ABSTRACT

Water Use by Saltcedar (*Tamarix* sp.) and Associated Vegetation on the Canadian,
Colorado and Pecos Rivers in Texas.
(May 2003)
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Chair of Advisory Committee: Dr. Larry D. White

Increasing water demands in Texas have led to state supported brush control programs for enhancing water yields. This study was initiated to: 1) determine a method for calculating estimated water use by saltcedar (*Tamarix* sp.) and associated vegetation from daily diurnal groundwater fluctuations, and 2) estimate water use under different situations to better target brush control efforts. Studies were initiated in April 2000 on the Colorado River in Borden County, September 2000 on the Pecos River in Loving County and October 2000 on the Canadian River in Hemphill County. At each location, shallow wells were hand cored into the groundwater table. Wells were equipped with loggers that utilize pressure transducer sensors to measure hourly water depth. Vegetation, depth to the water table, and specific yield differed between locations and wells. Seven methods of calculation were investigated. The Draw Down Recharge Method that estimated daily water use from draw down plus recharge during the draw down period was considered the best under these conditions. No method was found to estimate water use under unstable conditions, i.e. rapid water level changes due to river fluctuations that prevented a diurnal cycle. The estimated growing season water use ranged from 2.5885 m to 4.2650 m, 0.2715 m to 0.8524 m, and 0.0358 m to 2.9596 m for the Canadian, Colorado and Pecos locations respectively. Average daily water use was low in April, peaked in May – July, and decreased in the fall at the Canadian and Pecos locations. Paired plot analysis at the Colorado location for 2001 (one plot herbicide treated in August 2000 and one plot left untreated) revealed a potential water savings of 0.4043 m. due to herbicide treatment that achieved a 49% mortality with total top kill of saltcedar. Use of the paired plot method is the best procedure for determining immediate water savings; however, native vegetation had not reestablished. Therefore, results reported above do not reflect long term water savings. Saltcedar and associated vegetation water use differed depending on the depth to groundwater, soil texture, specific yield, stand density, and season.

DEDICATION

This thesis is dedicated to Amy, Mason and Kendall. Without their patience and support, it would not have been completed.

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Larry White for his help in completing this project. He encouraged me to go back to school to take on this project, traveled many miles and waded several rivers in support of this project. His knowledge, patience and friendship are greatly appreciated.

I would like to thank Drs. Charles Hart, Allan McGinty, and Bruce Lesikar for serving on my committee. Drs. Hart and McGinty not only provided sound advice but also labored in the field conducting vegetation surveys and hand coring the groundwater monitoring wells. Dr. Hart also downloaded the well data for me and spent a great deal of time looking at data in support of this project. Dr. Lesikar provided the expertise in assuring this project was set up properly and was always willing to answer questions along the way.

For their help in installing the wells, I would like to thank Lindi Clayton, Robbie Baxter, Katy Quitmeyer, Dan Cornett, J.F. Cadenhead, and Brad Simpson. Without their help, I would still be digging the wells. Dan, J.F. and Brad also provided help conducting vegetation surveys, and Brad downloaded the well data.

For providing research sites I would like to thank Texas Parks and Wildlife Department for allowing us to use the Gene Howe Wildlife Management Area, and the Colorado River Municipal Water District and Mr. Brent Murphy for allowing access to the study location on the Colorado River.

For assistance with data analysis and statistics, I would like to thank Dr. Roel Lopez, Brian Pierce, and Dr. Nova Silvy. Each of these gentlemen spent considerable time answering questions and looking at data. Their advice and encouragement were greatly appreciated.

For assistance with GPS/GIS, I would like to thank Dale Kubenka and my wife Amy. Their help and patience were appreciated. I also would like to thank Dr. Barron Rector and Dr. Bill Fox for their advice and encouragement throughout this project.

I also would like to thank my former supervisor, Dr. Wayne Hanselka. He allowed me time to take classes and encouraged me to take on this project. I also would like to thank my current supervisor, Dr. Neal Wilkins, for his advise, and help with data analysis and for allowing me time to attend classes and work on this thesis.

For financial support of this project, I would like to thank the International Boundary and Water Commission, United States Department of Agriculture-Environmental Quality Incentive Program, Texas A&M Ag Program soil and water conservation grants, and the Texas Cooperative Extension Rangeland Ecology and Management Program Unit.

I would like to thank my parents, Kenn and Judy Hays, for all of their support throughout my life. Most importantly, I thank my wife, Amy, for all of her support throughout this project.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

Page

Page

INTRODUCTION

A doubling of Texas' human population by 2030 with its projected increase in water demands has stimulated attempts to increase surface and groundwater yields through brush control programs on rangeland (TWDB 1997). One attempt to ward off water shortages is to target known noxious plants that have high water use. This effort can be costly. Actual water savings need to be validated to justify the cost for state supported efforts in the future. In addition, Goodrich et al. (2000) noted that "improved estimates of riparian [evapotranspiration] derived from groundwater and its seasonal distribution are necessary to improve regional groundwater models so that they can be used more reliably as near-term management tools versus their typical use for long-range planning".

One primary target plant is saltcedar (*Tamarix* sp.), a phreatophyte found along rivers and lakes in Texas, the Southwest, and especially in the western United States (James et al. 1991). Saltcedar is an introduced plant that transpires considerably more water than native vegetation (James et al. 1991), however some studies show native riparian vegetation can use as much water at saltcedar. (Inglis et al. 1996) found that native plants (cottonwoods and mesquite) that reestablished on a site that had been cleared of saltcedar used as much water as the saltcedar had prior to its removal. Since its introduction into North America in the 1800's, saltcedar has spread throughout the Southwest, down the Rio Grande and Colorado River drainages and throughout the

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This thesis is written to conform to the style of the Journal of Range Management.

Great Basin (Stevens et al. 1998). Saltcedar is now found in nearly every watercourse in the Southwest below 1830 m in elevation (James et al. 1991). Saltcedar invades lowlands and riparian areas where it competitively replaces native grasses, forbs, shrubs, and trees (Stevens et al. 1998) and is the most widely and evenly distributed phreatophyte in Texas (Ruesink 1983).

Excessive water use by saltcedar has long been verified by research and experience in western states, and control of saltcedar has been recognized as a practice for increasing water yields and restoring native vegetation. However, evapotranspiration rates vary based on water availability, stand density, weather conditions, soil characteristics and depth to groundwater (Davenport et al. 1982). Few studies have attempted to determine the water use of plants from hourly diurnal fluctuations in the water table. This method of estimating water use must take into account soils, vegetation and geographic location. When considering a method for estimating water use from hourly diurnal groundwater fluctuations in a river/riparian system, there is a need to choose a method that most closely relates to the natural inputs and outputs of a riparian based system with unconfined aquifers/shallow water table.

This thesis discusses and compares methods for determining water use by saltcedar and associated vegetation from hourly diurnal groundwater fluctuations, estimates the water use by the riparian vegetation on the Canadian, Colorado, and Pecos rivers in Texas, and evaluates the paired plot technique for determining water savings following brush control.

OBJECTIVES

This study was designed to utilize a pattern of groundwater monitoring wells to estimate daily water use by saltcedar and associated riparian vegetation on the Canadian, Colorado, and Pecos Rivers in Texas. The specific objectives of this study were to:

(1) identify the “best” method for calculating water use from diurnal groundwater table fluctuations

(2) determine water use by saltcedar and associated vegetation with the appropriate method, and compare results to the EPA (1993) Paired Plot Method following saltcedar control at the Colorado location

(3) describe effects of weather, soil, depth to the water table and vegetation characteristics on estimated water use, and

(4) propose appropriate methodology for analysis of long-term continuous well monitoring to estimate water use by riparian vegetation along river systems.

Other studies will determine direction and rates of flow for each study location. In addition, the results prior to saltcedar control will be used to estimate water savings following herbicide application for all locations.

LITERATURE REVIEW

Groundwater discharge by evapotranspiration from phreatophytes in arid and semiarid regions is a principal mechanism for water loss, and in some areas the sole mechanism (Nichols 1993 and Nichols 1994). Saltcedar is one of the phreatophytes that have spread throughout these regions in the United States. Several studies have been conducted to determine the water use (evapotranspiration) by this plant. The estimated rate of water use by saltcedar varies depending on method of measurement, location of study and other factors (Table 1).

Different techniques to determine evapotranspiration include: evapotranspirometers, stem-heat-balance, Bowen ratio, lysimeter, drums, well monitoring, Blaney-Criddle and Eddy covariance (Table 1). The Bowen ratio, Eddy covariance and Blaney-Criddle methods use meteorological measurements (temperature, wind speed, solar energy, daylength, CO_2 fluxes etc.) to estimate evapotranspiration. Whereas, evapotranspirometers, lysimeters, drums, and tanks utilize some type of container (which the plants are grown in) so that the amount of water that is added and the amount that remains after evapotranspiration can be measured. The difference is considered evapotranspiration loss.

Lysimeters are used to control lateral water movement through the soil (non-weighing). The weighing lysimeters can measure the weight of the soil at a determined interval. The difference between measurements is assumed to be evapotranspiration.

Table 1. Estimated annual water use by saltcedar (*Tamarix* sp.) in the Southwestern United States.

Reference	Location	Method	Water use Minimum	Water use Maximum
Meterological				
Gay and Fritschen (1979)	NM	Bowen ratio	7.2 mm/d	9.5 mm/d
Devitt, et al. (1998)	NV	Bowen ratio	75 cm/yr	145 cm/yr
King and Bawazir (2000)	NM	Eddy covariance	1193 mm/yr	1325 mm/yr
Luo (1994)	NM	Blaney-Criddle	1.4 ft/yr	4.7 ft/yr
*Bureau of Reclamation (1995)	CA	Mirco-meterological Data		2.5 ft/ yr
**Weeks et al. (1987)	NM	Energy budget	30 in/yr	42 in/yr
Lysimeter				
van Hylckama (1974)	AZ	Evapotranspirometer	92.4 cm/yr	228.7 cm/yr
Davenport, et al. (1982)	CA	Drums	2.21 mm/d	15.8 mm/d
**Bureau of Reclamation (1979)	NM	Non-weighing lysimeter	15.6 in/yr	56.4 in/yr
**Grosz (1972)	NV	Tanks	14.9 in/yr	29.2 in/yr
Gay and Fritschen (1979)	NM	Lysimeter	6.2 mm/d	9.4 mm/d
Plant Measurements				
Sala et al. (1996)	NV	Stem-heat-balance	5.9 mm/d	16.3 mm/d
Wells				
Inglis, et al. (1996)	NV	Wells	0.013 ft/d	0.034 ft/d
Watershed				
**Culler et al. (1982)	AZ	Water budget	25 in/yr	56 in/yr

Water use measurements reported as they are in the literature. *As cited in Lines and Bilhorn (1996). **As cited in Johns (1989).

The methodologies used for measuring water use have different strengths and weaknesses. One weakness is when the transpiration rates for saltcedar are expressed per unit of transpiring surface, the transpiring surface can be difficult to determine because of its small feathery foliage (Davenport et al. 1982). Devitt et al. (1998) suggested that a detailed spatial assessment of stand density and an evaluation of water availability to atmospheric water demand over time is needed to characterize the evapotranspiration of full stands of *Tamarix*. They found the Bowen method did not account for horizontal energy flow, which would need to be added to the energy balance equation. Anderson (1982) presented evidence

> indicating that the stomatal mechanism of *T. chinensis* provides a finely tuned system for preventing excessive water loss and increasing water use efficiency by responding to prevailing light and humidity conditions…It is clear that the plants are not just wicks in the ET equation. Failure to treat stomatal resistance as a variable in attempts to predict ET from meteorological data and stand characteristics may result in significant overestimates.

Evapotranspirometers also have problems as the equipment should be surrounded by a buffer zone of the same plants and all other conditions should be as similar to those in the instrument (van Hylckama 1974). If these conditions are not met then an oasis effect may result. The oasis effect can occur when plants are grown in a lysimeter without vegetation surrounding the lysimeter. The plant in the lysimeter will use more water if other plants do not surround it. This can lead to an over estimate of water use by saltcedar.

The problem with estimating water use by saltcedar for an entire site using only measurements from one part of a plant will depend on the conversion ratio. The conversion ratio can be difficult to determine and any errors can be magnified (Heikurainen 1963).

Estimating water use based on diurnal groundwater fluctuations observed in monitoring wells also has some problems. Estimates cannot be made when there are no diurnal fluctuations. For instance when the water table experiences a sharp rise associated with river levels. During this time recharge rates exceed evapotranspiration and no diurnal cycles are present.

Factors Affecting Evapotranspiration

Evapotranspiration rates for saltcedar vary based on water availability, stand density, weather conditions, soil characteristics, salinity, and depth to groundwater (Davenport et al. 1982 and Devitt et al. 1997). The majority of transpiration takes place during the daytime because sunlight and weather conditions are major components of transpiration and these will be discussed in the diurnal cycle of the groundwater table section.

Anderson (1977) stated that, "exchange of water vapor between the plant canopy and the atmosphere depends upon air and leaf temperatures, atmospheric humidity, aerodynamic or boundary layer resistance, and leaf diffusion (stomatal) resistance." He found the optimum leaf temperatures for photosynthesis in saltcedar were between 23° and 28°C, and that stomatal resistance in saltcedar increased as leaf temperatures increased between 14° and 50°C. He concluded that the increase in stomatal resistance would contribute to the decrease in net photosynthetic rate above 28°C.

Anderson (1982) found that saltcedar twigs under full sunlight at 30°C and 45 % relative humidity transpire a mass of water greater than their own fresh mass each hour. Van Hylckama (1969) using evapotranspirometers in Arizona discovered that saltcedar was temperature sensitive and it reduced water use on hot afternoons. The ecophysiological attributes (functional traits) of cottonwoods (*Populus* sp.), willows (*Salix* sp.), mesquite (*Prosopis* sp.), and saltcedar are different (Smith et al. 1998) (Table 2). Saltcedar is highly tolerant to water and salinity stress and has higher water use efficiency than mesquite, willows and cottonwoods. The peak transpiration rate (on a leaf area basis) for saltcedar and mesquite are moderate but high for cottonwoods and willows. However, on a stand basis saltcedar has the highest peak transpiration rate.

Table 2. Comparison of ecophysiological attributes of cottonwoods, willows, mesquite, and saltcedar. Adapted from (Smith et al. 1998).

Attribute	Cottonwoods/ Willows	Mesquite	Saltcedar
Stress Tolerance (water/salinity)	Low	Moderate	High
Peak Transpiration Rate (leaf area basis)	High	Moderate	Moderate
Peak Transpiration Rate (stand basis)	High	High	Very High
Water use efficiency*	Low	Moderate	High

*Water use efficiency is defined as the amount of organic matter produced by a plant divided by the amount of water used by the plant in producing it (www.co2science.org).

Depth to Water Table

Several investigators have studied the effects that depth to the water table has on plant water use. Devitt et al. (1997) found that sapflow decreased in saltcedar grown in lysimeters as the water table and soil water declined (lysimeters placed at desert edge, river edge and open stand). They found that "daily sapflow totals on a leaf area basis were higher for the plants growing along the river's edge, with midday hourly values significantly higher when a water table was present." This study also had a drydown phase that showed sapflow decreased in the river's edge and open stand lysimeters as the water table dropped.

Saltcedar grown in evapotranspirometers, in a dense thicket in Arizona, used 226. 4 cm/yr with a depth to the water table of 1.5 m and 86.5 cm/yr with a depth to the water table of 2.7 m (van Hylckama 1970) (Table 3). He concluded that given a lower water table saltcedar may thrive but use considerably less water.

Table 3. Water use by saltcedar decreased as depth to the water table increased. Modified from van Hylckama (1970).

Depth to Groundwater	Water Use cm/yr 1961	Water Use cm/yr 1962	Water Use cm/yr 1963	Average* cm/yr (STD)
1.5 meters	199.3	218.3	226.4	214.67 (13.91)
2.1 meters	141.1	137.1	159.4	145.87 (11.89)
2.7 meters	104.8	93.9	86.5	95.07 (9.21)

*Average and standard deviation was calculated for values shown using years as replications.

Gary (1963) studied root distribution in saltcedar and found their roots could adapt themselves to favorable soil moisture conditions. He found that in areas where the water table was deep, saltcedar produced long taproots and the branch roots where vertical in nature. The branch roots occupied the areas immediately above the groundwater table and were in the capillary fringe. He also found that when the water table was high, saltcedar developed a taproot and secondary roots that occupied all zones of the soil profile above the water table.

Carman and Brotherson (1982) found that the highest stand densities of saltcedar occurred where water tables were close to the surface. In a stable isotope study of saltcedar and associated vegetation in Arizona, Busch et al. (1992) found that saltcedar not only gets water from the water table but is capable of getting it from unsaturated alluvial soils. This evidently gives saltcedar a competitive advantage over native phreatophytes that are not able to survive when water levels are low or non-existent.

Salinity Effects

Van Hylckama (1970) showed that salinity levels affected water use by saltcedar. He compared flushed evapotranspirometers to non-flushed (those that did not have salt removed by flushing the system with fresh water) evapotranspirometers and showed that saltcedar in the flushed system used 229 cm of water compared to the non-flushed system, which used 115 cm of water. Cumulative water use from the evapotranspirometers showed that with an electrical conductivity of 10 (mmho cm $^{-1}$ at

25° C) saltcedar water use averaged approximately 300 cm/yr and with an electrical conductivity of 40 saltcedar water use averaged approximately 50 cm/yr.

Carman and Brotherson (1982) comparing sites infested and not infested with saltcedar and Russian olive found that saltcedar occurred on sites with soluble salt concentrations ranging from 700-15000 ppm and Russian olive occurred on sites with soluble salt concentrations ranging from 100-3500 ppm.

Saltcedar has shown resistance to salinity changes in excess of 30 dS m^{-1}, while other woody shrubs (i.e., *salix*) succumbed to the change (Smith et al. 1998). Tomanek and Ziegler (1962) found that transplanted saltcedar seedlings can withstand salt contents up to 4000 ppm but at 2500 ppm the seedlings are stressed. Busch and Smith (1995) found that saltcedar was likely to be tolerant to a relatively high degree of salinity and water stress and these adaptations benefited the plant in these environments.

Stand Characteristics

Davenport et al. (1982) found that evapotranspiration by saltcedar varied based on stand density (Fig. 1). Water use ranged from approximately 2.0 mm/day by a sparse stand of saltcedar to almost 16 mm/day for a dense stand.

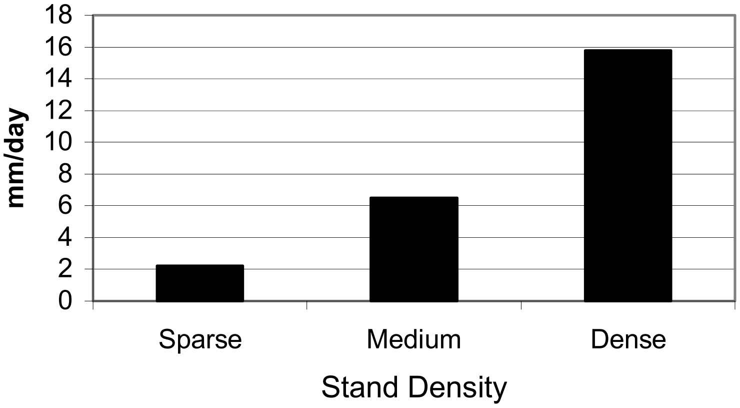

Fig. 1. Comparison of water use by saltcedar (mm/day) grown in drums located in different stand densities when local PET was 7 mm/day. Adapted from (Davenport et al. 1982).

Sala et al. (1996) found the key factors controlling water use by *Tamarix ramosissima, Pluchea sericea, Prosopis pubescens, and Salix exigua,* using the stem-heat-balance method, under moderate to high water tables (depths not given) include leaf area index (LAI) and stand density. They concluded that feedback mechanisms could reduce transpiration rates:

> under ample water availability, transpiration rates of *Tamarix ramosissima* measured on either leaf-area or dry-mass bases were no greater than those of sympatric native phreatophytes. Dense *Tamarix* stands can lose very high amounts of water under high evaporative demands, and this water loss tends to increase as individual leaf area increases. Such high rates of water loss in dense *Tamarix* stands may trigger feedback mechanisms due to the creation of a surface boundary layer that decreases vapor pressure deficit at the leaf level, resulting in reduced peak transpiration rates. However, strong advective conditions combined with high LAI [leaf area index] would tend to compensate for this boundary layer effect, resulting in stand ET

> [evapotranspiration] rates that can be almost twice as high as PET [potential evapotranspiration] during certain times of the year.

In a study conducted on saltcedar grown in evapotranspirometers it was noted that when 50% of the transpiring surface of the saltcedar was removed there was only a 10% to 15% decrease in the amount of water used (van Hylckama 1970).

Diurnal Cycle of the Groundwater Table

Maidment (1993) stated:

> water levels in piezometers fluctuate on time scales ranging from a few minutes to hundreds of years, depending upon the nature of the processes that initiate the fluid pressure variations. Short-term fluctuations in confined aquifers can be caused by changes in barometric pressure of the atmosphere, earth tides, and seismic events. Earth tides can lead to water-level changes of 1 or 2 cm; atmospheric pressure changes may cause fluctuations of several tens of centimeters, depending upon elastic properties of the aquifer and the magnitude of change in atmospheric pressure. These types of water-level changes are damped in unconfined aquifers. However, fluctuations can occur in response to time-varying rates in consumptive use of water by plants whose roots penetrate to the water table.

The difference between confined and unconfined aquifers is that confined aquifers are separated from the soil surface by a confining layer. This could be rock or a thick clay layer. The unconfined aquifer does not have this confining layer and water is able to move into the aquifer from the soil surface or river or lake.

Tromble (1977) explained the various components of the groundwater hydrograph. Groundwater fluctuations reflect varying rates of water use (evapotranspiration) and water movement through the soil. He pointed out there are several inflection points in the diurnal fluctuations (Fig. 2).

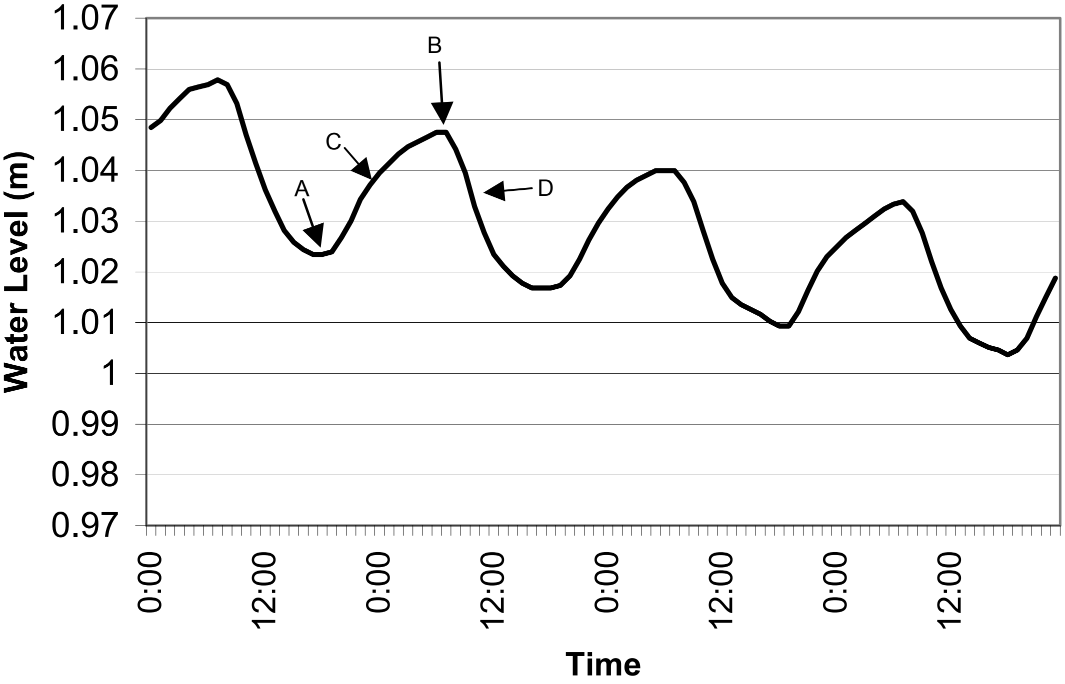

Fig. 2. Diurnal fluctuations of groundwater table with inflection points (Tromble 1977). At point (A) the inflow and outflow are about the same, at point (B) recharge and transpiration are at a minimum, at point (C) inflow is greater than outflow and at point (D) outflow is greater than inflow.

In Figure 2, at the lowest point (A) on the curve, the inflow and outflow of water are about the same; both high, and at the highest point on the curve (B) recharge and transpiration are at a minimum. When outflow is greater than inflow (D) transpiration is high and when inflow is greater than outflow (C) transpiration rates are lower for the day. The recharge stopped at point (B) because the water level had reached the static head. The nighttime peak (B) and the daytime low (A) decrease over time due to water loss from evapotranspiration from the shallow water table or flow from the system.

Numerous researchers (White 1932, Croft 1948, Kittredge 1948, Gatewood et al. 1950, Heikurainen 1963, van Hylckama 1974, Tromble 1977, Anderson 1982, Gerla 1992, Sala et al. 1996, Rosenberry and Winter 1997, Caldwell et al.1998, Dulohery et al. 2000, and King and Bawazir 2000) have noted the diurnal trends in groundwater levels. Of these White (1932), Kittredge (1948), Gatewood et al. (1950), Heikurainen (1963), van Hylckama (1974), Tromble (1977), Rosenberry and Winter (1997), and Dulohery et al. (2000) investigated these fluctuations as a way to measure plant water use. Goodrich et al. (2000) noted in their study of riparian evapotranspiration that stream flow exhibits a distinct diurnal fluctuation prior to the first hard freeze and that this pattern dissipates after the freeze. They attribute this fluctuation to air temperature and riparian evapotranspiration.

Laczniak et al. (1999) reported observing diurnal groundwater fluctuations in wells and attributed it primarily to local evapotranspiration. They noted that the "magnitude and timing of the fluctuation differs with well depth, vegetation and soil conditions, climate, and distance from a surface water source." Rosenberry and Winter (1997) in their investigations of groundwater fluctuations in prairie wetlands observed diurnal head fluctuations in groundwater monitoring wells and attributed it to daily evapotranspiration.

White (1932) noted that diurnal groundwater fluctuations, in an alfalfa field, began in the spring when plants put on leaves and ceased in the fall after killing frosts. He also found that "generally the daily fluctuations vary directly with the temperature, wind movement, and intensity of sunlight and inversely with the humidity, and they follow more or less closely the daily fluctuations in evapotranspiration from a free water source." He also found that the stage and vigor of plant growth influenced the amount of the daily groundwater fluctuation.

Soils/Specific Yield

White (1932) noted that the fluctuations in groundwater monitoring wells varied in amplitude with the amount of water discharged from the zone of saturation by evapotranspiration. He also noted

> that the amount of the daily rise and fall is a function of the texture of the material in the belt of fluctuation, which controls the capacity of the material to give up water under the pull of gravity after being saturated. This capacity is the specific yield of the soil. The specific yield of a rock or soil with respect to water is the ratio of 1) the volume of water which after being saturated it will yield by gravity to 2) its own volume. It is the measure of the volume of pore space alternately emptied and filled during the daily fall and rise of the water table, or it may be defined as the depth of water that drains out of the soil as the water table declined or enters the soil as the water table rises, expressed as a percentage of the depth of soil alternately drained or resaturated. For example, if the removal of a quantity of water representing a depth of 0.1 inch on a given area causes the water table to decline 1 inch under the area, the specific yield of the soil in which the decline takes place is 10 [percent].

Specific yield is directly related to soil texture. Johnson (1967) developed a specific yield triangle to determine specific yields based on soil texture. The specific yield of the soil increases as the percent of sand in the soil increases, and the more clay in the soil the lower the specific yield.

Comparison of Water Use Among Species

Saltcedar is not the only plant species present at the three study locations for this project. Different woody species are present as well as grasses and forbs. These plants also use water. The reported water use in the literature for the woody plants found at the study locations vary among species (Table 4).

Table 4. Representative examples of water use from the literature for important species found at the study locations.

Reference	Location	Species	**Growing Season Water Use
Robinson (1970) *	Nevada	Willow (*Salix*)	0.92 meters
Gatewood et al. (1950)	Arizona	Cottonwood (*Populus*)	1.52 – 2.35 meters
Gatewood et al. (1950)	Arizona	Mesquite (*Prosopis*)	1.02 meters
Luo (1994)	New Mexico	Russian Olive (*Elaegnus*)	0.46 - 2.90 meters

*As cited by Johns (1989). **Growing seasons may vary.

METHODOLOGY

Location and Description of Study Sites

Three locations (UTM NAD83 Zone 13 and 14) were chosen for this study. The first location was on the Colorado River in Borden County Texas (3610237.537 N 290269.114 E). This location was approximately 48.28 km from the start of the Colorado River in Texas and would be covered by 3.05 meters of water if Lake J.B. Thomas were at full capacity. The study location was approximately 460 m from the river channel. The soils at this location were alluvial deposits and consisted primarily of loams and sandy clay loams. The vegetation at this site consisted of young growth saltcedar with a sparse herbaceous understory. The above ground flow of the Colorado River at this location was not continuous. The river only flowed during high runoff events and the water table was well below the soil surface.

The second location was on the Texas Parks and Wildlife Department's Gene Howe Wildlife Management Area (3973311.081 N 385514.490 E) in Hemphill County Texas. The site was immediately adjacent to the North side of the Canadian River. The soils were sandy and the water table was close to the soil surface. Saltcedar was not the dominant woody vegetation at this location and there was a dense herbaceous understory. The Canadian River did not continuously flow above ground.

The third location consisted of two sites (Sites A and B) on the East side of the Pecos River in Loving County Texas (Site A 3515606.641 N 61725.083 E, Site B 3516763.900 N 61513.762 E) just west of Mentone. Both sites were immediately adjacent to the river channel. The soil at both sites was predominately sand. At both sites, wells were located in dense old growth saltcedar along the river, and one well at each site was located away from the river's edge in native vegetation. The Pecos River flowed throughout the growing season; however, the flow changed with water releases (for irrigation) from Red Bluff Lake.

Water Level Recorder

Global Water[1] (Global Water Instrumentation, Inc. Gold River, Ca. USA) WL14X water level loggers were used to measure hourly water levels in the wells. The sensor on the WL14X is a submersible pressure transducer that is amplified and temperature and barometric pressure compensated with an accuracy of 0.2%. Loggers used in this study had an accuracy of ± 0.0091 m. The loggers were battery powered, held 6000 readings and were downloadable in the field. The loggers were calibrated prior to being placed in the wells, and the data was downloaded and the batteries changed twice per year. The loggers were set to record water levels in feet every hour. All calculations were in feet and then converted to metric units.

Location and Installation of Wells

Shallow wells were installed at each study site to provide data on the fluctuation of the groundwater table. The wells were constructed by hand auguring below the water

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[1] Mention of brand names is provided for reference and does not imply endorsement.

table until gravel or a thick clay layer was encountered. All wells differed in depth and elevation at each location (Table 5).

Wells 3 and 4 at the Canadian location were similar in elevation because they were both located in a slough while Well 2 was located in the upland. The wells at the Colorado location were similar in elevation and depth. Wells 1 and 5 at Site A at the Pecos location were lower in elevation than Well 2 at the saltcedar edge. Wells 1 and 3 at Site B were lower in elevation than Wells 2 and 5, which were located at the saltcedar edge and the upland respectively.

Table 5. Depth of wells from the soil surface and surface elevations at each site.

Location and Well #	Depth from soil surface	Surface Elevation* (m)
Canadian 2	2.06(m)	30.48
Canadian 3	1.68 (m)	28.22
Canadian 4	1.29 (m)	28.44
Colorado 1	7.31 (m)	30.36
Colorado 2	7.73 (m)	29.84
Colorado 3	6.83 (m)	30.48
Pecos A 1	3.51 (m)	29.41
Pecos A 2	4.62 (m)	30.48
Pecos A 5	4.64 (m)	29.90
Pecos B 1	2.38 (m)	28.19
Pecos B 2	4.36 (m)	30.48
Pecos B 3	2.65 (m)	28.90
Pecos B 5	5.79 (m)	31.58

*These are not actual sea level elevations, but elevations in relation to one well designated to be 30.48 m.

River wells were installed by placing a PVC pipe down the bank of the river to the bottom of the river (Fig. 3). Each well, except for river wells, consisted of a 7.62 cm hand bored opening in which a 5.08 cm diameter PVC pipe with a 1.22m long well screen attached was inserted to the bottom of the boring. The slots in the well screen were 0.01 mm. The PVC pipe extended approximately 0.9 m above the soil surface. Blasting sand was used to fill the annular space around the well casing to within 0.3 m of the soil surface. The last 0.3 m of annular space was capped with pre mix cement to prevent overland flow entering the annular space around the well casing. During the coring process, soil samples were taken for each 0.3 m interval for laboratory analysis to determine soil particle size distribution (texture) (Fig. 4).

Fig. 3. River well installed at Canadian location.

Fig. 4. Soil sample collection at Colorado location, Well 1.

Triangular placement of the wells will allow determination of the direction of groundwater movement. Water can be moving parallel to the river through the riparian zone, from the river into the surrounding landscape or from the surrounding landscape into the river or percolating downward.

The exact elevation and distance of wells in relation to each other and the river were determined with a survey transit and range pole. One well was assumed to be at an elevation of 30.48 meters at the soil surface and the other well elevations were determined from this mark. Distance to the water table from the soil surface will be used to correct groundwater levels to a local benchmark in another phase of this long-term study.

Vegetation Monitoring

Plant density, cover and composition were determined for the Colorado and Canadian River sites each September using permanent line transects. Transects, 20 m long, were measured in each cardinal direction at each well. Bare ground, rock, litter, grass, forb or woody vegetation was recorded along each transect at 1m intervals directly below the left side of the tape (from the well). The nearest live plant was identified at each 1m interval to calculate species composition. Density, number of stems, and height of woody vegetation were determined by species size class (<5, 5 to 10, >10 cm in basal diameter) on 0.001 hectare (2 m radius) circular plots located at 7 m and 14 m along the transects (Blackburn et al. 1982).

Permanent line transects that bisected each well and transversed the landscape perpendicular to the river were used on the Pecos sites. Each transect began at the rivers edge for the initial date and extended beyond the upper edge of the existing saltcedar stand. Bare ground, rock, litter, grass, forb or woody vegetation was recorded along each transect at one meter intervals directly below the left side of the tape. Woody plant canopy intercept was recorded along each transect by species to determine canopy cover for each transect at the Pecos location. At each one-meter interval, the nearest live plant was identified for determining species composition. A 1.22 m belt transect, along the same line, was used to determine woody plant density. Stem diameter and height of woody vegetation was determined by species size class (<5, 5 to 10, >10 cm in basal diameter) within the belt transect. In 2001, woody vegetation data was gathered using a 20 m circular plot around Well 5 at the Pecos Location at both Sites A and B.

Soil Characterization and Specific Yield

The soils collected from each well were analyzed for each 0.3 m increment from the soil surface. The hydrometer method of soil texture analysis was attempted but several of the samples contained gypsum. The gypsum caused the clays to flocculate and this gave erroneous results. Soil texture analysis was conducted, by the Texas A&M Soil and Crop Sciences Soil Characterization Laboratory, using the pipette method (Kilmer and Alexander 1949 and Steele and Bradfield 1934) after the gypsum was leached from the soils. Once the soil texture was determined the specific yield for each increment was determined using a specific yield triangle (Johnson 1967).

By viewing all water level data for each growing season, the water bearing zone for each well was determined. The mean of the specific yields observed in the water bearing zone during the growing season was used in water use calculations. For example, if the depth of the water in the well remained in a 1 m zone throughout the growing season the specific yield of the soils in that zone were averaged and used as the specific yield for that well.

Procedures for Removing Logger Error

In order to estimate water use by saltcedar and associated vegetation from the hourly changes in water level (diurnal groundwater fluctuations), the daily high and low water level associated with each well had to be determined. However, several of the instruments had “error/fluctuations” that could not be explained. These instrument “error/fluctuations” varied among wells (loggers). These erratic readings were considered errors due to the instrument when the following hourly reading returned to a value “matching” the trend from the previous hourly reading. Preliminary analysis showed many of these erratic lows and highs would be used to calculate water use. This would result in higher water use estimates. In order to “smooth” these erratic readings a three-hour running average of the data was used. For example, if the water level for 10:00 was 5.9898, 11:00 was 5.7888, and 12:00 was 5.9444 the corrected water level reading for 11:00 would be 5.9077. To insure that thi “smoothing” procedure did not influence results between wells, all data was “smoothed” by taking the running average of three recordings as shown in the above example. The overall trend was maintained (Fig. 5). All data sets were “smoothed”, even when loggers were functioning properly.

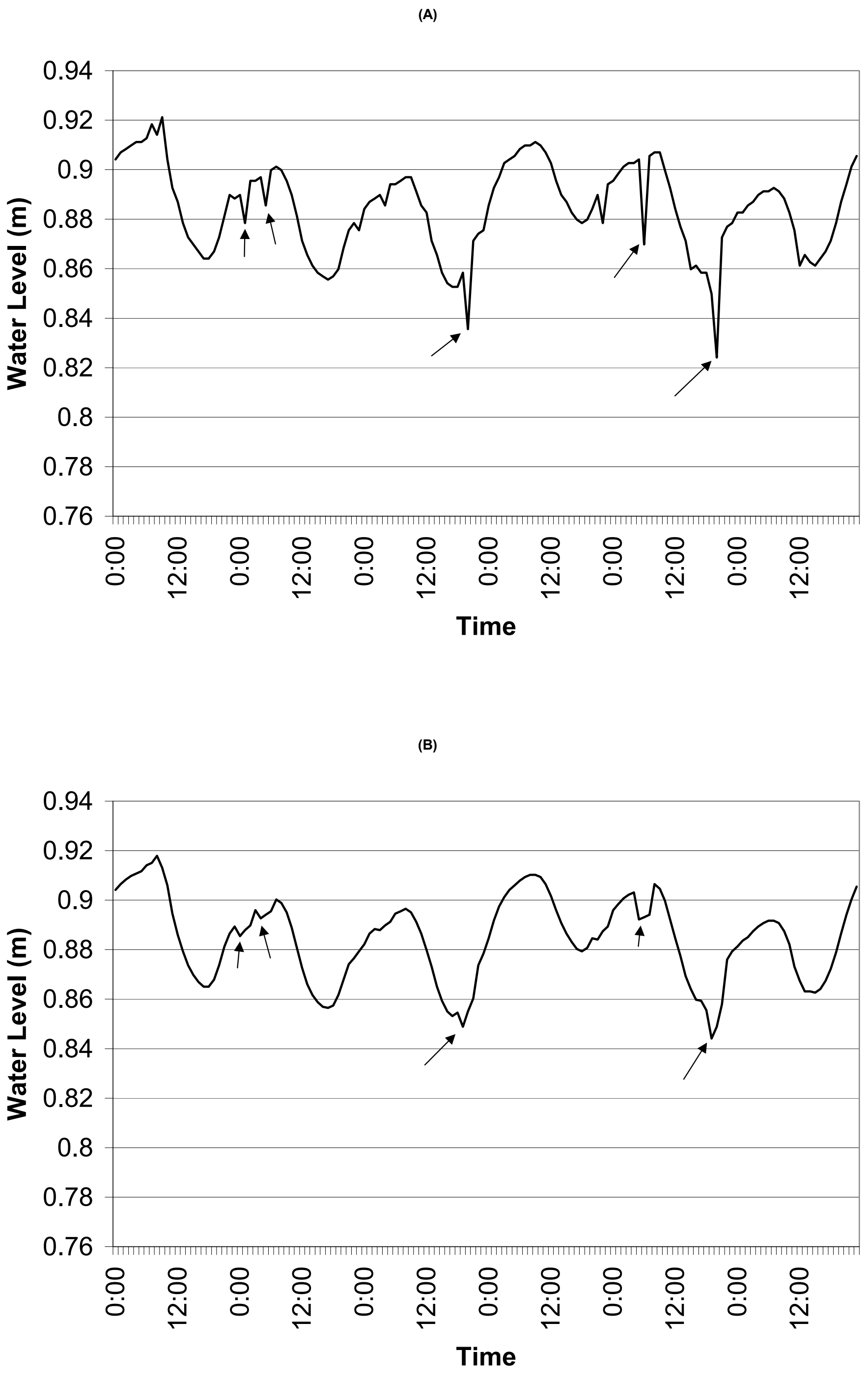

Fig. 5. Example raw data from Canadian Well 4 for June 18-23, 2001 showing erratic readings, indicated by ↑, believed due to logger error (A). The "smoothed" data removed the extreme values (B) by using a 3-hour running average.

Procedures for Estimating Water Use

Three basic methods were identified in the literature for estimating water use from hourly diurnal groundwater table fluctuations (White 1932, Troxell 1936, and Dulohery et al. 2000). White (1932) developed a formula for calculating evapotranspiration based on hourly fluctuations. He explained his theory for the formula as follows:

> During the day the capillary fringe is depleted by the plants, and the movement of groundwater by capillary action to meet the depletion is more rapid than recharge by hydrostatic or artesian pressure. Therefore the water table declines and the head increases. During the night transpiration and evaporation losses are small, the water table moves upward, and the pressure head declines.
>
> From about 6 to 10 in the evening and again from about 6 to 10 in the morning recharge approximately balances discharge, and for a few hours the water table is nearly at a stand still. This state of equilibrium would be reached earlier both in the evening and in the morning if it were not for lag in some operations. At or soon after sunset the rate of transpiration and evaporation declines to a small fraction of the rate that prevails during the day, but for a time the plants continue to draw some water to fill their circulatory systems, which have become somewhat depleted. (Nearly all plants become slightly wilted during the day, particularly on hot days, and tend to have a drooping appearance at night, quite in contrast with their fresh, turgid appearance in the morning.) Moreover, during the day the recharge of the capillary fringe from the zone of saturation lags somewhat behind the discharge by the plant action. By midnight, or slightly before, the veins of the plants have become filled with water. Meanwhile capillary equilibrium had been nearly established in the capillary fringe, and during the hours from midnight to morning there is little movement of water to the fringe from the zone of saturation.
>
> Between midnight and 4 a.m. the water table is approximately at a mean elevation for the 24-hour period, and therefore the head is

> also approximately at a mean, provided there is no gain or loss in water-table elevation during the 24-hour period. If the water table has a net fall during the 24 hours, the head in the early morning hours mentioned is slightly above the noon mean; and if it has a net rise, the head is slightly below the mean but the difference is generally not great. The velocity of water moving through a rock or soil varies approximately as the hydraulic gradient. Therefore if the slight losses by transpiration and evaporation between midnight and 4 a.m. are neglected, as well as the slight difference between the hydraulic head at this time and the true mean for the day, the hourly rate of recharge from midnight to 4 a.m. may be accepted as the average rate for the 24-hour period. The total quantity of groundwater withdrawn by transpiration and evaporation during the 24-hour period can then be determined by the formula $q=y(24r \pm s)$, in which q is the depth of water withdrawn, in inches, y is the specific yield of the soil in which the daily fluctuation of the water table takes place, r is the hourly rate of rise of the water table from midnight to 4 a.m., in inches, and s is the net fall or rise of the water table during the 24-hour period, in inches. In field experiments the quantities on the right hand side of the formula except specific yield can be readily determined from the automatic records of water-table fluctuation.

Inglis et al. (1996) in studying water use by saltcedar used White's (1932) formula. They believed for "improved estimates of water consumption, adjustments should be made to account for background fluctuation in stream flow. The relationship between stream stage and water levels in wells without the influence of vegetation and evaporation would need to be determined. Without accounting for stream stage fluctuation, calculated water consumption would likely decrease from wells adjacent to the stream channel." They did not show a correction for stream stage fluctuation in their paper.

Others have questioned the accuracy of White's (1932) formula. Troxell (1936) believed the formula is subject to a certain error. He believed the error was based on the assumption the rate of recharge (r) continued as a constant throughout the 24-hour period. He explained that as the water level dropped the rate of recharge increased and then slowed down when transpiration demands were lower.

Gatewood et al. (1950) used White's method in a study that compared calculated water use from well level fluctuations to actual transpiration loss from tank experiments. They found significant transpiration loss at night. Thus they computed a 1.25 correction factor for saltcedar water use based on twelve determinations (i.e. the calculated water use would be multiplied by this correction factor).

Nichols (1993) believed that White's formula underestimates the discharge of groundwater because "the volume of water moving laterally and vertically through the aquifer in response to increased groundwater gradients was not considered." He used energy budget micrometeorological measurements to determine water use.

Seven procedures for calculating water use (Q) from groundwater well data were compared in this study (Table 6). All of the calculations included multiplying the answer times the specific yield (sy) of the soil. (1) Method 1 involved calculating water use by using the current days maximum water level (H_1) minus the average of the two adjacent days low water levels (L_1,L_2) (Dulohery et al 2000). (2) Method 2 involved calculating water use by using the current days maximum (H_1) minus the current day minimum (L_1) minus the change in maximum water level from the current day (H_1) to the next day (H_2). (3) Method 3 involved calculating water use by using the current day maximum (H_1) minus the current day minimum (L_1) plus the change in maximum water level from the current day (H_1) to the next day (H_2). (4) Method 4 involved selecting the first high water level (H_1) for the day, then selecting the first low level (L_1) for the day and then the first high water level for the following day (H_2). These levels and the amount of time that passed between the highs and lows (T_1 and T_2) were used to calculate water use when transpiration exceeded recharge. (5) Method 5 is the same as method 4 except the net fall or rise of the water table (H_1-H_2) during the 24-hour period was added to the equation. For Methods 4 and 5, the data was divided into nighttime and daytime. Nighttime was considered to be from 9:00 pm to 8:00 am and daytime was from 9:00 am to 8:00 pm. (6) Method 6 was the method developed by Walter N. White (1932). A 24 hour recharge rate was estimated from the average rate of change in the water table from midnight to 4:00 am. This number was then multiplied by 24 and added to the change in maximum water level from one day to the next. (7) Method 7 is the same as the one developed and described by White (1932). The only difference was the 24 hour recharge rate was estimated between midnight and 2:00 am (Table 6).

Once the water use was calculated for each day of the growing season, the results were inspected and any day that had a negative water use was not included in the results. Additionally, days that showed extremely high water use were checked with the water level data and excluded if it was determined that there was an extreme increase or decrease in the water level due to river fluctuations that would cause the calculation method to over estimate the daily water use. The daily average water use was determined for each month from the remaining data (negative and extremely high water use results not included) and then multiplied by the number of days in the month to determine monthly water use. These were totaled for the growing season.

Table 6. Formulas evaluated for calculating water use.

Methods of Calculation	Formula
1	$Q=(H_1-(L_1+L_2/2))(sy)$
2	$Q=((H_1-L_1)-(H_1-H_2))(sy)$
3	$Q=((H_1-L_1)+(H_1-H_2))(sy)$
4	$Q=((H_1-L_1)+((H_2-L_1/T_1)xT_2))(sy)$
5	$Q=(((H_1-L_1)+((H_2-L_1/T_1)xT_2))+(H_1-H_2))(sy)$
6	$Q=sy(24r_1+s)$
7	$Q=sy(24r_2+s)$

Q = water use (meters)
sy = specific yield of the soil (percent)
H_1 = first high (meters)
H_2 = second high (meters)
L_1 = first low (meters)
L_2 = previous low (meters)
T_1 = number of hours between second high and first low
T_2 = number of hours between first high and first low
r_1 = the hourly rate of rise of the water table from 12:00 a.m. to 4:00 a.m. for formula 6
r_2 = the hourly rate of rise of the water table from 12:00 a.m. to 2:00 a.m. for formula 7
s = the net fall or rise of the water table during the 24 hour period (H_1-H_2)

Determining Length of Growing Season

The length of the growing season for each location was determined by observing when diurnal fluctuations began in the spring and ended in the fall (Fig. 6). The diurnal fluctuations at the study sites started at the end of April when daytime temperatures reached into the 20°C range and ceased after the first frost in the fall. White (1932) had observed these groundwater fluctuations occurred with leaf emergence and ceased when freezes caused defoliation.

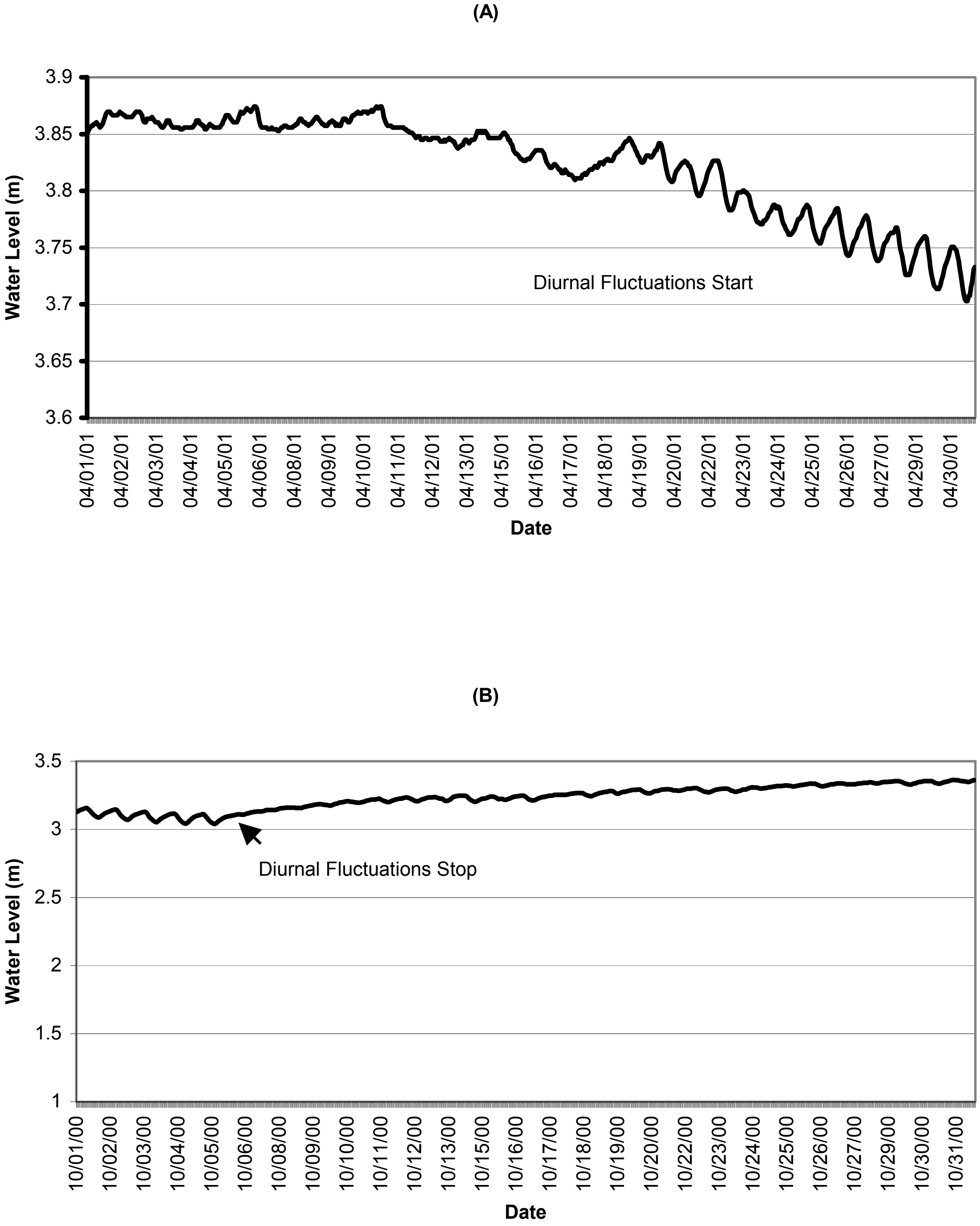

Fig. 6. Example of the beginning and ending of daily diurnal fluctuations in water level that were used to determine the length of the growing season at each location. (A) shows daily diurnal fluctuations began on 4/21/01 for Well 2 at the Colorado location and (B) stopped on 10/5/00 for Well 2 at the Colorado location.

Weather Characteristics

Several factors affect plant evapotranspiration (water use). These include relative humidity, barometric pressure, temperature, precipitation, wind, water quality, and depth to groundwater (Gatewood et al. 1950). Potential evapotranspiration (PET) data from the nearest weather station (Sweetwater, TX. 80 km from location) to the Colorado location was downloaded, from the Texas Cooperative Extension Biological and Agricultural Engineering Departments website (texaset.tamu.edu), for the 2001 growing season. Regression analysis was used to compare potential evapotranspiration (PET) on a daily basis throughout the 2001 growing season to results for estimated water use for Well 2. This was done to determine if PET could be used to estimate water use by saltcedar for this location. PET data was not available for the other study locations.

Statistical Analysis

Averages and standard deviations were used to determine if there were differences between each well at each site. If the averages fell within two standard deviations ($p<0.05$) then it was determined that there was no statistical difference between wells. Regression analysis was used for the paired plot analysis (EPA 1993) and the PET analysis for the Colorado location.

The water level loggers were set to record in feet. All of the water use calculations were calculated in feet and then converted to meters. The loggers also recorded to the eighth decimal place. When the data were sorted, they were rounded to the fourth decimal place to coincide with the accuracy of the loggers.

Paired Plot Analysis

A paired plot analysis was used for the Colorado location (EPA 1993). The procedure involved having paired plots (wells) that were calibrated prior to a treatment being initiated on one of the plots (wells). Well 1 and Well 2 served as the paired plots in this study. Both wells were monitored for one growing season prior to the area around Well 1 being treated with herbicide on August 21, 2000 (Fig. 7 and Fig. 8). The area around Well 2 was not treated with herbicide. The growing season calibration period provided information on how the water level in each well responded under the same conditions.

Fig. 7. Colorado location showing well location and herbicide treated area (shaded).

Fig. 8. Herbicide was applied to Well 1 at the Colorado location on August 21, 2000. A 49 % mortality of saltcedar was observed in September 2001.

A regression analysis for hourly water level fluctuations during the 2000 growing season was used to develop a regression equation. This equation was used with 2001 hourly water level values for Well 2 to predict what the water level should be for Well 1. The actual hourly water levels for Well 1 were subtracted from the predicted to determine any differences. Results were reported as the average difference in water table level. The "best" method for estimating water use was used to determine predicted verse actual water use for the 2001 growing season. Any difference between these values was believed to be due to treatment effects.

DETERMINING THE BEST METHOD FOR CALCULATING WATER USE

Results and Discussion

During this study, four types of groundwater data curves were observed (Fig. 9 - 12). A normal diurnal pattern was observed most of the time during the growing season (Fig. 9). During a "normal" pattern the water table increased or decreased with a discharge and recovery each day. All calculation methods worked when fluctuations were "normal".

Under different circumstances, the groundwater table can decline without distinct highs and lows (i.e. discharge during the day without recharge at night) (Fig. 10), increase without a low (i.e. recharge exceeds transpiration through one or more days) (Fig. 11), or increase with highs and lows (i.e. water table level increases over one or more days) (Fig. 12). Not all of the methods worked well under these conditions. For instance, the daily high and low water levels are necessary for components of the calculation in Methods 1, 2, 3, 4, and 5. For methods 5, 6, and 7 the difference between the high water levels are necessary for calculating the water use. If the second high were greater than the first high (i.e. the water table is rising with diurnal fluctuations present) the water use for the day could be negative.

Specific yield is a component of all the water use calculation methods. Since it is a constant characteristic for each well it does not affect the method of calculation; however, it affects the final water use estimated.

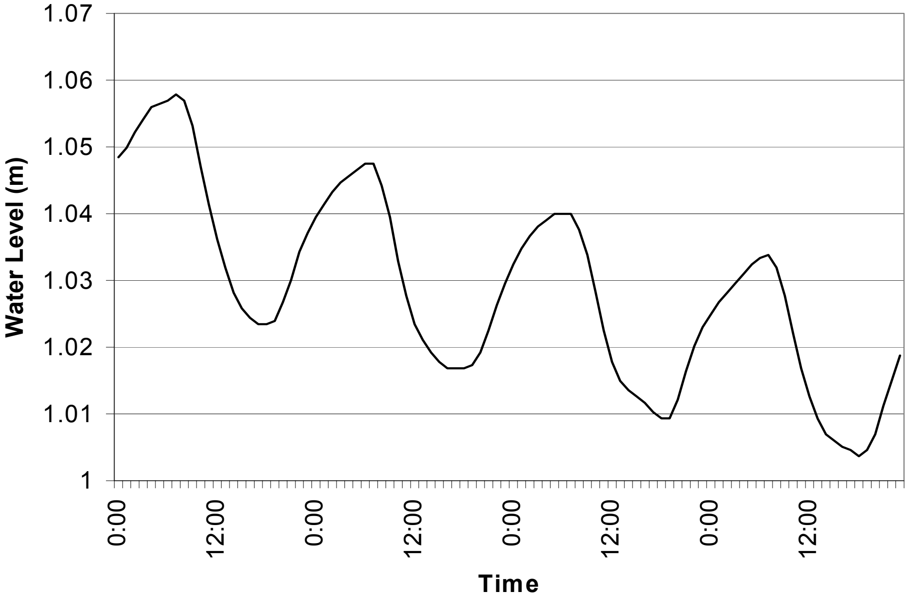

Fig. 9. Example of a "normal" daily diurnal fluctuation. The water table increases or decreases with a discharge and a recovery each day.

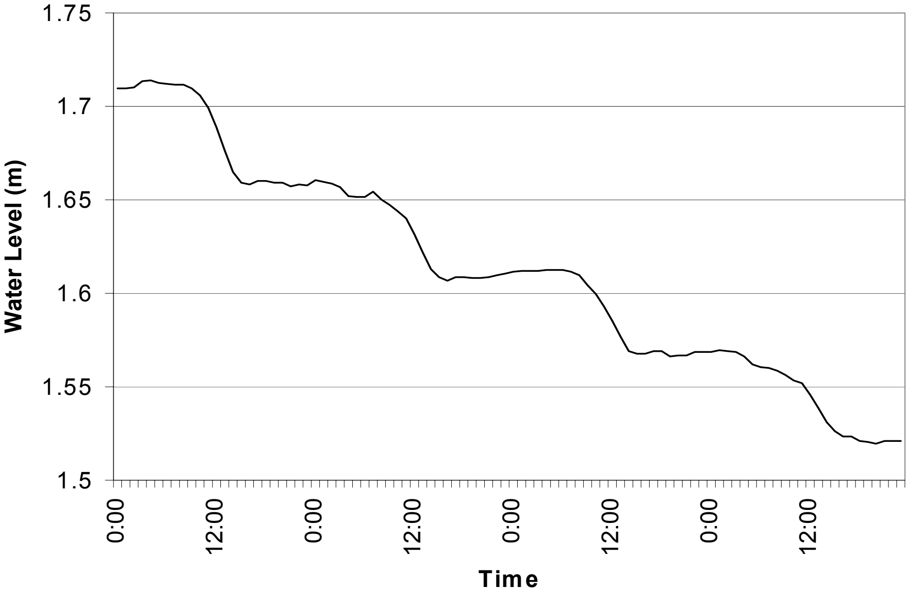

Fig. 10. Example of a fluctuation pattern where there was discharge during the daytime but no recharge at night.

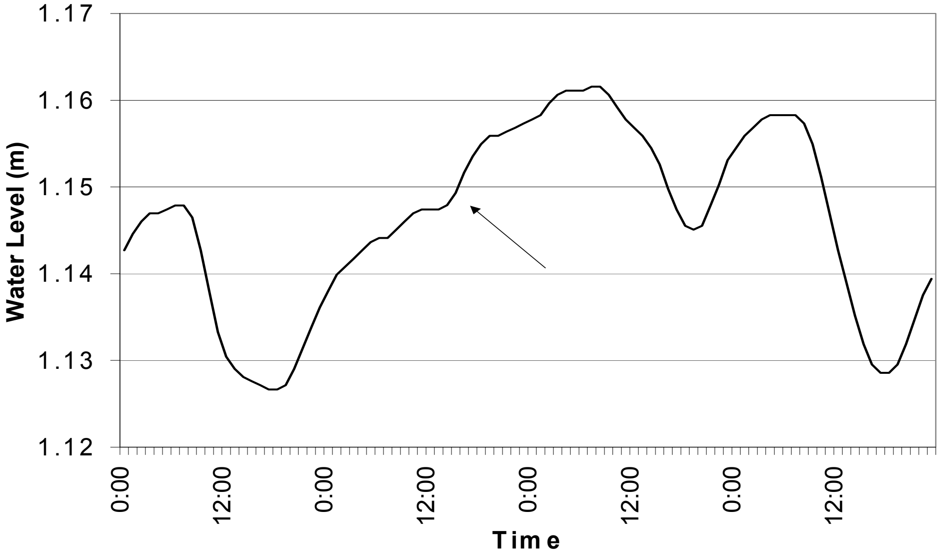

Fig. 11. Example of a fluctuation pattern where recharge exceeded transpiration throughout one or more days (↑).

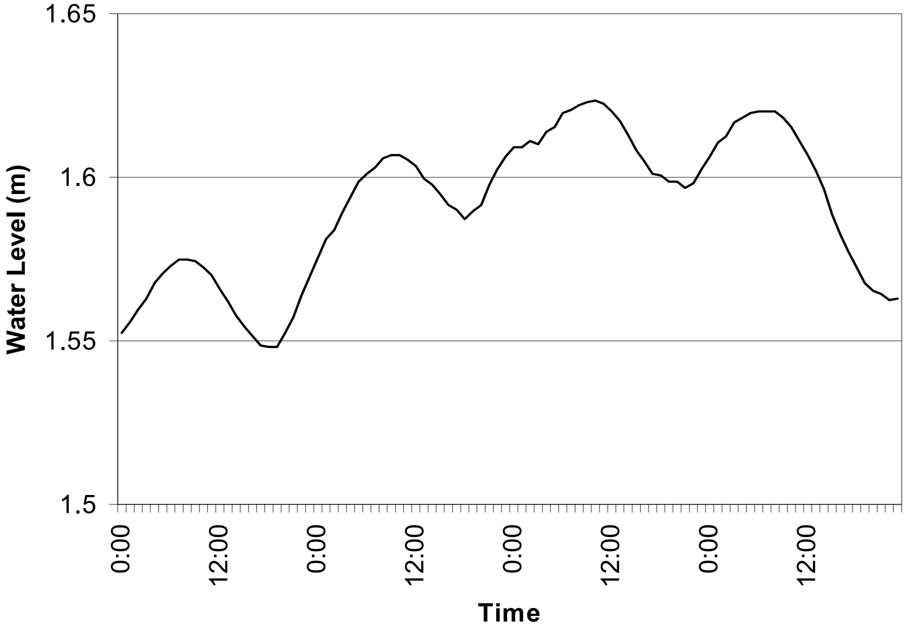

Fig. 12. Example of a fluctuation pattern where the water table level increased over one or more days.

Seven methods were evaluated for use in this study (Table 6). Each method was used for all locations and all wells for the entire growing season. Each method used data from the daily diurnal water table fluctuations (Fig. 13).

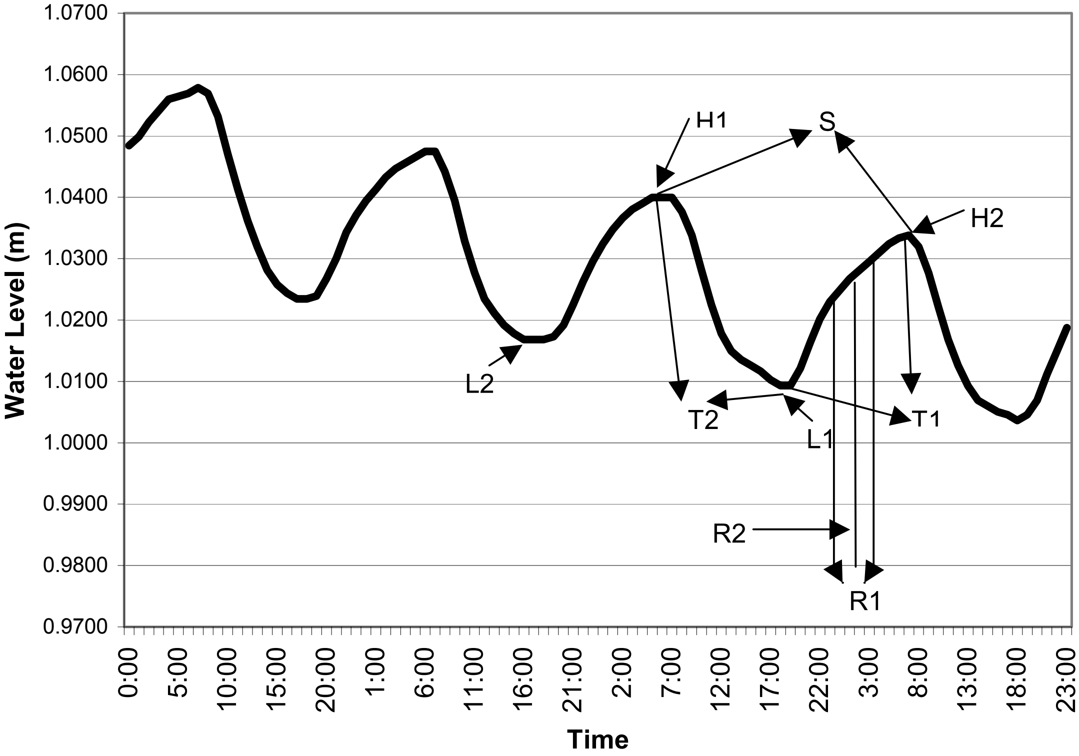

Fig. 13. Example of variables used in water use calculations from Well 2 at the Colorado Location (June 4, 2001) Measurements in meters for 6/4/01 are as follows: H_1= 1.040 m, H_2= 1.0338 m, L_1= 1.0168 m, S= 0.0062 m, R1= 0.0016 (m/hr), and R2= 0.0012 (m/hr).

Method 1

Method 1, $Q=(H_1-(L_1+L_2/2))(sy)$, was described by Dulohery (2000); however, he did not include specific yield in the formula. The specific yield was added to the formula by the investigator. This method only considers the highs and lows. It did not include any "corrections" for recharge during the time of discharge, transpiration at night, or the change in water table from one day to the next. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0270 meters. This does not include a correction for specific yield.

Method 2

Method 2, $Q=((H_1-L_1)-(H_1-H_2))(sy)$, measures the daily amplitude of the curves and subtracts the differences between the high from one day to the next. This method does not account for the recharge that takes place while evapotranspiration is occurring, or transpiration at night. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0245 meters. This does not include a correction for specific yield.

Method 3

Method 3, $Q=((H_1-L_1)+(H_1-H_2))(sy)$, is similar to Method 2. In Method 3 the difference between the two high water levels are added instead of subtracted. This method does not account for recharge that takes place while evapotranspiration is occurring, or transpiration at night. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0368 meters. This does not include a correction for specific yield.

Method 4 – Draw Down Recharge

Method 4, $Q=((H_1-L_1)+((H_2-L_1/T_1)xT_2))(sy)$, also uses the highs and low water level readings from the well hydrograph. However, this method also includes a recharge rate calculation. This formula works by taking the high for the night minus the low for the day (similar to Methods 1-3). However, a conservative estimate of recharge during this draw down period is estimated by subtracting the low from the next nights high divided by the number of hours during the recharge period to determine an estimated recharge rate. This is a conservative rate since some transpiration occurs at night. The amount of daytime draw down is added to the recharge rate times the number of hours during draw down to equal the estimate of water discharge for the well for the day. The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0551 meters. This does not include a correction for specific yield.

Method 5

Method 5, $Q=(((H_1-L_1)+((H_2-L_1/T_1)xT_2))+(H_1-H_2))(sy)$, is the same as Method 4 but it includes adding the difference between the two highs (s). The calculated water use for June 4, 2001 (Fig. 13) for this method was 0.0631 meters. This does not include a correction for specific yield.

Methods 6 and 7

Method 6, $Q=sy(24r_1+s)$, and Method 7, $Q=sy(24r_2+s)$, are essentially the same. The difference is the rate of recharge is calculated for a shorter period in Method 7. Method 6 was developed by White (1932) for using groundwater fluctuations to determine water use by plants. Recharge was calculated by multiplying 24 by the average hourly rise of the water table from midnight until 4:00 am (midnight until 2:00 am for Method 7). This number was then added to (s) the difference between the high water levels from one day to the next. The calculated water use for June 4, 2001 (Fig. 13) for Method 6 was 0.0458 meters and 0.0347 for Method 7. This does not include a correction for specific yield.

Results and Discussion

The estimated growing season water use varied by method and location from a low of 0.22 meters by Method 2 at the Colorado location to a high of 4.05 meters by Method 5 at the Canadian location (Table 7).

Biologically water use by saltcedar and associated vegetation occurs throughout the entire diurnal cycle and year round from live plants. During the wintertime transpiration would be minor compared to the growing season when leaf area is highest. Leaf area is one of the essential components of all of the direct transpiration measurement techniques. However, it is nearly impossible to extrapolate transpiration losses for an entire stand of saltcedar from measurements taken from a few leaves on a few trees.

Table 7. Average estimated water use in meters and standard deviation (STD) by each method for the growing season at each study site.

Method	Canadian 4/25/01 - 10/4/01	Colorado 5/1/00 - 10/5/00	Colorado 4/25/01 - 10/30/01	Pecos A* 4/25/01 - 10/4/01	Pecos B* 4/25/01 - 10/4/01
1	1.82 (0.50)	0.28 (0.21)	0.23 (0.21)	1.06 (0.75)	1.55 (0.26)
2	2.03 (0.51)	0.27 (0.21)	0.22 (0.21)	0.99 (0.69)	1.57 (0.23)
3	2.81 (0.51)	0.37 (0.20)	0.32 (0.18)	2.10 (0.94)	2.43 (0.23)
4	3.69 (0.95)	0.53 (0.36)	0.46 (0.34)	1.94 (1.44)	2.76 (0.14)
5	4.05 (0.91)	0.58 (0.35)	0.50 (0.34)	2.54 (1.52)	3.28 (0.23)
6	3.64 (0.60)	0.52 (0.23)	0.37 (0.33)	2.32 (1.26)	2.50 (0.84)
7	3.77 (0.77)	0.48 (0.10)	0.39 (0.25)	2.19 (1.19)	2.54 (0.68)

*Well 5 not included in calculation at Pecos Sites A and B

Well monitoring, on the other hand, reflects the entire impact of the climate and plant populations. The difficulty with well monitoring is that transpiration and recharge occur at the same time and at different rates throughout the diurnal cycle. This is further complicated in river systems where stream flows can fluctuate rapidly and influence recharge and discharge from surrounding soil profiles. Inglis et al. (1996) indicated that stream stage should be used to adjust water use calculations; however, he did not explain how to do this adjustment.

A narrow river system is a small body of water in relation to the riparian zones. The diurnal fluctuations in the river may be reflecting the diurnal water use and recharge from the riparian zone. Therefore, the diurnal fluctuations in the river may not need to be adjusted to estimate water use. A lake or large river system would be different.

Observations from these data suggest the transpiration from the riparian zone is causing the diurnal fluctuations in the river. The relatively high water uses observed in this study (Canadian and Pecos locations) under base flow conditions along miles of stream could account for the diurnal fluctuations in the river.

Very rapid changes in the flow of the river, if sustained, would raise the water table in the surrounding landscape due to recharge laterally and through flood plain percolation. During the period of this study, no high flows/flooding were experienced.

Thus, recharge rates would be a very important consideration in calculating water use. The water loggers accurately measure, during the draw down, the amount of evapotranspiration exceeding recharge. Since recharge is occurring at the same time, evapotranspiration (i.e. water use) would have to be considerably higher than just a calculation of draw down. Therefore, Method 1 that only used highs and lows for calculating water use would be inaccurate and extremely conservative compared to actual evapotranspiration during the entire 24-hour period.

Methods 2 and 3 used the same approach as Method 1 but included the change in nighttime highs from one day to the next. Although transpiration is considered low at night, this nighttime high occurs when transpiration and recharge are equal and lowest for the diurnal cycle.

The argument for using the difference between the high from one day to the next (s) is that if the water table rises in the 24 hour period that the head was greater and that recharge rates had increased for this 24 hour period over when the water table was stable or declining. Therefore, if the recharge rates were greater (s) would be negative and subtracted from results from other components of the equation in Methods 3,5,6, and 7 and added in Method 2 to compensate for high rates of recharge.

Method 4 encompasses (s) in its estimate of recharge because it calculates recharge from the low to the high. Method 4, believed to be a more accurate estimate of the average recharge rate during the diurnal cycle, accurately measures recharge which is changing in relation to the fluctuations, and is a better estimate of recharge rate for the day that includes the (s) concept. However, it does not compensate for transpiration at night. Therefore, it would result in a conservative water use estimate.

The change in the daily high water levels (s) should be added when soil water inflow/outflow are equal or does not occur. In these river systems (s) is believed to be greatly influenced by changes in the river water levels and should not be considered as evapotranspiration by plants. Therefore, adding (s) could bias results.

In order to determine which method worked best for the three study locations several characteristics were evaluated for each method of calculation (Table 8). Methods 6 and 7 were the only ones that considered transpiration at night. Method 1 was the only one that did not use or encompass the (s) concept, and Methods 4 and 5 were the only methods to consider the amount of time in which discharge takes place.

Method 4 considered recharge, the amount of time for discharge and encompassed the (s) concept. Method 5 is very similar to Method 4 (Method 5 just adds (s) to Method 4) however; by adding (s) in Method 5 the water use is probably overestimated because the (s) concept is already a part of the calculation of average recharge rate.

Method 6 and 7 considered recharge and daily changes in the water table level (s). However, (Troxell 1936) believed that these methods had problems because they assume that the recharge rate (r) remains constant for the 24 hour period, and Nichols (1993) believed that these methods underestimate water use because they do not account for water moving laterally or vertically through the aquifer during times of increased groundwater gradients.

Table 8. Characteristics evaluated in determining the "best" method of calculation from daily diurnal groundwater fluctuations.

Method	Recharge considered	Amount of time for discharge	Transpiration at night	Change in water table (s)	*Estimated water use June 4, 2001
1	No	No	No	No	0.0270 m
2	No	No	No	Yes	0.0245 m
3	No	No	No	Yes	0.0368 m
4	Yes	Yes	No	**No	0.0551 m
5	Yes	Yes	No	Yes	0.0631 m
6	Yes	No	Yes	Yes	0.0458 m
7	Yes	No	Yes	Yes	0.0347 m

*Does not include specific yield
**Encompasses the (s) concept

Conclusions

Method 4 was selected for determining water use in this study. A nighttime transpiration factor could be added but measurements for these sites are not available to determine an appropriate value. However, these estimates may be conservative by as much as 25% based on Gatewood's (1950) transpiration correction factor of 1.25. Hereafter Method 4 will be referred to as the Draw Down Recharge Method.

SOIL AND VEGETATION CHARACTERISTICS

Results and Discussion

The soils at each location are alluvial deposits in strata with different textures, specific yields, and hydraulic conductivity characteristics. These greatly affect the amount of free water and potential rate of recharge following evapotranspiration losses.

Canadian Location - Soils

Sand was the dominant soil texture class for all depths except for Well 4 where the top layer was a clay loam (Table 9). Well 4 was located in the upper part of a slough where soil deposition would occur during a flood stage. Soil samples for Well 4 could only be collected from 0 to 0.91 meters. Below this depth the soil was a slurry and could not be retained in the auger. Water levels during the growing season did not exceed 0.61 m, 0.30 m, and 0.30 m, for Wells 2, 3, and 4, respectively. Therefore, the specific yields used for calculating water use for each well were 40.2% for Well 2, 41.0% for Well 3, and 39.5% for Well 4.

Table 9. Soil properties by depth from the soil surface for wells at the Canadian location.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
2	0-0.30	92.9	4.2	2.9	Fine sand	35
2	0.30-0.61	91.0	6.6	2.4	Fine sand	35
2	0.61-0.91	94.4	4.3	1.3	Fine sand	**40**
2	0.91-1.22	96.6	2.4	1.0	Fine sand	**40**
2	1.22-1.52	96.6	2.2	1.2	Sand	**40**
2	1.52-1.83	97.3	1.5	1.2	Sand	**41**
3	0-0.30	72.4	17.9	9.7	Very fine sandy loam	20
3	0.30-0.61	96.8	1.6	1.6	Fine sand	**40**
3	0.61-0.91	96.1	2.3	1.6	Fine sand	**40**
3	0.91-1.22	98.4	0.9	0.7	Fine sand	**44**
4	0-0.30	39.5	28.4	32.1	Clay loam	4
4	0.30-0.61	91.0	4.5	4.5	Fine sand	**35**
4	0.61-0.91	98.1	0.0	1.9	Sand	**44**

The averages of the bold values were used for the specific yield for each respective well.

Colorado Location - Soils

Sand was the dominant soil texture class for all depths except for Well 3, 4.57 - 4.88 meters, where clay was dominant (Table 10). The texture class changed throughout the soil profiles because they were alluvial deposits. Water levels during the growing season did not exceed 6.10 m, 6.40 m, and 5.49 m, for Wells 1, 2, and 3, respectively. Therefore, the specific yields used for calculating water use at the Colorado location for each well were 15.67% for Well 1, 15.00% for Well 2, and 9.33% for Well 3.

There was a gravel layer at the bottom of each boring that prevented further auguring. Hydraulic conductivity was assumed to be high for this gravel strata.

Table 10. Soil properties by depth from the soil surface for wells at the Colorado location.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
1	4.88-5.18	54.8	24.1	21.1	Sandy clay loam	10
1	5.18-5.49	73.0	10.8	16.2	Fine sandy loam	16
1	5.49-5.79	61.2	15.9	22.9	Sandy clay loam	10
1	5.79-6.10	49.6	25.5	24.9	Sandy clay loam	5
1	6.10-6.40	63.5	15.7	20.8	Sandy clay loam	**10**
1	6.40-6.71	75.8	9.8	14.4	Sandy loam	**16**
1	6.71-7.01	80.6	7.7	11.7	Sandy loam	**21**
2	4.57-4.88	38.3	35.9	25.8	Loam	5
2	4.88-5.18	41.9	33.3	24.8	Loam	5
2	5.18-5.49	48.7	27.9	23.4	Sandy clay loam	7
2	5.49-5.79	49.6	26.4	24.0	Sandy clay loam	6
2	5.79-6.10	41.9	32.5	25.6	Loam	5
2	6.10-6.40	41.2	33.7	25.1	Loam	5
2	6.40-6.71	74.5	12.9	12.6	Course sandy loam	**19**
2	6.71-7.01	67.5	18.2	14.3	Sandy loam	**15**
2	7.01-7.32	63.1	16.9	20.0	Sandy clay loam	**11**
2	7.32-7.62	55.1	19.5	25.4	Sandy clay loam	6
3	4.57-4.88	23.3	38.0	38.7	Clay loam	3
3	4.88-5.18	37.3	28.8	33.9	Clay Loam	4
3	5.18-5.49	46.7	23.4	29.9	Sandy clay loam	4
3	5.49-5.79	58.3	18.7	23.0	Sandy clay loam	**9**
3	5.79-6.10	60.5	17.1	22.4	Sandy clay loam	**10**
3	6.10-6.40	59.2	17.8	23.0	Sandy clay loam	**9**

The averages of the bold values were used for the specific yield for each respective well.

Pecos Location Sites A and B - Soils

At Site A sand was the dominant soil texture class for all depths except at the bottom of Wells 1 and 5 (Table 11 and Table 12). Water levels during the growing season did not exceed 0.30 m, 1.22 m, and 3.35 m, for Wells 1, 2, and 5, respectively. Therefore, the specific yields used for calculating water use at Site A for each well were

37.70% for Well 1, 34.60% for Well 2, and 1.00% for Well 5. Well 3 at Site A was not included. This well was abandoned during the study because the logger kept malfunctioning.

Table 11. Soil properties by depth from the soil surface for Wells 1 and 2 at Pecos location Site A.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
1	0-0.30	87.1	6.4	6.5	Loamy sand	**30**
1	0.30-0.61	96.9	1.5	1.6	Sand	**40**
1	0.61-0.91	97.6	0.8	1.6	Sand	**42**
1	0.91-1.22	97.7	0.9	1.4	Sand	**42**
1	1.22-1.52	96.1	2.0	1.9	Sand	**40**
1	1.52-1.83	96.6	1.6	1.8	Sand	**40**
1	1.83-2.13	96.1	2.0	1.9	Fine sand	**40**
1	2.13-2.44	95.5	1.9	2.6	Fine sand	**40**
1	2.44-2.74	79.0	9.4	11.6	Sandy loam	**25**
1	2.74-3.05	51.0	25.5	23.5	Sandy clay loam	7
1	3.05-3.35	46.7	21.8	31.5	Sandy clay loam	4
1	3.35-3.66	31.4	21.7	46.9	Clay	1
2	0-0.30	76.3	14.1	9.6	Fine sandy loam	17
2	0.30-0.61	75.3	15.6	9.1	Very fine sandy loam	17
2	0.61-0.91	85.7	8.9	5.4	Loamy fine sand	30
2	0.91-1.22	61.8	23.7	14.5	Very fine sandy loam	15
2	1.22-1.52	84.8	9.4	5.8	Loamy fine sand	**30**
2	1.52-1.83	93.5	2.8	3.7	Fine sand	**35**
2	1.83-2.13	92.3	3.1	4.6	Fine sand	**35**
2	2.13-2.44	93.1	3.1	3.8	Fine sand	**35**
2	2.44-2.74	91.0	5.7	3.3	Fine sand	**35**
2	2.74-3.05	91.4	4.3	4.3	Fine sand	**35**
2	3.05-3.35	95.1	2.8	2.1	Fine sand	**40**
2	3.35-3.66	90.1	4.7	5.2	Fine sand	**35**
2	3.66-3.96	91.2	4.7	4.1	Fine sand	**35**
2	3.96-4.27	92.3	4.1	3.6	Sand	**35**
2	4.27-4.57	93.9	3.5	2.6	Fine sand	**35**

The averages of the bold values were used for the specific yield for each respective well.

Table 12. Soil properties by depth from the soil surface for Well 5 at Pecos River Site A.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
5	0-0.30	17.2	56.3	26.5	Silty loam	4
5	0.30-0.61	38.4	42	19.6	Loam	10
5	0.61-0.91	83.2	8.7	8.1	Loamy fine sand	25
5	0.91-1.22	87.6	5.6	6.8	Loamy fine sand	30
5	1.22-1.52	91.4	5.1	3.5	Fine sand	35
5	1.52-1.83	89.0	5.8	5.2	Fine sand	35
5	1.83-2.13	88.5	5.9	5.6	Fine sand	35
5	2.13-2.44	90.9	5.0	4.1	Fine sand	35
5	2.44-2.74	88.5	6.5	5.0	Fine sand	35
5	2.74-3.05	96.2	1.4	2.4	Fine sand	40
5	3.05-3.35	49.2	25.5	25.3	Sandy clay loam	5
5	3.35-3.66	18.4	52.4	29.2	Silty clay loam	**3**
5	3.66-3.96	5.2	35.1	59.7	Clay	**<1**
5	3.96-4.27	5.0	38.4	56.6	Clay	**<1**

The averages of the bold values were used for the specific yield for each respective well.

At Site B sand was the dominant soil texture class for all depths except at the bottom of Well 5 and at the surface for Wells 1 and 3 (Table 13 and Table 14). Wells 1 and 3 are close to the river and the surface soil was affected by sediment deposition from the river. Water levels during the growing season did not exceed 0.91 m, 2.44 m, 0.61 m, and 3.35 m for Wells 1, 2, 3, and 5, respectively. Therefore, the specific yields used for calculating water use at Pecos location Site B for each well were 32.50% for Well 1, 33.75% for Well 2, 31.67% for Well3, and 3.75% for Well 5.

Table 13. Soil properties by depth from the soil surface for Wells 1 and 2 at Pecos River Site B.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
1	0-0.30	21.9	36.7	41.4	Clay	2
1	0.30-0.61	30.5	38.9	30.6	Clay loam	4
1	0.61-0.91	16.7	47.0	36.3	Silty clay loam	2
1	0.91-1.22	59.2	24.8	16.0	Fine sandy loam	**15**
1	1.22-1.52	87.3	8.8	3.9	Sand	**35**
1	1.52-1.83	94.4	3.8	1.8	Sand	**40**
1	1.83-2.13	94.6	3.3	2.1	Sand	**40**
2	0-0.30	69.5	19.2	11.3	Fine sandy loam	20
2	0.30-0.61	73.9	17.7	8.4	Fine sandy loam	25
2	0.61-0.91	88.4	7.9	3.7	Fine sand	35
2	0.91-1.22	94.4	3.9	1.7	Fine sand	35
2	1.22-1.52	65.4	24.8	9.8	Fine sandy loam	20
2	1.52-1.83	59.0	27.3	13.7	Fine sandy loam	15
2	1.83-2.13	71.5	19.2	9.3	Fine sandy loam	20
2	2.13-2.44	71.5	20.0	8.5	Very fine sandy loam	20
2	2.44-2.74	76.6	16.9	6.5	Fine sandy loam	**25**
2	2.74-3.05	96.2	2.0	1.8	Fine sand	**40**
2	3.05-3.35	90.5	4.5	5.0	Fine sand	**35**
2	3.35-3.66	91.1	4.6	4.3	Fine sand	**35**
2	3.66-3.96	75.2	11.6	13.2	Sandy loam	20
2	3.96-4.27	71.1	11.0	17.9	Fine sandy loam	15

The averages of the bold values were used for the specific yield for each respective well.

Table 14. Soil properties by depth from the soil surface for Wells 3 and 5 at Pecos River Site B.

Well #	Soil Profile (m)	Total Sand (%)	Total Silt (%)	Total Clay (%)	Texture Class	Specific Yield (%)
3	0-0.30	12.7	35.2	52.1	Clay	1
3	0.30-0.61	39.3	39.4	21.3	Loam	10
3	0.61-0.91	78.5	13.5	8.0	Loamy fine sand	**25**
3	0.91-1.22	90.3	5.4	4.3	Sand	**35**
3	1.22-1.52	88.4	6.6	5.0	Sand	**35**
3	1.52-1.83	93.2	2.9	3.9	Sand	**35**
3	1.83-2.13	94.6	3.0	2.4	Sand	**35**
3	2.13-2.44	85.7	4.3	10.1	Loamy sand	**25**
5	0-0.30	36.3	44.9	18.8	Loam	10
5	0.30-0.61	1.7	55.9	42.4	Silty clay	1
5	0.61-0.91	1.5	71.1	27.4	Silty clay loam	3
5	0.91-1.22	2.7	58.2	39.1	Silty clay loam	2
5	1.22-1.52	34.4	50.8	14.8	Silty loam	14
5	1.52-1.83	24.0	62.1	13.9	Silty loam	10
5	1.83-2.13	25.2	59.3	15.5	Silty loam	10
5	2.13-2.44	29.5	55.5	15.0	Silty loam	11
5	2.44-2.74	7.0	57.4	35.6	Silty clay loam	5
5	2.74-3.05	4.9	50.6	44.5	Silty clay	1
5	3.05-3.35	3.4	52.9	43.7	Silty clay	1
5	3.35-3.66	27.2	38.1	34.7	Clay loam	**3**
5	3.66-3.96	20.4	41.3	38.3	Clay loam	**3**
5	3.96-4.27	13.5	67.6	18.9	Silty loam	**6**
5	4.27-4.57	3.6	65.4	31.0	Silty clay loam	**3**

The averages of the bold values were used for the specific yield for each respective well.

Specific yield of the soils at each well is an important component in estimating water use. The soils at the Canadian and Pecos sites had double the specific yield percentages the Colorado site had. However, Well 5 at Pecos Sites A and B had the lowest specific yield percentages because the growing season water level remained in the clay layer at these well sites at all times.

Vegetation Characteristics

Canadian Location

Wells 3 and 4 were located in a slough that apparently is an abandoned path of the Canadian River. Well 2 was located in the upland (Fig. 14).

Fig. 14. Winter 1996 Digital Orthoquarter Quad of Canadian location showing the river and the monitoring wells.

There were no statistical differences ($p<0.05$) between years for ground cover composition (Table 15). However, bareground was the dominant cover at Well 2, and litter was the dominant ground cover at Wells 3 and 4.

There were no statistical differences between years for species composition (Table 16). However, little bluestem (*Schizachyrium scoparium*) was the dominant species at Well 2, and Bermuda grass (*Cynodon dactylon*) was the dominant species at Wells 3 and 4.

There were no statistical differences between years for woody plant density (Table 17). However, the dominant woody species at Wells 2, 3 and 4 were plum (*Prunus* sp.), saltcedar (*Tamarix* sp.), and willow (*Salix* sp.), respectively. The woody plants around Well 2 (upland) were predominantly short plum trees while the woody species surrounding Wells 3 and 4 (slough) were tall trees with large basal diameters. The canopy cover by woody vegetation in the slough was nearly 100%.

There were differences in stem basal diameter and woody species present at each well (Table 18). The woody plants around Well 2 had small basal diameters compared to the old growth woody plants located in the slough around Well 3 and 4.

Table 15. Ground cover composition (percent) and standard deviation (STD) for well locations at Canadian River Site measured in October 2000 and August 2001.

Cover Class	Well 2 Average % (STD) Year observed		*Well 3 and 4 Average % (STD) Year observed	
	2000	2001	2000	2001
Bareground	51.25 (18.87)	52.50 (15.55)	26.25 (13.82)	23.75 (9.16)
Litter	28.80 (20.20)	36.25 (13.77)	68.75 (16.20)	71.87 (9.61)
Grass	18.75 (7.50)	11.25 (7.50)	6.25 (2.50)	3.12 (3.72)
Woody	0.0 (0.0)	0.0 (0.0)	1.87 (3.72)	1.25 (2.32)
Forb	1.25 (2.5)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Total	100.05	100.00	103.12	99.99

*Wells 3 and 4 (slough) combined to compare to Well 2 (upland)

Table 16. Life form composition (percent) and standard deviation (STD) for well locations at Canadian River Site measured in October 2000 and August 2001.

Cover Class	Well 2 Average % (STD) Year observed		*Well 3 and 4 Average % (STD) Year observed	
	2000	2001	2000	2001
Grass	83.75 (7.50)	75.00 (18.71)	79.37 (10.50)	76.25 (17.88)
Woody	1.25 (2.50)	2.50 (2.89)	8.12 (8.84)	8.12 (9.23)
Forb	15.00 (5.77)	22.50 (19.36)	12.50 (8.86)	15.63 (12.08)
Total	100.00	100.00	99.99	100.00

*Wells 3 and 4 (slough) combined to compare to Well 2 (upland)

Table 17. Woody plant density (per hectare) and standard deviation (STD) for Canadian location.

Species	Number of plants/hectare (STD) Year observed		Number of stems/hectare (STD) Year observed		Average Height Meters (STD) Year observed	
	2000	2001	2000	2001	2000	2001
Well 2						
Plum	3810	4325	7207	7310	0.56	0.59
(*Prunus* sp.)	(5246)	(5105)	(11362)	(10196)	(0.25)	(0.33)
Sumac	741	309	10811	1544	0.91	0.91
(*Rhus* sp.)	(1441)	(618)	(21622)	(3089)	(0.0)	(0.91)
Saltcedar	515	309	824	618	1.01	0.91
(*Tamarix* sp.)	(394)	(394)	(752)	(788)	(0.20)	(0.91)
Willow	2471	2265	4839	5148	0.84	0.77
(*Salix* sp.)	(2753)	(2436)	(6222)	(5571)	(0.33)	(0.28)
Eastern red cedar	0	103	0	103	0	0.30
(*Juniperus* sp.)		(206)		(206)		(0.0)
Well 3						
Lead plant	515	0	1647	0	2.16	0.0
(*Amorpha* sp.)	(618)		(1932)		(0.44)	(0.0)
*Russian olive	309	103	309	103	5.28	3.25
(*Elaeagnus* sp.)	(206)	(206)	(206)	(206)	(0.35)	(0.70)
*Saltcedar	5458	3501	12406	7928	2.52	2.41
(*Tamarix* sp.)	(1555)	(1280)	(4889)	(1319)	(1.09)	(0.89)
Willow	412	306	515	412	3.05	3.25
(*Salix* sp.)	(476)	(389)	(618)	(583)	(0.96)	(0.70)
Well 4						
Button bush	206	206	2060	1853	2.74	2.59
(*Cephalanthus* sp.)	(238)	(238)	(2378)	(2528)	(1.29)	(1.51)
*Russian olive	309	206	309	206	5.69	6.25
(*Elaeagnus* sp.)	(394)	(238)	(394)	(238)	(0.35)	(1.08)
Saltcedar	1030	454	4119	2574	2.77	3.12
(*Tamarix* sp.)	(980)	(548)	(4346)	(2290)	(1.06)	(0.83)
Willow	3089	1133	7517	4736	2.19	2.63
(*Salix* sp.)	(2637)	(1030)	(8080)	(7847)	(1.88)	(2.20)
Persimmon	206	206	1133	206	1.95	2.90
(*Diospyros* sp.)	(412)	(412)	(2265)	(412)	(1.91)	(1.08)

*One dead in 2001

Table 18. Woody species and stem basal diameter-Canadian location.

Species	% Stems < 5 cm Year observed		% Stems 5-10 cm Year observed		% Stems > 10 cm Year observed	
	2000	2001	2000	2001	2000	2001
Well 2						
Plum (*Prunus* sp.)	100.00	100.00	0.0	0.0	0.0	0.0
Sumac (*Rhus* sp.)	100.00	100.00	0.0	0.0	0.0	0.0
Saltcedar (*Tamarix* sp.)	100.00	100.00	0.0	0.0	0.0	0.0
Willow (*Salix* sp.)	100.00	100.00	0.0	0.0	0.0	0.0
Well 3						
Lead plant (*Amorpha* sp.)	60.00	0.0	20.00	0.0	20.00	0.0
*Russian olive (*Elaeagnus* sp.)	0.0	0.0	0.0	0.0	100.00	100.00
*Saltcedar (*Tamarix* sp.)	28.30	38.24	24.53	61.76	47.17	0.0
Willow (*Salix* sp.)	20.00	33.33	60.00	33.33	20.00	33.33
Well 4						
Button bush (*Cephalanthus* sp.)	0.0	50.00	50.00	50.00	50.00	0.0
*Russian olive (*Elaeagnus* sp.)	0.0	0.0	0.0	0.0	100.00	100.00
Saltcedar (*Tamarix* sp.)	30.00	25.00	30.00	62.50	40.00	12.50
Willow (*Salix* sp.)	79.17	72.73	4.17	9.1	16.67	25.00
Persimmon (*Diospyros* sp.)	50.00	50.00	25.00	50.00	25.00	0.0

Wells 3 and 4 were located in a slough and Well 2 was located in the upland. Although there were no statistical differences between the three wells for ground cover composition, species composition, or number of woody plants per hectare the plant community structure was different for Well 2 compared to Wells 3 and 4 (Figure 15-17). Well 2 was a more open site, while Wells 3 and 4 were more of a closed canopy with a dense herbaceous understory.

Fig. 15. Well 2 at Canadian location showing open area around well and woody vegetation in background (slough) where Wells 3 and 4 were located.

Fig. 16. Vegetation transect at Well 2 at the Canadian location. Note the open grassland around this area.

Fig. 17. Vegetation transect at Well 3 at the Canadian location. Note the dense herbaceous understory and the dense woody canopy cover.

Colorado Location - Vegetation

Wells 1, 2, and 3 are located in a young growth saltcedar thicket and Well 4 is located on the Colorado River (Fig. 18). There were no statistical differences between years for ground cover composition (Table 19). However, bareground was the dominant cover at Well 1 and 3, and litter was the dominant cover at Well 2. The increase in bareground composition in 2001 was attributed to the drought.

There were no statistical differences between years for species composition (Table 20) except for woody composition at Well 2. This is attributed to the drought, which eliminated the grass and forbs. Sand dropseed (*Sporobolus* sp.) was the dominant species at Wells 1 and 3. Saltcedar was the dominant species at Well 2.

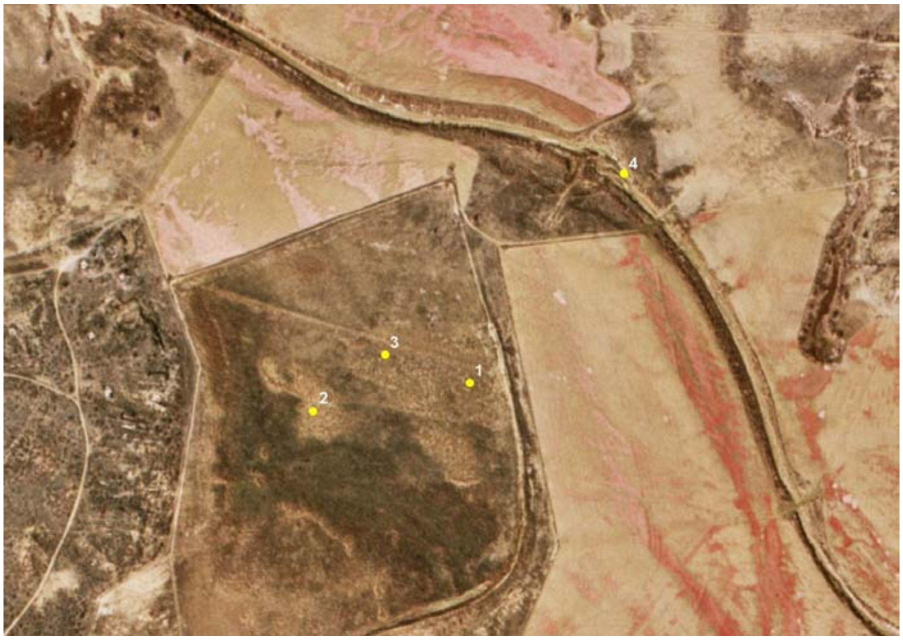

Fig. 18. Fall 1996 Digital Orthoquarter Quad of Colorado location showing well locations.

Table 19. Ground cover composition (percent) and standard deviation (STD) for well locations at Colorado location measured in August 2000 and 2001.

Cover Class	Well 1 Average % (STD) Year observed		Well 2 Average % (STD) Year observed		Well 3 Average % (STD) Year observed	
	2000	2001	2000	2001	2000	2001
Bareground	50.51 (7.35)	57.50 (8.66)	38.75 (4.79)	40.00 (10.80)	58.75 (6.29)	76.25 (10.31)
Litter	42.89 (2.30)	41.25 (7.50)	56.25 (8.54)	58.75 (11.81)	33.75 (2.5)	20.00 (12.25)
Grass	3.89 (4.84)	1.25 (2.50)	0.0 (0.0)	0.0 (0.0)	5.00 (5.77)	2.50 (2.89)
Woody	2.70 (3.12)	0.0 (0.0)	3.75 (4.79)	1.25 (2.50)	1.25 (2.50)	1.25 (2.50)
Forb	0.0 (0.0)	0.0 (0.0)	1.25 (2.50)	0.0 (0.0)	1.25 (2.50)	0.0 (0.0)
Total	99.99	100.00	100.00	100.00	100.00	100.00

Table 20. Life form composition (percent) and standard deviation (STD) for well locations at Colorado River Location measured in August 2000 and 2001.

Cover Class	Well 1 Average % (STD) Year observed		Well 2 Average % (STD) Year observed		Well 3 Average % (STD) Year observed	
	2000	2001	2000	2001	2000	2001
Grass	62.40 (26.20)	77.50 (6.45)	6.25 (4.79)	0.0 (0.0)	57.50 (17.08)	78.75 (9.46)
Woody	16.93 (2.86)	22.50 (6.45)	67.50 (8.66)	100.0 (0.0)	11.25 (10.31)	20.00 (10.80)
Forb	20.70 (23.9)	0.0 (0.0)	26.25 (13.15)	0.0 (0.0)	31.25 (17.97)	1.25 (2.50)
Total	100.03	100.00	100.00	100.00	100.00	100.00

There were no statistical differences between years for woody plant density (Table 21). However, all of the area around Well 1 and half of the area around Well 3 was sprayed August 21, 2000. Drift from the herbicide application was noted around Well 2 (Fig. 19). This resulted in 49% of the stems around Well 1, 9% of the stems around Well 2 and 19% of the stems around Well 3 to be classified as dead in the 2001 collection period. The remaining stems around Well 1 and Well 3 either had basal or canopy sprouts and were not recorded as dead. An estimated canopy reduction of 99% was recorded for Well 1. The dominant woody species at each well was saltcedar, and all saltcedar plants had basal stem diameters < 5 cm.

Table 21. Woody plant density (per hectare) and standard deviation (STD)-Colorado River Location.

Species	Number of plants/hectare Year observed		**Number of stems/hectare Year observed		Average Height (m) Year observed	
	2000	2001	2000	2001	2000	2001
Well 1						
Saltcedar	9782	10708	43760	50246	1.43	1.34
(*Tamarix* sp.)	(6584)	(7908)	(20155)	(25498)*	(0.76)	(0.53)
Well 2						
Saltcedar	12664	12459	90196	87417	1.61	1.48
(*Tamarix* sp.)	(5550)	(4701)	(23262)	(20709)*	(0.58)	(0.59)
Well 3						
Saltcedar	7413	11017	50556	57660	1.74	1.52
(*Tamarix* sp.)	(4449)	(7089)	(28726)	(35617)*	(0.45)	(0.47)

*All of the area around Well 1 and half of the area around Well 3 were sprayed August 21, 2000. Drift effects were seen in the area around Well 2, all stems were counted.
**All stems < 5 cm.

Fig. 19. Well 2 at the Colorado location depicting drift effect on foliage (approximately 9.0% of the stems were dead).

Pecos Location - Vegetation

At both Sites A and B Wells 1 and 3 were located in the saltcedar zone along the Pecos River, Well 2 was located at the edge of the saltcedar and Well 5 was located in the upland (Fig. 20-22). Well 3 at Site A was abandoned due to logger malfunctions, but vegetation characteristics were collected.

Fig. 20. Fall 1996 Digital Orthoquarter Quad of Pecos location Sites A and B in Loving County, Texas near Mentone.

Fig. 21. Fall 1996 Digital Orthoquarter Quad of Pecos location Site A showing well locations.

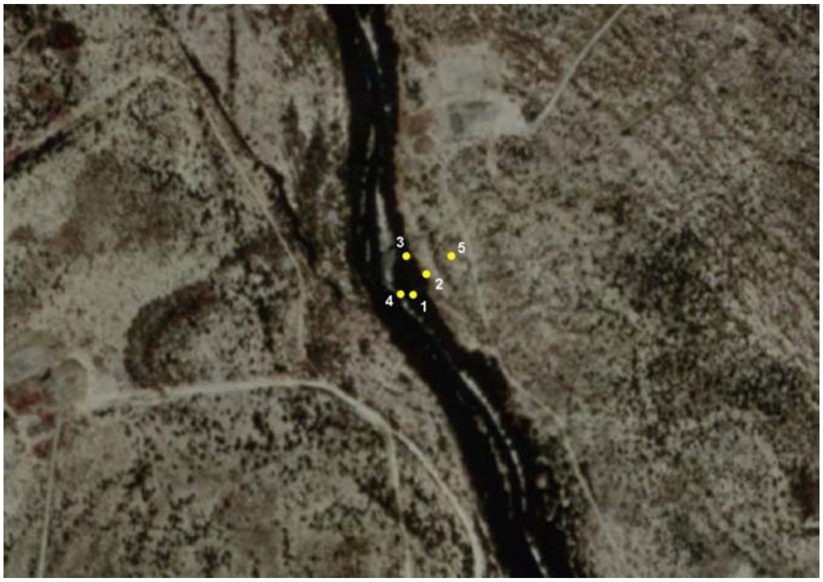

Fig. 22. Fall 1996 Digital Orthoquarter Quad of Pecos location Site B showing well locations.

There were no statistical differences between years for ground cover composition at Site A or B (Table 22). Litter was the dominant ground cover at both sites. There were no statistical differences between years for species composition at Sites A or B (Table 23). Twoflowered trichloris (*Trichloris* sp.) was the dominant plant at both Sites A and B. There were no statistical differences between years for woody plant density at Site A (Table 24), Site B (Table 25), or for canopy cover percent (Table 26).

Table 22. Ground cover composition (percent) and standard deviation (STD) for Site A and B at the Pecos location in the saltcedar zone (well locations 1, 2, and 3 only).

Cover Class	Well Average % (STD) Site A Year observed		Well Average % (STD) Site B Year observed	
	2000	2001	2000	2001
Bareground	17.10 (15.00)	18.95 (11.99)	56.15 (13.42)	34.76 (14.86)
Litter	75.33 (11.80)	72.63 (16.74)	30.25 (4.23)	63.90 (13.53)
Grass	4.74 (5.73)	5.33 (9.24)	12.20 (18.4)	1.33 (2.31)
Woody	1.23 (2.14)	3.09 (2.75)	1.45 (2.51)	0.0 (0.0)
Forb	1.59 (2.75)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Total	99.99	100.00	100.05	99.99

Table 23. Life form composition (percent) and standard deviation (STD) for Site A and B at Pecos location in the saltcedar zone (well locations 1, 2, and 3 only).

Cover Class	Well Average % (STD) Site A Year observed		Well Average % (STD) Site B Year observed	
	2000	2001	2000	2001
Grass	55.18 (16.90)	45.40 (35.30)	74.12 (4.18)	48.20 (22.20)
Woody	24.41 (5.08)	43.40 (22.70)	13.28 (8.33)	31.20 (18.20)
Forb	20.40 (12.07)	11.26 (13.05)	12.61 (6.14)	20.62 (6.68)
Total	99.99	100.06	100.01	100.02

Table 24. Woody plant density for Site A-Pecos location. Saltcedar stem diameters all > 10 cm, mesquite and four-wing saltbush stem diameters < 5 cm.

Species	Number of plants/hectare Year observed		Number of stems/hectare Year observed		Average Height (m) and standard deviation Year observed	
	2000	2001	2000	2001	2000	2001
Well 1						
Saltcedar (*Tamarix* sp.)	2059	2059	4119	4530	4.45 (2.01)	4.76 (1.19)
Well 2						
Saltcedar (*Tamarix* sp.)	3089	1236	4324	3398	4.34 (0.76)	4.27 (0.83)
Well 3						
Saltcedar (*Tamarix* sp.)	1647	549	1922	1373	3.96 (0.53)	5.03 (0.65)
Mesquite (*Prosopis* sp.)	0	275	0	275	0	0.30 (0.0)
Four-wing saltbush (*Atriplex* sp.)	0	275	0	824	0	0.61 (0.0)
Well 5						
Mesquite (*Prosopis* sp.)	*	423	*	No data**	*	1.62 (0.81)
Four-wing saltbush (*Atriplex* sp.)	*	502	*	No data**	*	0.51 (0.17)

*Well 5 was not established until 2001

**Stem numbers were not collected

Table 25. Woody plant density for Site B-Pecos location.

Species	Number of plants/hectare Year observed		Number of stems/hectare Year observed		Average Height (m) and standard deviation Year observed	
	2000	2001	2000	2001	2000	2001
Well 1						
Saltcedar (*Tamarix* sp.)	618	927	618	1544	3.20 (0.65)	3.15 (0.76)
Mesquite (*Prosopis* sp.)	2471	2471	2780	4324	1.03 (0.84)	0.93 (0.70)
Well 2						
Saltcedar (*Tamarix* sp.)	549	549	549	824	3.81 (0.22)	4.42 (0.22)
Well 3						
Mesquite (*Prosopis* sp.)	0	353	0	353	0.0 (0.0)	0.15 (0.0)
Four-wing saltbush (*Atriplex* sp.)	0	353	0	2118	0.0 (0.0)	0.61 (0.0)
Well 5						
Mesquite (*Prosopis* sp.)	*	502	*	No data**	*	1.14 (0.28)
Four-wing saltbush (*Atriplex* sp.)	*	3137	*	No data**	*	0.49 (0.21)

*Well 5 was not established until 2001
**Stem data not collected

Table 26. Woody plant canopy cover percent for Pecos location Sites A and B.

Well	Site A Canopy Cover % Year observed		Site B Canopy Cover % Year observed	
	2000	2001	2000	2001
1	84	86	34	38
2	76	76	78	80
3	77	79	65	71
Average (Standard deviation)	79.00 (4.36)	80.33 (5.13)	59.00 (22.60)	63.00 (22.10)

Saltcedar was the dominant woody plant at Wells 1, 2, and 3 at Site A and at Wells 1 and 2 at Site B (Table 24 and 25). Fourwing saltbush (*Atriplex* sp.) and mesquite (*Prosopis* sp.) were the dominant woody species at Well 5 at Site A and Wells 3 and 5 at Site B. The saltbush and mesquite at Well 3 were encountered towards the end of the transect at the edge of the riparian zone and the beginning of the upland. Although, no saltcedar were encountered along the belt transect the saltcedar canopy cover for this transect was 65% in 2000 and 71% in 2001.

All saltcedar stem basal diameters at Site A and B were greater than 10 cm. However, Site B had varying stem basal diameters for mesquite (Table 27). Stem diameter measurements were not collected for Well 5 at Site A or B.

Table 27. Stem diameters for woody plants Site B-Pecos River location.

Species	% Stems < 5 cm Year observed		% Stems 5-10 cm Year observed		% Stems > 10 cm Year observed	
	2000	2001	2000	2001	2000	2001
Well 1						
Saltcedar (*Tamarix* sp.)	0.0	0.0	0.0	0.0	100.00	100.00
Mesquite (*Prosopis* sp.)	100.00	87.50	0.0	12.50	0.0	0.0
Well 2						
Saltcedar (*Tamarix* sp.)	0.0	0.0	0.0	0.0	100.00	100.00
Well 3						
Mesquite (*Prosopis* sp.)	0.0	100.00	0.0	0.0	0.0	0.0
Four-wing saltbush (*Atriplex* sp.)	0.0	100.00	0.0	0.0	0.0	0.0

Conclusions

Soils and Specific Yield

The soils and specific yields for each well at the Canadian location were very similar. Sands and fine sands were the dominant soil texture class in the water bearing level of all three wells. This resulted in this location having the highest specific yields of the three study locations. The specific yields for this location fell within 1.5% of each other.

There were differences in soil texture class between the wells at the Colorado location. Wells 1 and 2 had similar soil texture classes (sandy loam, sandy clay loam) in the water bearing level of the wells that resulted in similar specific yields. However, Well 3 had more clay in the water bearing level of the well, thus a lower specific yield.

Sand was the dominant soil texture class for the soils at Pecos location Sites A and B. However, the soils in the water bearing level for Well 5 at both sites were clays. This resulted in a low specific yield for these two wells. The other wells had relatively high specific yields because of the sand.

The Canadian location had the highest specific yields. Wells 2, 3, and 4 at the Pecos sites had the next highest specific yields followed by the Colorado location. Well 5 at the Pecos location Sites A and B had the lowest specific yield.

Vegetation

There was a difference in vegetative structure at the Canadian location. Wells 3 and 4 were located in a slough and Well 2 was located in the upland. The area surrounding Well 2 was open grassland with some scattered woody vegetation. The areas around Well 3 and 4 were typically a brushy overstory with a thick herbaceous understory in a slough.

There were no differences in the vegetation between well locations at the Colorado location. The area around all of the wells was young growth saltcedar. The understory consisted of scattered forbs and grasses.

There were differences in vegetation at the Pecos location. The area around the wells located in the riparian zone (Wells 1, 2, and 3) was old growth saltcedar with an occasional mesquite or fourwing saltbush and a herbaceous understory. The area around Well 5 at Sites A and B were dominated by short mesquite and fourwing saltbush with open bareground interspaces.

The Canadian location had the most diverse plant community. There were several species of woody plants and a dense understory in the slough and tallgrasses and scattered woody species in the upland. Saltcedar did not dominate these sites.

The Colorado location was dominated by young growth saltcedar, and the Pecos location was dominated by old growth saltcedar with a dense understory in the riparian areas. The upland at the Pecos location was dominated by fourwing saltbush and mesquite.

WATER LEVEL FLUCTUATIONS

Results and Discussion

All groundwater levels fluctuated throughout the growing season at each well and at each location (Fig. 23-27). At times, the river had an impact on these fluctuations at the Canadian and Pecos locations. For example, if the river level rose suddenly the water in the wells closest to the river responded similarly. This affected the water use calculation when this occurred.

A river well was installed at the Colorado location; however, there were very few events where surface runoff occurred. The data suggests that the river flows did not coincide with changes in the water levels at these wells. This was probably because the wells are not in the riparian zone of the river and the soils are clay with low specific yields and hydraulic conductivity.

Canadian Location

A significant correlation ($p<0.05$) resulted when comparing hourly water levels between Wells 2, 3, and 4 during the 2001-growing season. Wells 2, 3, and 4 were poorly correlated with the river well although it was significant (Table 28). However, Figures 23 shows that the wells have similar fluctuations to those that occurred in the river.

Table 28. Coefficient of determination (R^2) for hourly water level fluctuations at the Canadian Location during the 2001 growing season (4/25/01 - 10/4/01).

	River	Well 2	Well 3	Well 4
River	1	0.28	0.20	0.32
Well 2		1	0.99	0.99
Well 3			1	0.99
Well 4				1

Appendix B contains the ANOVA and regression formula.

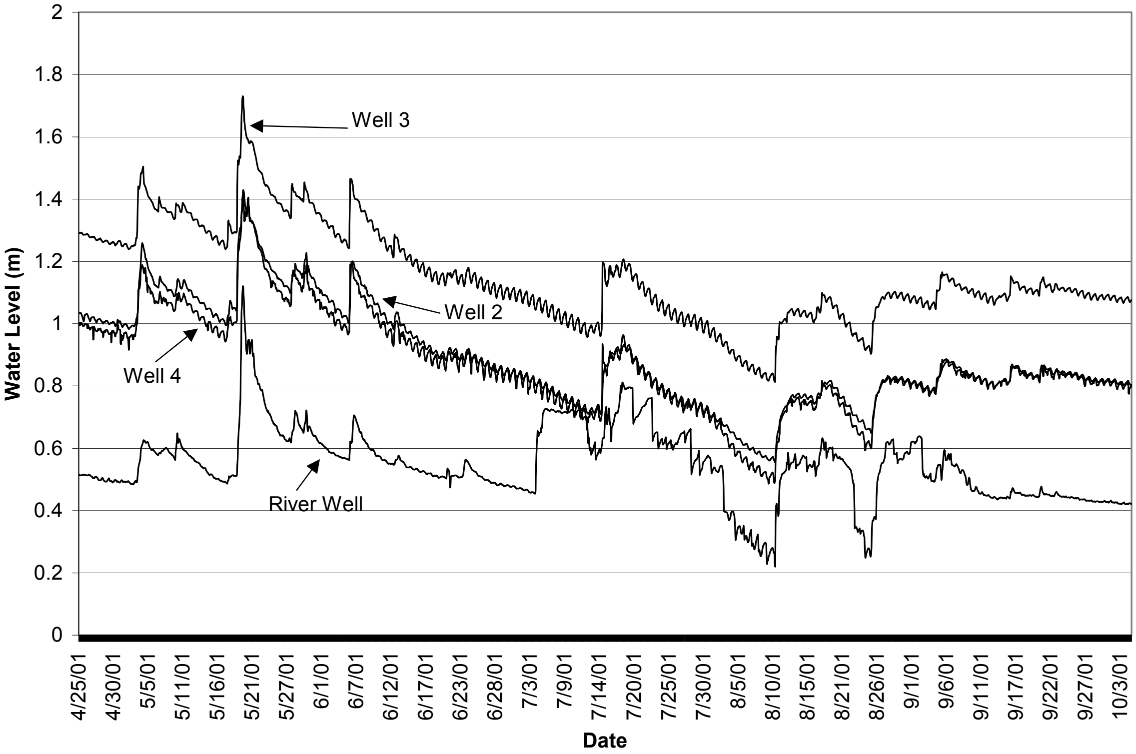

Fig. 23. 2001 Growing season groundwater levels at the Canadian location.

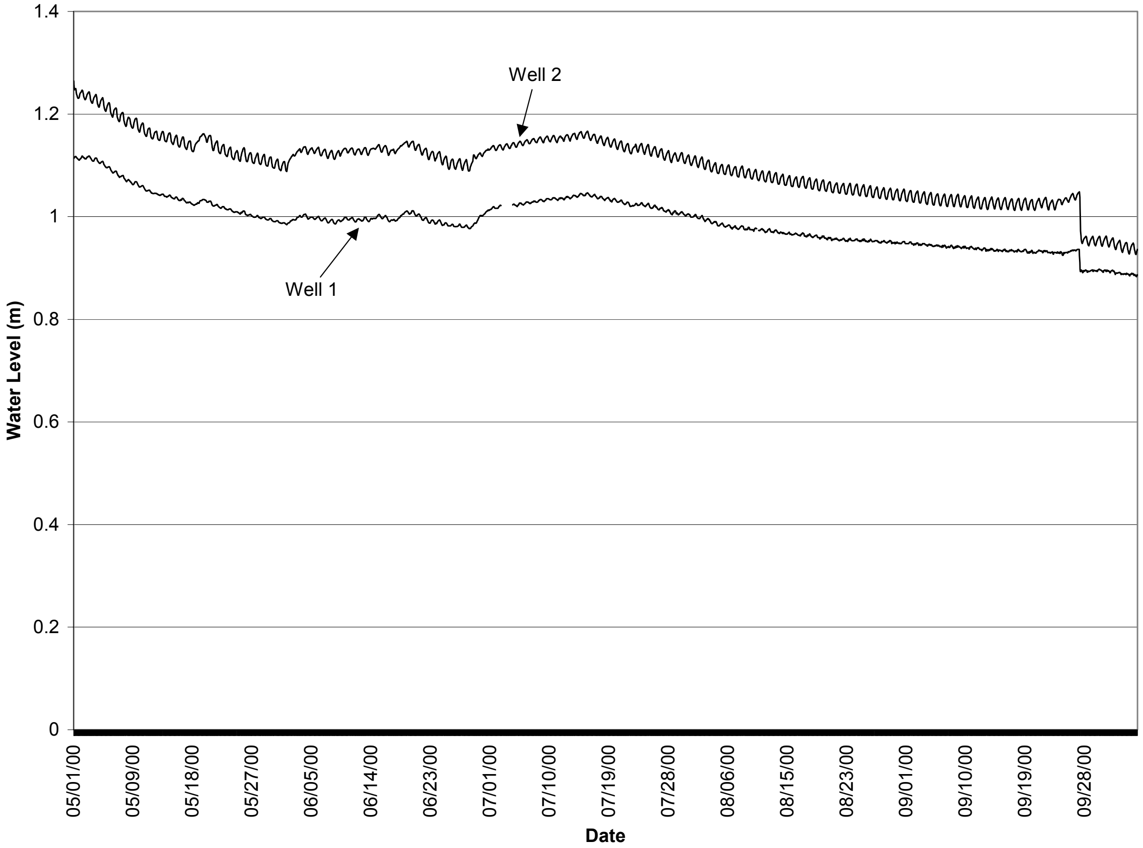

Fig. 24. 2000 growing season groundwater levels at the Colorado location.

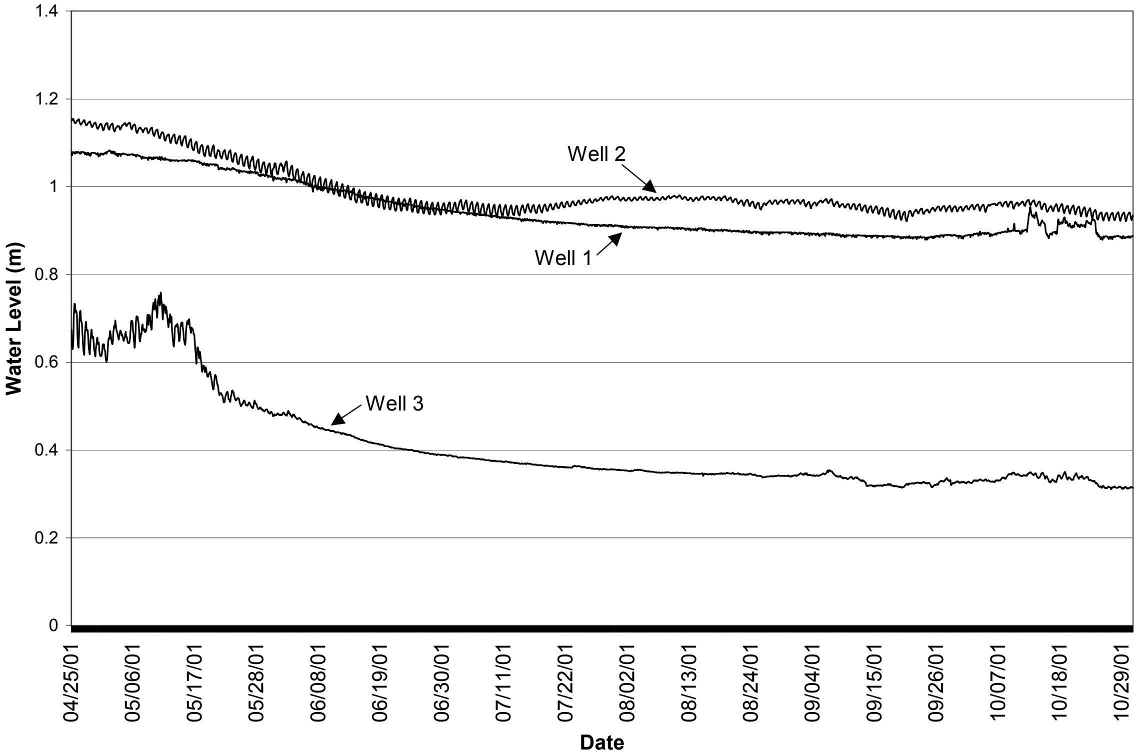

Fig. 25. 2001 growing season water levels at the Colorado location.

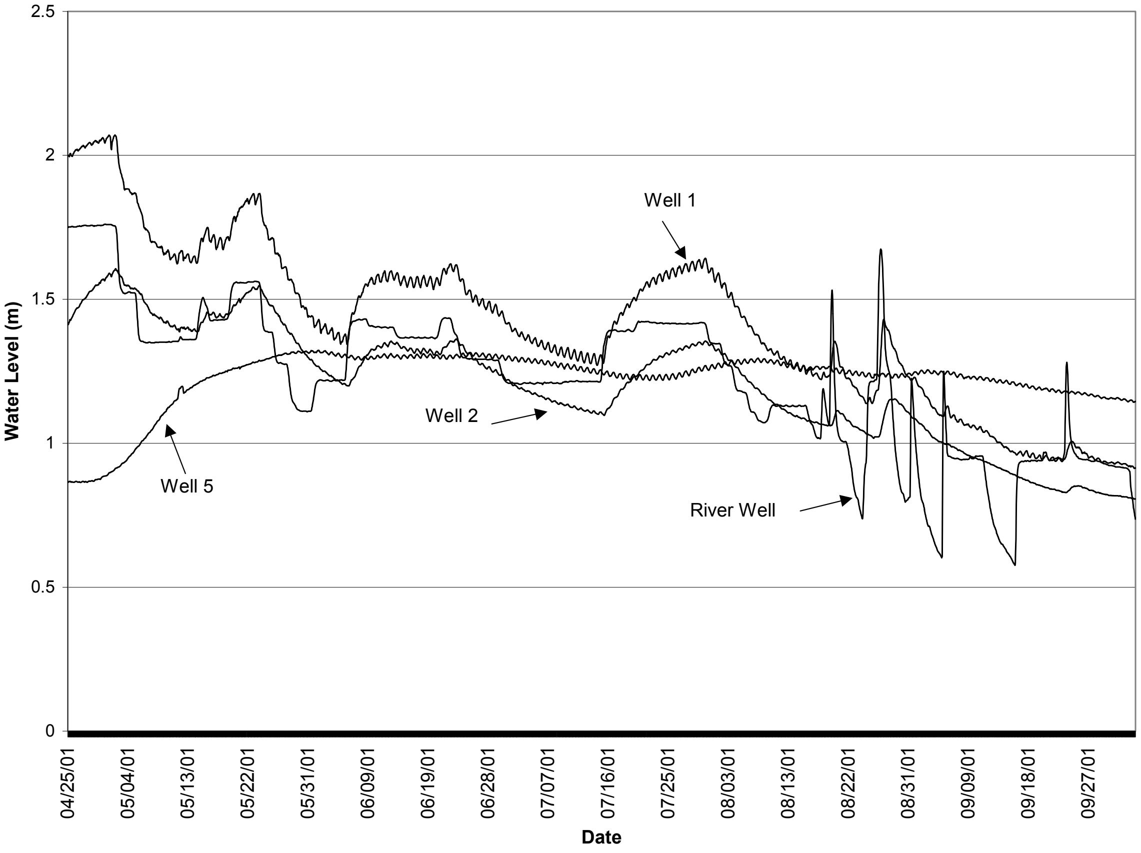

Fig. 26. 2001 Growing season water levels Pecos location Site A.

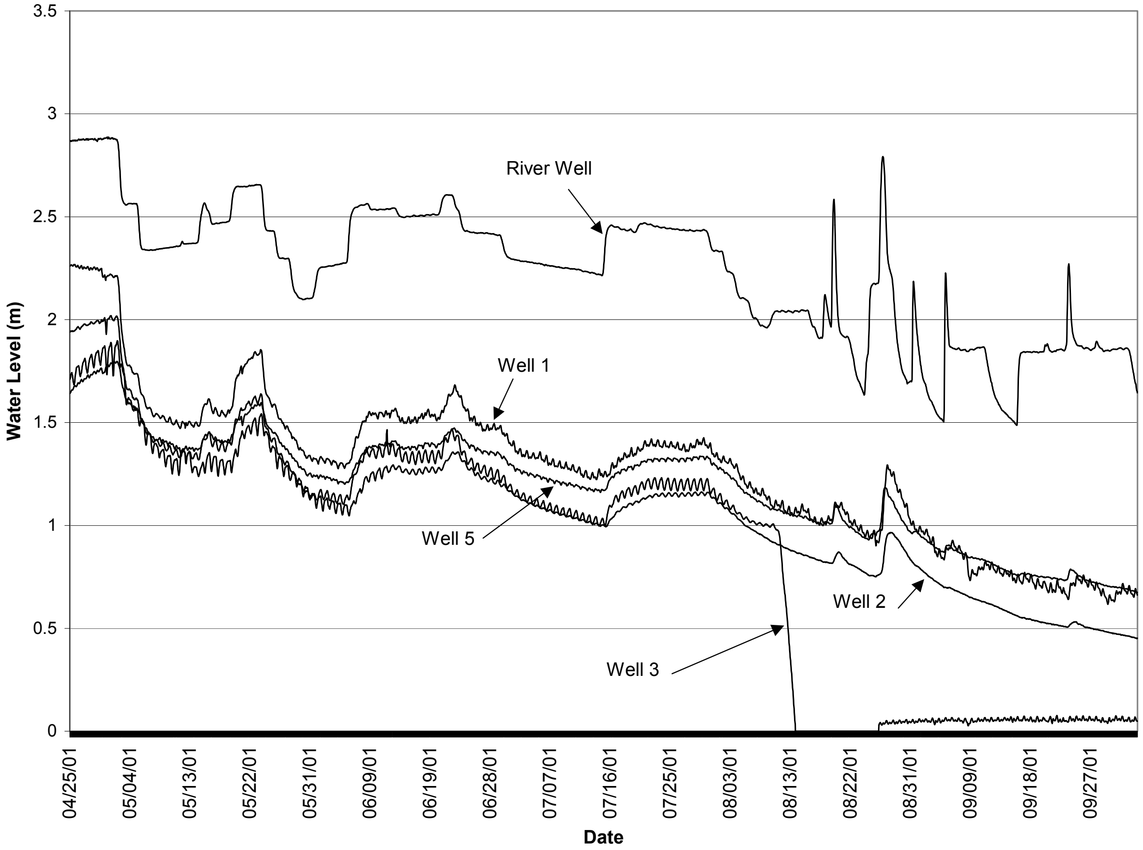

Fig. 27. 2001 Growing season water levels for Pecos location Site B.

Colorado Location

A significant correlation ($p<0.05$) resulted when comparing hourly water level fluctuations between Wells 1 and 2 during the 2000 growing season (Table 29) and between Wells 1, 2 and 3 during the 2001 growing season (Table 30). However, the correlation between Wells 1 and 2 was lower in 2001. The area surrounding Well 1 was herbicide treated in August 2000 and a 49% mortality of saltcedar was observed in 2001. Well 3 was not operational in 2000.

Table 29. Coefficient of determination (R^2) for hourly water level fluctuations at the Colorado location during the 2000 growing season (5/1/00-10/5/00).

	Well 1	Well 2
Well 1	1	.95
Well 2		1

Table 30. Coefficient of determination (R^2) for hourly water level fluctuations at the Colorado location during the 2001 growing season (4/25/01-10/30/01)

	Well 1	Well 2	Well 3
Well 1	1	.84	.91
Well 2		1	.91
Well 3			1

Pecos Location

A significant correlation resulted when comparing hourly water level fluctuations for Sites A and B during the 2001 growing season (Table 31). However, Well 5 at Site A was poorly correlated to the wells at Site A and B. Well 5 at Site A had only gradual changes due to distance from the river and clay water bearing strata (Fig. 26). The other wells at Site A and B all responded with river level fluctuations (Figs. 26 and 27).

Table 31. Coefficient of determination (R^2) for hourly water level fluctuations at the Pecos location Sites A and B during the 2001 growing season (4/25 - 10/4, 2001).

		Site A				Site B				
		River	Well 1	Well 2	Well 5	River	Well 1	Well 2	Well 3	Well 5
Site A	River	1	0.80	0.70	0.10	0.97	0.80	0.77	0.78	0.81
	Well 1		1	0.96	0.11	0.77	0.95	0.96	0.86	0.96
	Well 2			1	0.04	0.69	0.88	0.93	0.85	0.94
	Well 5				1	0.06	0.12	0.10	0.04	0.06
Site B	River					1	0.81	0.80	0.80	0.83
	Well 1						1	0.98	0.88	0.97
	Well 2							1	0.90	0.98
	Well 3								1	0.92
	Well 4									1

Conclusions

The water level fluctuations in Wells 2, 3, and 4 at the Canadian location were very similar. This suggested that the wells were responding similarly to the surrounding environment. The groundwater level at this location was close to the soil surface, at times within 0.30 meters from the soil surface.

The water level fluctuations at the Colorado location in 2000 were very similar for Wells 1 and 2 in 2000. However, the correlation was not as strong in 2001. This was attributed to the area around Well 1 being sprayed at the end of the 2000 growing season. The groundwater level at the Colorado location was the lowest of all the study sites. It was at least 5.49 meters below the soil surface.

The analysis of the groundwater fluctuations at Sites A and B at the Pecos location showed a strong correlation between wells at a site and between sites (Table 31). However, Well 5 at Site A did not have a good correlation with any of the other wells at Site A or Site B. This seems to be due to the fact that Well 5 at Site A was located on the other side of an old oxbow in the Pecos River. Apparently, this has cut Well 5 off from the influence of the river and the groundwater associated with it. Perhaps the groundwater was moving parallel to the river through this abandoned oxbow. Additionally, the groundwater at Well 5 Site A had the highest salinity levels (among all wells at Site A and B) in May and November 2002 (personal communication L.D. White, September 2002). These factors may help explain why Well 5 does not have very good correlation with the other wells at Site A or Site B.

Another interesting phenomenon was that the River Well at Site A had better correlation with the wells located at Site B. This was attributed to the fact that there was a diversion dam located just south of Site A. Evidently, this was backing up the water, which increased the groundwater levels in the riparian zone, and influenced the wells at Site B. The groundwater level at this location ranged from 0.30 meters under the soil surface to 3.35 meters below the soil surface. The groundwater fluctuations at each site had strong correlation between wells except for Site A Well 5 at the Pecos location. The Canadian location had the highest water table and the Colorado location had the lowest.

WATER USE BY SALTCEDAR AND ASSOCIATED VEGETATION

Results and Discussion

Canadian Location – Draw Down Recharge Method

Estimated water use for the Canadian location was similar for Wells 3 and 4 (slough), but lower for Well 2 (upland) (Table 32). Average daily water use at each well was highest in June and July and became lower in August and September. The stomatal resistance and high air temperatures in August and September appeared to cause the low daily water use. The lowest daily water use occurred in April and October.

Table 32. Estimated monthly and daily water use (meters) and standard deviation (STD) Canadian Location 2001.

Month	Well 2		Well 3		Well 4		Monthly Average (STD)
	Month	Day	Month	Day	Month	Day	
April (6 days)	0.0773	0.0129	0.0477	0.0080	0.1225	0.0204	0.0825 (0.0376)
May (31 days)	0.4972	0.0160	0.7056	0.0228	0.7192	0.0232	0.6407 (0.1244)
June (30 days)	0.6453	0.0215	1.1371	0.0379	1.0693	0.0356	0.9507 (0.2664)
July (31 days)	0.6435	0.0208	1.1037	0.0356	1.1709	0.0378	0.9726 (0.2871)
August (31 days)	0.3856	0.1244	0.7226	0.0233	0.6546	0.0211	0.5877 (0.1783)
September (30 days)	0.3146	0.0105	0.4609	0.0154	0.4683	0.0156	0.4145 (0.0866)
October (4 days)	0.0250	0.0062	0.0397	0.0099	0.0604	0.0151	0.0417 (0.0178)
Total	2.5885		4.2173		4.2650		3.6911 (0.9540)

Colorado Location – Draw Down Recharge Method

Estimated water use at Wells 1 and 2 at the Colorado location were different in 2000 (Table 33). The estimated water uses in 2001 were lower for Wells 1 and 3, but higher for Well 2 (Table 34). Well 2 had the highest estimated water use in 2000 and 2001. All wells had higher water use estimates in 2001 because the growing season was longer by 31 days.

The average daily water use at Wells 1 and 2, and 3 did not show evidence of seasonal changes as observed at the Canadian location during the 2001 growing season. During the 2001 growing season average daily water use at Wells 1 and 3 decreased after May. This suggested that the herbicide activity reduced the foliage after the plants attempted leaf out in the spring. The drift from the herbicide application also resulted in canopy reduction at Well 2.

Table 33. Estimated monthly and daily water use (meters) and standard deviation (STD)-Colorado Location 2000.

Month	Well 1		Well 2		Average (standard deviation)
	Month	Day	Month	Day	
May (31 days)	0.0591	0.0019	0.1891	0.0061	0.1241 (0.0920)
June (30 days)	0.0493	0.0016	0.1059	0.0035	0.0776 (0.0400)
July (31 days)	0.0536	0.0017	0.1275	0.0041	0.0905 (0.0521)
August (31 days)	0.0516	0.0017	0.1707	0.0055	0.1113 (0.0841)
September (30 days)	0.0480	0.0016	0.1613	0.0054	0.1045 (0.0802)
October (5 days)	0.0099	0.0020	0.0276	0.0055	0.0187 (0.0125)
Total	0.2715		0.7822		0.5270 (0.3612)

Table 34. Estimated monthly and daily water use (meters)-Colorado Location 2001*.

Month	Well 1		Well 2		Well 3	
	Month	Day	Month	Day	Month	Day
April (6 days)	0.0195	0.0033	0.0194	0.0032	0.0323	0.0054
May (31 days)	0.0709	0.0023	0.1772	0.0057	0.1198	0.0039
June (30 days)	0.0449	0.0015	0.2336	0.0078	0.0114	0.0004
July (31 days)	0.0337	0.0011	0.1347	0.0043	0.0088	0.0003
August (31 days)	0.0314	0.0010	0.0710	0.0023	0.0069	0.0002
September (30 days)	0.0343	0.0011	0.1005	0.0033	0.0203	0.0007
October (30 days)	0.0694	0.0023	0.1161	0.0039	0.0214	0.0007
Total	0.3041		0.8524		0.2209	

*Monthly average and standard deviation not computed because the area around Well 1 and part of the area around Well 3 were treated with herbicide at the end of the growing season in 2000.

Pecos Location – Draw Down Recharge Method

Estimated water uses for the 2001 growing season at the Pecos location at Site A Well 1 (Table 35) and Site B Wells 1, 2, and 3 (Table 36) were similar. Wells 1 and 3 were located in the riparian zone and Well 2 was located at the edge of the riparian zone. Well 5 at Sites A and B, located in the upland with only native vegetation, had the lowest estimated water use for this location. Well 2 at Site A had a much lower estimated water use than the other wells located in and at the edge of the saltcedar zone.

Table 35. Estimated monthly and daily water use (meters) and standard deviation (STD)-Pecos Location Site A 2001.

Month	Well 1		Well 2		Well 3*		Well 5		Monthly Average (standard deviation)**
	Month	Day	Month	Day	Month	Day	Month	Day	
April (6 days)	0.0693	0.0115	0.0186	0.0031			0.0002	0.0000	0.0439 (0.0358)
May (31 days)	0.6482	0.0209	0.2407	0.0078			0.0014	0.0000	0.4444 (0.2880)
June (30 days)	0.6910	0.0230	0.2462	0.0082			0.0080	0.0003	0.4688 (0.3146)
July (31 days)	0.7082	0.0228	0.1907	0.0062			0.0104	0.0003	0.4496 (0.3661)
Aug. (31 days)	0.5458	0.0176	0.1377	0.0044			0.0088	0.0003	0.3417 (0.2886)
Sept. (30 days)	0.2765	0.0092	0.0794	0.0026			0.0065	0.0002	0.1780 (0.1393)
Oct. (4 days)	0.0206	0.0052	0.0052	0.0013			0.0006	0.0001	0.0129 (0.0109)
Total	2.9596		0.9185				0.0358		1.9385 (1.4448)

*No data for Well 3, ** does not include Well 5

Table 36. Estimated monthly and daily water use (meters) and standard deviation (STD)-Pecos Location Site B 2001.

Month	Well 1		Well 2		Well 3		Well 5		Monthly Average (standard deviation)*
	Month	Day	Month	Day	Month	Day	Month	Day	
April (6 days)	0.0464	0.0077	0.3076	0.0513	0.0758	0.0126	0.0020	0.0003	0.4700 (0.1433)
May (31 days)	0.5533	0.0178	1.3805	0.0445	0.6603	0.0213	0.0209	0.0007	0.8647 (0.4499)
June (30 days)	0.2825	0.0094	0.6494	0.0216	0.9097	0.0303	0.0305	0.0010	0.6139 (0.3152)
July (31 days)	0.4153	0.0134	0.2102	0.0068	0.8497	0.0274	0.0261	0.0008	0.4916 (0.3264)
Aug. (31 days)	0.6105	0.0197	0.0903	0.0029	0.2840	0.0092	0.0359	0.0012	0.3283 (0.2630)
Sept. (30 days)	0.6444	0.0215	0.0905	0.0030	0.1078	0.0036	0.0122	0.0004	0.2810 (0.3149)
Oct. (4 days)	0.0794	0.0199	0.0149	0.0037	0.0307	0.0077	0.0007	0.0002	0.0417 (0.0336)
Total	2.6317		2.7434		2.9180		0.1282		2.7642 (0.1442)

* Does not include Well 5

EPA Paired Plot Technique

Study design and applied treatments at the Colorado location enabled evaluation of further methods to estimate water use. A regression analysis was run on the smoothed data for Well 1 and Well 2 groundwater levels for May 1, 2000 through October 5, 2000. The regression equation was then used to predict what Well 1 water levels should have been in 2001 if the area had not been sprayed. The regression equation was Well 1 = 0.533 + 0.753 Well 2. The actual values minus the predicted values indicated that the average daily water table levels during the growing season were 0.0396 meters higher in 2001 than they would have been if the area had not been treated (Fig. 28). The regression predicted daily water levels for Well 1 were used in the Draw Down

Recharge Method to determine what the daily water use would have been if the treatment had not been applied (Fig. 29). The actual average daily water use was 0.0014 m and the predicted average daily water use was 0.0036 m. The difference of 0.0022 m/day was water "saved" due to treatment. The growing season total for actual water use was 0.1679 m and the predicted growing season water use was 0.5722 m, a savings of approximately 0.4043 m.

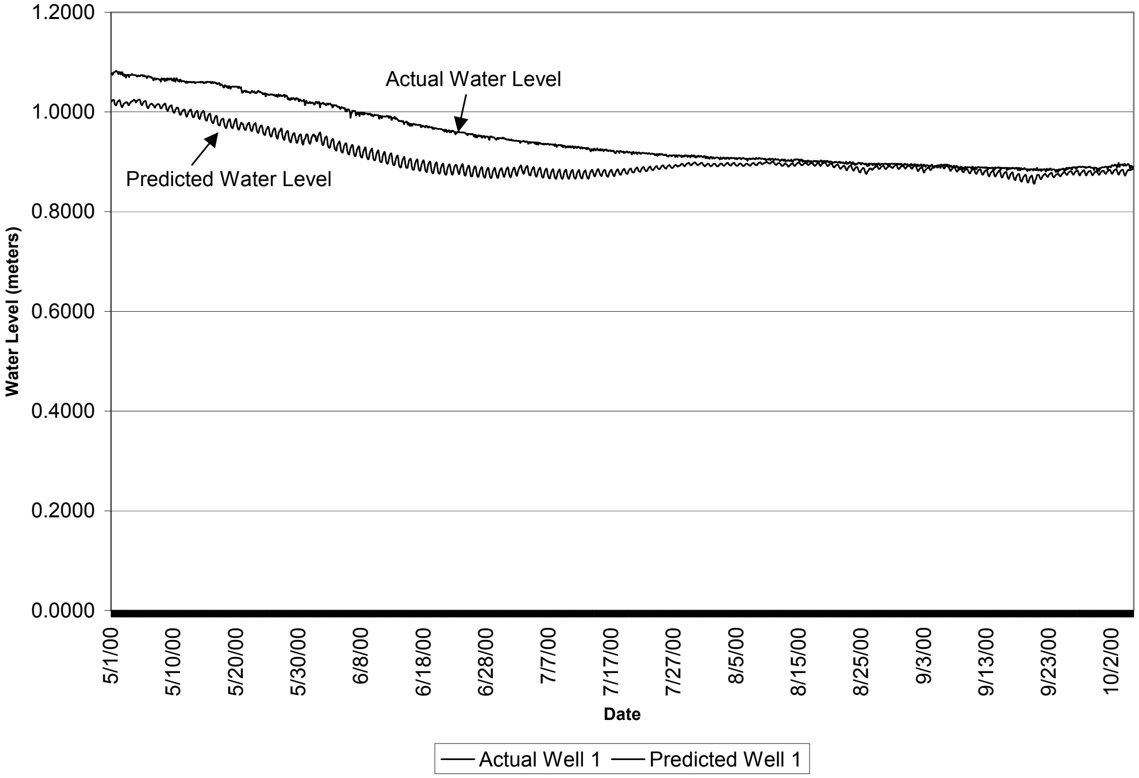

Fig. 28. Regression predicted water levels (based on 5/1 - 10/5, 2000 data) and actual water levels for Well 1 Colorado location (5/1 - 10/5, 2001).

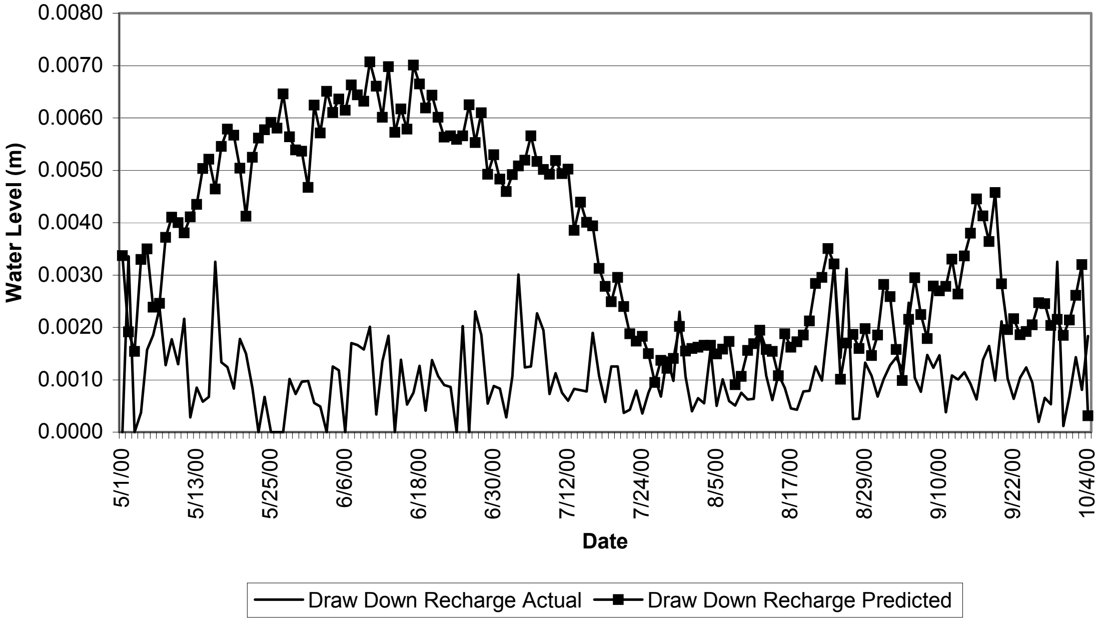

Fig. 29. Estimated daily water use by the Draw Down Recharge Method on actual and predicted data for Well 1 at the Colorado location (5/1 -10/5, 2001).

Potential Evapotranspiration

Daily potential evapotranspiration (PET) data was obtained from a weather station located in Sweetwater, Texas that was approximately 80 kilometers from the Colorado location. The PET was calculated using the Penman-Monteith method. The daily water use results from Well 2 at the Colorado location for April 25, 2001 through October 30, 2001 were compared to the PET data for the same day. A regression/correlation analysis was performed for the same day, for one day prior and one day past (i.e. estimated water use always began on 4/25 and PET began on 4/24, 4/25, and 4/26) for the PET data. This was done to see if there was any lag effect. The results of this analysis were R^2 of 0.33, R^2 of 0.23, and R^2 of 0.16 for one day prior, same day, and one day past respectively.

Draw Down Recharge Method - With Modified Recharge Rate

Considering White's (1932) argument on recharge rate, a modification was made to Method 4 to evaluate the use of (*r*) calculated as the recharge rate for 4 hours preceding the current days high. However, in Method 6 the recharge rate was calculated from 12:00 a.m. to 4:00 p.m.

Water levels for June 2001 Well 2 at the Colorado location were used to calculate water use with the new recharge rate. Results showed the original Method 4 water use to be 0.2336 m compared to 0.1940 m for June 2001 using "White's" (*r*) concept. The calculated recharge rate was lower than the original Draw Down Recharge Method calculation. This analysis was conducted to determine how changing the recharge rate would affect water use estimates.

Conclusions

The estimated water use at the Canadian location was different between wells. Well 3 and 4 had similar water uses that were both greater than Well 2. Data suggest this was a result of Wells 3 and 4 being located in a slough with dense vegetation. Wells 3 and 4 at the Canadian location had the highest water uses of all wells and all locations. Probably due to the shallow water table and dense understory/overstory vegetation.

Well 2 had the highest water use at the Colorado location in 2000 and 2001. The water use declined between years (May - September 2000 and 2001) for Wells 1 and 2 at this location. This was believed to be the result of the herbicide application, which killed approximately 49% of the saltcedar plants around Well 1. The Colorado location had the lowest estimated water use among the three study locations due to the depth to the water table, young saltcedar, and low specific yield.

The estimated water use for the wells at the Pecos location were similar for Site A Well 1 and Site B Wells 1, 2, and 3. However, Well 5 at both Sites A and B had much lower water use estimates, and Well 2 Site B had a much higher water use estimate than Well 2 at Site A. Well 5 at both sites was much lower because the wells were located in the upland and had low specific yields, surrounded by mesquite and fourwing saltbush, and had a greater depth to the water table. The difference in the water use estimates between Well 2 at both sites could not be determined.

The daily water use estimates for all wells at all locations are lower at the beginning of the growing season and increase until August, at which time they begin to decline. This suggests that the saltcedar is not using as much water when the temperatures begin to rise in the summer. Van Hylckama (1969) found that saltcedar was temperature sensitive and reduced its water use on hot afternoons. Anderson (1977) found that the optimum leaf temperatures for saltcedar photosynthesis were between 23° and 28°C, and that stomatal resistance in saltcedar increased as leaf temperatures increased between 14° and 50°C.

The EPA Method was used to determine if there was a difference in water levels at Well 1 at the Colorado location after applying a herbicide treatment. The daily water levels were higher in Well 1 the year following herbicide application. This was attributed to the fact that the saltcedar was no longer using as much water after being treated.

The predicted data from the EPA method was used in the Draw Down Recharge Method to determine if there was a difference in estimated water use between the actual and predicted water levels at Well 1 at the Colorado location. The data suggests that the actual growing season water use was 0.2162 meters and the predicted water use would have been 0.5722 meters. This suggests that the herbicide treatment lowered the water use at Well 1 by 0.3560 meters.

The PET investigation did not show a strong correlation between estimated daily water use and weather station data. This was probably due to the fact that the weather station data was obtained from a location a considerable distance from the study location.

The modified Draw Down Recharge Method study was done to determine if the method for calculating recharge, described by Walter N. White (1932), was "better" than the recharge rate calculation in the Draw Down Recharge Method. The results showed that the estimated water use would be lower using the White (1932) method of calculating recharge. This is logical because the recharge rate in the modified Draw Down Recharge Method was calculated at the top of the diurnal curve when recharge rates were lower, further confirming that the original Draw Down Recharge Method was probably the "best" approach to date. This evaluation of recharge rate calculation helped identify Draw Down Recharge Method as the "best" calculation method because the recharge rate in the Draw Down Recharge Method was calculated from the low to the next high water level; thus, giving a better estimate of water use for these systems. Therefore White's (1932) recharge rate estimate does not reflect the average recharge rate while transpiration is occurring and this method would be too conservative under the conditions of this study.

CONCLUSIONS

This study sought to determine the "best" method for estimating water use by saltcedar and associated vegetation based on daily diurnal groundwater table fluctuations. Seven methods were investigated and the Draw Down Recharge Method 4 was chosen as the "best" method for the situations at the study locations. However, when the groundwater table fluctuated rapidly in the riparian areas none of the methods evaluated worked for estimating water use.

Several factors (depth to the water table, vegetative characteristics, soil texture, and specific yield) also affected the estimated water use at each location. For example, at the Colorado location, water use was apparently limited due to the low specific yield and the depth to the groundwater table as well as the fact that the plants were young growth saltcedar. Where as at the Canadian and Pecos locations water use was much higher because the water table was close to the soil surface and the specific yield was higher than the Colorado location. The vegetation at the Canadian (Wells 3 and 4) and Pecos (Wells 1, 2, and 3) locations consisted of old growth woody plants resulting in higher water use estimates than the Colorado location which consisted of young growth saltcedar. A dense herbaceous understory at the Canadian location also influenced the water use at this location.

The average daily water use at the Canadian and Pecos locations were higher in the early summer months and declined in late summer. This showed that if the plant water use were only investigated during the high daily water use days (early summer) and extrapolated for the entire growing season the water use for the growing season would be greatly over estimated or vice versa if measurements were taken in August and October.

The Environmental Protection Agency's Paired Plot Method appears to be another option for determining the amount of water used by saltcedar, however only one location was evaluated with this method in this study. The results indicated a savings of approximately 0.4043 m of water at the Colorado location.

The investigation into whether or not potential evapotranspiration could be used to estimate saltcedar water use was inconclusive. The relationship between these might be better evaluated if a weather station was installed at each study location.

By comparing the water use results for saltcedar presented in (Table 1) to the 163 day growing season at the Canadian (3.6911 m) and Pecos (2.4344 m) locations the water use estimates by the Draw Down Recharge Method were higher than all of those presented in the literature for the Canadian location and only two were higher than the Pecos location.

The results of this study indicate that groundwater monitoring wells are an inexpensive way to determine water use by saltcedar and associated vegetation by both the Draw Down Recharge Method and the EPA Paired Plot Method. However, this study was conducted for only one growing season at the Canadian and Pecos locations and for two growing seasons at the Colorado location. Continued monitoring of the wells would produce long term data sets that will differ from year to year based on local environmental changes.

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APPENDIX A

Table 37. Ground cover percent composition for Well 2-Canadian location.

Cover Class	Well 2 North Transect		Well 2 South Transect		Well 2 East Transect		Well 2 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	65.00	75.00	50.00	45.00	25.00	50.00	65.00	40.00
Litter	5.00	20.00	40.00	50.00	50.00	30.00	20.00	45.00
Grass	25.00	5.00	10.00	5.00	25.00	20.00	15.00	15.00
Woody	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Forb	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 38. Ground cover percent composition for Well 3-Canadian location.

Cover Class	Well 3 North Transect		Well 3 South Transect		Well 3 East Transect		Well 3 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	40.00	40.00	20.00	30.00	5.00	30.00	10.00	20.00
Litter	45.00	55.00	75.00	70.00	95.00	65.00	85.00	70.00
Grass	10.00	0.0	5.00	0.0	0.0	5.00	5.00	10.00
Woody	5.00	5.00	0.0	0.0	0.0	0.0	0.0	0.0
Forb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 39. Ground cover percent composition for Well 4-Canadian location.

Cover Class	Well 4 North Transect		Well 4 South Transect		Well 4 East Transect		Well 4 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	30.00	15.00	30.00	25.00	30.00	15.00	45.00	15.00
Litter	70.00	80.00	65.00	70.00	60.00	80.00	55.00	85.00
Grass	0.0	5.00	5.00	5.00	0.0	0.0	0.0	0.0
Woody	0.0	0.0	0.0	0.0	10.00	5.00	0.0	0.0
Forb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 40. Nearest neighbor percent composition for Well 2-Canadian location.

Cover Class	Well 2 North Transect		Well 2 South Transect		Well 2 East Transect		Well 2 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	75.00	50.00	80.00	80.00	90.00	95.00	90.00	75.00
Woody	5.00	0.0	0.0	5.00	0.0	0.0	0.0	5.00
Forb	20.00	50.00	20.00	15.00	10.00	5.00	10.00	20.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 41. Nearest neighbor percent composition for Well 3-Canadian location.

Cover Class	Well 3 North Transect		Well 3 South Transect		Well 3 East Transect		Well 3 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	70.00	50.00	90.00	80.00	100.00	65.00	95.00	100.00
Woody	15.00	25.00	0.0	0.0	0.0	5.00	5.00	0.0
Forb	15.00	25.00	10.00	20.00	0.0	30.00	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 42. Nearest neighbor percent composition for Well 4-Canadian location.

Cover Class	Well 4 North Transect		Well 4 South Transect		Well 4 East Transect		Well 4 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	90.00	100.00	75.00	80.00	70.00	75.00	75.00	60.00
Woody	0.0	0.0	10.00	15.00	25.00	5.00	10.00	15.00
Forb	10.00	0.0	15.00	5.00	5.00	20.00	15.00	25.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 43. Number of woody plants per acre at the Canadian location.

	North Transect		South Transect		East Transect		West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Well 2	11943	10707	7001	4942	413	1236	10707	11533
Well 3	4942	3294	9062	3707	5765	4119	7413	5765
Well 4	7826	3294	4530	2471	3294	2471	4119	2058

Table 44. Ground cover percent composition for Well 1-Colorado location.

Cover Class	Well 1 North Transect		Well 1 South Transect		Well 1 East Transect		Well 1 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	52.63	65.00	45.00	50.00	44.44	50.00	60.00	65.00
Litter	42.11	35.00	45.00	50.00	44.44	45.00	40.00	35.00
Grass	0.0	0.0	10.00	0.0	5.55	5.00	0.0	0.0
Woody	5.26	0.0	0.0	0.0	5.55	0.0	0.0	0.0
Forb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	99.98	100.00	100.00	100.00

Table 45. Ground cover percent composition for Well 2-Colorado location.

Cover Class	Well 2 North Transect		Well 2 South Transect		Well 2 East Transect		Well 2 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	35.00	45.00	40.00	40.00	45.00	50.00	35.00	25.00
Litter	65.00	50.00	45.00	60.00	55.00	50.00	60.00	75.00
Grass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Woody	0.0	5.00	10.00	0.0	0.0	0.0	5.00	0.0
Forb	0.0	0.0	5.00	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 46. Ground cover percent composition for Well 3-Colorado location.

Cover Class	Well 3 North Transect		Well 3 South Transect		Well 3 East Transect		Well 3 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Bareground	60.00	85.00	60.00	85.00	50.00	65.00	65.00	70.00
Litter	35.00	5.00	30.00	15.00	35.00	30.00	35.00	30.00
Grass	0.0	5.00	10.00	0.0	10.00	5.00	0.0	0.0
Woody	0.0	5.00	0.0	0.0	5.00	0.0	0.0	0.0
Forb	5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 47. Nearest neighbor percent composition for Well 1-Colorado location.

Cover Class	Well 1 North Transect		Well 1 South Transect		Well 1 East Transect		Well 1 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	26.32	75.00	80.00	85.00	83.32	80.00	60.00	70.00
Woody	21.05	25.00	15.00	15.00	16.66	20.00	15.00	30.00
Forb	52.63	0.0	5.00	0.0	0.0	0.0	25.00	0.0
Total	100.00	100.00	100.00	100.00	99.98	100.00	100.00	100.00

Table 48. Nearest neighbor percent composition for Well 2-Colorado location.

Cover Class	Well 2 North Transect		Well 2 South Transect		Well 2 East Transect		Well 2 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	10.00	0.0	0.0	0.0	10.00	0.0	5.00	0.0
Woody	75.00	100.00	60.00	100.00	75.00	100.00	60.00	100.00
Forb	15.00	0.0	40.00	0.0	15.00	0.0	35.00	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 49. Nearest neighbor percent composition for Well 3-Colorado location.

Cover Class	Well 2 North Transect		Well 2 South Transect		Well 2 East Transect		Well 2 West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Grass	35.00	85.00	65.00	85.00	75.00	80.00	55.00	65.00
Woody	10.00	10.00	0.0	15.00	10.00	20.00	25.00	35.00
Forb	55.00	5.00	35.00	0.0	15.00	0.0	20.00	0.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 50. Number of woody plants per acre at the Colorado location.

	North Transect		South Transect		East Transect		West Transect	
Year	2000	2001	2000	2001	2000	2001	2000	2001
Well 1	2884	4530	12356	11943	6178	4942	17710	21417
Well 2	20594	18533	7824	7826	10297	13591	11943	9884
Well 3	1648	2058	6178	8649	10707	17298	11120	16062

Table 51. Ground cover percent composition for Site A-Pecos location.

Cover Class	Well 1		Well 2		Well 3	
Year	2000	2001	2000	2001	2000	2001
Bareground	9.52	5.26	7.41	24.00	34.38	27.59
Litter	85.71	89.47	77.77	56.00	62.5	72.41
Grass	0.0	0.0	11.11	16.00	3.12	0.0
Woody	0.0	5.26	3.70	4.00	0.0	0.0
Forb	4.76	0.0	0.0	0.0	0.0	0.0
Total	99.99	99.99	99.99	100.00	100.00	100.00

Table 52. Nearest neighbor percent composition for Site A-Pecos location.

Cover Class	Well 1		Well 2		Well 3	
Year	2000	2001	2000	2001	2000	2001
Grass	38.09	5.26	55.55	72.00	71.89	58.80
Woody	28.57	68.42	25.92	24.00	18.75	37.93
Forb	33.33	26.32	18.50	4.00	9.39	3.45
Total	99.99	100.00	99.97	100.00	100.03	100.18

Table 53. Ground cover percent composition for Site B-Pecos location.

Cover Class	Well 1		Well 2		Well 3	
Year	2000	2001	2000	2001	2000	2001
Bareground	40.74	24.00	62.50	51.72	65.22	28.57
Litter	25.93	72.00	34.38	48.28	30.43	71.43
Grass	33.33	4.00	3.13	0.0	0.0	0.0
Woody	0.0	0.0	0.0	0.0	4.35	0.0
Forb	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.00	100.00	100.01	100.00	100.00	100.00

Table 54. Nearest neighbor percent composition for Site B-Pecos location.

Cover Class	Well 1		Well 2		Well 3	
Year	2000	2001	2000	2001	2000	2001
Grass	77.77	68.00	75.02	24.14	69.56	52.38
Woody	3.70	12.00	18.75	48.28	17.40	33.34
Forb	18.52	20.00	6.26	27.59	13.05	14.28
Total	99.99	100.00	100.03	100.01	100.01	100.00

APPENDIX B

Pecos Location

```
The regression equation is
Pecos River A = 0.383 + 0.783 Pecos W1 A

Predictor       Coef      StDev        T       P
Constant     0.38348     0.02976      12.89    0.000
Pecos W1     0.783070    0.006276     124.77    0.000

S = 0.3687     R-Sq = 79.9%     R-Sq(adj) = 79.9%

The regression equation is
Pecos River A = 0.0072 + 1.02 Pecos W2 A

Predictor       Coef      StDev        T       P
Constant     0.00717     0.04279       0.17    0.867
Pecos W2      1.01550     0.01067      95.21    0.000

S = 0.4518     R-Sq = 69.9%     R-Sq(adj) = 69.9%

The regression equation is
Pecos River A = 7.05 - 0.754 Pecos W5 A

Predictor       Coef      StDev        T       P
Constant      7.0512      0.1500      47.00    0.000
Pecos W5     -0.75370     0.03722     -20.25    0.000

S = 0.7829     R-Sq = 9.5%      R-Sq(adj) = 9.5%

The regression equation is
Pecos River A = - 1.61 + 0.769 Pecos River B

Predictor       Coef      StDev        T       P
Constant    -1.61303     0.01479    -109.07    0.000
Pecos Ri    0.768823    0.001997     385.04    0.000

S = 0.1319     R-Sq = 97.4%     R-Sq(adj) = 97.4%
```

```
The regression equation is
Pecos River A = 1.48 + 0.601 Pecos W1 B

Predictor      Coef      StDev        T       P
Constant     1.48359     0.02149     69.05    0.000
Pecos W1     0.600913    0.004884     123.03    0.000

S = 0.3729     R-Sq = 79.5%     R-Sq(adj) = 79.5%

The regression equation is
Pecos River A = 1.71 + 0.666 Pecos W2 B

Predictor      Coef      StDev        T       P
Constant     1.71411     0.02128     80.56    0.000
Pecos W2     0.666309    0.005861     113.69    0.000

S = 0.3966     R-Sq = 76.8%     R-Sq(adj) = 76.8%

The regression equation is
Pecos River A = 2.88 + 0.375 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor      Coef      StDev        T       P
Constant     2.88073     0.01249    230.60    0.000
Pecos W3     0.375490    0.003363     111.67    0.000

S = 0.3924     R-Sq = 77.6%     R-Sq(adj) = 77.6%

The regression equation is
Pecos River A = 0.731 + 0.837 Pecos W5 B

Predictor      Coef      StDev        T       P
Constant     0.73110     0.02577     28.37    0.000
Pecos W5     0.837472    0.006395     130.95    0.000

S = 0.3546     R-Sq = 81.4%     R-Sq(adj) = 81.4%
```

```
The regression equation is
Pecos W1 A = - 0.731 + 1.36 Pecos W2 A

Predictor       Coef      StDev        T       P
Constant    -0.73051    0.01748   -41.78   0.000
Pecos W2     1.36002    0.00436   312.11   0.000

S = 0.1846     R-Sq = 96.1%     R-Sq(adj) = 96.1%

The regression equation is
Pecos W1 A = 8.40 - 0.934 Pecos W5 A

Predictor       Coef      StDev        T       P
Constant      8.3991     0.1697    49.50   0.000
Pecos W5    -0.93367    0.04209   -22.18   0.000

S = 0.8855     R-Sq = 11.2%     R-Sq(adj) = 11.2%

The regression equation is
Pecos W1 A = - 1.09 + 0.783 Pecos River B

Predictor       Coef      StDev        T       P
Constant    -1.08889    0.05003   -21.77   0.000
Pecos Ri    0.782558   0.006754   115.86   0.000

S = 0.4462     R-Sq = 77.4%     R-Sq(adj) = 77.4%

The regression equation is
Pecos W1 A = 1.49 + 0.748 Pecos W1 B

Predictor       Coef      StDev        T       P
Constant     1.48504    0.01261   117.78   0.000
Pecos W1    0.748411   0.002866   261.11   0.000

S = 0.2188     R-Sq = 94.6%     R-Sq(adj) = 94.6%

The regression equation is
Pecos W1 A = 1.70 + 0.851 Pecos W2 B

Predictor       Coef      StDev        T       P
Constant     1.69763    0.00988   171.91   0.000
Pecos W2    0.851357   0.002720   313.00   0.000

S = 0.1841     R-Sq = 96.2%     R-Sq(adj) = 96.2%
```

```
The regression equation is
Pecos W1 A = 3.25 + 0.458 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor       Coef      StDev         T       P
Constant     3.24982     0.01137     285.74    0.000
Pecos W3     0.458078    0.003061     149.64    0.000

S = 0.3572      R-Sq = 86.1%     R-Sq(adj) = 86.1%

The regression equation is
Pecos W1 A = 0.563 + 1.04 Pecos W5 B

Predictor       Coef      StDev         T       P
Constant     0.56327     0.01334      42.22    0.000
Pecos W5      1.03911     0.00331     313.84    0.000

S = 0.1836      R-Sq = 96.2%     R-Sq(adj) = 96.2%

The regression equation is
Pecos W2 A = 5.64 - 0.420 Pecos W5 A

Predictor       Coef      StDev         T       P
Constant      5.6411      0.1270      44.43    0.000
Pecos W5     -0.41975     0.03149     -13.33    0.000

S = 0.6625      R-Sq = 4.3%      R-Sq(adj) = 4.3%

The regression equation is
Pecos W2 A = 0.0577 + 0.532 Pecos River B

Predictor       Coef      StDev         T       P
Constant     0.05767     0.04245       1.36    0.174
Pecos Ri    0.531589    0.005731      92.75    0.000

S = 0.3786      R-Sq = 68.8%     R-Sq(adj) = 68.7%
```

```
The regression equation is
Pecos W2 A = 1.75 + 0.522 Pecos W1 B

Predictor      Coef      StDev        T       P
Constant     1.74958    0.01327    131.84   0.000
Pecos W1     0.521774   0.003017    172.96   0.000

S = 0.2303     R-Sq = 88.4%    R-Sq(adj) = 88.4%

The regression equation is
Pecos W2 A = 1.86 + 0.605 Pecos W2 B

Predictor      Coef      StDev        T       P
Constant     1.85831    0.00933    199.18   0.000
Pecos W2     0.604941   0.002570    235.41   0.000

S = 0.1739     R-Sq = 93.4%    R-Sq(adj) = 93.4%

The regression equation is
Pecos W2 A = 2.95 + 0.328 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor      Coef      StDev        T       P
Constant     2.95467    0.00858    344.33   0.000
Pecos W3     0.327855   0.002310    141.95   0.000

S = 0.2695     R-Sq = 84.8%    R-Sq(adj) = 84.8%

The regression equation is
Pecos W2 A = 1.04 + 0.741 Pecos W5 B

Predictor      Coef      StDev        T       P
Constant     1.04329    0.01205     86.58   0.000
Pecos W5     0.740637   0.002990    247.67   0.000

S = 0.1658     R-Sq = 94.0%    R-Sq(adj) = 94.0%
```

```
The regression equation is
Pecos W5 A = 4.59 - 0.0774 Pecos River B

Predictor       Coef      StDev        T       P
Constant     4.58523     0.03659    125.33   0.000
Pecos Ri   -0.077443    0.004939    -15.68   0.000

S = 0.3263     R-Sq = 5.9%     R-Sq(adj) = 5.9%

The regression equation is
Pecos W5 A = 4.42 - 0.0956 Pecos W1 B

Predictor       Coef      StDev        T       P
Constant     4.42140     0.01818    243.16   0.000
Pecos W1   -0.095569    0.004133    -23.12   0.000

S = 0.3156     R-Sq = 12.0%    R-Sq(adj) = 12.0%

The regression equation is
Pecos W5 A = 4.37 - 0.100 Pecos W2 B

Predictor       Coef      StDev        T       P
Constant     4.36542     0.01708    255.55   0.000
Pecos W2   -0.100395    0.004705    -21.34   0.000

S = 0.3184     R-Sq = 10.4%    R-Sq(adj) = 10.4%

The regression equation is
Pecos W5 A = 4.12 - 0.0344 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor       Coef      StDev        T       P
Constant     4.11885     0.01091    377.51   0.000
Pecos W3   -0.034445    0.002937    -11.73   0.000

S = 0.3427     R-Sq = 3.7%     R-Sq(adj) = 3.7%
```

```
The regression equation is
Pecos W5 A = 4.39 - 0.0938 Pecos W5 B

Predictor       Coef      StDev        T       P
Constant     4.38636     0.02369    185.15   0.000
Pecos W5   -0.093832   0.005879    -15.96   0.000

S = 0.3260     R-Sq = 6.1%     R-Sq(adj) = 6.1%

The regression equation is
Pecos River B = 4.04 + 0.779 Pecos W1 B

Predictor       Coef      StDev        T       P
Constant     4.03679     0.02645    152.60   0.000
Pecos W1     0.779459   0.006013    129.62   0.000

S = 0.4591     R-Sq = 81.1%     R-Sq(adj) = 81.1%

The regression equation is
Pecos River B = 4.34 + 0.862 Pecos W2 B

Predictor       Coef      StDev        T       P
Constant     4.34406     0.02663    163.15   0.000
Pecos W2     0.861903   0.007334    117.52   0.000

S = 0.4963     R-Sq = 77.9%     R-Sq(adj) = 77.9%

The regression equation is
Pecos River B = 5.86 + 0.486 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor       Coef      StDev        T       P
Constant     5.86430     0.01511    388.08   0.000
Pecos W3     0.485805   0.004067    119.44   0.000

S = 0.4746     R-Sq = 79.8%     R-Sq(adj) = 79.8%
```

```
The regression equation is
Pecos River B = 3.06 + 1.09 Pecos W5 B

Predictor      Coef      StDev        T       P
Constant     3.05967    0.03151     97.11   0.000
Pecos W5      1.08657    0.00782     138.97   0.000

S = 0.4335     R-Sq = 83.2%    R-Sq(adj) = 83.2%

The regression equation is
Pecos W1 B = 0.356 + 1.12 Pecos W2 B

Predictor      Coef      StDev        T       P
Constant    0.356400   0.009310     38.28   0.000
Pecos W2      1.11668    0.00256    435.48   0.000

S = 0.1735     R-Sq = 98.0%    R-Sq(adj) = 98.0%

The regression equation is
Pecos W1 B = 2.40 + 0.600 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor      Coef      StDev        T       P
Constant     2.39962    0.01368    175.40   0.000
Pecos W3    0.600148   0.003682     162.98   0.000

S = 0.4297     R-Sq = 88.1%    R-Sq(adj) = 88.0%

The regression equation is
Pecos W1 B = - 1.10 + 1.36 Pecos W5 B

Predictor      Coef      StDev        T       P
Constant    -1.10378    0.01540    -71.69   0.000
Pecos W5      1.35590    0.00382    354.90   0.000

S = 0.2118     R-Sq = 97.0%    R-Sq(adj) = 97.0%
```

```
The regression equation is
Pecos W2 B = 1.83 + 0.538 Pecos W3 B

3606 cases used 306 cases contain missing values

Predictor       Coef       StDev         T       P
Constant     1.82889     0.01106    165.37   0.000
Pecos W3    0.537786    0.002977    180.66   0.000

S = 0.3474     R-Sq = 90.1%     R-Sq(adj) = 90.1%

The regression equation is
Pecos W2 B = - 1.29 + 1.21 Pecos W5 B

Predictor       Coef       StDev         T       P
Constant    -1.29283     0.01002   -129.02   0.000
Pecos W5     1.21046     0.00249    486.79   0.000

S = 0.1379     R-Sq = 98.4%     R-Sq(adj) = 98.4%

The regression equation is
Pecos W3 B = - 5.07 + 2.07 Pecos W5 B

3606 cases used 306 cases contain missing values

Predictor       Coef       StDev         T       P
Constant    -5.06531     0.04128   -122.72   0.000
Pecos W5     2.06596     0.01010    204.48   0.000

S = 0.5475     R-Sq = 92.1%     R-Sq(adj) = 92.1%

Colorado Location
The regression equation is
Colorado W1 2000 = 0.533 + 0.753 Colorado W2 2000

3746 cases used 46 cases contain missing values

Predictor       Coef       StDev         T       P
Constant    0.533154    0.009837     54.20   0.000
Colorado    0.753431    0.002727    276.24   0.000

S = 0.03411    R-Sq = 95.3%     R-Sq(adj) = 95.3%
```

```
The regression equation is
Colorado W1 2001 = - 0.0041 + 0.957 Colorado W2 2001

Predictor       Coef      StDev         T       P
Constant    -0.00406     0.02032      -0.20    0.842
Colorado     0.957177    0.006247     153.23    0.000

S = 0.08381     R-Sq = 83.8%     R-Sq(adj) = 83.8%

The regression equation is
Colorado W1 2001 = 2.37 + 0.541 Colorado w3 2001

Predictor       Coef      StDev         T       P
Constant     2.37422     0.00348    681.54    0.000
Colorado     0.541423    0.002496     216.89    0.000

S = 0.06177     R-Sq = 91.2%     R-Sq(adj) = 91.2%

The regression equation is
Colorado W2 2001 = 2.55 + 0.518 Colorado w3 2001

Predictor       Coef      StDev         T       P
Constant     2.54846     0.00330    771.30    0.000
Colorado     0.518267    0.002368     218.89    0.000

S = 0.05858     R-Sq = 91.4%     R-Sq(adj) = 91.4%

Canadian Location
The regression equation is
Canadian River = 0.670 + 0.385 Canadian W2

Predictor       Coef      StDev         T       P
Constant     0.67009     0.02916      22.98    0.000
Canadian     0.384578    0.009789      39.29    0.000

S = 0.3271      R-Sq = 28.3%     R-Sq(adj) = 28.3%



The regression equation is
Canadian River = 0.269 + 0.405 Canadian W3
```

```
Predictor       Coef      StDev         T       P
Constant     0.26865    0.03899      6.89   0.000
Canadian     0.40451    0.01023     39.55   0.000

S = 0.3265     R-Sq = 28.6%     R-Sq(adj) = 28.6%

The regression equation is
Canadian River = 0.590 + 0.422 Canadian W4

Predictor       Coef      StDev         T       P
Constant     0.59037    0.02848     20.73   0.000
Canadian    0.421773   0.009797     43.05   0.000

S = 0.3182     R-Sq = 32.2%     R-Sq(adj) = 32.1%

The regression equation is
Canadian W2 = - 1.01 + 1.04 Canadian W3

Predictor       Coef      StDev         T       P
Constant    -1.00629    0.00614   -163.95   0.000
Canadian     1.04190    0.00161    647.19   0.000

S = 0.05139    R-Sq = 99.1%     R-Sq(adj) = 99.1%

The regression equation is
Canadian W2 = 0.00886 + 1.02 Canadian W4

Predictor       Coef      StDev         T       P
Constant    0.008865   0.005837      1.52   0.129
Canadian     1.02116    0.00201    508.64   0.000

S = 0.06520    R-Sq = 98.5%     R-Sq(adj) = 98.5%

The regression equation is
Canadian W3 = 0.979 + 0.978 Canadian W4

Predictor       Coef      StDev         T       P
Constant    0.979141   0.004360    224.56   0.000
Canadian    0.978409   0.001500    652.41   0.000

S = 0.04871    R-Sq = 99.1%     R-Sq(adj) = 99.1%
```

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