Evaluating Potential Barriers to Cottonwood Regeneration in the Big Gypsum Study Area: Dolores River, CO

By Rob Anderson
June 30, 2010

Introduction

In many rivers and streams in the arid Southwest, cottonwood (*Populus sp.)* forests are an integral part of riparian ecosystems (Nalger et al. 2005; Lytle and Merritt 2004, Braatne et al. 96). Cottonwood forests influence natural processes such as nutrient cycling, light and water availability, deposition and erosion of sediments, river meandering, habitat heterogeneity, and species diversity of riparian ecosystems (Lytle and Merritt 2004, Merritt and Cooper 2000). Several studies have found an observable decline in riparian cottonwood forests among streams in the arid Southwest (Lytle and Merritt 2004, Vandersande et al. 2001, Levine and Stromberg 01, Braatne et al. 1996). Causes contributing to this decline may include altered flows (Orhtman 2009, Busch and Smith 95, Shafroth et al. 2002), the proliferation of invasive species (Shafroth 95, Busch and Smith 95), and livestock over-grazing (Braatne et al. 96).

Cottonwood species have adapted to, and are highly dependent on fluvial processes including: the seasonal availability of groundwater; groundwater drawdown rates; and fluvial patterns that promote the formation of bare alluvial bars and floodplains (Merritt and Poff 10, Merritt and Cooper 2000). Alteration of fluvial processes including timing, magnitude, duration, and interannual variability of flow regimes can have a detrimental effect on cottonwood species (Merritt and Poff 2010). In many cases, the decline in cottonwood forests and subsequent replacement by invasive species has coincided with changes in natural flow regimes (Merritt and Poff 10), reductions in flood disturbances (Shafroth et al. 2002), declines in alluvial water tables (Shafroth et al. 2000) and the interruption of the natural sedimentation processes (Levine et al. 02, Levine and Stromberg 2001) through water diversion and the building of dams (Lytle and Merritt, 2004, Sher et al. 2002, Ellis et al. 99, Shafroth 95, Busch and Smith 95).

Among many perennial streams in the southwestern U.S., (Sher et al. 2002, Shafroth 95), native forests have been replaced by invasive species such the highly successful tamarisk shrub (*tamarix ramosissima*). It is estimated that the tamarisk now occupies 1.0 million to 1.6 million acres in the western United States and northern Mexico, and is spreading at a rate of 1.3% to 2.5% per year (Barz 2008). Tamarisk proliferation has shown to be strongest along waterways that are dammed, dewatered, heavily used for agriculture, or that have large concentrations of dissolved solids (Levine and Stromberg 2001).

The invasion of tamarisk in southwestern U.S. floodplain ecosystems has profoundly altered fundamental riparian ecosystem properties (Busch and Smith 95). Negative impacts from tamarisk proliferation include: increased water consumption and loss; increased soil salinity; increased wildfire frequency; decreased plant species diversity; and degraded habitat for native wildlife (Barz 2008, Vandersande et al. 2001). The tamarisk shrub has the ability to absorb and utilize large extremely saline water; leaving the salt on the soil surface through leaf exudates, creating salinity levels that are toxic to native shrubs and trees (White et al. 2003, Shafroth, 95, Vandersande et al.

2001). Tamarisk may benefit riparian ecosystems by controlling erosion and providing habitat for several avian species (Shafroth et al. 2005, Barz et al. 2009). There is a growing recognition that the costs and benefits of tamarix invasion at a particular location should be weighed against the management goals for that location (Barz et al. 2008).

The availability of suitable sites for cottonwood germination and survival is dependent on several conditions. Optimal sites for cottonwood seed germination include bare, moist soils scoured or deposited by spring floods (Braatne et al. 1996). The availability of these sites must coincide with cottonwood seed release. Both wind and the receding high flows serve to disperse cottonwood seeds. Sites optimal for seedling survival and recruitment are typically located above the bank full elevation, as seedlings are less likely to be scoured away and/or mortally inundated in subsequent years (Braatne et al. 1996). Given these optimal site conditions, barriers to cottonwood seedling survival include soil salinity toxicity, substrate particle size (Sher and Marshal 2003), groundwater drawdown rates, depth of alluvial water tables, and repeated inundation (Braatne et al. 1996).

Annual spring floods mitigate soil salinity toxicity by physically moving salt downstream (Vandersande et al. 2001).The maximum salinity (electric conductivity) for cottonwood growth and establishment is 4 mmhos/cm, while plant performance begins to be observably and measurably reduced above 2 mmhos/cm (Sher et al., 2010). Therefore, a properly timed flood of a magnitude that scours vegetation and leaves bare, less-saline soils can be a good mechanism for creating a suitable site for cottonwood establishment (Braatne et al. 96). Once seeds have germinated, groundwater drawdown rates must be less than 2.5 cm/day to allow seedling roots access to available soil moisture during the critical first stage of growth (Lytle and Merritt, 2004, Braatne et al. 96). The movement of plant-available water throughout the soil horizon is a major variable that shapes vegetation patterns of riparian ecosystems and is a function of water table height and physical soil characteristics (Castelli et al. 2000). On the Lower Dolores River, as in many sections of river downstream of impoundments, water table height after spring spills is largely controlled by management of the reservoir and dam.

In this study, the goal was to monitor channel cross sections, hydrologic regime parameters, soil salinity, and substrate particle size in conjunction with vegetation patterns in the Big Gypsum Valley reach of the Dolores River in Southwest Colorado. The Dolores River flows from the high-alpine environment of the San Juan Mountains, through montane forests and Sonoran-like desert land where it confluences with the Colorado River in Utah (Siscoe, 2005). Dolores River water has been diverted for irrigation since early settlement of the San Juan River Valley in the late 1890's (Richard et al. 2007). McPhee Dam was completed in 1984 near the town of Dolores, Colorado, and impounds 381,195 acre-feet of water used for irrigation as well as municipal, recreational and industrial water supplies (Siscoe, 2005). Operation of McPhee Dam has substantially altered the flow regime of the Lower Dolores River; pre- and post-dam analyses have shown that the mean annual flood has decreased by 40-50%, the duration of the high pulse has decreased by 60%, and base flows have been increased (Richard et al. 2007).

Materials and Methods

Study sites

The Big Gypsum Study Area (BGSA) is located 72 miles downstream of McPhee Dam at an elevation of 5300 ft. Big Gypsum Valley is also 18.5 miles downstream from the confluence of Disappointment Creek, a major contributor of saline sediment to the Dolores (Richard et al. 2007).

The Big Gypsum Study Area has been divided into five reaches (Figure 1). The reaches were identified so that each reach has characteristics similar to those of five distinct reaches of the Lower Dolores River between McPhee Dam and the confluence with the San Miguel River.

A second study site was established for monitoring groundwater drawdown rates in the Lone Dome State Wildlife Area. This site is located about 6 miles downstream of McPhee Dam at an elevation of 6600 feet.

Cross-Sectional Analysis

Cross-section #3, one of three channel cross-sections surveyed within the study area, will be monitored annually in order to monitor channel dimensions and migration in conjunction with changes in soil salinity and texture, groundwater and soil moisture dynamics, and vegetation.

All cross-sections and transects in this study were established perpendicular to the river at each location, extending into the upland vegetation and so encompassing all riparian vegetation.

Soil Salinity and Texture

Soil salinity was measured at 6 transects in the Big Gypsum Study Site. At each transect, soil was collected in several different locations along each transect, and at three depths. The samples were collected in 10- or 20-foot intervals beginning with sample 1 at the river's edge. At each sample location, 3 samples were taken, unless otherwise noted: sample *a* at 0-2 cm, sample *b* at 2-6 cm, and sample *c* at 6-10 cm.

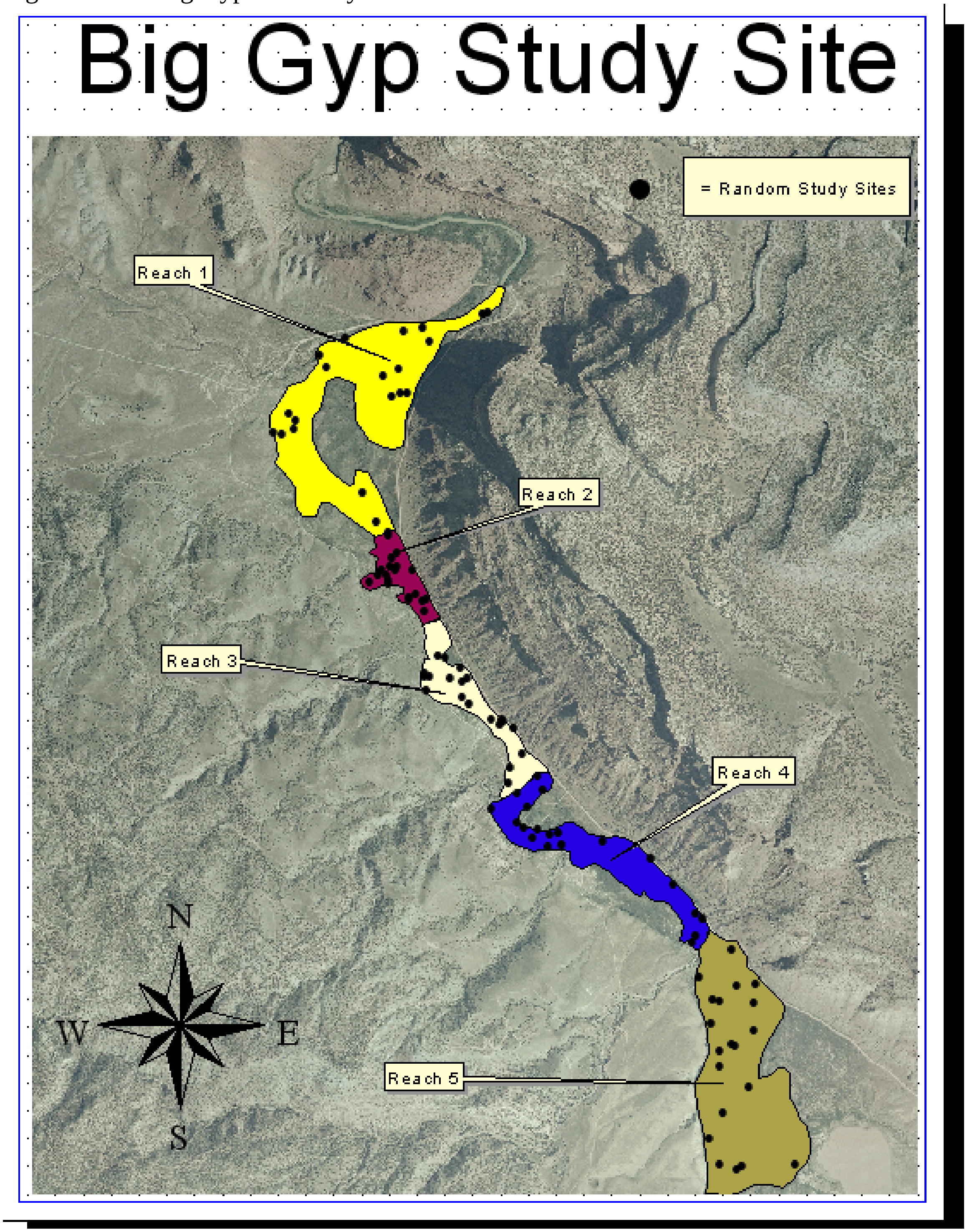
Soil salinity of each sample was quantified by determining the electric conductivity (EC) of soil slurries in the field. In order to determine EC of soils, an Omega conductivity meter and probe (CDH222) was used with analytical grade calibration solutions of 1.413 mmhos/cm and 12.88 mmhos/cm. Soil was mixed in a plastic beaker with distilled water so that the slurry formed a saturated paste, and the EC of the sample was recorded.

Soil texture was determined in the field using the texture-by-feel method.

Groundwater Drawdown Rates

Groundwater drawdown rates were determined using peizometers and soil moisture probes (gypsum blocks) along cross-section #3 in Reach 1 of BGSA. In order to observe the rise and fall of the water table, peizometers were installed in 3 locations distributed along the transect. Peizometer #1 was installed 16 feet from the river's edge (at base flow), peizometer #2 was installed 70 feet from the river and peizometer #3 was installed 110 feet from the river. Each peizometer was equipped with a pressure transducer and data logger so that water table stage height was recorded several times per day.

Figure 1: The Big Gypsum Study Area Divided into 5 Reaches.



Adjacent to peizometers #1 and #2 in the BGSA, gypsum blocks were installed to monitor the movement of plant available soil moisture. Gypsum blocks are able to detect the water tension in bars (a unit of pressure) in which water is being held in the soil matrix. All gypsum blocks were connected to a data logger and measurements were recorded at eight-hour intervals.

Adjacent to peizometer #1, two soil moisture probes were installed at 22.9 cm and 45.7 cm depths. Adjacent to peizometer #2, four gypsum blocks were installed at 24.1cm, 47.0 cm, 66 cm, and 94.0 cm depths.

To determine the rate of groundwater drawdown, the time (in days) in which it took an arbitrary water tension (10 or 20 centibars) to move the distance between gypsum blocks (through the soil profile) was calculated.

At the site in Lone Dome Recreational Area, a transect of 3 peizometers and 2 sets of gypsum blocks were installed. Similar analyses of groundwater drawdown rates (as described above) will be performed for this site in the near future and will be available to the general public. The gypsum blocks and data loggers installed in these sites are estimated to be effective for three years.

Vegetation Survey

Vegetation was surveyed along cross-section #3 in Reach 1 of the BGSA both before and after the 2010 spill. This transect was chosen for the vegetation survey so that the patterns of vegetation could be compared with soil moisture parameters also being measured along cross-section #3.

The percentage cover of each species was estimated at 5-foot intervals and including all vegetation within 3 feet (1.5 feet on both sides) perpendicular to the tape. Species of cottonwood were noted at any and all marks on the tape so that seedlings could be quantified in each subsequent year. The percentage of bare soil observed at each 5-foot interval was also estimated.

Results and Discussion

Cross-Sectional Analysis

Figure 2 graphs the elevation change in the channel looking downstream for cross-section #3 in Reach 1of the BGSA.

Soil Salinity and Texture

Soil texture in all sites was determined to be coarse. The range of soil texture was between sandy and sandy loam soils.

Soil salinity measurements were performed in the winter of 2009 (pre-2010 spill) in order to observe the patterns of soil salinity throughout the BGSA (figures 5 and 6). In these figures, soil salinity (EC in units of mmhos) is on the *y*-axis, and the distance from the river's edge (at base flow) in feet is shown on the *x*-axis. It is important to note that the ranges of soil salinity (EC) are markedly different in these graphs. Electric conductivity ranges from 0 to 1.4 mmhos in transects where tamarisk is not abundant, while EC ranges from 0 to 30 mmhos in those transects where tamarisk is abundant.

Figure 3 shows the EC measurements in 4 reaches of the BGSA where tamarisk is not abundant. In all 4 transects, EC is within a range that is conducive to cottonwood growth and regeneration. Electric conductivity in these transects is well below the threshold for cottonwood regeneration (4.0 mmhos/cm) and levels that have proven to hinder plant growth and performance (2.0 mmhos/cm). Soil salinity in these transects tends to be higher in samples closest to the river.

Soil salinity (EC) in two transects dominated by tamarisk is shown in Figure 4 below. In all sites within twenty feet of the river's edge, EC exceeds the threshold for native

Figure 2:

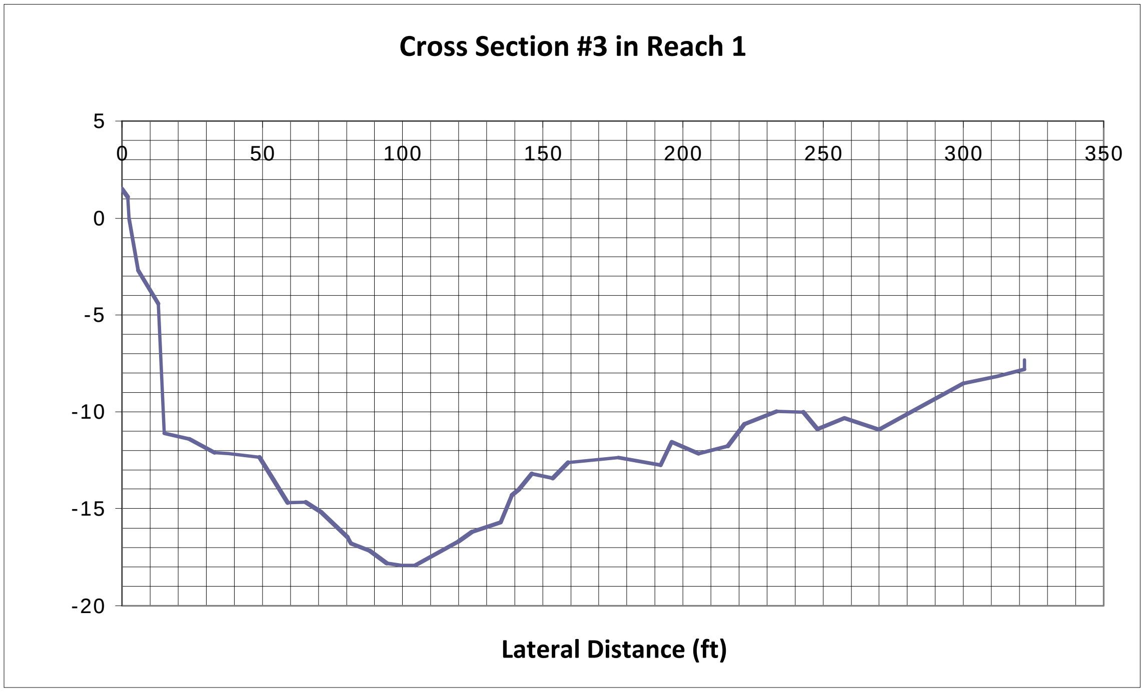
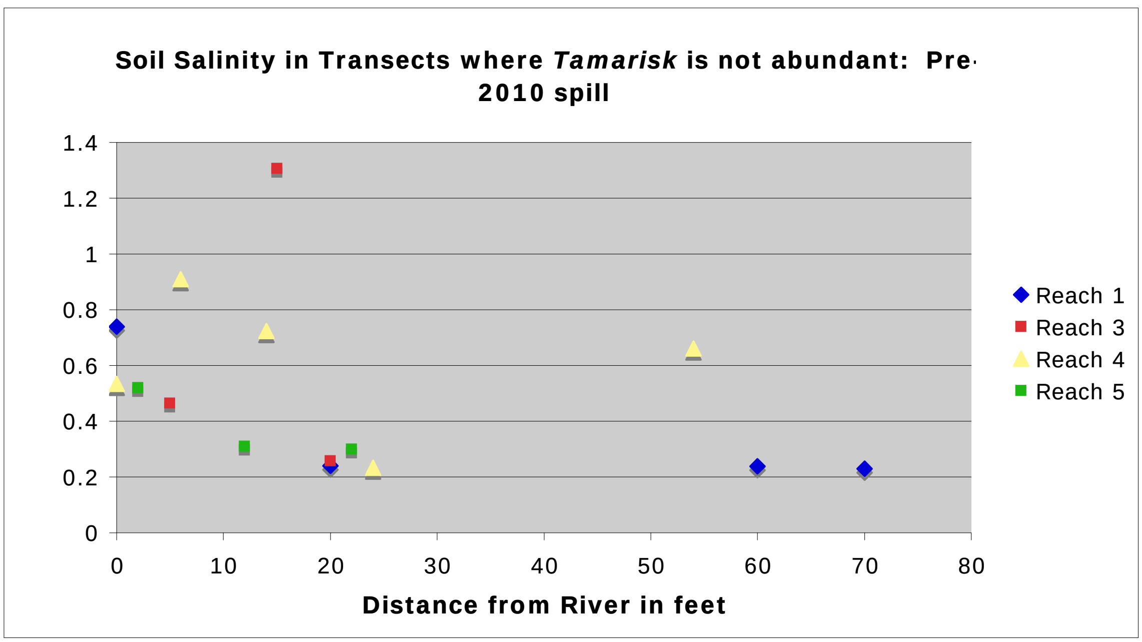


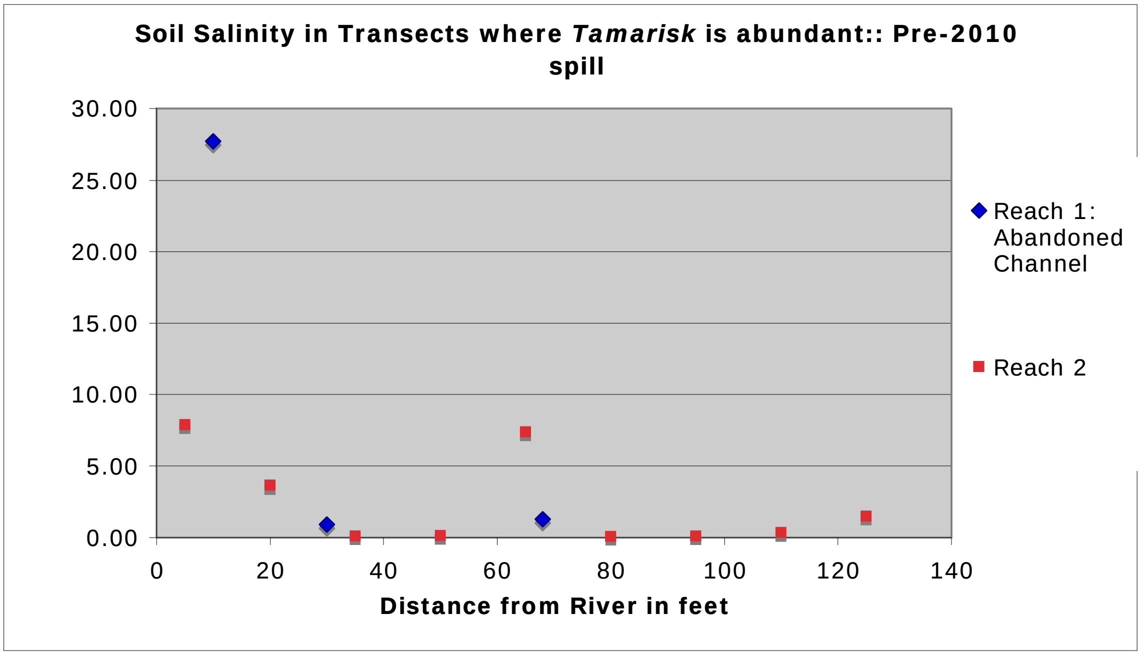
Figure 3:



cottonwood regeneration (4.0 mmhos/cm). Also, in several samples in transects where tamarisk is abundant, soil salinity is at levels that have proven to hinder plant growth and performance (2.0 mmhos/cm). In these transects, soil salinity is highest among samples closest to tamarisk shrubs, which tend to be close to the river.

In all transects sampled, regardless of tamarisk abundance, soil salinity tends to be higher in samples closest to the river's edge. It is possible that saline sediment from tributaries such as Disappointment Creek could be contributing to soil salinity close to these sites.

Figure 4:



In summer of 2010 after the spill and drawdown from McPhee Dam, EC was re-measured in four of the six previously sampled transects (figures 5 to 7). In these transects, EC was only measured within the channel to reflect alterations in soil salinity that may have occurred as a result of the 2010 spill. Again, note the difference in the range of EC among these graphs.

Figure 5 below shows post-2010 spill EC in 3 transects where tamarisk is not abundant. In all 3 transects, EC is within a range that is conducive to cottonwood growth and regeneration. Electric conductivity in these transects is well below the threshold for cottonwood regeneration (4.0 mmhos/cm) and levels that have proven to hinder plant growth and performance (2.0 mmhos/cm).

Figure 6 shows pre- and post-2010 spill EC measurements in a transect where tamarisk is abundant (Reach 3). In all sites within 20 feet of the river's edge, EC exceeds the threshold for native cottonwood regeneration (4.0 mmhos/cm). In the post-2010 spill samples in this transect, EC is higher than in the pre-2010 spill samples. Soil salinity in these samples has increased in the six-month period between sampling. This could be a result of continual tamarisk proliferation in this area.

Figure 7 shows pre- and post-2010 spill EC measurements in a transect where tamarisk is not abundant (Reach 1). In all samples (both pre- and post-2010 spill) in this transect, EC is within a range that is conducive to cottonwood growth and regeneration. In the post-2010 spill samples in this transect, EC is lower than in the pre-2010 spill samples. Soil salinity in these samples has decreased in the six-month period between sampling. This could be a result of the 2010 spring spill physically moving salt downriver.

Figure 5:

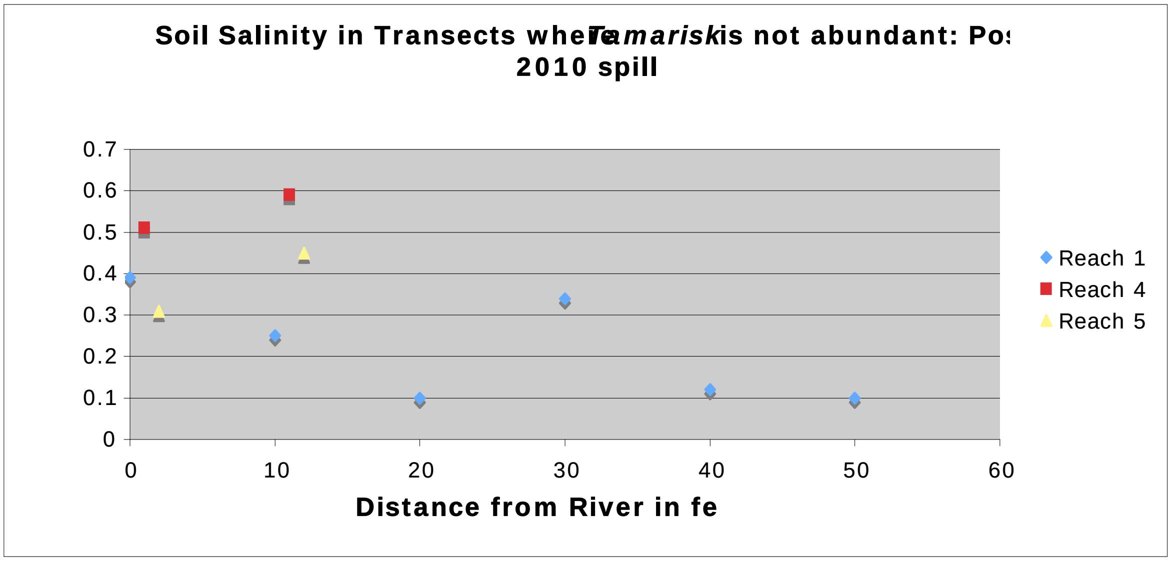


Figure 6:

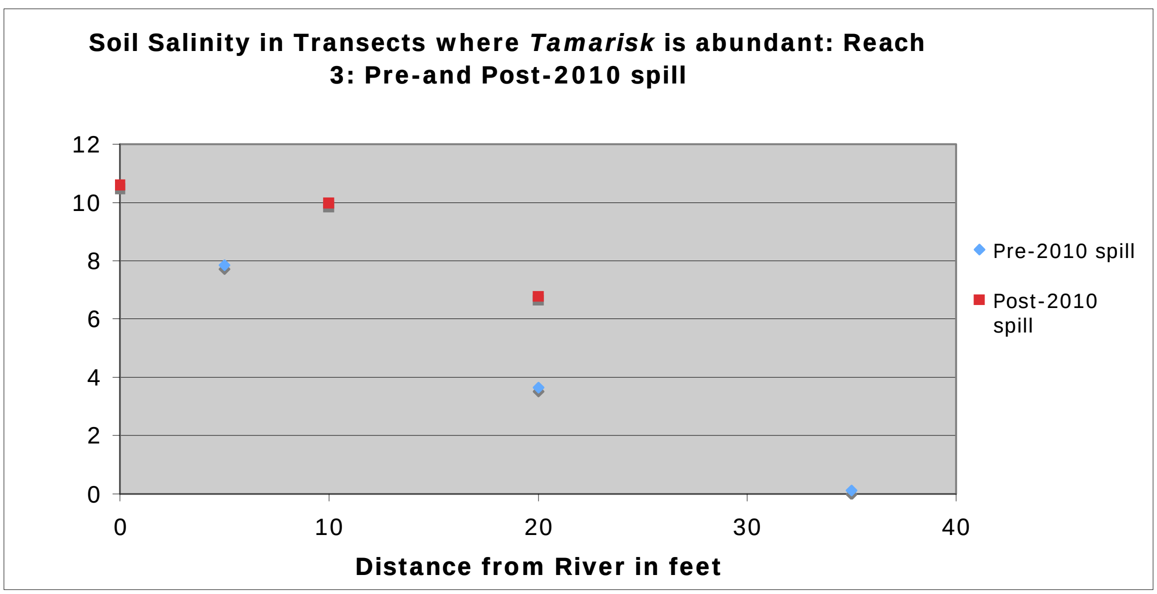
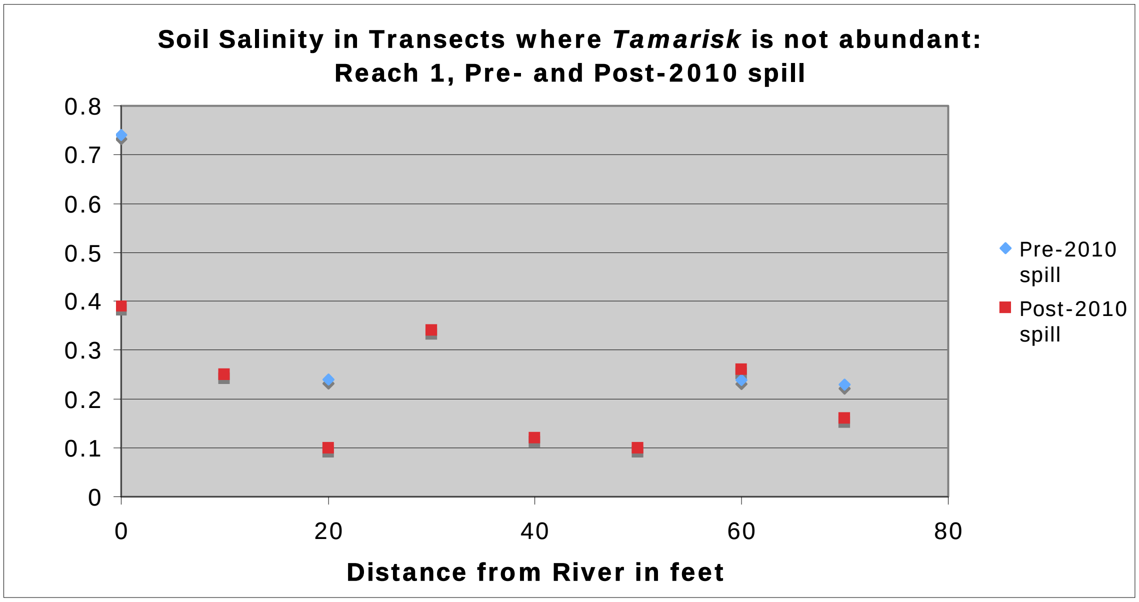


Figure 7:



Groundwater Drawdown Rates

Groundwater drawdown rates were determined in 2 sites along transect #3 in the BGSA. In site #1 (16 feet from the river's edge at base flow), the rate of groundwater drawdown was found to be 5.0 cm/day. At site #2, (60 feet from the river's edge), the rate of groundwater drawdown was found to be 1.4 cm/day.

The rate of groundwater drawdown in site #1 is 2 times higher than the established threshold rate of 2.5 cm/day for cottonwood regeneration (Lytle and Merritt, 2004, Braatne et al. 1996). The rate of groundwater drawdown in site #2 is below the threshold for cottonwood regeneration. These data suggests that groundwater drawdown rates are an obstacle for cottonwood regeneration in the BGSA.

Vegetation Survey

The vegetation in this 200-foot transect (oriented perpendicular to the channel) transitions from a riparian area dominated by coyote willow (*Salix exigua*) near the river to upland vegetation dominated by basin big sage (*Artemesia tridentata*). Coyote willow is the dominant woody species from 0 to 50 feet from the river's edge (photo #1), while small numbers of tamarisk, New Mexico wild privet (*Foresteira pubescens*), and cottonwood are also present. From 50 to 100 feet from the river's edge, the vegetation transitions from a coyote willow-dominated community, into an upland area dominated by big basin sage (Photo #2). In this area, there are a few individuals of privet, rabbitbrush (*Chrysothamnus nauseosus),* and many dead coyote willow carcasses (photo #3). From 100 to 200 feet from the river's edge, the vegetation is predominantly big basin sage (photo #3). In this area, there are a few individuals of rabbitbrush and dead coyote willow carcasses.

All of the mature cottonwood trees in this transect showed signs of beaver damage (photo #4). These trees stand about 2 feet tall and have several trunks, with 1-2 inch diameters, that have been severed by beavers. It appears that beaver damage in this transect is a barrier to cottonwood growth. There were no new cottonwood seedlings along the entire transect.

Throughout the transect, the average percentage of bare soil observed was 56.7 % and ranged from 10 to 100%. Photo #1 portrays the amount of bare soil adjacent to the channel. The presence of bare soil suggests that the potential of spring floods to create bare soil is not a barrier to cottonwood regeneration in this transect.

Photo #1: Transect #3 Near the River's Edge Dominated by Coyote Willow.

Photo #2: Transect #3 in the Transition Area from Coyote Willow to Sage.

Photo #3: Transect #3 in the Area Dominated by Big Basin Sage

Photo #4: Transect #3, Beaver Damaged Cottonwood Trees

Conclusions and Next Steps

This study documents soil salinity, soil moisture, hydrological regimes, vegetation patterns and channel cross-section which are all pertinent to the regeneration of cottonwood species. Equipment has been installed in two transects along the Lower Dolores River that will effectively monitor hydrologic variables for 3 years. Annual pre- and post-spill monitoring of soil salinity, soil hydrologic regimes, and channel cross-sections are next steps in detecting changes in these variables over time and the relationship of these variables to river flows.

The results obtained concerning soil salinity show that soil salinity is only a limiting factor in sites dominated by tamarisk. Currently, a tamarisk removal effort is underway in the BGSA by the Tamarisk Coalition. Ongoing monitoring of soil salinity in sites currently dominated by tamarisk in conjunction with the removal of tamarisk could be valuable in determining the timeline for mitigation of these saline soils. In sites were tamarisk is not abundant, although soil salinity was higher in samples close to the river, it was still well below the threshold for cottonwood growth and regeneration. These data suggest that the Dolores River is potentially contributing to soil salinity in these sites. Further monitoring of salinity in this area as well as in and above

Disappointment Creek (a major contributor to saline sediments) would be beneficial in addressing this variable.

The analysis of groundwater drawdown rates in transect #3 in the BGSA suggests that groundwater drawdown rates are a barrier to cottonwood regeneration in this study area. Groundwater drawdown rates are largely driven by changes in river flows. If cottonwood regeneration on the Lower Dolores River becomes a priority, adjustments in ramping down of springtime spills from McPhee dam could be considered.

This study analyzed groundwater drawdown rates in only one transect. Data from another transect in Lone Dome Recreational Area is also being collected and analyzed and will build on the information developed at the BGSA. Also, comparisons of groundwater drawdown rates with water table stage heights and the 2010 hydrograph will provide more insight on this variable. Several more transects of soil moisture probes would be beneficial in further investigating this potential barrier to cottonwood regeneration on the Lower Dolores River.

The vegetation survey (pre- and post-2010 spill) in transect #3 documented all woody vegetation at 5-foot intervals. Small numbers of cottonwoods were documented throughout the entire length of the transect. There were no new (2010) cottonwood seedlings present along the transect. All mature cottonwood trees in this transect showed sign of beaver damage. These findings suggest that beaver damage may be an obstacle to cottonwood growth.

Of the variables monitored in transect #3 (soil salinity, groundwater drawdown rates, and percentages of bare soil), the rate of groundwater drawdown appears to be the only limiting factor to the regeneration of cottonwoods.

Acknowledgements

The author thanks the Suckla family for generously providing access to their private land for the purposes of this study. The expert advice in the field and editing from Chris Massingill, Ann Oliver, Jim Siscoe and David Graf is very much appreciated; this study is much better because of you all. Thanks to Larry Kawanabi with NRCS in Cortez for the gypsum blocks and data loggers. Thanks also to Brooke Childrey and Darcy Craig for field assistance. Thanks to Dr. Korb, Dr. Dott, Dr. Gianini and Melissa Boley at Fort Lewis College for purchasing and installing the peizometers. Funding for this project came from the Colorado Water Conservation Board Severance Tax Trust Fund.

Sources Cited

Barz, D., R.P. Watson, J.F. Kanney, J.D. Roberts, and D.P. Groeneveld. 2008. Cost/Benefit Considerations for Recent Saltcedar Control, Middle Pecos River, New Mexico. Environmental Management 43: 282-298

Bay, R.F., and A.A. Sher. 2008. Success of Active Revegetation after *Tamarix* Removal in Riparian Ecosystems of the Southwestern United States: A Quantitative Assessment of Past Restoration Projects. Restoration Ecology 16: 113-128

Braatne, J.H., S.B. Rood, and P.E. Heilman. 1996. Life, History, Ecology and Conservation of Riparian Cottonwoods in North America. A Chapter for Biology of Populus

Busch, D.E. and S.D. Smith. 1995. Mechanisms Associated with Decline of Woody Species in Riparian Ecosystems of the Southwestern U.S. Ecological Monographs 65 347-370.

Castelli, R.M., J.C. Chambers, and R.J. Tausch. 2000. Soil-Plant Relations Along Soil-Water Gradient in Great Basin Riparian Meadows. The Society of Wetland Scientists 20: (No.2) 251-266

Ellis, L.M., M.C. Molles Jr., and C.C. Crawford. 1999. Influence of Experimental Flooding on Litter Dynamics in a Rio Grande Riparian Forest, New Mexico. Restoration Ecology 7: 193-204

Levine, C.M., and J.C. Stromberg. 2002. Effects of Flooding on Native and Exotic Plant Seedlings: Implications for Restoring South-Western Riparian Forests by Manipulating Water and Sediment Flows. Journal of Arid Environments 49: 111-131

Levine, C.M. and J.C Stromberg. 2001. Effects of Flooding on Native and Exotic Plant Seedlings: Implications for Restoring South-Western Riparian Forests by Manipulating Water and Sediment Flows. Journal of Arid Environments 49: 111-131

Lytle, D.A., and D.M. Merritt. 2004. Hydrologic Regimes and Riparian Forests: A Structured Population Model for Cottonwood. Ecology 85: 2493-2503

Merritt, D.M., and D.J. Cooper. 2000. Riparian Vegetation and Channel Change in Response to River Regulation: A Comparative Study of Regulated and Unregulated Streams in the Green River Basin, USA. Regulated Rivers: Research and Management 16: 543-564

Merritt, D.M., and N.L. Poff. 2010. Shifting Dominance of Riparian *Populus* and *Tamarix* Along Gradients of Flow Alteration in Western North American Rivers. Ecological Applications 20(1): 135-153

Ohrtman, M.K. 2009. Quantifying Soil and Groundwater Chemistry in Areas Invaded by *Tamarix* SPP. Along the Middle Rio Grande, New Mexico. A Dissertation presented to the Faculty of Natural Sciences and Mathematics at The University of Denver.

Nalger, P.L., O. Hinojosa-Huerta, E.P. Glenn, J. Garcia-Hernandez, R. Romo, C. Curtis, A.R. Huete, and S.G. Nelson. 2005. Regeneration of Native Trees in the Presence of Invasive Saltcedar in the Colorado River Delta, Mexico. Conservation Biology 10.1111: 1523-1739

Richard, G.A., and R.M. Anderson. 2007. Channel-Forming Discharge on the Dolores River and Yampa River, Colorado. Colorado Division of Wildlife Technical Publication No. 44.

Shafroth, P.B., J.R. Cleverly, T.L. Dudley, J.P. Taylor, C. Van Riper III, E.P. Weeks, and J.N. Stuart. 2005. Control of *Tamarix* in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration. Environmental Management 35: 231-246

Shafroth, P.B., J.M. Friedman, and L.S. Ischinger. 1995. Effects of Salinity on Establishment of *Populus Fremontii* (Cottonwood) and *Tamarix Ramosissima* (Saltcedar) in Southwestern United States. Great Basin Naturalist 55: 58-65

Shafoth, P.B., J.C. Stromberg, and D.C. Patten. 2002. Riparian Vegetation Response to Altered Disturbance and Stress Regimes. Ecological Applications 12: 107-123.

Shafroth, P.B., J.C. Stromberg, and D.C. Patten. 2000. Woody Riparian Response to Different Alluvial Water Table Regimes. Western North American Naturalist 60: 66-76

Sher, A. A. and K. Lair. 2010. Best Management Practices for Revegetation after Tamarisk Removal in the Upper Colorado River Basin Handbook. Report for the Central Utah Project Completion Act.

Sher, A.A., and D.L. Marshall. 2003. Seedling Competition Between Native *Populus Deltoides* (Salicaceae) and Exotic *Tamarix Ramosissima* (Tamaricaceae) Across Water Regimes and Substrate Types. American Journal of Botany 90: 413-422

Sher, A.A., D.L. Marshall, J.P. Taylor. 2002. Establishment of Native Populus and Salix in the Presence of Invasive Nonnative Tamarix. Ecological Applications 12: 760-772

Siscoe, J. 2005. Core Science Report For The Dolores River Dialogue. Introduction: 4-7.

Stromberg, J.C. 2001. Restoration of Riparian Vegetation in the South-Western United States: Importance of Flow Regimes and Fluvial Dynamism. Journal of Arid Environments 49: 17-34

Stomberg, J.C., S. Lite, and C. Paradzick. 2005. Tamarisk and River Restoration Along the San Pedro and Gila Rivers. USDA Forest Service Proceedings RMRS-P-36

Vanderssande, M.W., E.P. Glenn, and J.L. Walworth. 2001. Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. Journal of Arid Environments 49: 147-159

White, L.D., K.B. Hays, an K.M. Schmidt. 2003. Water use by saltcedar and associated vegetation along selected rivers in Texas. (Saltcedar symposium 2003).