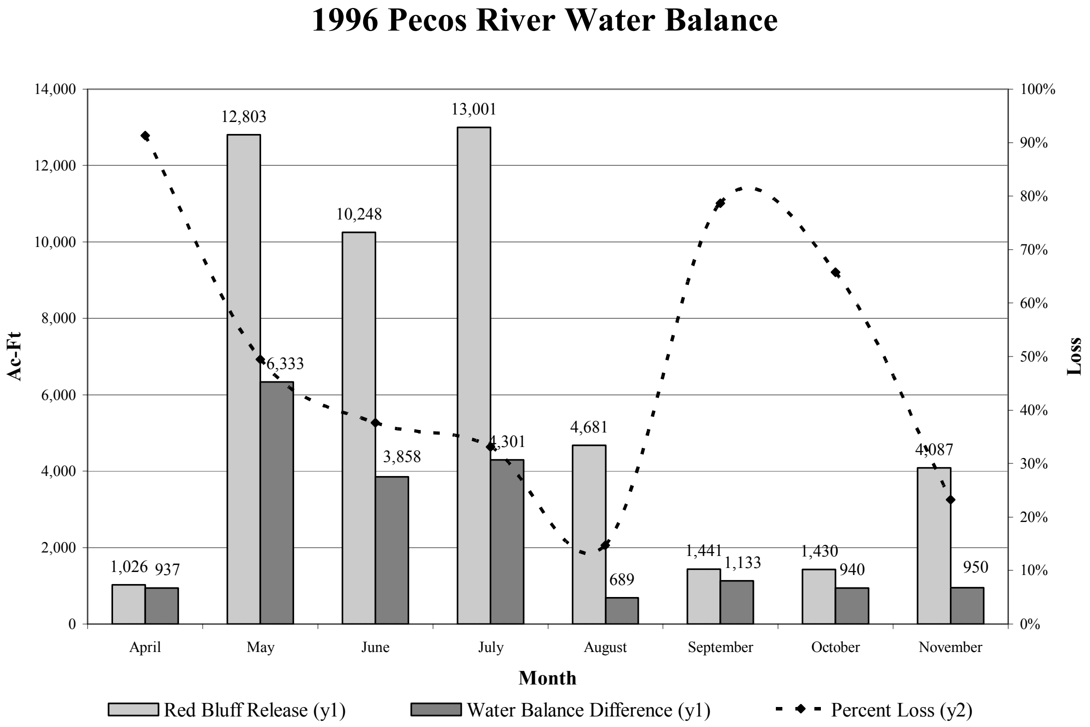

Fig. F9. Water balance by monthly release and percent loss during the irrigation delivery period of 1996.

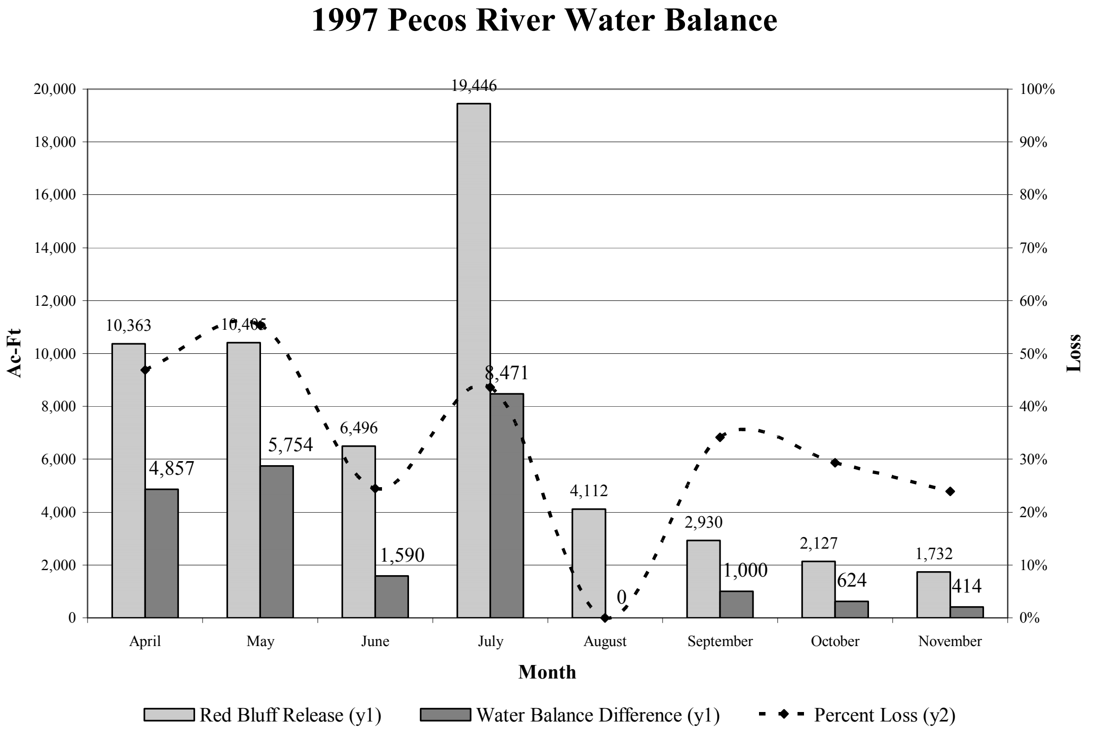

Fig. F10. Water balance by monthly release and percent loss during the irrigation delivery period of 1997.

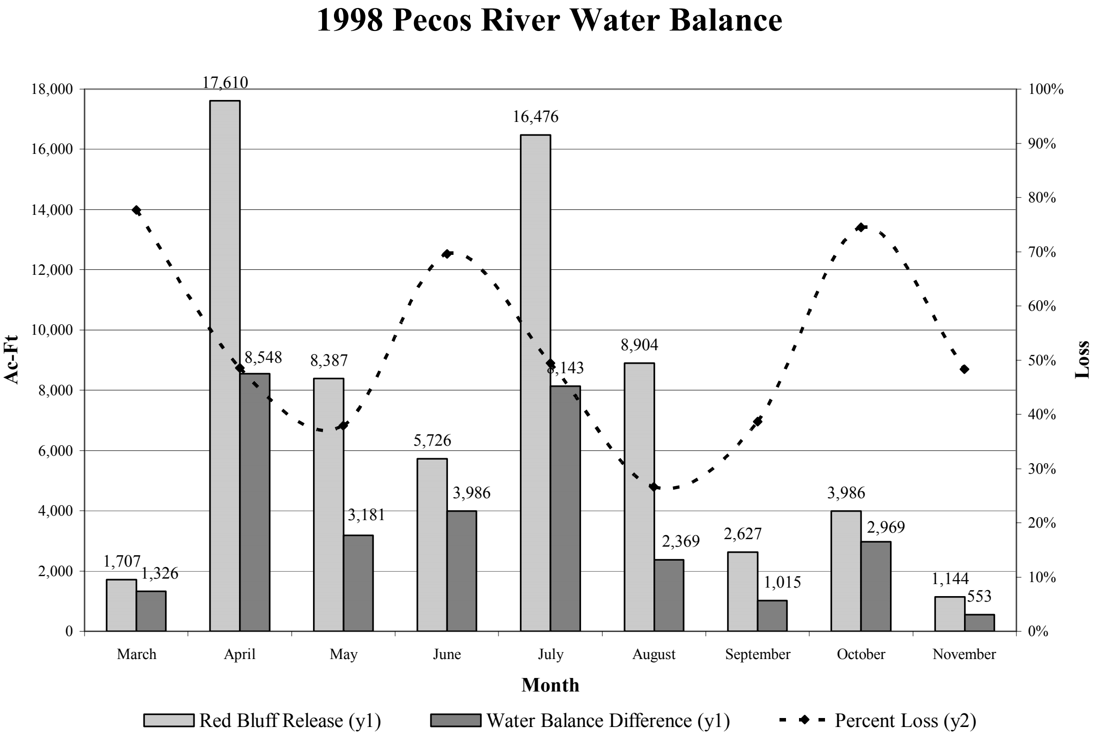

Fig. F11. Water balance by monthly release and percent loss during the irrigation delivery period of 1998.

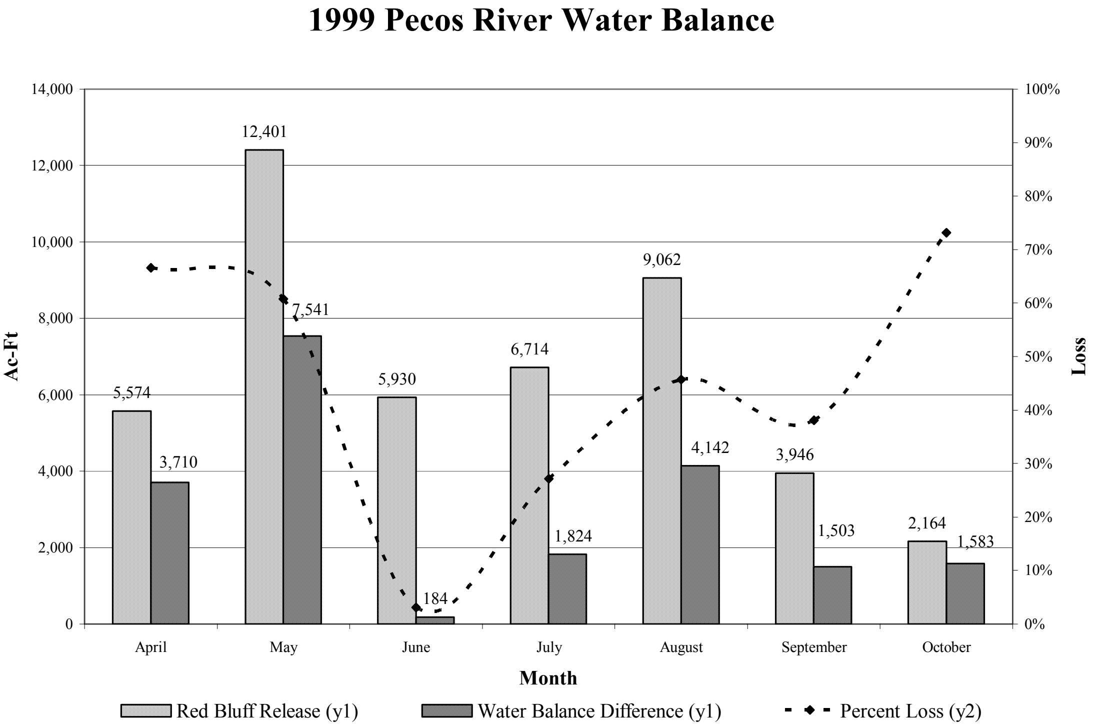

Fig. F12. Water balance with monthly release and percent loss during the irrigation delivery period of 1999.

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