WATER LOSS AND POTENTIAL SALVAGE IN SALTCEDAR (*TAMARIX* spp.) STANDS ON THE PECOS RIVER IN TEXAS

THESIS

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WILLIAM L. HATLER

Stephenville, Texas
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TABLE OF CONTENTS

LIST OF GRAPHICS

TABLE

FIGURE

Hatler, William L., Water Loss and Potential Salvage in Saltcedar (*Tamarix* spp.) Stands on the Pecos River in Texas, Master of Science (Environmental Science), December, 2008, 93 pp., 28 tables, 15 figures, references cited, 53 titles.

Water use by saltcedar (*Tamarix* spp.), an invasive phreatophyte, is of significant concern in many riparian zones in the western United States. This study analyzed diurnal groundwater fluctuations to estimate evapotranspiration and water salvage in saltcedar stands over a five-year period following herbicide application on the Pecos River in Texas. Seasonal stand-level saltcedar water loss at an untreated control site ranged from 0.42 m/yr – 1.18 m/yr. Seasonal water salvage ranged from 31% four years after treatment to 63% two years after treatment. Significant water savings may be achieved by chemical saltcedar control, dependent upon water use by replacement vegetation and saltcedar re-growth. A re-growth management strategy is essential to maintain long-term water salvage.

INTRODUCTION

Saltcedar (*Tamarix* spp.), a phreatophytic tree native to Eurasia, was introduced into the United States by nurserymen in the 1820s (Di Tomaso 1998). Subsequent to being planted as an ornamental and for erosion control, it is documented that saltcedar escaped cultivation in the 1870s and began to be recognized as an environmental concern in the 1920s (Di Tomaso 1998; Hart et al. 2005; Robinson 1965; van Hylckama 1974). Since the 1920s, saltcedar infestations have increased at a rate of approximately 3-4% per year in the southwestern United States and the plant now dominates more than an estimated 600,000 ha (Di Tomaso 1998; Hart et al. 2005; Robinson 1965). The plant thrives in arid southwestern climates and is commonly found in riparian areas in Utah, Nevada, Arizona, California, New Mexico, Colorado, Oklahoma, and Texas (Di Tomaso 1998).

Saltcedar establishment in riparian areas causes several significant environmental concerns. Saltcedar has a marked advantage over native woody species because of its ability to produce seeds almost continually. These have the capability of germinating in conditions unfavorable for most natives (Di Tomaso 1998; Sala et al.1996). This contributes to the creation of saltcedar monocultures in areas once inhabited by cottonwoods (*Populus* spp.), willows (*Salix* spp.), and other riparian species. In addition, mature saltcedar recovers quickly following fires and can tolerate extreme drought and flooding conditions (Di Tomaso 1998; Hart et al. 2005; Robinson 1965). Soil surfaces beneath the saltcedar canopy usually exhibit increased salinity due to the plant's ability to use more saline water than other species. Excess salt is excreted from leaves and drops onto the soil surface beneath the canopy leading to drastically reduced plant diversity in saltcedar stands (Hart et al. 2005; Robinson 1965; Shafroth et al. 2005). It may also increase the salinity of nearby surface water. As native species such as willows and cottonwoods are replaced by saltcedar, wildlife preferring the native vegetation for cover and food are usually displaced (Di Tomaso 1998).

Water use by saltcedar is a large concern in areas of infestation. Its deep roots give it access to water at depths up to 10 m and saltcedar has been known to negatively affect spring flow and surface water levels due to its high evapotranspiration (ET) potential (Di Tomaso 1998; Hart et al. 2005; Robinson 1965; van Hylckama 1974).

OBJECTIVES

The objectives of this study were to examine the effects of saltcedar control on saltcedar water use along the Pecos River in Texas. The study monitored groundwater levels in a network of wells located within saltcedar stands to estimate the effects on the shallow riparian aquifer. In particular there were two objectives:

1) Estimate the amount of water lost seasonally through ET in saltcedar stands along the Pecos River near Mentone, Texas.
2) Estimate potential stand-level water salvage achieved by chemically treating saltcedar.

Within a larger context, this study was initiated as a result of activities related to the Pecos River Ecosystem Project (PREP). The PREP was begun in 1999 to address the issue of saltcedar infestation along the banks of the Pecos River and its tributaries in Texas. Local, state, and federal entities collaborated to chemically treat a total of 5,462 ha of saltcedar between 1999 and 2005 in an effort to achieve more efficient irrigation deliveries and water conservation within the Red Bluff Water and Power Control District (Hart 2005). Clayton (2002) found that substantial amounts of water released from Red Bluff Reservoir are lost between the release and delivery points, ranging from 39 – 67% on a monthly basis. Results from this study will be used in analyses to estimate the amount of water savings achieved by the PREP.

LITERATURE REVIEW

Concerns regarding saltcedar water use and its potentially negative effects on streamflows, springs, groundwater, and reservoir levels are well documented throughout the literature (Carman and Brotherson 1982; Davenport et al. 1982a, 1982b; Di Tomaso 1998; Gay and Hartman 1982; Hart et al. 2005; Sala et al. 1996; Robinson 1965; van Hylckama 1970, 1974; Weeks et al. 1987; Williams and Anderson 1977). Numerous studies have attempted to quantify the amount of saltcedar water use, resulting in a corresponding number of varying estimates. Disparities among water use estimates have created some debate regarding the value of saltcedar removal, especially with regard to some of the large-scale removal projects that have been undertaken throughout the southwestern United

States. Shafroth et al. (2005) point out that “Despite decades of saltcedar invasion and control attempts, conflicting opinions remain about how, where, or if controlling saltcedar is likely to provide ecological or economic benefits that justify its removal.” Recent studies have pointed out that water use by individual saltcedar trees is comparable to that of native species it commonly replaces, such as cottonwoods and willows (Glenn and Nagler 2005, Nagler et al. 2003). However, when making comparisons at the stand-level, saltcedar often has a substantially higher leaf area index than natives, allowing it to transpire considerably more water (Di Tomaso 1998; Sala et al. 1996). Many factors affect the ET potential of saltcedar and some of the differences among the estimates of water use have undoubtedly resulted from site variability.

Factors Influencing Evapotranspiration

Site-specific environmental factors play a critical role in determining the amount of water saltcedar is capable of using. Depth to groundwater has a marked affect on ET rates, with plants having access to shallower water tables exhibiting the highest water use (Davenport et al. 1982b; Cooper et al. 2006; Robinson 1965; van Hylckama 1970, 1974). Butler at al. (2007) notes that solar radiation is a key factor in plant water use and measured a considerable reduction in plant water uptake on overcast days. Solar radiation was cited as an influencing factor by Davenport et al. (1982b), who conversely found that potential saltcedar ET rates may not always be realized due to increased stomatal resistance on the hottest days under dry soil conditions and that some estimates of water use have been exaggerated for this reason. Other climatic conditions such as wind, temperature, and humidity affect saltcedar ET (Gatewood et al. 1950; Devitt et al. 1997; Robinson 1965). In experimental data generated by Davenport et al. (1982b) and presented in Table I, the effects of environmental conditions on saltcedar ET are clearly demonstrated. Gatewood et al. (1950) states that saltcedar ET is at its lowest when relative humidity is the highest.

Table I. Influence of weather conditions on saltcedar evapotranspiration (ET) (adapted from Davenport et al. 1982b)

	Saltcedar ET	Solar radiation	Max. temp.	Wind
	mm/day	Ly/day	˚C	km/day
June 7-8	4.6	514	28	97
June 17-18	10.3	733	35	282

As previously mentioned, stand density has a very large impact on the amount of water saltcedar uses and its ability to dominate the vegetative landscape in areas is often the reason for its comparatively high consumption (Davenport et al. 1982a; 1982b). Weeks et al. (1987) noticed much lower ET rates in stands of saltcedar with scattered growth compared with stands having moderate to dense growth. In addition, the size of the plants affects the amount of water required for respiration and consequently ET is less for smaller trees or those with less foliage (Robinson 1965).

Methods of Evapotranspiration Measurement

A number of methods have been employed to derive estimates of water use by saltcedar in previous studies. The most common techniques include the use of evapotranspirometers, lysimeters, water budget studies, sap flow measurement, ET equations utilizing Bowen ratio, Blaney-Criddle, eddy covariance and groundwater level monitoring. Each method has strengths and weaknesses and corresponding debate regarding which is the most appropriate for determining saltcedar water use.

The use of evapotranspirometers and weighing lysimeters are methods similar in the fact that plants are grown in tanks or drums into which known quantities of water are applied (Hays 2003; van Hylckama 1974). Evapotranspirometers are tanks filled with soil in which the vegetation to be measured grows, with tank sizes varying with the size of the plant being studied (van Hylckama 1974). A measured amount of water is then applied to the soil and the amount collected from drain holes in the bottom of the tank is subtracted to determine ET values. Weighing lysimeters differ from evapotranspirometers because they utilize the weight of increments of, or the entire soil block contained within the tank to determine the change in water content (Hays 2003). The disadvantages of these methods are that they can be quite expensive and many overestimate ET due to the “oasis effect” (Shafroth et al. 2005; van Hylckama 1974). The “oasis effect” occurs when ET measurements are taken on a plant standing alone rather than within a typical stand surrounded by other vegetation, exposing the measured plant to unrealistic sunlight, wind, and heat and perhaps giving it ready access to more water than those in the natural environment. Extrapolation to the stand-level of tree-level data collected in this manner may significantly overstate water loss (van Hylckama 1974).

The water budget method consists of tracking the total amount of water inflows and outflows within an entire designated system, such as a reservoir or river reach (Culler et al. 1982; Shafroth et al. 2005). Culler et al. (1982) used the water budget method to estimate phreatophyte ET along the Gila River in Arizona by tracking variables such as streamflow, channel storage, tributary inflow, precipitation, soil moisture, basin-fill inflow, and groundwater movement. The complexities and difficulty of maintaining accurate records of these inflows and outflows make this method somewhat disadvantageous.

Sap flow measurement is another method that has been used to determine saltcedar water use. This method estimates only transpiration, rather than ET, by inserting electronic sensors into the tree xylem to monitor the amount of water flowing inside the plant (Owens and Moore 2007). A measure of sap flow per unit area is obtained and then extrapolated from leaf-level data to tree or stand-level transpiration using the leaf-area index (LAI) or multiplying by the whole-tree sapwood area (Owens and Moore 2007; Shafroth et al. 2005). This method can provide a high level of accuracy estimating transpiration on the leaf or tree basis, but may not be applicable when estimating water loss over a large area or trying to determine total water loss through ET.

Bowen ratio, Blaney-Criddle, and eddy covariance methods measure the micrometeorological environment above plants to calculate ET. Bowen ratio measures the difference in temperature and water vapor pressure between two instrument stations located above the saltcedar canopy (Drexler et al. 2004; Glenn and Nagler 2005; Weeks et al. 1987). This method assumes there is no horizontal variability of flow in the air mass directly above the stand and may lead to error in ET estimates by ignoring horizontally transported energy if it exists (Drexler et al. 2004). The eddy covariance method is based on the fact that air moving upward from vegetation contains more water vapor than that moving downward, and utilizes an instrument station above the canopy to measure the difference between these updrafts and downdrafts of air (Drexler et al. 2004; Glenn and Nagler 2005; Weeks et al. 1987). Shafroth et al. (2005) believe the eddy covariance method to be the most accurate because biases that may occur in other methods can be readily corrected. The equipment used in both the Bowen ratio and eddy covariance methods is very expensive and both require a fetch of at least 100 m which limits the areas to which these methods are applicable (Glenn and Nagler 2005).

Analysis of diurnal fluctuations in wells screened in shallow aquifers has been used as a method to determine groundwater consumption by phreatophytes (Butler et al. 2007; Gatewood et al. 1950; Gerla 1992; Hays 2003; Loheide et al. 2005; Rosenberry and Winter 1997; Schilling 2007; Shafroth et al. 2005; Troxell 1936; White 1932; Zhang and Schilling 2006). Butler et al. (2007) performed groundwater fluctuation analyses on phreatophytes such as cottonwood, mulberry (*Morus* spp.), and willow in the riparian zone on the Arkansas River. Gatewood et al. (1950), Hays (2003), and Inglis et al. (1996) used groundwater fluctuations to calculate water use by saltcedar. Rosenberry and Winter (1997) calculated evapotranspiration by wetland vegetation using water table fluctuations in central North Dakota.

As plants transpire during the day, the water table lowers if water use is significant. During the night when transpiration decreases or stops completely, the water table recharges (Loheide et al. 2005). This pattern was recognized by White (1932), who developed a method (White method) for analyzing well hydrographs to estimate plant water use. This approach can be readily implemented at relatively low costs and provides continuous data, which is difficult to obtain with other methods. Water table fluctuations are very small (often less than 10 mm) requiring that high-resolution equipment be used to achieve these levels of detection. Soil specific yield is a critical element of the White method and care must be taken to ensure the appropriate values are used in the equation (Loheide et al. 2005). Problems with determining the correct specific yield values are common in studies using groundwater fluctuation analysis and there is much debate on this (Butler et al. 2007; Gatewood et al. 1950; Loheide et al. 2005; Johnson 1967; Rosenberry and Winter 1997; Schilling 2007; Shafroth et al. 2005; Tan et al. 2006; Timlin et al. 2003). Because of the difficulties often encountered when assigning specific yield, some believe the

White method tends to overstate ET (Loheide et al. 2005; Rosenberry and Winter 1997; Shafroth et al. 2005).

Johnson (1967) developed a soil textural triangle based on specific yield values compiled from other studies (Figure 1). This particular figure has been used in some groundwater fluctuation studies to determine specific yield based on soil particle size; however, Johnson (1967) states that “Probably, at best, this method represents a speedy but only approximate means for estimating specific yield.” Loheide et al. (2005) performed detailed analyses on the Johnson (1967) specific yield values and offered a table of alternate values that may be used based on soil particle size (Table II). Comparing the differences between the Johnson (1967) and Loheide et al. (2005) values provides an example of the variation that occurs throughout the literature regarding specific yield.

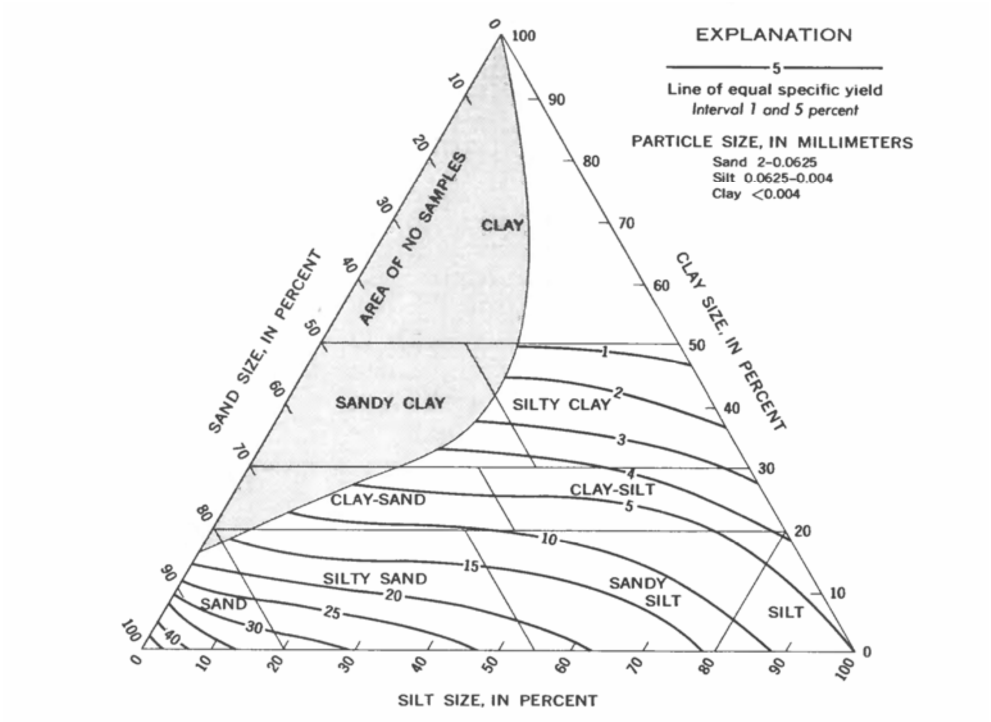

Figure 1. Soil texture triangle showing relationship between particle size and specific yield (copied from Johnson 1967)

Table II. Example of specific yield values based on soil particle size (adapted from Loheide et al. 2005)

			Specific yield	
Sediment texture	Sand	Clay	Johnson (1967)	Loheide et al. (2005)
			%	
Sand	92.7	2.9	34	32
Loamy sand	80.9	6.4	26	26
Sandy loam	63.4	11.1	19	17
Loam	40.0	19.7	9.5	7.5
Silt	5.8	9.5	6	2.6
Silt loam	16.6	18.5	7	3.7
Sandy clay loam	54.3	27.4	5	7.2
Clay loam	29.8	32.6	3.8	2.1
Silty clay loam	7.6	33.2	2.9	1.2
Sandy clay	47.5	41.0	2.5	1.5
Coarse sand				38
Medium sand				36
Fine sand				33
Very fine sand				31

Saltcedar Water Use Estimates

A number of saltcedar water use estimates have been generated through studies conducted at numerous locations using all of the methods previously described. Variability within and between previous studies is evidence of the site-specific nature of saltcedar water use and the need to consider each estimate within the context of local environmental conditions and methodology used. A compilation of estimates found in the literature is presented in Table III.

Table III. Compilation of stand-level saltcedar evapotranspiration estimates from published studies (adapted from Cleverly et al. 2002; Hays 2003; Shafroth et al. 2005)

Citation	Method	ET minimum	ET maximum
		mm/day	
Cleverly et al. (2002)	Eddy covariance	3.4	5.4
Davenport et al. (1982b)	Lysimeter	2.2	15.8
Gatewood et. al (1950)	Wells	1.0	14.4
Gay and Fritschen (1979)	Bowen ratio	7.2	9.5
Gay and Fritschen (1979)	Lysimeter	6.2	9.4
Hansen & Gorbach (1997)	Blaney-Criddle	2.0	2.7
Hays (2003)	Wells	1.0	37.8
Inglis et al. (1996)	Wells	3.9	10.4
Sala et al. (1996)	Sap flow	5.4	20.2
		m/yr	
Culler et al. (1982)[a]	Water budget	0.64	1.42
Devitt et al. (1998)[a]	Bowen ratio	0.75	1.45
Gatewood et al. (1950)	Lysimeter	1.20	3.00
Hays (2003)	Wells	1.93	2.76
King & Bawazir (2000)[a]	Eddy covariance	1.19	1.33
Luo (1994)[a]	Blaney-Criddle	0.43	1.43
van Hylckama (1974)[a]	Evapotranspirometer	0.92	2.29
Weeks et al. (1987)[a]	Energy budget	0.77	1.07

[a] Daily ET estimates were not provided in the original source

Water Salvage Estimates

Very little experimental data estimating water salvage from saltcedar control can be found in the literature and some estimates have been calculated by comparing saltcedar ET with that of likely or existing replacement vegetation (Shafroth et al. 2005). Weeks et al. (1987) point out that estimates derived from comparisons with replacement vegetation have a high degree of uncertainty and potential error due to extrapolation in space and time. Weeks et al. (1987) attempted to quantify water salvage from saltcedar control along the Pecos River in New Mexico by comparing baseflow of the river before and after mechanically clearing 8,700 ha of saltcedar. No increases in baseflow were detected, possibly due to “large variations in the water budget” such as groundwater pumping for irrigation and unusual amounts of rainfall in pre-control years (Weeks et al. 1987). Using calculations of ET rates between saltcedar and replacement vegetation such as grasses, forbs, and saltbush (*Atriplex patula*), a potential water salvage range of 0.20 – 0.40 m/yr was then predicted (Weeks et al. 1987). Culler et al. (1982) also calculated water salvage after mechanically clearing 2,191 ha of saltcedar along the Gila River in Arizona. Saltcedar ET measured pre-clearing was compared with that of measurements taken on post-treatment bare ground and annual vegetation to arrive at a water salvage estimate range of 0.36 – 0.66 m/yr, although salvage was predicted to decline as more replacement vegetation was established (Culler et al. 1982). Hays (2003) estimated water salvage at a location along the Colorado River in Texas using the EPA (1993) Paired Plot

Technique. Saltcedar ET was calculated on multiple sites and a relationship between the sites established before chemically treating one of them. The established pre-treatment relationship was then used to predict what the ET at the treated site would have been under a no treatment situation and the difference in predicted and actual ET was used to arrive at an estimated water salvage of 0.40 m/yr (Hays 2003).

This study was a continuance, reevaluation, and expansion of the saltcedar water use study initiated by Hays (2003) on the Pecos River in Texas. The main objective of the Hays (2003) study was to determine the best method for calculating water use by analyzing diurnal fluctuations in groundwater levels at this particular site. Hays (2003) reported water use at this site for 2001 (pre-treatment) and this study reports water loss for 2001-2006, reevaluates the 2001 water loss figures and estimates potential water salvage after chemically treating saltcedar.

MATERIALS AND METHODS

STUDY SITE DESCRIPTION

The study area was located in a stand of riparian saltcedar along approximately 2 miles of the Pecos River near the town of Mentone in Loving County, Texas. The area is located in the Chihuahuan Desert and is characterized by an arid climate, with approximately 11 inches of precipitation annually, most of which falls during the summer during short thunderstorms (NCDC 2004). The primary aquifer underlying the study area is the Cenozoic Pecos Alluvium which is composed of Tertiary and Quaternary unconsolidated to poorly cemented alluvium (Boghici 1999; Jones 2001; White 1971). Area soils are typically clay, silty clay, and silty loam of the Arno-Pecos-Patrole Series (Jaco 1980). Soils at the study site were predominantly fine sand, sandy loam, and clay loam with a clay layer present at varying depths in the soil profile. Riparian vegetation in the area was predominantly dense saltcedar growth, with fourwing saltbush (*Atriplex canescens*) and honey mesquite (*Prosopis glandulosa*) commonly occurring in the floodplain (Figure 2)

The study site was located approximately 30 miles to the southeast of Red Bluff Reservoir, which is situated just below the Texas/New Mexico state line. Red Bluff Reservoir stores water for scheduled releases to irrigation districts within the Red Bluff Power and Control District. The streamflow in this section of the Pecos River is highly regulated by releases from Red Bluff and the river bed has been known to go dry if sufficient water releases are not maintained. Clayton (2002) found that substantial amounts of water released from Red Bluff Reservoir are lost between the release and delivery points, ranging from 39 – 67% on a monthly basis.

Figure 2. Photo of study area near Mentone, TX

MONITORING WELLS

Overall project design for this study site was developed by Hays (2003) and in place when this study began. Additional information regarding the study design may be obtained from the Hays manuscript. The study site was designed following the EPA (1993) Paired Plot Study Design to allow comparison between 2 sites (A and B) under different saltcedar treatment scenarios (Figure 3). Eight groundwater monitoring wells, 4 at each site, were installed along the river before the growing season in 2001. The wells were hand augered and cased with 5.08 cm diameter PVC pipe with a 1.22 m-long well screen attached to the bottom of the casing, and approximately 0.9 m of casing extended above the soil surface (Figure 4). Wells 1, 2, and 3 at both sites were placed in a triangular formation on the bank immediately adjacent to the river, with wells 1 and 3 located inside the riparian saltcedar stand and well 2 situated at the edge of the stand. Well 5 at both sites, located outside the saltcedar stand in the floodplain, was used to compare water loss of floodplain vegetation with that of saltcedar.

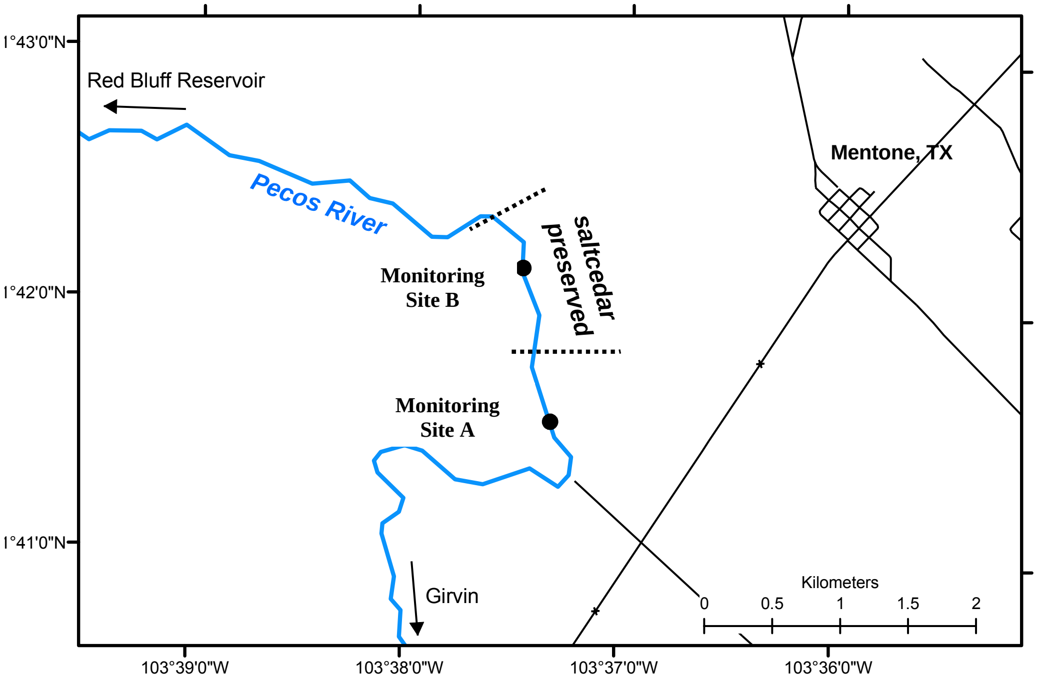

Figure 3. Map of study site near Mentone, TX

Annular space around the wells up to 0.3 m below the soil surface was filled with frac sand to prevent the 0.01 m slots in the well screens from clogging, and capped with concrete at the soil surface. A well (A4 & B4) was also installed in the river at each site to monitor water levels in the stream channel. Surface elevations of the wells relative to each other were determined by using a survey transit and range pole and depth of the wells was measured by lowering a weighted tape measure to the bottom of each well (Table IV). Each well was cleaned once per year by scrubbing the well screen with a long-handled brush to remove roots and flushed with a pressurized water hose to clean any silting that could potentially clog the well screen.

Figure 4. Photo of groundwater monitoring well

Table IV. Monitoring well depths and surface elevations

Well ID#	Depth from soil surface	Surface elevation
	m	
A1	3.51	813.86
A2	4.62	815.09
A3	3.05	813.41
A4 (river)	N/A	812.11
A5	4.64	814.54
B1	2.38	812.79
B2	4.36	815.05
B3	2.65	813.44
B4 (river)	N/A	811.84
B5	5.79	816.28

Water Loss Calculation

Each groundwater monitoring well was equipped with a pressure transducer data logger (Global Water Instrumentation, Inc. Model WL15X). The battery powered data loggers measured and recorded hourly groundwater levels with an accuracy of 0.2% or +-0.0091 m. Loggers were installed prior to the growing season in 2001-2006 and remained in the wells throughout the season each year. After the growing season in 2001, Site A was aerially treated with Arsenal^{TM} (Imazapyr) herbicide and the saltcedar growing at Site B was left untreated.

Hays (2003) developed a modified White (1932) equation (Equation 1) to measure water loss at this site, and that equation was used in this study.

$$Q = ((H_1-L_1) + ((H_2-L_1/T_1) \times T_2)) (sy) \qquad [1]$$

The equation uses the first high groundwater water level of the day (H_1), the lowest groundwater level (L_1), the first high groundwater level for the following day (H_2), the number of hours between the second high and first low (T_1), the number of hours between the first high and first low (T_2) and soil specific yield (sy) to calculate water loss due to ET (Figure 5).

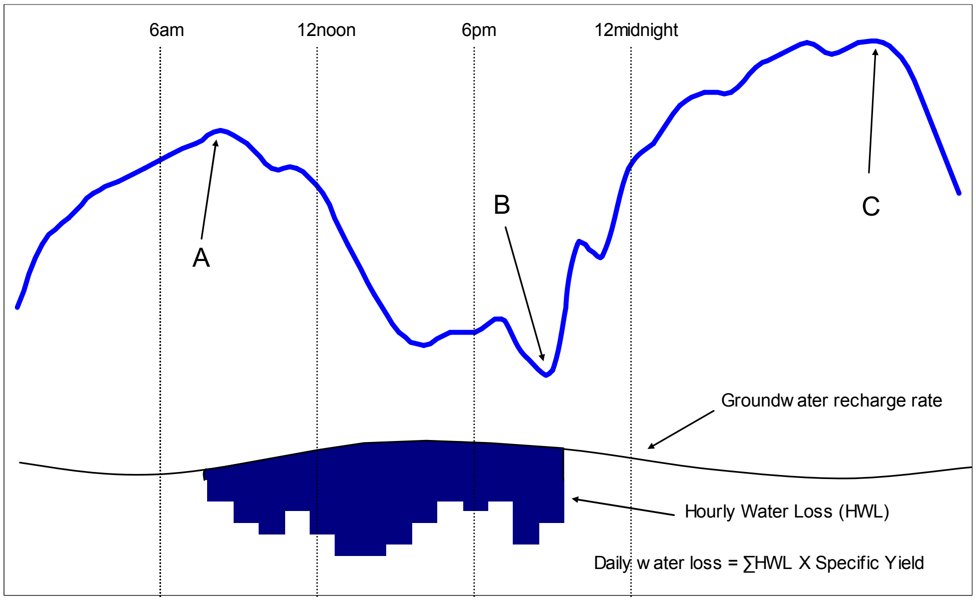

Figure 5. Example diurnal groundwater fluctuation. A = High 1, B = Low 1, C = High 2

Use of the modified White equation was complicated by the dynamic nature of upstream releases from Red Bluff Reservoir. In order to account for situations where groundwater fluctuations were influenced by streamflow changes, a procedure for eliminating these events was used. Instrument “noise”, or variability, was reduced by using a 3-period running average for each hourly water level reading. The allowable “stable” (S) value for the change in high water level between days was deemed to be 0.03 m, based on analysis of water fluctuations compared with upstream reservoir releases. Any calculation in which the water table fluctuation exceeded the (S) value was eliminated, thus reducing the impact of streamflow change from reservoir releases and recharge resulting from significant rainfall events. Calculations with drawdown or recharge time of less than 4 hrs, negative, or equal to zero were eliminated. Remaining daily water loss calculations for wells A 1-3 (treated) and B 1-3 (untreated), located within the saltcedar stands, were pooled to get an average daily water loss for each site. Monthly water loss was estimated by multiplying the average daily water loss by the number of days in the month. Average daily water loss was multiplied by the number of days in the growing season of April 1st – September 30th (183 days) to arrive at seasonal water loss estimates. Water loss at wells A5 and B5, located outside the saltcedar zone, was calculated in the same manner.

This method assumes that there was no saltcedar ET at night and that no measurable water losses occurred prior to April or after September. These assumptions were detailed by White (1932) and are supported by other studies (Cleverly et al. 2002; Gatewood et al. 1950; Gay and Hartman 1982; Loheide et al. 2005). As depicted in Figure 6, groundwater hydrographs developed in this study show that diurnal groundwater fluctuations are not detectable until the latter part of April and become undetectable again in October at this particular site.

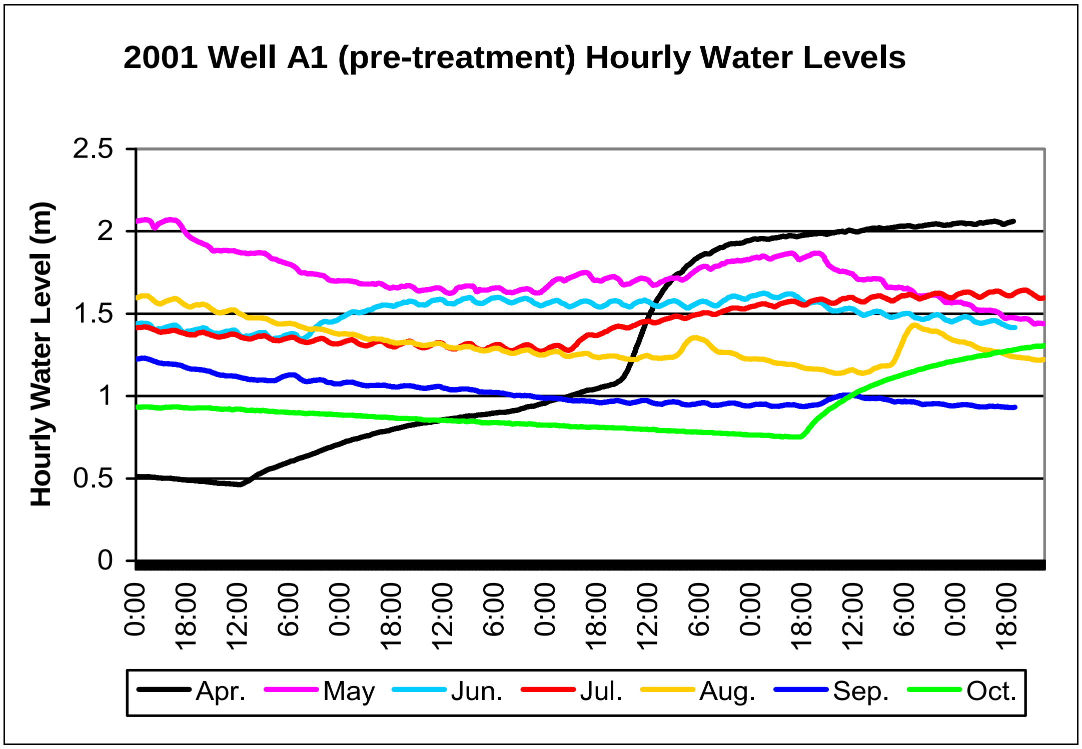

Figure 6. 2001 Well A1 (pre-treatment) hourly water levels

Specific Yield

The White (1932) method assumes that soil specific yield values used to calculate water loss due to ET can be accurately determined. As discussed in the literature review, this often proves to be quite difficult and may result in erroneous ET calculations if improper specific yield values are used.

Soil samples for each 0.3 m increment in the soil profile were collected at each well during the initial drilling and analyzed for texture by Hays (2003). Hays (2003) used specific yield values derived from the soil texture triangle provided in Johnson (1967) (Figure 1) to determine water loss at this study site for 2001. This study used the original samples in analyses to calculate specific yield by the sample saturation and drainage method (Johnson 1967). A 50 cm^3 sample of each 0.3 m increment in the soil profile of each well was oven dried in a sample can for 24 hours. The sample was then saturated, covered to prevent evaporation, and allowed to drain through a sieve into a holding pan for 24 hours. Specific yield was then calculated by subtracting the weight of the gravity drained sample from the weight of the saturated sample, divided by the total volume of water applied. This process was repeated 3 times for each 0.3 m increment and averaged for specific yield calculations.

Water Salvage Calculation

A comparison of hourly water level fluctuations at Sites A (treated) and B (untreated) in 2001 (pre-treatment) showed a significant correlation between wells 1-3 within and between sites (Table V). This relationship was used to estimate water salvage at Site A (treated) in 2002-2006 after chemically treating saltcedar.

Table V. Coefficient of determination (R^2) for 2001 Site A and B hourly water level fluctuations (adapted from Hays 2003)

Well	A1	A2	A3	A5	B1	B2	B3	B5
A1	1	0.96	0.98	0.11	0.95	0.96	0.86	0.96
A2		1	0.86	0.04	0.88	0.93	0.85	0.94
A3			1	0.07	0.97	0.93	0.98	0.88
A5				1	0.12	0.10	0.04	0.06
B1					1	0.98	0.88	0.97
B2						1	0.90	0.98
B3							1	0.92
B5								1

In order to estimate potential water salvage from saltcedar control, data from adjacent Sites A (treated) and B (untreated) was collected 1 year prior to treatment (2001) for baseline data and to determine their relationship. After chemical treatment of Site A at the end of 2001, the control (Site B) was used in subsequent years (2002-2006) to predict what the water use calculation would have been under a no-treatment situation. This allowed for a simple comparison between actual and predicted water loss at Site A (treated) to arrive at estimated salvage due to saltcedar control (Equation 2).

$$\text{Salvage} = ((A_1 \text{ x } (B_y/B_1)) - (A_y) \qquad [2]$$

The equation uses the Site A pre-treatment (2001) seasonal water loss (A_1), untreated Site B seasonal water loss for the year in question (B_y), untreated Site B seasonal water loss in 2001 (B_1), and Site A post-treatment seasonal water loss for the year in question (A_y).

STATISTICAL ANALYSES

Statistical analyses were performed on water loss calculations for both Sites A and B in all years to identify outliers and determine if treatment effects were significant. Daily water loss calculations for each well were analyzed for outliers on a yearly basis using boxplots (Frigge et al. 1989). Values that fell outside 1.5 times the interquartile range were examined in relation to surrounding days and daily water loss estimates found in the literature and were excluded from final seasonal water loss calculations if they were deemed unreasonable. A

Levene’s test for homogeneity of variances was conducted on average daily water loss calculations on each well by season (Zar 1999). Upon discovering heteroscedasticity, the Welch and Brown-Forsythe corrections were applied after conducting single-factor analysis of variance (ANOVA) on the average daily water loss calculations at each site to determine if there were significant differences between years of data and treatments (Zar 1999). A Games-Howell pair-wise post hoc test was then conducted to determine homogeneous subsets of seasonal water loss calculations (Day and Quinn 1989). Standard error of the mean daily water loss for both sites was calculated on a yearly basis for use in displaying variability in the results (Freund 1984). The standard error values for Site A (treated) were utilized to display variability in water salvage estimates for each year.

RESULTS AND DISCUSSION

SPECIFIC YIELD

Laboratory tests to determine specific yield produced significantly different results for this study site when compared to those reported by Hays (2003). The majority of specific yield values used in this study's calculations were notably lower than the Hays (2003) estimates, which led to the lower water loss estimates for 2001 discussed in the water loss section. Specific yield values used by Hays (2003) are compared to those used in this study in Tables VI and VII.

Table VI. Comparison of Site A (treated) specific yield values used in this study (Hatler) and in Hays (2003)

Well ID#	Water level[a]	Soil texture	Specific yield	
			Hays (2003)	Hatler
	m		--------------%-------------	
A1	0 - 0.30	Clay	1	4
A1	0.30 - 0.61	Sandy Clay Loam	4	10
A1	0.61 - 0.91	Sandy Clay Loam	7	10
A1	0.91 - 1.22	Sandy Loam	25	14
A1	1.22 - 1.52	Fine Sand	40	17
A1	1.52 - 1.83	Fine Sand	40	20
A1	1.83 - 2.13	Sand	40	19
A1	2.13 - 2.44	Sand	40	20
A1	2.44 - 2.74	Sand	42	17
A1	2.74 - 3.05	Sand	42	17
A1	3.05 - 3.35	Sand	40	21
A1	3.35 - 3.66	Loamy Sand	30	20
A2	0 - 0.30	Fine Sand	35	17
A2	0.30 - 0.61	Sand	35	17
A2	0.61 - 0.91	Fine Sand	35	17
A2	0.91 - 1.22	Fine Sand	35	16
A2	1.22 - 1.52	Fine Sand	40	20
A2	1.52 - 1.83	Fine Sand	35	16
A2	1.83 - 2.13	Fine Sand	35	18
A2	2.13 - 2.44	Fine Sand	35	18
A2	2.44 - 2.74	Fine Sand	35	18
A2	2.74 - 3.05	Fine Sand	35	18
A2	3.05 - 3.35	Loamy fine sand	30	13
A2	3.35 - 3.66	Very fine sandy loam	15	5
A2	3.66 - 3.96	Loamy fine sand	30	12
A2	3.96 - 4.27	Very fine sandy loam	17	8
A2	4.27 - 4.57	Fine sandy loam	17	8
A3[b]	0 - 0.30	N/A	N/A	4
A3 [b]	0.30 - 0.61	N/A	N/A	5
A3 [b]	0.61 - 0.91	N/A	N/A	17
A3 [b]	0.91 - 1.22	N/A	N/A	19
A3 [b]	1.22 - 1.52	N/A	N/A	15
A3 [b]	1.52 - 1.83	N/A	N/A	7
A3 [b]	1.83 - 2.13	N/A	N/A	3
A3 [b]	2.13 - 2.44	N/A	N/A	3
A3 [b]	2.44 - 2.74	N/A	N/A	5
A5	0.30 - 0.61	Clay	1	3
A5	0.61 - 0.91	Clay	1	3

Table VI, Continued

Well ID#	Water level[a]	Soil texture	Specific yield	
			Hays (2003)	Hatler
	m		--------------%-------------	
A5	0.91 - 1.22	Silty clay loam	3	5
A5	1.22 - 1.52	Sandy clay loam	5	7
A5	1.52 - 1.83	Fine Sand	40	20
A5	1.83 - 2.13	Fine Sand	35	16
A5	2.13 - 2.44	Fine Sand	35	18
A5	2.44 - 2.74	Fine Sand	35	17
A5	2.74 - 3.05	Fine Sand	35	16
A5	3.05 - 3.35	Fine Sand	35	17
A5	3.35 - 3.66	Loamy fine sand	30	11
A5	3.66 - 3.96	Loamy fine sand	25	9
A5	3.96 - 4.27	Loam	10	7
A5	4.27 - 4.57	Silty loam	4	6

[a] Level of water in the well listed in order from the bottom of the well up to the soil surface.

[b] Well A3 data was not used by Hays (2003) and its soil samples were not analyzed for texture.

Table VII. Comparison of Site B (untreated) specific yield values used in this study (Hatler) and in Hays (2003)

			Specific yield	
Well ID#	Water level[a]	Soil texture	Hays (2003)	Hatler
	m		--------------%-------------	
B1	0 - 0.30	Sand	40	22
B1	0.30 - 0.61	Sand	40	21
B1	0.61 - 0.91	Sand	35	17
B1	0.91 - 1.22	Fine sandy loam	15	13
B1	1.22 - 1.52	Silty clay loam	2	4
B1	1.52 - 1.83	Clay loam	4	3
B1	1.83 - 2.13	Clay	2	3
B2	0 - 0.30	Fine sandy loam	15	13
B2	0.30 - 0.61	Sandy Loam	20	14
B2	0.61 - 0.91	Fine Sand	35	17
B2	0.91 - 1.22	Fine Sand	35	16
B2	1.22 - 1.52	Fine Sand	40	20
B2	1.52 - 1.83	Fine sandy loam	25	8
B2	1.83 - 2.13	Very fine sandy loam	20	5
B2	2.13 - 2.44	Fine sandy loam	20	7
B2	2.44 - 2.74	Fine sandy loam	15	5
B2	2.74 - 3.05	Fine sandy loam	20	6
B2	3.05 - 3.35	Fine Sand	35	17
B2	3.35 - 3.66	Fine Sand	35	17
B2	3.66 - 3.96	Fine sandy loam	25	8
B2	3.96 - 4.27	Fine sandy loam	20	6
B3	0 - 0.30	Loamy sand	25	11
B3	0.30 - 0.61	Sand	35	18
B3	0.61 - 0.91	Sand	35	17
B3	0.91 - 1.22	Sand	35	17
B3	1.22 - 1.52	Sand	35	19
B3	1.52 - 1.83	Loamy fine sand	25	16
B3	1.83 - 2.13	Loam	10	8
B3	2.13 - 2.44	Clay	1	4
B5	0 - 0.30	Silty clay loam	3	3
B5	0.30 - 0.61	Silty loam	6	5
B5	0.61 - 0.91	Clay loam	3	4
B5	0.91 - 1.22	Clay loam	3	4
B5	1.22 - 1.52	Silty clay	1	3
B5	1.52 - 1.83	Silty clay	1	3
B5	1.83 - 2.13	Silty clay loam	5	6
B5	2.13 - 2.44	Silty loam	11	9
B5	2.44 - 2.74	Silty loam	10	8

Table VII, Continued

Well ID#	Water level[a]	Soil texture	Specific yield Hays (2003)	 Hatler
	m		--------------%	-------------
B5	2.74 - 3.05	Silty loam	10	7
B5	3.05 - 3.35	Silty loam	14	8
B5	3.35 - 3.66	Silty clay loam	2	4
B5	3.66 - 3.96	Silty clay loam	3	4
B5	3.96 - 4.27	Silty clay	1	4
B5	4.27 - 4.57	Loam	10	6

[a] Level of water in the well listed in order from the bottom of the well up to the soil surface.

WATER LOSS

Inside the Saltcedar Zone

A comparison of 2001 seasonal water loss values calculated in this study and in Hays (2003) for wells located within the saltcedar zone is shown in Tables VIII and IX. The water loss values calculated in this study are notably lower than those reported by Hays (2003). This is due to the differences in specific yield values used and to a lesser extent the more aggressive analysis for outliers conducted in this study. The differences in water loss estimates reached by two different studies using the same study site, data, and almost identical methodology highlight the influence of specific yield on the White (1932) method. It should be noted that Hays (2003) calculated seasonal water loss by adding the monthly averages together, whereas this study multiplied the seasonal daily average by number of days in the growing season (183). Both methods of reporting seasonal water loss were compared during this study and there were minimal differences in the results. This study found that multiplying the seasonal daily average by number of days in the growing season more robustly accounts for months having less data.

Table VIII. Comparison of 2001 Site A (treated) total monthly and seasonal water loss values calculated in this study (Hatler) and in Hays (2003)

	Well A1		Well A2		Well A3[a]	
	Hays (2003)	Hatler	Hays (2003)	Hatler	Hays (2003)	Hatler
			m			
Apr.	0.0693	0.1096	0.0186	0.1013	N/A	0.0371
May	0.6482	0.3227	0.2407	0.1395	N/A	0.0781
Jun.	0.6910	0.3496	0.2462	0.1488	N/A	N/A
Jul.	0.7082	0.3057	0.1907	0.0948	N/A	N/A
Aug.	0.5458	0.2360	0.1377	0.0923	N/A	N/A
Sept.	0.2765	0.1172	0.0794	0.0463	N/A	N/A
Total	2.939	1.5217	0.9185	0.6850	N/A	N/A

[a] Well A3 data was not reported by Hays (2003). Well A3 April and May data were used in this study for Site A (treated) averages in 2001.

Table IX. Comparison of 2001 Site B (untreated) total monthly and seasonal water loss values calculated in this study (Hatler) and in Hays (2003)

	Well B1		Well B2		Well B3	
	Hays (2003)	Hatler	Hays (2003)	Hatler	Hays (2003)	Hatler
			m			
Apr.	0.0464	0.0319	0.3076	0.2160	0.0758	0.1365
May	0.5533	0.0641	1.3805	0.7496	0.6603	0.4045
Jun.	0.2825	0.0417	0.6494	0.3717	0.9097	0.5409
Jul.	0.4153	0.0522	0.2102	0.1012	0.8497	0.4830
Aug.	0.6105	0.2010	0.0903	0.1212	0.2840	0.2594
Sept.	0.6444	0.2702	0.0905	0.0521	0.1078	0.0382
Total	2.5524	0.7144	2.7285	1.7743	2.8873	1.8017

A summary of monthly and seasonal combined average water loss for wells located within the saltcedar zone is presented in Table X. Monthly variations in water loss are notable at both sites in all years. Water loss was typically lowest in April and September and highest in the warmer months of May through August.

Table X. Monthly and seasonal average water loss for wells in the saltcedar zone

	Pre-Treatment	Post-Treatment				
	2001	2002	2003	2004	2005	2006
				m		
Site A (treated)						
Apr.	0.0812	0.0282	0.0231	0.0335	0.0592	0.0418
May	0.2238	0.0223	0.0196	0.0388	0.0670	0.0168
Jun.	0.2470	0.0204	0.0222	0.0200	0.0368	0.0628
Jul.	0.2023	0.0273	0.0450	0.0414	0.0528	0.1749
Aug.	0.1843	0.0195	0.0337	0.0695	0.0274	0.2027
Sept.	0.1020	0.0602	0.0150	0.0437	0.0540	0.1134
Total	1.1076	0.1607	0.1460	0.2082	0.2975	0.5393
Site B (untreated)						
Apr.	0.0823	0.0617	0.0969	0.1010	0.0598	0.0323
May	0.2032	0.0725	0.1224	0.1277	0.0937	0.0671
Jun.	0.3144	0.0833	0.1388	0.0373	0.0483	0.1198
Jul.	0.2756	0.0824	0.2170	0.1216	0.0427	0.2693
Aug.	0.1804	0.0711	0.1721	0.1487	0.0901	0.1154
Sept.	0.1329	0.0658	0.1170	0.0276	0.1159	0.1036
Total	1.2509	0.4331	0.8252	0.5867	0.4228	0.5817

Daily and seasonal water loss calculations for wells located within the saltcedar zone at Sites A (treated) and B (untreated) are shown in Table XI and Figure 7. There was no significant difference ($p<0.05$) in stand-level calculated water loss in 2001 (pre-treatment) between Site A and B and, as a result, data from both sites were averaged to arrive at a pre-treatment baseline seasonal water loss calculation of 1.18 m. This figure is significantly lower than the 2.35 m average of Site A and B reported by Hays (2003) due to the given changes in specific yield values used and the removal of outliers.

Hart et al. (2005) also reported the Hays (2003) water loss figures at this site for 2001 and went on to report water loss in 2002 and 2003 with notably different results than those reported in this study. Hart et al. (2005) reported Site B (untreated) water loss for 2002 and 2003 as 1.94 m and 2.03 m and Site A (treated) as 0.17 m and 0.04 m, respectively. This study calculated 2002 and 2003 Site B (untreated) water loss as 0.43 m and 0.86 m and Site A (treated) as 0.16 m and 0.15 m, respectively. Hart et al. (2005) used the same specific yield values reported in Hays (2003) to calculate water loss by the White (1932) method at this site, which may explain the discrepancies between studies.

Gatewood et al. (1950) and Inglis et al. (1996) also used the White (1932) method to calculate saltcedar stand-level ET, and reported a notably wider range of daily water use than this study. Gatewood et al. (1950) reported a range of 1.0 – 14.4 mm/day water use by saltcedar in the Lower Safford Valley in Arizona. The estimated saltcedar water use by Inglis et al. (1996) in the Lake Mead National Recreation Area of Nevada ranged from 3.9 – 10.4 mm/day. The daily average water loss calculated in this study ranged from 2.3 – 6.5 mm/day.

Saltcedar initial mortality rates at Site A in 2002 following chemical control were approximately 90%, leaving virtually no living vegetation present in the riparian zone and producing barely detectable diurnal groundwater fluctuations (Figures 8 and 9). Post-treatment water loss at Site A dropped to 0.16 m in 2002, or 14% of the baseline, and Site B (untreated) also dropped to 0.43 m, or 37% of 2001. Site A (treated) water loss remained significantly ($p<0.05$) lower than Site B (untreated) through 2005. In 2006, differences in water loss were no longer significant and although water loss never again equaled that of the baseline data, the relationship between sites was similar.

Table XI. Daily and seasonal saltcedar water loss calculations for wells in the saltcedar zone

		Daily avg.	Daily Std. err.	Daily min.	Daily max	Seasonal avg.	Seasonal Std. err.	Seasonal min.	Seasonal max	% of 2001
	n	----------	----------	----------	----------	-----m-----	----------	----------	----------	%
Pre-treatment baseline										
2001	422	0.0065	0.00027	0.0062	0.0067	1.18	0.049	1.13	1.23	
Site A (treated)										
2002	85	0.0009	0.00007	0.0008	0.0010	0.16	0.013	0.15	0.17	14
2003	209	0.0008	0.00006	0.0007	0.0009	0.15	0.012	0.13	0.16	12
2004	98	0.0011	0.00008	0.0011	0.0012	0.21	0.015	0.19	0.22	18
2005	67	0.0016	0.00015	0.0015	0.0018	0.30	0.028	0.27	0.33	25
2006	171	0.0029	0.00020	0.0027	0.0031	0.54	0.037	0.50	0.58	46
Site B (untreated)										
2002	157	0.0024	0.00016	0.0022	0.0025	0.43	0.030	0.40	0.46	37
2003	248	0.0045	0.00017	0.0043	0.0047	0.83	0.032	0.79	0.86	70
2004	88	0.0032	0.00023	0.0030	0.0034	0.59	0.041	0.55	0.63	50
2005	109	0.0023	0.00018	0.0021	0.0025	0.42	0.032	0.39	0.46	36
2006	160	0.0032	0.00024	0.0029	0.0034	0.58	0.044	0.54	0.63	49

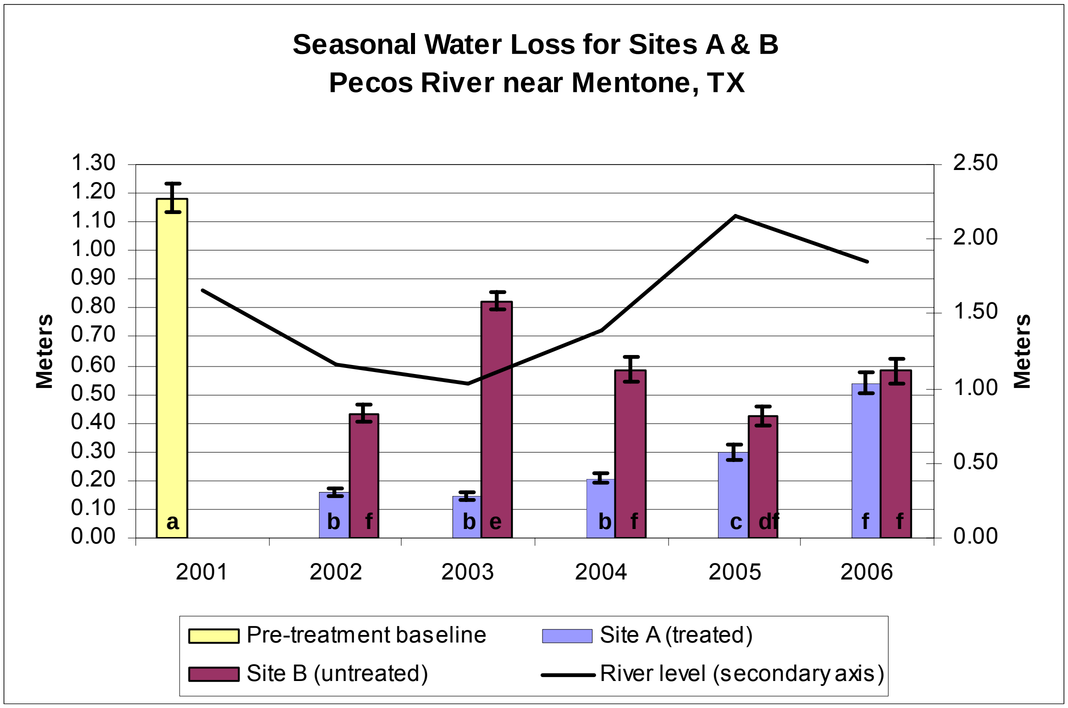

Figure 7. Seasonal water loss at Sites A and B 2001-2006. Error bars indicate +- 1 STD err. Letters within bars indicate significant difference ($p < 0.05$)

Figure 8. Photo of study area 1 year after treatment

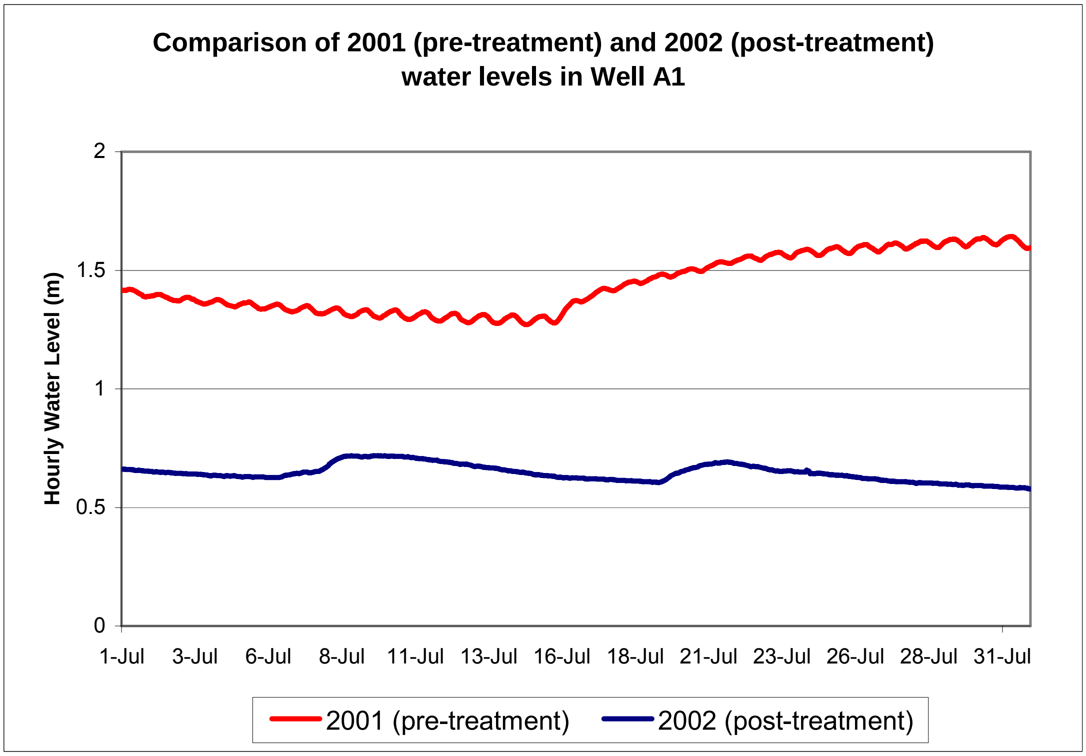

Figure 9. Comparison of 2001 (pre-treatment) and 2002 (post-treatment) water levels in Well A1 for the month of July

The data raises a number of unexpected questions. Water loss at the untreated Site B dropped significantly in 2002, although only the treated Site A was expected to do so. Severe drought in 2002 and 2003 resulted in no water releases from upstream Red Bluff Reservoir in those years and consequently some of the monitoring wells went dry. The water table dropped approximately 0.9 m from 2001 to 2002, and was likely below the saltcedar root zone at Site B (untreated) in 2002, drastically reducing evapotranspiration (ET). Decreased saltcedar water use related to a declining water table has been noted in other studies (Butler et al. 2007; Cooper et al. 2006; Devitt et al. 1997). By 2003, the roots may have recovered and again found the water table, as evidenced by the sharp increase in water loss at Site B (untreated). In contrast, water loss at Site B (untreated) dropped significantly again in 2004 and 2005 due to flooding at the site. Heavy rainfall events and large releases from Red Bluff led to saturated soils and water above ground for extended periods of time at much of the site. Readily available soil moisture in 2004 and 2005 potentially reduced diurnal groundwater fluctuations and the ability to detect saltcedar water loss at the rates seen in 2003 and 2001. Gatewood et al. (1950) encountered a similar scenario, noting that "the hygrograph from a well for a day when the soil moisture is plentiful will show a low use of water." Environmental conditions in 2006 were the most similar to 2001 and Site B (untreated) water loss increased to 0.58 m, but never recovered to the pre-treatment baseline of 1.18 m. Riparian saltcedar was treated both up and down river of Site B (untreated), leaving it to be the only living stand of trees in the area. Treatment of the saltcedar directly upriver may have had a direct effect on Site B (untreated) resulting in under-estimated water loss.

The range of water loss attributable to saltcedar calculated at Site B (untreated) throughout the course of this study agrees quite well with other estimates found throughout the literature. As summarized in Table III, the minimum seasonal ET estimate found in the literature was 0.43 m and the maximum was 3.0 m per year. This study calculated an average seasonal minimum of 0.42 m and a maximum of 1.18 m in years 5 and 1, respectively.

As expected, water loss at the treated Site A decreased dramatically following saltcedar control and remained very low through 2004. Pre-treatment vegetation transects completed by Hays (2003) show that prior to 2002, the vegetation at Site A (treated) was dominated by a saltcedar monoculture. Therefore, a portion of the water loss reduction is attributable to saltcedar control. Vegetation began returning to Site A (treated) in the form of grasses and forbs the second year after saltcedar treatment (Figure 10). Weeks et al. (1987) used the eddy correlation method to measure daily water use by replacement vegetation after clearing saltcedar on the Pecos River in New Mexico and found that grasses and forbs were using 0.5 – 1.4 mm/day. Comparably, daily water loss at Site A (treated) was calculated at 0.9 – 1.1 mm/day post-treatment in 2002-2004. Water loss in the year after treatment (2002) is attributable to evaporation from the bare soil, as there was no living vegetation on the site at that time. Water loss at Site A (treated) did not increase significantly in 2003 and 2004, even though grasses and forbs had returned to the site, whereas water loss did increase significantly at Site B (untreated) in 2003 due to the ability of saltcedar to tap the deeper water resources. Notable saltcedar re-growth began to take place in 2005 and increasingly so in 2006 (Figure 11) and is likely the cause of corresponding increases in water loss at Site A (treated) in those years. A simple plant count transect at Site A (treated) completed in 2008 revealed that approximately 60% of saltcedar had re-grown by the 6th year after treatment.

Figure 10. Photo of replacement vegetation at Site A (treated) 3 years after treatment

Figure 11. Photo of saltcedar re-growth at Site A (treated) 5 years after treatment

Outside the Saltcedar Zone

Two wells (A5 and B5) were located outside the saltcedar zone at both the treated (A) and untreated (B) sites, respectively. Vegetation surrounding these wells, predominantly fourwing saltbush (*Atriplex canescens*) and honey mesquite (*Prosopis glandulosa*), received no chemical treatment throughout the course of the study. Daily and seasonal average water loss for both of these wells is presented in Table XII.

Table XII. Daily and seasonal average water loss for wells A5 and B5 (outside the saltcedar zone), 2001-2006

		Daily Avg.	Daily Std err.	Seasonal Avg.	Seasonal Std err.
	n	m			
Well A5					
2001	163	0.0040	0.00020	0.7320	0.0374
2002	171	0.0005	0.00002	0.0984	0.0028
2003	56	0.0002	0.00003	0.0444	0.0050
2004	135	0.0022	0.00016	0.4032	0.0284
2005	138	0.0027	0.00013	0.4983	0.0240
2006	127	0.0018	0.00008	0.3312	0.0150
Well B5					
2001	118	0.0018	0.00013	0.2231	0.0238
2002	14	0.0002	0.00005	0.0300	0.0084
2003	88	0.0006	0.00005	0.0135	0.0084
2004	34	0.0005	0.00004	0.1229	0.0077
2005	80	0.0006	0.00004	0.1519	0.0071
2006	116	0.0009	0.00005	0.1010	0.0100

Water loss at well B5 was significantly ($p<0.05$) lower than the average water loss of wells located in the saltcedar zone at Site B (untreated) in all years. Water loss at well B5 displayed much lower water loss in 2002 and 2003 in response to drought conditions and no releases from upstream Red Bluff

Reservoir. Of particular interest was the continued decrease in water loss at well B5 from 2002 to 2003, as opposed to the sharp increase in water loss at wells B1-3 (saltcedar zone) in 2003 (Figure 12). This is indicative of the ability of saltcedar to access deeper groundwater than the native species located in the floodplain. In contrast to the 2002 to 2003 scenario, water loss at well B5 increased in 2004 and 2005 while water loss at wells B1-3 (saltcedar zone) decreased. Site flooding and water above ground at wells B1-3 (saltcedar zone) in those years affected the ability to detect diurnal groundwater fluctuations. More readily available water in the floodplain, and the ability to detect increased diurnal fluctuations contributed to the increased water loss at well B5. This indicates that water loss was probably under-estimated in the saltcedar zone at Site B (untreated) in 2004 and 2005.

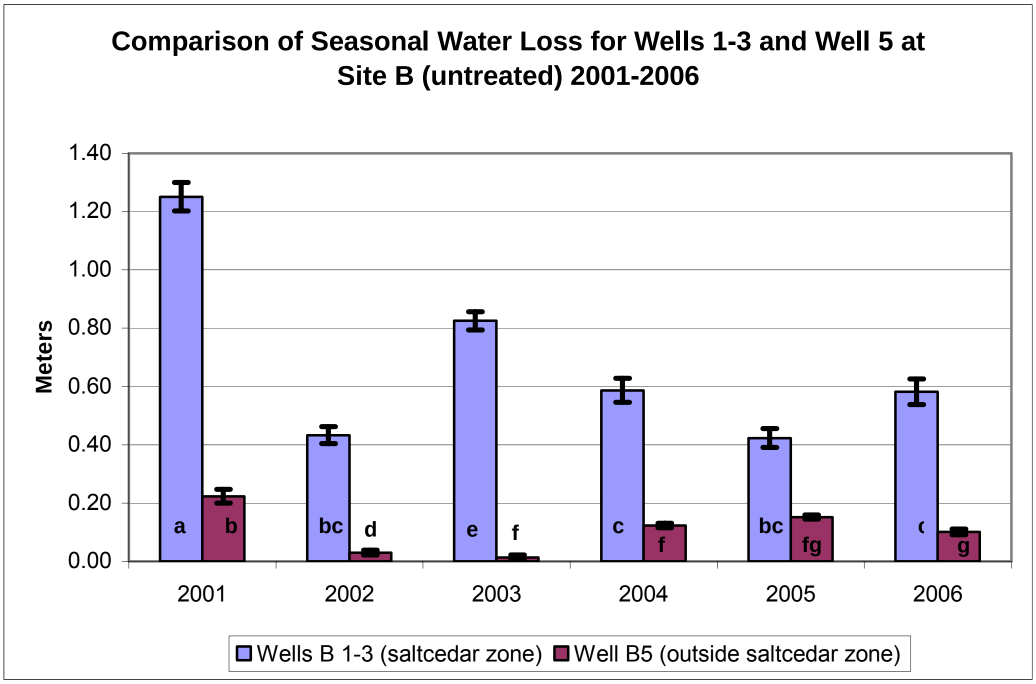

Figure 12. Comparison of seasonal water loss for wells 1-3 and well 5 at Site B (untreated), 2001-2006. Error bars indicate +- 1 STD err. Letters within bars indicate significant differences (p<0.05)

Water loss at well A5 was significantly lower (p<0.05) than the average water loss of wells A1-3 (saltcedar zone) in 2001-2003 and displayed the same downward trend as that of well B5 water loss (Figure 13). The relationship between well A5 and wells A1-3 (saltcedar zone) changed dramatically in 2004 and 2005 with well A5 showing significantly higher water loss than those located in the saltcedar zone for those years. Water availability on site from increased precipitation and upstream reservoir releases possibly made groundwater more accessible to the floodplain vegetation surrounding well A5 in the absence of riparian saltcedar water use. In 2006, wells A5 and A1-3 (saltcedar zone) returned to an approximation of their original relationship with wells within the saltcedar zone showing significantly higher water loss than well A5. This may be attributed to increased water loss at wells A1-3 (saltcedar zone) due to saltcedar re-growth. Caution must be used when making direct comparisons between wells A1-3 (saltcedar zone) and well A5 due to very low correlation between hourly diurnal water fluctuations (Table V) and very low correlation between well A5 and river level.

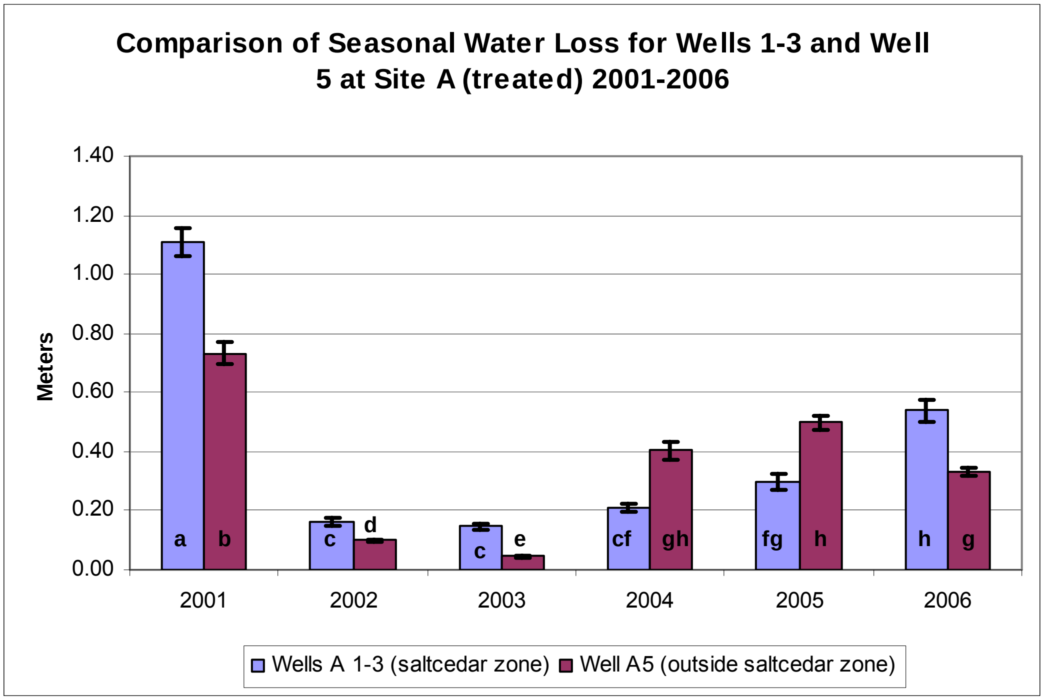

Figure 13. Comparison of seasonal water loss for wells 1-3 and well 5 at Site A (treated), 2001-2006. Error bars indicate +- 1 STD err. Letters within bars indicate significant differences (p<0.05)

WATER SALVAGE

The original strategy for calculating water salvage from saltcedar control was to use the Site B (untreated) water loss calculations to predict what water loss would have been at Site A in 2002-2006 had it been left untreated. Since no significant difference (p=0.94) between sites existed in 2001 (pre-treatment), the data was pooled to arrive at an average pre-treatment baseline water loss of 1.18 m. Given the high degree of correlation between sites presented in Table V and the pooled pre-treatment data, water loss at Site A (treated) was simply subtracted from water loss at Site B (untreated) on a yearly basis in 2002-2006 to calculate seasonal water salvage. Seasonal water salvage results are presented in Table XIII and Figure 14.

Table XIII. Seasonal water salvage for Site A (treated) 2002-2006

	Water Salvage Avg.	Water Salvage Avg.	Std. err.	Water Salvage Min.	Water Salvage Max
	%	----------------------------------	-----------m-----------	-------------------------------	
2002	63	0.27	0.013	0.26	0.28
2003	82	0.68	0.012	0.67	0.69
2004	65	0.38	0.015	0.37	0.40
2005	31	0.13	0.028	0.10	0.16
2006	7	0.04	0.037	0.00	0.08

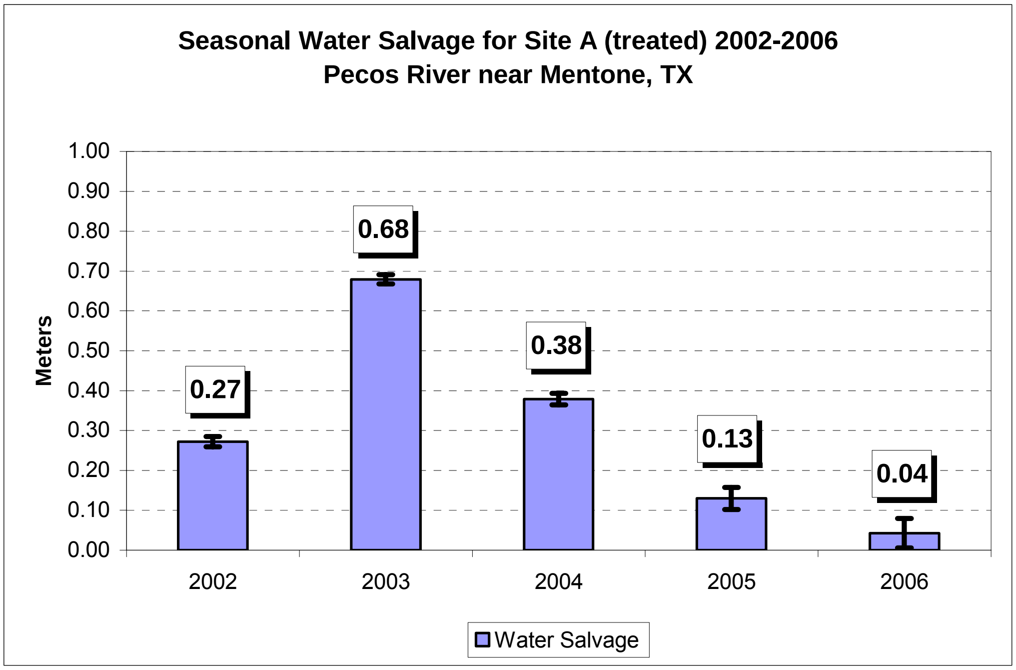

Figure 14. Seasonal water salvage for Site A (treated) 2002-2006. Error bars indicate +- 1 STD err.

Water salvage immediately following chemical saltcedar control in 2002 was calculated to be 0.27 m and was surprisingly low compared to the 2003 and 2004 figures. As stated previously in the water loss discussion, the area experienced drought conditions in 2002, which led to a significant drop in the water table and less water available for saltcedar ET. Consequently the potential water salvage was decreased significantly due to the substantially lower water loss calculated at Site B (untreated) that year. The highest potential water salvage occurred in 2003, resulting directly from the increased water losses calculated at the untreated Site B that year. Although site conditions were similar in 2002 and 2003, it appears that the saltcedar root system at Site B (untreated) was able to access and begin "pumping" groundwater again, registering higher diurnal fluctuations and water loss in 2003. In the absence of competition from saltcedar, grasses and forbs began returning to Site A (treated) in 2003 and were present throughout the growing season in all following years of the study. It is apparent that these plants were incapable of tapping the shallow aquifer in drought years when saltcedar was able to do so. Water salvage remained significant in 2004 and 2005 while decreasing in response to lower water losses at Site B (untreated) and higher ET losses at Site A (treated) due to saltcedar re-growth. There was no significant difference (p=1.00) in water loss calculations for Site A (treated) and B (untreated) in 2006; therefore, the water salvage figure for 2006 presented herein is not significant.

Nagler et al. (2008) estimated potential water salvage by saltcedar removal on the Lower Colorado River by assuming an annual saltcedar ET rate of 1.0 m/yr and comparing that to potential replacement vegetation. They estimated potential water salvage to be 0.6 to -0.2 m/yr based on ET rates of 0.4 m/yr for Saltgrass (*Distichlis spicata*) and 1.2 m/yr for Cottonwoods (Nagler et al. 2008). This study calculated a water salvage range of 0.13 – 0.68 m/yr with replacement vegetation (grasses and forbs) having ET rates of 0.15 – 0.30 m/yr dependent upon annual site conditions. Nagler et al. (2008) also cautioned that bare soil above shallow water tables could display as much as 0.6 m/yr water loss after saltcedar removal due to evaporation. This study calculated water loss of 0.16 m/yr in 2002 under bare soil conditions at Site A (treated).

CONCLUSIONS

Stand-level water loss due to saltcedar ET and potential water salvage from saltcedar control data presented herein agree with other estimates found in the literature. Estimates of annual saltcedar water use found in the literature ranged from 0.43 – 3.0 m/yr. The range of average seasonal water loss in saltcedar stands at this study site was calculated to be 0.42 – 1.18 m/yr and was highly dependent on site-specific variability. The highest water loss estimate was calculated during optimum conditions for the methodology employed by this study leading to the conclusion that the lowest estimates may underestimate the true level of water loss in those years. Recent sap flow studies (Owens and Moore 2007) also have shown that saltcedar does transpire at night, although at a much lower rate, which is not considered in the White (1932) method used in this study. Taking these factors into consideration, it is believed that the water loss figures calculated in this study are conservative.

Water salvage resulting from saltcedar control or removal is highly dependent on replacement vegetation and other site-specific conditions. Weeks et al. (1987) predicted water salvage on the Pecos River in New Mexico to be 0.20 – 0.40 m/yr with replacement vegetation consisting of grasses, forbs, and saltbush (*Atriplex patula*). Culler et al. (1982) calculated a water salvage range of 0.36 – 0.66 m/yr on bare ground following saltcedar removal on the Gila River in

Arizona. Hays (2003) estimated 0.40 m/yr annual water salvage from chemically controlling saltcedar on the Colorado River in Texas, but did not report the composition of replacement vegetation. Nagler et al. (2008) estimated potential water salvage from saltcedar control to range from 0.6 to -0.2 m/yr, based on site re-vegetation by saltgrass and cottonwood trees. This study calculated water salvage resulting from chemical control of saltcedar to be 0.13 – 0.68 m/yr, based on natural re-vegetation of the study site with grasses, forbs, and saltcedar re-growth. This assumption is appropriate for the Pecos River in Texas, as grasses and forbs comprised the natural riparian vegetation along the river prior to saltcedar invasion (Wilcox et al. 2006). The lowest seasonal water salvage (0.13 m) occurred 4 years after treatment presumably due to saltcedar re-growth at the treated site. Although re-growth at the treated site 4 and 5 years after treatment did not equal the density of saltcedar growth prior to chemical treatment, the "oasis effect" possibly increased the ET potential of individual trees.

Significant localized, temporary water savings were achieved at this study site by chemically controlling saltcedar. Beneficial effects on the shallow aquifer adjacent to the Pecos River were observed for approximately 4 years, after which the effects appeared to be negligible. A follow-up management strategy to control saltcedar re-growth will need to be implemented if long-term water savings are to be achieved by chemical control. Long-term water savings are not likely to be realized in areas where aggressive and sustained saltcedar re-growth monitoring and treatment are not physically or economically feasible. Others researching saltcedar water use also have expressed the need for a post-treatment management program to achieve sustained water salvage (Glenn and Nagler 2005; Sala et al. 1996). The natural re-vegetation that occurred on this study site exhibited lower ET potential than the saltcedar it replaced, resulting in net water salvage in the years after treatment and before significant saltcedar re-growth. This study may not be applicable to, and long-term net water salvage may not occur on other river systems where cottonwoods, willows, or other phreatophytes are likely to be the replacement vegetation following control or removal of saltcedar.

A simplified analysis of saltcedar control conducted by the Pecos River Ecosystem Project (PREP) was an example of the ways in which water salvage data from this study may be applicable on a larger scale for the Pecos River in Texas or other similar river systems. The PREP, a collaboration of local, state and federal entities, chemically treated 5,462 ha (13,497 acres) of saltcedar along the Pecos River in Texas between 1999 and 2005 (Hart 2005). Using water salvage data calculated in this study for years 1-4 post-treatment, an approximation of the total amount of water saved per acre treated by the PREP in 1999-2005 can be estimated. Water salvage reported will be converted to acre-feet for use in this discussion (Table XIV).

Table XIV. Estimated water salvaged by the Pecos River Ecosystem Project, 2000-2009

	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
Treated					ac			
	658	676	1,439	3,567	3,730	2,697	730	13,497
Water Salvage					AF			
2000	586	-	-	-	-	-	-	586
2001	1,467	602	-	-	-	-	-	2,069
2002	816	1,507	1,281	-	-	-	-	3,604
2003	270	838	3,209	3,175	-	-	-	7,492
2004	-	277	1,784	7,954	3,320	-	-	13,335
2005	-	-	590	4,423	8,318	2,400	-	15,731
2006	-	-	-	1,462	4,625	6,014	650	12,751
2007	-	-	-	-	1,529	3,344	1,628	6,501
2008	-	-	-	-	-	1,106	905	2,011
2009	-	-	-	-	-	-	299	299
Total	3,139	3,224	6,864	17,014	17,792	12,864	3,482	64,379

If seasonal water salvage from this study of 0.89, 2.23, 1.24 and 0.41 feet in years 1-4 post-treatment, respectively, is multiplied by the number of acres chemically treated by the PREP in each corresponding year after treatment, a total approximate water salvage of 64,379 acre-feet (21 billion gallons) is the result. The total amount of local, state, and federal money spent on chemically treating saltcedar by the PREP during 1999-2005 was $2,693,915 (Hart 2005), which amounts to approximately $42/acre-foot ($.0001/gallon). This estimate could be significantly lowered by implementing a follow-up management strategy, thereby increasing treatment life. This is a very speculative estimate as site-specific conditions across the entire area treated by the PREP are unknown.

A more detailed economic analysis of water salvaged by the PREP is needed to determine the accuracy of economic efficiency estimates presented herein, but it is evident that saltcedar control on the Pecos River in Texas has yielded significant water savings. Questions remain regarding the fate of the salvaged water and whether or not water delivery efficiencies have been increased in the Red Bluff Power and Control District as a result of PREP activities. It also is evident that to maintain water savings achieved from initial investment by the PREP, saltcedar re-growth monitoring and management will need to be implemented. Results from this study indicate that water salvage on the Pecos River in Texas will be negligible after 2009 if follow-up saltcedar maintenance does not occur. Figure 15 presents a depiction of water loss and salvage trends calculated in this study in years 1-5 post-treatment and indicates that follow-up management should begin during or before the 3rd year post-treatment.

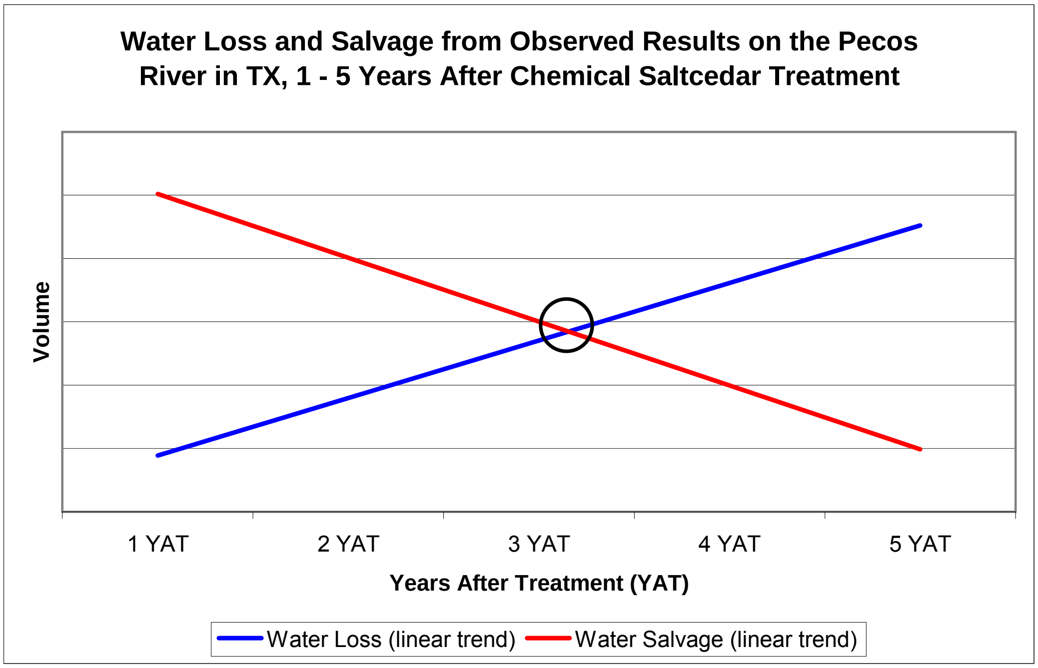

Figure 15. Water loss and salvage trends on the Pecos River in TX

Examining PREP activities strictly from an economic standpoint does not take into consideration the potential ecological benefits of saltcedar control. A return of the Pecos River riparian habitat to its historical vegetation could yield positive results for both the flora and fauna in the watershed. Native vegetation will thrive in the absence of competition from saltcedar, significantly increasing riparian plant diversity and providing valuable habitat for wildlife that relies on native plants. If additional studies conclude that water salvaged by the PREP does not increase Pecos River baseflow or irrigation water delivery efficiency, the ecological benefits of increased water availability in the floodplain and uplands, and increased aquifer recharge should not be discounted.

In summary, this study concludes that significant water salvage may be achieved by chemical control of saltcedar. The volume of water savings is ultimately dependent upon site-specific environmental conditions and more importantly replacement vegetation. Assuming net water salvage is the goal of saltcedar control, the Pecos River in Texas is amenable to this practice based on results from this study indicating significantly lower ET rates by native vegetation. This study also concludes that water salvage following chemical control of saltcedar will be short-lived if a strategy for re-growth maintenance is not implemented. It is recommended that sites be inspected and, if needed, saltcedar re-growth treated no later than the 3rd year post-treatment if optimum long-term water salvage is the objective. Based on the agreement of results from this study with others in the literature reasonably accurate estimates of ET can be calculated by the White (1932) method assuming accurate specific yield values are used in the formula. Adverse site conditions affected the methodology used in this study and produced conservative estimates of saltcedar water loss and salvage from chemical control. Site conditions in 2001 and 2006 were the most representative of “normal” environmental conditions for the study area and had conditions been as such throughout the study, saltcedar water loss and salvage from chemical control estimates may have been significantly higher. For future studies using well data to calculate ET, it is recommended that pre-treatment baseline data be established for a minimum of 3 years. The differences in environmental conditions between years in this study made it more difficult to make comparisons between the baseline and post-treatment data.

REFERENCES CITED

Butler, J.J., G.J. Kluitenberg, D.O. Whittemore, S.P. Loheide II, W. Jin, M.A. Billinger, and X. Zhan. 2007. A field investigation of phreatophyte-induced fluctuations in the water table. *Water Resources Research* 43, W02404, doi:10.1029.2005WR004627.

Boghici, R. 1999. Changes in groundwater conditions in parts of Trans-Pecos, Texas, 1988-1998. Texas Water Development Board, Report 348.

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

Clayton, L.A. 2002. Saltcedar management strategies and effects on water quality and quantity of the Pecos River. M.S.thesis. College Station, TX: Texas A&M University. 87 p.

Cleverly, J.R., C.N. Dahm, J.R. Thibault, D.J. Gilroy, and J.E. Allred Coonrod. 2002. Sesonal estimates of actual evapo-transpiration from *Tamarix ramosissima* stands using three-dimensional eddy covariance. *Journal of Arid Environments* 52(2002): 181-197.

Cooper, D.J., J.S. Sanderson, D.I. Stannard, and D.P. Groeneveld. 2006. Effects of long-term water table drawdown on evapotranspiration and vegetation in an arid phreatophyte community. *Journal of Hydrology* 325(2006): 21-34.

Culler, R.C., R.L. Hanson, R.M. Myrick, R.M. Turner, and F.P. Kipple. 1982. Evapotranspiration before and after clearing phreatophytes, Gila River flood plain, Graham County, Arizona. Geological Survey Professional Paper 655-P. United States Government Printing Office, Washington, D.C.

Davenport, D.C., P.E. Martin, and R.M. Hagan. 1982a. Evapotranspiration from riparian vegetation: Conserving water by reducing saltcedar transpiration. *Journal of Soil and Water Conservation* 37(4): 237-239.

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

Day, R.W. and G.P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecological Monographs* 59(4): 433-463.

Devitt, D.A., Piorkowski, J.M., Smith, S.D., Cleverly, J.R. and A. Sala. 1997. Plant water relations of *Tamarix ramossissima* in response to the imposition and alleviation of soil moisture stress. *Journal of Arid Environments* 35:527-540.

Di Tomaso, J.M. 1998. Impact, biology, and ecology of saltcedar (Tamarix spp.) in the southwestern United States. *Weed Technology* 12(2):326-336.

Drexler, J.Z., R.L. Snyder, D. Spano, and K.T. Paw U. 2004. A review of models and micrometeorological methods used to estimate wetland evapotranspiration. *Hydrological Processes* 18(2004): 2071-2101.

Environmental Protection Agency. 1993. Paired watershed study design. United States Government Printing Office, Washington, DC. Paper 841-F-93-009.

Freund, J.E. 1984. Modern Elementary Statistics. 6th ed. Prentice Hall, Inc.: Englewood Cliffs, NJ. Pp. 250-252.

Frigge, M., D.C. Hoaglin, B. Iglewicz. 1989. Some implementations of the boxplot. *The American Statistician* 43(1): 50-54.

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. Geological Water-Supply Paper 1103. United States Government Printing Office, Washington, D.C.

Gay, L.W. and L.J. Fritschen. 1979. An energy budget analysis of water use by saltcedar. *Water Resources Research* 15: 1589-1592.

Gay, L.W. and R.K. Hartman. 1982. ET measurements over riparian saltcedar on the Colorado River. 1982. *Hydrology and Water Resources in Arizona and the Southwest* 12: 9-15.

Gerla, P.J. 1992. The relationship of water table changes to the capillary fringe, evapotranspiration, and precipitation in intermittent wetlands. *Wetlands* 12(2)91-98.

Glenn, E.P. and P.L. Nagler. 2005. Comparative ecophysiology of *Tamarix ramosissima* and native tress in western U.S. riparian zones. *Journal of Arid Environments* 61(2005): 419-446.

Hansen, S. and C. Gorbach. 1997. Middle Rio Grande water assessment: final report. U.S. Bureau of Reclamation, Albuquerque Area Office. 151 p.

Hart, C.R. 2005. Pecos River Ecosystem Project Progress Report. Pecos River Basin Assessment Program website. http://pecosbasin.tamu.edu. Accessed: 11-17-08.

Hart, C.R., L.D. White, A. McDonald, and Z. Sheng. 2005. Saltcedar control and water salvage on the Pecos River, Texas 1999-2003. *Journal of Environmental Management* 75(4):399-409.

Hays, K.B. 2003. Water use by saltcedar (Tamarix spp.) and associated vegetation on the Canadian, Colorado and Pecos Rivers in Texas. M.S.thesis. College Station, TX: Texas A&M University. 132 p.

Inglis, R., C. Deuser, and J. Wagner. 1996. The effects of tamarisk removal on diurnal ground water fluctuations. U.S. Department of Interior, National Park Service, Technical Report NPS/NRWRD/NRTR-96/93. United Stated Department of the Interior, National Park Service, Washington, D.C.

Jaco, H.B. 1980. Soil Survey of Reeves County, Texas. National Cooperative Soil Survey, U. S. Department of Agriculture.

Johnson, A.I. 1967. Specific yield-compilation of specific yields for various materials Geological Survey Water-Supply Paper 1662-D. United States Government Printing Office, Washington, D.C.

Jones, I. C. 2001. Cenozoic Pecos Alluvium Aquifer. Texas Water Development Board. http://www.twdb.state.tx.us/gam/eddt_p/SAF3_ET-p_Part2.pdf. Accessed: October 9, 2008.

King, J.P. and A.S. Bawazir. 2000. Riparian evapotranspiration studies of the Middle Rio Grande. New Mexico Water Resources Institute. Technical Completion Report Project 1-4-23955. Las Cruces, NM.

Loheide, S.P., Butler, J.J, and S.M. Gorelick. 2005. Estimation of groundwater consumption by phreatophytes using diurnal water table fluctuations: A saturated-unsaturated flow assessment. *Water Resources Research* 41: W07030.

Luo, W. 1994. Calibrating the SCS Blaney-Criddle crop coefficients for the Middle Rio Grande Basin, New Mexico. M.S. thesis. New Mexico State University, Las Cruces, NM.

Nagler, P.L., E.P. Glenn, K. Didan, J. Osterberg, F. Jordan, and J. Cunningham. 2008. Wide-Area estimates of stand structure and water use of *Tamarix* spp. on the Lower Colorado River: Implications for restoration and water management projects. *Restoration Ecology* 16(1): 136-145.

Nagler, P.L., E.P. Glenn, and T.L. Thompson. 2003. Comparison of transpiration rates among saltcedar, cottonwood and willow tress by sap flow and canopy temperature methods. *Agricultural and Forest Meteorology* 116 (2003): 73-89.

National Climate Data Center (NCDC). 2004. Monthly summary data for NWS and cooperative U.S. stations. http://www.ncdc.noaa.gov/rcsg/database/html. Accessed: October 6, 2008.

Owens, M.K. and G.W. Moore. 2007. Saltcedar water use: Realistic and unrealistic expectations. *Rangeland Ecology and Management* 60(5): 553-557.

Robinson, T.W. 1965. Introduction, Spread and Areal Extent of Saltcedar (Tamarix) in the Western States. U.S.G.S Professional Paper No. 491-A. 1-11.

Rosenberry, D.O. and T.C. Winter. 1997. Dynamics of water-table fluctuations in an upland between two prairie-pothole wetlands in North Dakota. *Journal of Hydrology* 191(1997): 266-289.

Sala, A., S.D. Smith, and D.A. Devitt. 1996. Water use by *Tamarix ramosissima* and ssociated phreatophytes in a Mojave Desert floodplain. *Ecological Applications* 6(3): 888-898.

Schilling, K.E. 2007. Water table fluctuations under three riparian land covers, Iowa (USA). *Hydrological Processes* DOI: 10.1002/hyp.6393.

Shafroth, P.B., J.R. Cleverly, T.L. Dudley, J.P. Taylor, C. Van Riper III, E.P. Weeks, and J.N. Stuart. 2005. Control of *Tamarix* in the Western United States: Implications for water salvage, wildlife use, and riparian restoration. *Environmental Management* 35(3): 231-246.

Tan, S.B.K, E.B. Shuy, L.H.C. Chua, and N. Mzila. 2006. Estimation of areal specific yield in sands using the central limit theorem. *Hydrological Processes* 20(2006): 3975-3987.

Timlin, D., J. Starr, R. Cady, and T. Nicholson. 2003. Comparing ground-water recharge estimates using advanced monitoring techniques and models. NUREG/CR-6836. Prepared for: Division of Systems Analysis and Regulatory Effectiveness, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, D.C.

Troxell, H.C. 1936. The diurnal fluctuation in the ground-water and flow of the Santa Anna River and its meaning. Transactions, American Geophysical Union. 17:496-504.

van Hylckama, T.E.A. 1970. Water use by saltcedar. *Water Resources Research* 6(3): 728-735.

van Hylckama, T.E.A. 1974**.** Water use by saltcedar as measured by the Water Budget Method. Geological Survey Professional Paper 491-E. United States Government Printing Office, Washington, DC.

Weeks, E.P., Weaver, H.L., Campbell, G.S. and B.D. Tanner. 1987. Water use by saltcedar and replacement vegetation in the Pecos River floodplain between Acme and Artesia, New Mexico. U.S. Geological Survey, Professional Paper 491-G.

Wilcox, B.P., M.K. Owens, W.A. Dugas, D.N. Ueckert, and C.R. Hart. 2006. Shrubs, streamflow, and the paradox of scale. *Hydrological Processes* 20(2006): 3245-3259.

Williams, M.E. and J.E. Anderson. 1977. Diurnal trends in water status, transpiration, and photosynthesis of saltcedar. *Hydrology and Water Resources in Arizona and the Southwest* 7: 119-124.

White, D. E. 1971. Water resources of Ward Country, Texas. Texas Water Development Board, Report 125, 235 p.

White, W.N. 1932**.** A method of estimating ground-water supplies based on discharge by plants and evaporation from soil. U.S. Geological Survey Water Supply Paper 659-A. United States Government Printing Office, Washington, DC.

Zar, J.H. 1999. Biostatistical Analysis. 4th ed. Prentice Hall, Inc.: Upper Saddle River, NJ. Pp. 166-189.

Zhang, Y.K. and K.E. Schilling. 2006. Effects of land cover on water table, soil moisture, evapotranspiration, and groundwater recharge: A field observation and analysis. *Journal of Hydrology* 319(2006): 328-338.

APPENDIX

Table XV. Site A average daily water loss calculations for wells 1-3, 2001-2006

Day	2001	2002	2003	2004	2005	2006
			m			
1-Apr				0.000388	0.001895	0.000857
2-Apr	0.005485			0.000250	0.000957	0.001150
3-Apr	0.006654			0.000258	0.002430	0.002350
4-Apr	0.002359	0.001213	0.000382	0.000645	0.001094	0.000990
5-Apr	0.002202	0.000102	0.001376		0.002835	0.000838
6-Apr	0.001731	0.001268	0.001144		0.001580	0.001752
7-Apr						
8-Apr	0.002525	0.001152	0.000552			0.001812
9-Apr		0.000296	0.000683			0.000479
10-Apr		0.000225	0.000471			0.000639
11-Apr		0.000187	0.001694			0.001081
12-Apr		0.000440	0.002043			0.001118
13-Apr		0.002020	0.001129			0.001166
14-Apr			0.000436		0.001938	
15-Apr			0.000888			
16-Apr		0.000734	0.000362			0.003692
17-Apr		0.001001	0.000576	0.001816	0.001220	0.000666
18-Apr		0.001134	0.001284			0.000672
19-Apr			0.000325	0.001446		0.001134
20-Apr				0.001368		0.005771
21-Apr		0.002268			0.003207	
22-Apr	0.001752		0.000481	0.001588	0.002231	
23-Apr	0.001468		0.001064			
24-Apr	0.002289		0.000303			
25-Apr	0.002901		0.000562			
26-Apr	0.001646	0.000934	0.000528	0.002030	0.001174	
27-Apr	0.002488		0.000662	0.001780		
28-Apr	0.002602	0.001144	0.000374		0.002852	
29-Apr	0.003057		0.000387			
30-Apr	0.003430		0.000745			0.000460
1-May	0.007929	0.000388	0.000515			0.000579
2-May			0.000598	0.001239		0.000419
3-May			0.000340	0.001666		0.001106
4-May	0.003396		0.000344	0.001780	0.002495	0.000839
5-May			0.000351	0.001317		0.000883
6-May		0.000341	0.000419	0.001132		0.000716
7-May			0.000473	0.001717		0.000731
8-May	0.004860	0.000905	0.000363			0.000410
9-May	0.006651	0.001139	0.000410	0.001239		0.001614

Table XV, Continued

Day	2001	2002	2003	2004	2005	2006
	m					
10-May	0.007050	0.000572	0.000467			
11-May	0.008864	0.001207	0.003948	0.001272		
12-May	0.005852	0.000337	0.002566	0.001818		
13-May	0.007804		0.000357	0.001803		
14-May	0.004875	0.000286	0.000327			0.000222
15-May		0.001382	0.000294			
16-May	0.010362	0.000413	0.000747			
17-May	0.010663	0.000428	0.000212			
18-May	0.010536	0.000267	0.000499			0.000186
19-May		0.000786	0.000200			0.000190
20-May		0.000559	0.000191			0.000322
21-May	0.003479					0.000101
22-May	0.006469		0.000876			0.000186
23-May	0.007653	0.001115	0.000513			0.000395
24-May			0.000192	0.001095		0.000205
25-May		0.001113	0.000461			
26-May		0.001935	0.000220		0.000781	
27-May		0.000436	0.000461	0.001372	0.001557	
28-May		0.000667			0.001029	
29-May		0.000858		0.000302		
30-May		0.000762	0.000165	0.000771		
31-May		0.000397	0.000292	0.000555	0.003554	0.000247
1-Jun	0.010252	0.000463			0.000745	
2-Jun	0.007060	0.000524	0.000165	0.000897	0.001174	0.000307
3-Jun	0.005479	0.001029			0.002351	
4-Jun	0.006103	0.001166		0.000552		0.000891
5-Jun	0.006748			0.000885		0.000779
6-Jun	0.005044	0.000377		0.000488	0.001354	0.000712
7-Jun		0.000865		0.000680		
8-Jun			0.000377	0.000626	0.000858	0.001157
9-Jun	0.005092	0.000334	0.000334	0.000546	0.001514	0.001671
10-Jun	0.007027	0.000708	0.000516	0.000414	0.002293	
11-Jun	0.008583	0.000381		0.000914	0.000880	
12-Jun	0.010185			0.000815	0.001321	
13-Jun	0.007337	0.000429	0.003701	0.000771	0.000895	
14-Jun	0.010803		0.002780	0.000523	0.001472	
15-Jun	0.009981		0.001234	0.000490		
16-Jun	0.010877		0.000656	0.000591	0.000701	
17-Jun	0.011945			0.000431	0.000916	0.001342

Table XV, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
18-Jun	0.009880		0.001151	0.000488		0.000686
19-Jun	0.011834		0.000529	0.000367		0.000949
20-Jun	0.006737		0.000202	0.000244	0.002734	0.001319
21-Jun	0.008686		0.000837	0.000487	0.001402	
22-Jun	0.005575		0.000659	0.001198	0.000791	0.005416
23-Jun	0.004479		0.000914			0.005047
24-Jun			0.000348	0.000680	0.000521	0.003863
25-Jun	0.009747		0.001097	0.000888		0.004129
26-Jun	0.007813		0.000326	0.000331		0.001288
27-Jun	0.007982		0.000744	0.000636		0.003840
28-Jun	0.008814		0.000258	0.000242	0.000389	0.003468
29-Jun	0.007355	0.001207	0.000272	0.000747	0.000470	0.003429
30-Jun	0.004456		0.000125	0.000541	0.000922	0.001988
1-Jul	0.005878		0.000184		0.001672	0.001686
2-Jul	0.005180	0.001265	0.002509		0.001208	
3-Jul	0.005837	0.000305	0.000850		0.001178	0.004819
4-Jul	0.005870	0.001064	0.000070		0.000714	0.001210
5-Jul	0.004886	0.000793	0.000776			0.003193
6-Jul	0.006039	0.001001	0.000286	0.001042		0.003526
7-Jul	0.006595		0.000252			
8-Jul	0.007104					
9-Jul	0.006737	0.000749				
10-Jul	0.006916				0.000804	0.000412
11-Jul	0.007180					0.001755
12-Jul	0.007563				0.001064	0.005486
13-Jul	0.007548					
14-Jul	0.007265		0.000847			0.003992
15-Jul	0.005598			0.002018		
16-Jul		0.000244	0.002992			0.006325
17-Jul			0.004832			0.004915
18-Jul		0.001098				0.009173
19-Jul	0.003125					0.009579
20-Jul	0.006504					
21-Jul	0.004241			0.001114		
22-Jul	0.008060		0.004628	0.001542		0.005658
23-Jul	0.006372	0.001720		0.000969	0.002564	0.006347
24-Jul	0.006704				0.002829	0.007516
25-Jul	0.007251				0.001727	0.009018
26-Jul	0.007745					0.008100

Table XV, Continued

Day	2001	2002	2003	2004	2005	2006
	m					
27-Jul	0.006486				0.003745	
28-Jul	0.007926		0.000559			0.008949
29-Jul	0.007697	0.001391	0.002973		0.000524	0.007081
30-Jul	0.008229	0.001042			0.001843	0.006959
31-Jul	0.004220	0.000383	0.000116		0.001291	0.007754
1-Aug	0.011652	0.000143				0.005512
2-Aug	0.005084					0.007278
3-Aug	0.005152		0.004030			0.006311
4-Aug			0.000409			0.008285
5-Aug		0.000388	0.002475			0.008073
6-Aug						0.006630
7-Aug	0.005103		0.000490			0.004663
8-Aug	0.005913		0.003043			0.007182
9-Aug	0.006197		0.001974			0.006847
10-Aug	0.005880					0.006128
11-Aug	0.006356					0.004696
12-Aug	0.007534	0.001837	0.000793	0.003245		0.003461
13-Aug	0.005842	0.000515	0.000563	0.001717		0.007444
14-Aug	0.004801	0.000589	0.000464	0.001645		0.006764
15-Aug	0.005047		0.001123			0.005797
16-Aug	0.003731		0.000378			
17-Aug	0.007322			0.002517		
18-Aug	0.002702		0.000247			
19-Aug			0.000419	0.001073		
20-Aug			0.001213			
21-Aug						0.007432
22-Aug			0.001460			
23-Aug			0.001692			
24-Aug	0.008989	0.000310	0.000744			
25-Aug	0.004890		0.000542			
26-Aug						
27-Aug			0.003098			
28-Aug			0.000633			0.006974
29-Aug						0.009475
30-Aug			0.001443			0.005261
31-Aug	0.007754		0.000665		0.000883	
1-Sep		0.002851	0.000455			
2-Sep			0.000238			0.005601
3-Sep			0.000539			

Table XV, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
4-Sep			0.000578	0.001549	0.005893	
5-Sep	0.003819		0.000311	0.001313	0.000779	
6-Sep	0.004503	0.002901		0.000891	0.000590	
7-Sep	0.003760		0.000307		0.000528	
8-Sep	0.003682	0.002829	0.000282	0.001710	0.001241	0.002249
9-Sep	0.002815			0.000459		
10-Sep	0.004550		0.000312	0.000663		0.005979
11-Sep	0.003869	0.002591	0.000461	0.000696		0.005763
12-Sep			0.000384	0.000590		0.006708
13-Sep			0.000464	0.001596		
14-Sep			0.000761	0.000419		0.003656
15-Sep	0.002327		0.000301	0.000824		0.004967
16-Sep	0.004003		0.000396			0.003375
17-Sep	0.004670	0.001239	0.000200			0.004006
18-Sep	0.005003	0.000232	0.000806			
19-Sep	0.002467		0.000178	0.002933		0.002026
20-Sep	0.002885		0.000123	0.003067		0.002197
21-Sep	0.003936			0.002045		0.003212
22-Sep	0.003536		0.000159			0.004173
23-Sep	0.002272		0.000911			0.003289
24-Sep	0.001611		0.000238			0.004566
25-Sep	0.002516		0.000222			0.004237
26-Sep	0.004203		0.001370			0.003625
27-Sep	0.004203					0.003860
28-Sep	0.003293	0.001412	0.000178			0.003115
29-Sep	0.002557		0.000816		0.001778	0.003783
30-Sep	0.001929		0.000221			0.003408

Table XVI. Site B average daily water loss calculations for wells 1-3, 2001-2006

Day	2001	2002	2003	2004	2005	2006
	m					
1-Apr	0.005060				0.001629	0.000698
2-Apr	0.002599				0.000884	0.001060
3-Apr	0.002904			0.004365	0.001212	0.002059
4-Apr		0.002142	0.002278		0.001746	0.000359
5-Apr		0.001038	0.002937			0.000528
6-Apr		0.001846	0.004218			0.001738
7-Apr		0.000232	0.001929			
8-Apr		0.000349	0.003101			0.001801
9-Apr		0.001507	0.001388			0.000405
10-Apr		0.003694	0.002238			0.000473
11-Apr		0.003329	0.001186			0.002104
12-Apr		0.005338	0.003109		0.002459	0.000626
13-Apr			0.000984		0.002324	0.000608
14-Apr			0.002946			0.000123
15-Apr		0.004722	0.001602			0.004621
16-Apr		0.001317	0.002191			0.003400
17-Apr		0.000686				0.000255
18-Apr		0.001302	0.002934			0.000437
19-Apr			0.001887			0.000657
20-Apr						
21-Apr			0.003435		0.003545	
22-Apr	0.001937	0.001520	0.003583			
23-Apr	0.000969	0.002351	0.004212			
24-Apr	0.001906	0.002300	0.003295	0.004795	0.001958	
25-Apr	0.001479	0.001936	0.004835		0.002780	
26-Apr	0.001979	0.001002	0.005996	0.002899		
27-Apr	0.001176	0.000366	0.005433	0.002692		0.000448
28-Apr	0.001415	0.003745	0.003890	0.002793	0.002957	
29-Apr	0.002191	0.000929	0.003192			0.000256
30-Apr	0.010051	0.003337	0.004460			
1-May	0.004464	0.004287	0.004180	0.003387		0.000688
2-May		0.001628	0.004558	0.002997		0.000478
3-May		0.002963	0.004495	0.004228	0.004533	0.000868
4-May		0.001879	0.003394	0.002498	0.002391	0.000503
5-May		0.002164	0.003294	0.003134	0.003138	0.000571
6-May	0.003779	0.002422	0.003849	0.004084	0.001097	0.000490
7-May	0.002171	0.002351	0.002870	0.004385	0.005896	0.000744
8-May	0.006807	0.002393	0.004139	0.004748	0.006884	0.000795
9-May	0.008054		0.002813	0.003739	0.003696	

Table XVI, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
10-May	0.007656	0.001715	0.003429	0.007145	0.001086	
11-May	0.009746	0.000723	0.005887	0.005496		
12-May	0.011938	0.000577	0.002733	0.007052		
13-May	0.006056	0.001362	0.003453	0.003432		
14-May		0.002781	0.004165	0.004969		0.002195
15-May		0.002303	0.002004			0.001566
16-May		0.001835	0.002916			0.001353
17-May	0.010171	0.003079	0.005006			0.002941
18-May	0.008460	0.001943	0.004454			0.003511
19-May	0.000671	0.001824	0.005092			0.003736
20-May		0.001986	0.003670			0.003814
21-May		0.004349	0.004739			0.004250
22-May	0.006692	0.002237	0.004631	0.003645		0.005854
23-May	0.006505	0.004793	0.004982	0.001875		0.005424
24-May	0.001281	0.001964	0.002763			
25-May	0.002028	0.001648	0.012367		0.001138	
26-May		0.004247	0.001205	0.003569		
27-May		0.002958	0.003645			0.002985
28-May		0.002161	0.004015			0.002196
29-May	0.000932	0.002368	0.002965	0.003850		0.002927
30-May		0.002558	0.001297	0.004175		0.004479
31-May	0.006402	0.003561	0.003079	0.005328	0.002636	0.001785
1-Jun	0.007900	0.002520	0.004226		0.001511	
2-Jun	0.007475	0.004454			0.002712	0.001922
3-Jun	0.007647	0.004417				0.003966
4-Jun	0.009416	0.004869				0.005099
5-Jun	0.007609	0.003701	0.003348			0.006290
6-Jun		0.003923	0.007598			0.004331
7-Jun		0.003431	0.006252	0.002316		
8-Jun		0.002863	0.009017	0.002568	0.001074	
9-Jun	0.016387	0.002982	0.005989	0.002275	0.001875	
10-Jun	0.010369	0.002974	0.004750		0.002284	
11-Jun	0.001634	0.002025	0.005517		0.001416	
12-Jun	0.002562	0.002386	0.005125		0.001278	
13-Jun	0.020479	0.002537	0.005766		0.000922	
14-Jun	0.022840	0.001755	0.004107		0.002708	
15-Jun	0.010758		0.005665	0.001387	0.000684	
16-Jun	0.011462		0.005408		0.000877	
17-Jun	0.019277		0.003453		0.000997	

Table XVI, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
18-Jun	0.021291		0.003154	0.000920	0.001649	
19-Jun	0.011038			0.000614		
20-Jun					0.002583	
21-Jun			0.000618	0.000811	0.001358	
22-Jun			0.001266		0.000883	
23-Jun	0.003338		0.005513	0.001142		
24-Jun			0.007050	0.000766	0.001101	
25-Jun	0.017926		0.000278	0.000930	0.001280	
26-Jun	0.008127	0.002487	0.005169	0.000617	0.001817	
27-Jun	0.009935		0.003862	0.000590	0.001875	0.003022
28-Jun	0.009674	0.002124	0.001264		0.002176	0.003333
29-Jun	0.009106		0.001474		0.002437	
30-Jun			0.001443		0.001545	
1-Jul	0.015076		0.002907		0.001561	0.003059
2-Jul	0.012497	0.000510	0.003785		0.001672	0.003927
3-Jul	0.007752	0.004226	0.002385		0.001419	
4-Jul	0.007595	0.003021	0.002482		0.001333	
5-Jul	0.007696		0.008004	0.001941		0.003716
6-Jul	0.009049	0.000659	0.009904	0.001906	0.000868	
7-Jul	0.008174				0.000814	
8-Jul	0.007792	0.007702			0.001000	
9-Jul	0.007678	0.003574			0.000523	
10-Jul	0.007993	0.004185			0.001200	
11-Jul	0.007880				0.001786	
12-Jul	0.008078				0.001925	
13-Jul	0.008345				0.001356	
14-Jul	0.008354				0.001562	0.009822
15-Jul	0.001777	0.000286				0.010265
16-Jul		0.000463	0.008724			
17-Jul	0.006847		0.004716	0.005617		
18-Jul	0.005772		0.008198	0.004998		0.010332
19-Jul	0.013237	0.000494	0.008774	0.006157	0.000645	0.009599
20-Jul	0.007468	0.000341	0.008279	0.005527	0.000971	
21-Jul	0.012425		0.007697	0.002827	0.001073	
22-Jul	0.009770		0.008509	0.004425	0.001872	0.008548
23-Jul	0.010890	0.005559	0.009541		0.001614	0.010326
24-Jul	0.011511	0.004626	0.009377		0.002333	0.015066
25-Jul	0.011234	0.000039	0.009627		0.002333	0.011199
26-Jul	0.011308		0.008861			

Table XVI, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
27-Jul	0.009432		0.009064			
28-Jul	0.010422		0.006658			0.006966
29-Jul	0.010189		0.006837		0.000950	0.009865
30-Jul	0.010512		0.005449		0.001392	0.010471
31-Jul	0.001516		0.004594		0.001453	0.007125
1-Aug	0.015799		0.007667		0.000682	0.007759
2-Aug	0.002389	0.003158	0.007603			0.004411
3-Aug	0.006767	0.001034	0.007703			0.003394
4-Aug			0.008891			0.003584
5-Aug	0.008205		0.007631		0.002469	0.003975
6-Aug	0.004751		0.008304			0.004839
7-Aug	0.005510		0.007778			0.004923
8-Aug	0.005294		0.003334	0.003896		0.004675
9-Aug	0.005936		0.006472	0.004046		0.004414
10-Aug	0.008835		0.006289	0.003750		0.002730
11-Aug	0.006825			0.005315		0.005415
12-Aug	0.009944	0.006786	0.001096	0.003814		0.006422
13-Aug	0.008856					0.001361
14-Aug	0.009298	0.002889	0.006015			0.001112
15-Aug		0.005368	0.005948			0.000975
16-Aug	0.006122		0.011980			
17-Aug	0.006852	0.000754	0.000298	0.006912		
18-Aug	0.008486	0.000097		0.006347		
19-Aug		0.000113				
20-Aug	0.002032	0.000432	0.006303			0.001046
21-Aug						
22-Aug	0.008371		0.005403			0.000495
23-Aug	0.007729		0.004207			0.000802
24-Aug	0.007430		0.004761			
25-Aug	0.006568		0.003626			
26-Aug	0.001773		0.003223			
27-Aug	0.000730		0.003066			
28-Aug	0.000790					0.002301
29-Aug	0.000956		0.004812			0.003478
30-Aug	0.000697		0.008136			0.003812
31-Aug	0.000855		0.000482	0.004203	0.004238	
1-Sep	0.005290		0.002773			
2-Sep	0.004068		0.007203			
3-Sep	0.000998		0.008118	0.000699		0.009815

Table XVI, Continued

Day	2001	2002	2003	2004	2005	2006
			m			
4-Sep	0.001100		0.002869	0.000386		
5-Sep	0.000774		0.004959	0.001175		
6-Sep	0.001679		0.003207	0.000640	0.004343	0.004795
7-Sep	0.004324	0.003950	0.000084		0.003599	
8-Sep	0.001591		0.000422	0.000432		
9-Sep	0.002014	0.001206			0.004200	
10-Sep	0.004346		0.008149	0.000908		
11-Sep	0.002718		0.005515			
12-Sep	0.005390	0.002161	0.002992	0.000677	0.005185	0.002496
13-Sep	0.009847	0.000524	0.007396	0.000299	0.001267	0.001983
14-Sep	0.005802	0.002081	0.004072	0.001278	0.001250	0.002893
15-Sep	0.002625	0.000999	0.005178	0.000785	0.003852	0.002500
16-Sep	0.005776		0.004314		0.004272	0.001821
17-Sep	0.006181	0.003088	0.003497		0.004139	0.004896
18-Sep	0.005231		0.005400	0.001781		
19-Sep	0.001103		0.002753	0.001452	0.001121	0.001267
20-Sep	0.005636		0.002348	0.001896		0.002493
21-Sep	0.007269		0.002466	0.000455		0.004062
22-Sep	0.006801		0.003374			0.004591
23-Sep	0.001577		0.002900		0.004788	0.003343
24-Sep	0.001606		0.002579			0.002955
25-Sep	0.003778		0.004146			0.002804
26-Sep	0.006003	0.003544	0.002921			0.003431
27-Sep	0.006530		0.005696			0.004148
28-Sep	0.006819		0.003465			0.003243
29-Sep	0.001797		0.004421			0.004306
30-Sep	0.002106		0.005258			0.004814

Table XVII. Site A 2001 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m--------------------		n
Well A1			
Apr.	0.003653	0.109589	9
May	0.010409	0.322688	13
Jun.	0.011652	0.349557	23
Jul.	0.009862	0.305726	26
Aug.	0.007614	0.236019	16
Sept.	0.003907	0.117216	22
Total/Avg	0.008316	1.521768	109
Well A2			
Apr.	0.003378	0.101344	7
May	0.0045	0.139498	14
Jun.	0.004959	0.148759	24
Jul.	0.003059	0.094824	25
Aug.	0.002977	0.092301	9
Sept.	0.001545	0.046349	6
Total/Avg	0.003743	0.685047	85
Well A3			
Apr.	0.001237	0.037099	9
May	0.002521	0.078146	2
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	N/A	N/A	11
Well A5			
Apr.	0.000219	0.00657	27
May	0.001217	0.037717	14
Jun.	0.005204	0.156129	30
Jul.	0.00667	0.206769	31
Aug.	0.005656	0.175326	31
Sept.	0.003029	0.09087	30
Total/Avg	0.004	0.732044	163

Table XVIII. Site A 2002 average daily water loss by well

Month	Daily Avg	Total	
	-------------------m	--------------------	n
Well A1			
Apr.	0.000941	0.028233	15
May	0.00076	0.023551	19
Jun.	0.000703	0.021075	9
Jul.	0.000892	0.027661	8
Aug.	0.000416	0.012892	3
Sept.	N/A	N/A	0
Total/Avg	0.000801	0.146602	54
Well A2			
Apr.	N/A	N/A	0
May	0.000639	0.019797	9
Jun.	0.000639	0.019176	5
Jul.	0.000761	0.023605	8
Aug.	0.000845	0.026193	3
Sept.	0.002008	0.060236	7
Total/Avg	0.003743	0.685047	32
Well A3			
Apr.	N/A	N/A	0
May	N/A	N/A	0
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	N/A	N/A	0
Well A5			
Apr.	0.000555	0.01666	24
May	0.000576	0.017848	31
Jun.	0.000479	0.014356	30
Jul.	0.000432	0.013402	31
Aug.	0.000589	0.018249	30
Sept.	0.000615	0.018446	25
Total/Avg	0.000538	0.098419	171

Table XIX. Site A 2003 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m---------------------		n
Well A1			
Apr.	0.000472	0.014171	10
May	0.000427	0.013225	5
Jun.	0.000365	0.010942	6
Jul.	0.000323	0.010005	6
Aug.	0.000528	0.016353	9
Sept.	0.00032	0.0096	18
Total/Avg	0.000398	0.072824	54
Well A2			
Apr.	0.00134	0.040207	17
May	0.001624	0.050346	8
Jun.	0.001148	0.034431	15
Jul.	0.002187	0.067793	11
Aug.	0.001817	0.056336	16
Sept.	0.001295	0.038856	8
Total/Avg	0.000988	0.180856	75
Well A3			
Apr.	0.000436	0.013067	20
May	0.000344	0.010657	24
Jun.	0.000309	0.009266	9
Jul.	0.000121	0.003751	1
Aug.	0.000427	0.013242	10
Sept.	0.00032	0.009587	17
Total/Avg	0.000365	0.0668	81
Well A5			
Apr.	0.000386	0.011582	9
May	N/A	N/A	0
Jun.	7.51E-05	0.002252	10
Jul.	0.0002	0.006192	23
Aug.	0.000308	0.009541	5
Sept.	0.00036	0.010799	9
Total/Avg	0.000243	0.044435	56

Table XX. Site A 2004 average daily water loss by well

Month	Daily Avg	Total	
	------------------------m	--------------------	n
Well A1			
Apr.	0.001307	0.039205	5
May	0.001314	0.04072	5
Jun.	0.001126	0.03378	6
Jul.	N/A	N/A	0
Aug.	0.003429	0.106306	1
Sept.	0.001461	0.043836	12
Total/Avg	0.001408	0.257599	29
Well A2			
Apr.	0.001147	0.034417	4
May	N/A	N/A	0
Jun.	0.001115	0.033449	2
Jul.	0.001115	0.034564	1
Aug.	0.002003	0.06208	5
Sept.	0.001448	0.043449	9
Total/Avg	0.001695	0.310161	21
Well A3			
Apr.	0.000903	0.02709	5
May	0.001228	0.038081	13
Jun.	0.000613	0.01839	27
Jul.	0.001337	0.041446	5
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	0.000874	0.160015	50
Well A5			
Apr.	0.00052	0.015605	20
May	0.001188	0.036832	30
Jun.	0.001662	0.049869	15
Jul.	0.003037	0.094135	28
Aug.	0.004703	0.145792	22
Sept.	0.001899	0.056985	20
Total/Avg	0.002203	0.403227	135

Table XXI. Site A 2005 average daily water loss by well

Month	Daily Avg	Total	
	---------------------m---------------------		n
Well A1			
Apr.	0.002459	0.073755	6
May	0.002299	0.071261	5
Jun.	0.001687	0.050615	7
Jul.	0.002437	0.075553	8
Aug.	0.000975	0.030236	1
Sept.	0.003835	0.115062	2
Total/Avg	0.002283	0.417735	29
Well A2			
Apr.	0.001651	0.049525	9
May	0.001476	0.045757	1
Jun.	0.001129	0.033868	17
Jul.	0.000867	0.026884	7
Aug.	0.00079	0.024497	1
Sept.	0.000785	0.023536	4
Total/Avg	0.001167	0.213616	39
Well A3			
Apr.	N/A	N/A	0
May	N/A	N/A	0
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	N/A	N/A	0
Well A5			
Apr.	0.001305	0.039138	27
May	0.001696	0.05259	21
Jun.	0.003599	0.10797	23
Jul.	0.003231	0.100159	18
Aug.	0.003162	0.098033	20
Sept.	0.003475	0.104247	29
Total/Avg	0.002723	0.498348	138

Table XXII. Site A 2006 average daily water loss by well

Month	Daily Avg	Total	
	---------------------m--------------------		n
Well A1			
Apr.	0.001471	0.044119	13
May	0.001261	0.03909	9
Jun.	N/A	N/A	0
Jul.	0.007608	0.235837	13
Aug.	0.006537	0.202661	19
Sept.	0.004988	0.149641	18
Total/Avg	0.004769	0.872713	72
Well A2			
Apr.	0.001806	0.05417	17
May	0.000325	0.010064	14
Jun.	0.002317	0.069504	18
Jul.	0.003088	0.095724	10
Aug.	N/A	N/A	0
Sept.	0.002502	0.075055	17
Total/Avg	0.001978	0.362036	76
Well A3			
Apr.	0.000591	0.017722	10
May	0.000202	0.006274	10
Jun.	0.00075	0.022493	3
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	N/A	N/A	23
Well A5			
Apr.	0.00139	0.041699	26
May	0.000507	0.015715	6
Jun.	0.003189	0.095661	16
Jul.	0.002378	0.073712	29
Aug.	0.001751	0.054279	31
Sept.	0.000864	0.025933	19
Total/Avg	0.00181	0.331215	127

Table XXIII. Site B 2001 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m---------------------		n
Well B1			
Apr.	0.002068	0.064097	12
May	0.001389	0.041676	15
Jun.	0.001682	0.052155	26
Jul.	0.006484	0.201018	17
Aug.	0.009006	0.270174	20
Sept.	0.003904	0.714409	100
Total/Avg			
Well B2			
Apr.	0.007199	0.215969	11
May	0.024182	0.749635	11
Jun.	0.012389	0.37168	23
Jul.	0.003265	0.1012	25
Aug.	0.003909	0.121165	2
Sept.	0.001738	0.052146	5
Total/Avg	0.009696	1.774343	77
Well B3			
Apr.	0.00455	0.136507	8
May	0.013047	0.404469	12
Jun.	0.018031	0.540931	19
Jul.	0.015581	0.483011	28
Aug.	0.008368	0.259406	7
Sept.	0.001273	0.0382	29
Total/Avg	0.009845	1.801679	103
Well B5			
Apr.	0.000853	0.025595	8
May	0.002201	0.068218	12
Jun.	0.003132	0.093974	19
Jul.	0.003184	0.098692	28
Aug.	0.000711	0.022054	22
Sept.	0.000347	0.010418	29
Total/Avg	0.001759	0.321974	118

Table XXIV. Site B 2002 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m--------------------		n
Well B1			
Apr.	0.003491	0.10472	12
May	0.004187	0.129782	27
Jun.	0.004365	0.130961	15
Jul.	0.005287	0.163883	7
Aug.	0.005015	0.155454	3
Sept.	0.002578	0.077338	2
Total/Avg	0.004206	0.769736	66
Well B2			
Apr.	0.000403	0.012102	10
May	0.000418	0.012945	14
Jun.	0.00032	0.00959	6
Jul.	0.000318	0.009865	9
Aug.	0.000486	0.015066	5
Sept.	0.000999	0.029974	1
Total/Avg	0.000402	0.073571	45
Well B3			
Apr.	0.002145	0.06434	15
May	0.001133	0.035132	19
Jun.	0.001268	0.038053	6
Jul.	N/A	N/A	0
Aug.	0.003158	0.097907	1
Sept.	0.00228	0.068387	5
Total/Avg	0.001649	0.301829	45
Well B5			
Apr.	0.000217	0.006501	6
May	0.000158	0.004904	3
Jun.	0.000107	0.003221	2
Jul.	0.00021	0.006508	1
Aug.	0.00021	0.006495	1
Sept.	0.000673	0.020182	1
Total/Avg	0.00022	0.040282	14

Table XXV. Site B 2003 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m--------------------		n
Well B1			
Apr.	0.002543	0.076291	18
May	0.003854	0.119469	24
Jun.	0.005794	0.173808	13
Jul.	0.007148	0.221591	22
Aug.	0.006314	0.195748	22
Sept.	0.005461	0.163838	27
Total/Avg	0.005216	0.954526	126
Well B2			
Apr.	0.004442	0.133274	39
May	0.004069	0.126129	53
Jun.	0.004427	0.13282	44
Jul.	0.0006	0.018587	1
Aug.	0.001655	0.051293	11
Sept.	0.002889	0.086656	26
Total/Avg	0.0038	0.695361	174
Well B3			
Apr.	0.002246	0.067375	7
May	0.003378	0.104727	1
Jun.	0.003368	0.10103	11
Jul.	0.007287	0.225883	11
Aug.	N/A	N/A	0
Sept.	0.0007	0.021012	8
Total/Avg	0.003734	0.683353	38
Well B5			
Apr.	0.000113	0.003398	10
May	0.000188	0.005819	9
Jun.	0.001068	0.032033	7
Jul.	0.000968	0.029993	19
Aug.	0.000774	0.02399	17
Sept.	0.00043	0.012894	26
Total/Avg	0.000602	0.110237	88

Table XXVI. Site B 2004 average daily water loss by well

Month	Daily Avg	Total	
	----------------------m----------------------		n
Well B1			
Apr.	0.004115	0.123462	5
May	0.003762	0.116615	17
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	N/A	N/A	0
Total/Avg	0.003842	0.703115	22
Well B2			
Apr.	0.002442	0.073273	1
May	0.001322	0.040988	2
Jun.	N/A	N/A	0
Jul.	0.00181	0.056099	2
Aug.	0.003154	0.097768	3
Sept.	0.000919	0.027569	14
Total/Avg	0.001411	0.258139	22
Well B3			
Apr.	0.002425	0.072742	3
May	0.004957	0.153658	14
Jun.	0.001245	0.037341	12
Jul.	0.004526	0.140319	7
Aug.	0.005412	0.167774	8
Sept.	N/A	N/A	0
Total/Avg	0.003786	0.692846	44
Well B5			
Apr.	0.000418	0.01255	6
May	0.000375	0.011614	6
Jun.	0.000425	0.012743	7
Jul.	0.000819	0.02538	6
Aug.	0.000716	0.022207	9
Sept.	N/A	N/A	
Total/Avg	0.000561	0.10275	34

Table XXVII. Site B 2005 average daily water loss by well

Month	Daily Avg	Total	
	-----------------------m-----------------------		n
Well B1			
Apr.	0.000511	0.015336	7
May	0.00094	0.029131	7
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	0.001085	0.032548	7
Total/Avg	0.000845	0.154687	21
Well B2			
Apr.	0.002116	0.063489	8
May	0.001942	0.060206	4
Jun.	0.00161	0.048315	23
Jul.	0.001376	0.042664	23
Aug.	0.001905	0.059057	3
Sept.	0.003917	0.117507	6
Total/Avg	0.00183	0.334893	67
Well B3			
Apr.	0.002849	0.085474	9
May	0.005717	0.177237	6
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	0.005912	0.183265	1
Sept.	0.006594	0.197812	7
Total/Avg	0.00487	0.891241	23
Well B5			
Apr.	0.000802	0.024059	14
May	0.00048	0.014867	9
Jun.	0.000645	0.019335	23
Jul.	0.000556	0.017243	24
Aug.	0.001058	0.032797	3
Sept.	0.000678	0.020332	7
Total/Avg	0.000645	0.118115	80

Table XXVIII. Site B 2006 average daily water loss by well

Month	Daily Avg	Total	
	--------------------m---------------------		n
Well B1			
Apr.	0.00039	0.011711	15
May	N/A	N/A	0
Jun.	N/A	N/A	0
Jul.	N/A	N/A	0
Aug.	0.001002	0.03106	20
Sept.	N/A	N/A	0
Total/Avg	N/A	N/A	35
Well B2			
Apr.	0.001343	0.040284	14
May	0.002727	0.08455	19
Jun.	0.004321	0.129638	5
Jul.	N/A	N/A	0
Aug.	N/A	N/A	0
Sept.	0.002667	0.080017	16
Total/Avg	0.002498	0.457168	54
Well B3			
Apr.	0.001545	0.046338	14
May	0.000637	0.01976	7
Jun.	0.003177	0.09532	2
Jul.	0.008799	0.272757	17
Aug.	0.007351	0.227868	15
Sept.	0.004154	0.124632	18
Total/Avg	0.005028	0.920152	73
Well B5			
Apr.	0.000458	0.013731	17
May	0.000958	0.029709	21
Jun.	0.001457	0.043714	15
Jul.	0.001662	0.051523	17
Aug.	0.000628	0.019464	26
Sept.	0.000446	0.013387	20
Total/Avg	0.000855	0.15641	116