Colorado River Basin
Tamarisk and Russian Olive Assessment
December 2009

Prepared by the Tamarisk Coalition
for

The Parties to the Memorandum of Understanding (MOU) to coordinate activities for tamarisk management in the Colorado River Basin. The Parties to the MOU are the Central Arizona Water Conservation District, Colorado Water Conservation Board, New Mexico Interstate Stream Commission, Six Agency Committee, Southern Nevada Water Authority, Utah Division of Water Resources, and Wyoming State Engineer’s Office.
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This report was prepared by the Tamarisk Coalition, a nonprofit organization whose mission is to provide technical assistance and education in support of the restoration of riparian lands.

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Executive Summary

On May 1, 2008 a Memorandum of Understanding (MOU) was signed by water representatives (Parties) from each of the seven states that comprise the Colorado River Basin. The MOU’s intent was to further the seven Colorado River Basin States’ (Basin States) investigations of potential water augmentation options that might provide future water supplies within the Basin. Although several studies have been completed, there is a lack of consensus as to whether the spread of tamarisk and Russian olive (TRO) can be controlled in a cost-effective way and if such control could result in system benefits to water supplies. In particular, three questions have given rise to considerable debate:

1. Can water be saved by managing TRO?
2. Is controlling TRO to save water cost-effective?
3. Can saved water be recovered?

Answering these questions before undertaking large-scale tamarisk management provides valuable information in determining if augmenting the flow of water in a river is possible. The purpose of this TRO Assessment is to provide enough information for the Basin States to make informed decisions about the potential desirability and cost-effectiveness of large-scale TRO management to save water lost to evapotranspiration (ET) and thus potentially augment water flow in the Basin’s river systems. The Assessment has reviewed all of the extant literature and concludes “yes” to the first two questions. The third question was beyond the scope of the Assessment.

In July 2008, the Parties contracted with the Tamarisk Coalition to perform this TRO Assessment. Four separate but interconnected tasks were undertaken to address the following three primary purposes:

- Use existing data and information to assess TRO water use (ET) and implications for water recovery (salvage), distribution, the state-of-the-science, the range of information available on impacts, management techniques, restoration, potential sources of funding, and gaps in current knowledge where additional research is appropriate.

- Evaluate programmatic issues such as economics, permitting and monitoring which are important to develop and overall approach for resolving TRO management problems, and assemble all known mapping data in the Colorado River Basin.

- Develop a list of potential demonstration sites for TRO management and research for possible funding pursuant to Public Law 109-320, Salt Cedar and Russian Olive Control Demonstration Act.

Task 1: ET Panel. A panel of experts was convened in November 2008 to try to answer 10 specific ET questions. The ET Panel, composed of ten scientists, provided expertise in the areas of riparian and floodplain upper terrace ecosystems ecology; ET rate measurement of vegetation associated with these ecosystems; hydrologic interaction between vegetation, groundwater and surface water; climate change, and TRO management (control and revegetation) approaches.
The Panel’s resulting report is an independent evaluation of the ET issue. Incorporating opinions from these interrelated fields creates a balance that is critical for policy makers as it provides expert advice that sifts out biases inherent in each field of research. Although consensus was desired and there is general agreement, there are dissenting positions on a couple of the questions.

**Task 2: TRO Management, state-of-the-science.** Task 2 focuses on the current understanding of TRO distribution, impacts to wildlife and sensitive species, sediment and salinity issues, cultural and recreational impacts, biological control, biomass utilization, and best management approaches.

**Task 3: Programmatic issues and the economics of TRO management.** This task’s purpose is to evaluate the costs and impacts of TRO management compared to potential water savings. Important research needs and consistency with other environmental management programs are also identified.

**Task 4: Demonstration Projects.** The information compiled in Tasks 1 through 3 is integrated in this task to identify a potential list of candidate demonstration sites for large-scale TRO management to support research on water savings and other important research needs.

**Findings** – The following represent the major findings of the TRO Assessment:

1. The information in this report provides the basis for the further expenditure of funds to continue to investigate large-scale TRO management, address further research questions, or begin pilot management projects. Final costs and potential water savings are strongly dependent on site specific factors. Based on sites selected for TRO management, infestation characteristics, conditions, and revegetation goals there is opportunity to save water within the Colorado River system at a reasonable cost per acre-foot.

2. The ET Panel was a diverse collection of scientists brought together to arrive at a common ET value for planning purposes. A task of the Panel was to identify ET rates that account for differences in climate, elevation, and latitude. The ET Panel noted that rates from the same tamarisk species can vary widely under the same general climatic conditions due to wide variation in vegetation density, soil type, vegetation health, height and age, nature of understory vegetation, salinity, access to ground-water, geology, and stream-ground-water interactions (hydrologic connectivity).

3. Based on all available data, the basin-wide function that was developed, and the views of the Panel, the Panel reached consensus that the typical range of tamarisk ET as a basin-wide average of 2.3 to 4.6 acre-feet per acre per year. This range is considered conservative. Because the largest concentration of tamarisk infestations occur in the Lower Basin where ET rates would tend to be higher, the mean value for tamarisk ET for the entire Basin should tend towards the upper limit of 4.6 acre-feet per acre. Under similar site conditions, ET rates for the Upper Basin will tend towards the lower rate as will replacement vegetation ET rates tend to be lower than the same species found in the Lower Basin.
4. The greatest potential for water savings is by managing TRO on upland sites adjacent to rivers. In these areas the TRO would be controlled and depending on conditions, sites would either be managed to allow natural recruitment of native species or would be revegetated with upland, xeric species. Although strongly dependent on site factors, based on the species used for revegetation and conditions such as seasonal groundwater depth variability, in general potential water savings would range from 50-60% of the value of tamarisk ET. For a representative site within the basin that has 60% tamarisk canopy cover, of which 75% of the area would be revegetated with xeric vegetation, it is estimated that approximately 1 acre-foot can be saved for each 1.85 acres of TRO managed, or 0.54 acre-feet per acre.

5. In the Colorado River Basin, mapped tamarisk and Russian olive accounts for a total stand acreage (aerial extent) of approximately 250,000 and 40,000 acres, respectively. These values must be considered low because a significant amount of the data is point data with no actual acreage assigned to this information. It is reasonable to expect that without TRO management both species will continue to expand in both the Upper and Lower Basins.

6. At its current rate of expansion, the biological control agent for tamarisk (the tamarisk leaf beetle, *Diorhabda* spp.) will spread throughout the Upper Colorado River Basin by the end of 2010. It is almost certain that within 5 to 10 years the beetles will be in the Lower Colorado River system expanding from either the Upper Basin populations or beetle populations introduced in California and/or Texas.

7. Each of the TRO management methods, when used appropriately for specific site conditions, can be effective in controlling TRO. The choice of which one to implement is a function of many site conditions such as the level of difficulty of site access, density of infestation, and availability of replacement vegetation.

8. Effects of invasive plants on wildlife are diverse and depend on the species considered. The endangered Southwestern willow flycatcher is of greatest concern in the Lower Basin. Tamarisk provides suitable habitat for this bird, and some are concerned that tamarisk control efforts might slow its recovery. Biological control of tamarisk with the tamarisk leaf beetle has been particularly controversial. In the Upper Basin, it has been suggested that tamarisk management may benefit several endangered fish species including the Colorado pikeminnow and razorback sucker.

9. Planning level estimates of the cost per acre-foot of water saved by TRO management in the Colorado River Basin have been developed. The costs for this TRO management effort and subsequent water savings are competitive with other augmentation approaches the Basin States are evaluating. Normalized unit costs of water saved by TRO management for a representative site within the Basin range from $260 to $1,050 per acre-foot. Using a suite of available and common techniques, TRO management costs are estimated to be less than $400 per acre-foot. Other benefits will generally result to aquatic and terrestrial habitats, wildfire threats, and cultural and recreational uses. Sedimentation and bank erosion issues
are complex and can be viewed as either a beneficial or negative impact. The value of saved water is dependent on the ability to measure and/or model savings.

10. Although it is possible to identify that water can be saved in the Colorado River Basin by means of TRO management, the amount of water that can be recovered (salvaged) cannot be predicted. Demonstration projects coupled with groundwater and surface water measurement and modeling are needed to predict where in the system this saved water will be available.

11. A list of potential Demonstration Projects for TRO management in the Colorado River Basin was developed as a starting point for possible future submittal to U.S. Bureau of Reclamation (USBR) for federal funding consideration pursuant to Public Law 109-320. Eight potential sites are identified for large-scale demonstrations – four in the Upper Basin and four in the Lower Basin.
Introduction

Background
On May 1, 2008 a Memorandum of Understanding was signed by water representatives from each of the seven states that comprise the Colorado River Basin – Central Arizona Water Conservation District, Colorado Water Conservation Board, New Mexico Interstate Stream Commission, Six-Agency Committee (of California), Southern Nevada Water Authority, Utah Division of Water Resources, and Wyoming State Engineer’s Office (see Appendix A).

The MOU’s intent was to further the seven Colorado River Basin States’ investigations of potential water augmentation options that might provide future water supplies within the Basin. By controlling invasive phreatophytes, specifically tamarisk (*Tamarix* spp., also known as saltcedar) and Russian olive (*Elaeagnus augustifolia*), which have a reputation for using significant quantities of water, it has been postulated that water currently lost through evapotranspiration processes could be reduced and thus made available to augment water supplies.

Two reports have been developed by the Basin States that reviewed the opportunity and economics of tamarisk management as a means of augmenting water supplies in the Basin (Ryan 2006, SNWA 2009). These two reports reached preliminary conclusions that water could be saved and be economically competitive with other engineered water augmentation options. A review of the literature in the Ryan paper estimated that a 1,000,000 acre tamarisk management program could potentially salvage one to four million acre-feet of water annually and the SNWA paper estimated 300,000 acres of tamarisk infestation in the Colorado River Basin with a potential of 20,000 acre-feet and 150,000 acre-feet of water salvage in the Virgin River and Lower Colorado River systems respectively. One purpose of this TRO Assessment is to refine those numbers.

This TRO Assessment documents mapped stand acreage of tamarisk in the Colorado River Basin, (aerial extent) of approximately 250,000 acres. This value must be considered low because a significant amount of the data is point data with no actual acreage assigned to this information.

The U.S. Bureau of Reclamation is currently underway with another study that is evaluating the broader tamarisk problem throughout the West. Information developed as part of the Basin States effort to better articulate the tamarisk and Russian olive problem within the Colorado River Basin is being provided to the USBR for their use.

Although these reports and several other research studies have been completed or are underway, there lacks an overall the consensus as to whether the spread of tamarisk and Russian olive can be controlled in a cost-effective way and if such control could result in system benefits to both water supplies and river habitat ecosystems. In particular, three questions have given rise to considerable debate:

1. Can water be saved by managing TRO?
2. Is controlling TRO to save water cost-effective?
3. Can saved water be recovered?
Answering these questions before undertaking large-scale tamarisk management provides valuable information in determining if augmenting the flow of water in a river is possible. The Assessment has reviewed all of the extant literature and concludes “yes” to the first two questions. The third question was beyond the scope of the Assessment.

If water can be saved through TRO control and revegetation / restoration efforts, the Parties to the MOU may desire is to implement a coordinated and integrated approach toward tamarisk management in the Colorado River Basin with the goal of potentially increasing the yield of flows in the Colorado River. The Parties have also expressed support for the development of multi-state, long-term management strategies and demonstration projects in the Colorado River Basin administered under Public Law 109-320, *Salt Cedar and Russian Olive Control Demonstration Act* (see Appendix B). The Parties may consider a future agreement with the U.S. Bureau of Reclamation to cost-share potential projects under the demonstration program identified in this Public Law.

In July 2008, the Parties contracted with the Tamarisk Coalition to perform this TRO Assessment. The following paragraphs describe the objectives and tasks of the assessment. This information was also provided to USBR who is performing an overall assessment for TRO throughout the Plain States and the West.

**The Colorado River**
The Colorado River begins in the snowcapped mountains of north central Colorado and winds southwest for more than 1,400 miles toward the Gulf of California.

The river and its tributaries - including the Green, Gunnison, San Juan, Virgin, Little Colorado, Bill Williams, and Gila rivers - and the lands these waters drain are all part of the "Colorado River Basin." The rivers drain 242,000 square miles in the United States, or one-twelfth of the country's continental land area, and 2,000 square miles in Mexico.

The Colorado River Compact divided the Colorado River Basin into the Upper Basin and the Lower Basin. The division point is Lees Ferry, a point in the mainstem of the Colorado River about 30 river miles south of the Utah-Arizona boundary, just downstream of Glen Canyon Dam.

The "Upper Basin" includes those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming within and from which waters naturally drain into the Colorado River system above Lees Ferry, and all parts of these States that are not part of the river's drainage system but may benefit from water diverted from the system above Lees Ferry.

The "Lower Basin" includes those parts of the states of Arizona, California, Nevada, New Mexico, and Utah within and from which waters naturally drain into the Colorado River system below Lees Ferry, and all parts of these States that are not part of the river's drainage system but may benefit from water diverted from the system below Lees Ferry.
Objectives
The overall objective of the TRO Assessment is to provide enough information for the Basin States to make informed decisions about the potential desirability and cost-effectiveness of large-scale TRO management to save water lost to evapotranspiration (ET) and thus potentially augment water flow in the Basin’s river systems. For the purposes of this report the following definitions are used:

- “TRO management” includes control, biomass reduction, revegetation, monitoring, and long-term maintenance.
- “Water savings” is the difference in ET rates between TRO and replacement vegetation.
- “Salvaged water” represents the reduction in ET (water savings) that can actually be recovered near the site of the TRO management and used for a beneficial use.

This report does not identify specifically where water savings may 1) occur throughout the Basin or 2) equate to water salvage as each of the seven Basin States administers their state’s water resources differently.

The TRO Assessment has three primary purposes:

- Use existing data and information sources to assess: TRO evapotranspiration use; distribution; the state-of-the-science; the range of information available on impacts; TRO management techniques; restoration; potential sources of funding; and gaps in current knowledge where additional research is appropriate.

- Evaluate programmatic issues such as economics, permitting, and monitoring which are important to develop an overall approach for resolving TRO management problems in the Colorado River Basin.

- Develop a list of potential TRO control demonstration projects that may be submitted to the USBR for consideration for federal funding pursuant to Public Law 109-320.

Project Components to Decision-making
To accomplish these stated objectives, four tasks were undertaken:

Task 1: Evapotranspiration by Riparian Vegetation: The purpose of this task was to synthesize information on TRO ET rates as well as those of potential replacement vegetation. The literature on TRO and native riparian vegetation describes a wide range of ET rates for each vegetation type, and there is also no agreement if a reduction in TRO will increase the availability of water resources. Due to the wide range of reported ET rates and lack of consensus over water savings potential, it cannot currently be determined: a) how much water is being used by TRO, b) how much water could potentially be saved by controlling TRO and revegetating treated areas with native plants, and c) the cost-effectiveness of a TRO management program vis-à-vis the potential benefits.
A panel of ten experts (Panel) was convened in November 2008 to try to answer this question. These individuals were identified based on their knowledge and expertise in the areas of riparian and floodplain upper terrace ecosystems ecology; ET rate measurement of vegetation associated with these ecosystems; hydrologic interaction between vegetation, groundwater and surface water; and TRO control and revegetation approaches. The Panel’s resulting report is an independent evaluation of the ET issue. The Tamarisk Coalition’s role was organize and facilitate the Panel’s review and to provide formatting and grammatical editing of the report. An independent peer panel approach was selected as the best means of advising policy makers in the Basin States because many experts from different fields provide a balanced understanding of the problem. Incorporating opinions from these interrelated fields creates a balance that is critical for policy makers as it provides expert advice that sifts out biases inherent in each field of research. Although consensus was desired, there are dissenting positions on a couple of the questions. The Panel’s report, although incorporated within this report, is a stand alone document.

**Task 2: TRO Management, state-of-the-science:** This task focused on the current understanding of TRO distribution, impacts, and management approaches. These include:

- Rate of TRO infestation and methods of spread.
- Extent of TRO infestations to include a detailed distribution map based on existing data.
- Wildlife habitat and biodiversity impacts especially as it relates to endangered and threatened species specifically the Southwestern willow flycatcher and the four endangered Colorado River fish species.
- Sediment deposition and transport impacts.
- Salinity and soil chemistry impacts.
- Wildfire threat.
- Cultural resources impacts.
- Recreation impacts.
- Ecosystem response to widespread tamarisk biological control by the tamarisk leaf beetle (*Diorhabda elongata*).¹
- Biomass utilization.

**Task 3: Programmatic issues and the economics of TRO management.** The purpose of this task is to evaluate:

- Costs of TRO management compared to potential water savings.
- Future impacts if control actions are implemented vs. future impacts of no management.
- Planning and permitting constraints.
- Potential habitat mitigation requirements.
- Consistency of TRO management activities with other environmental programs and concerns.

¹ Biological control is the use of living organisms, such as predators, parasitoids, and pathogens, to control pest insects, weeds, or diseases.
Other items addressed include permitting, coordination, monitoring, funding opportunities, impacts of TRO infestations outside of the Colorado River watershed, and an inventory of ongoing projects. This task will identify issues and potential obstacles to implementing an effective large-scale TRO management program.

**Task 4: Demonstration Projects.** This task integrates the information compiled in Tasks 1 through 3 and articulates knowledge gaps that require research. A preliminary list of candidate demonstration sites is identified based on each site’s abilities to address these research needs. A prioritization framework will be developed for projects including the control and revegetation of treated areas in both the Upper and Lower Basins. This list will provide the Basin States potential demonstration projects for submittal to the USBR for consideration under Public Law 109-320.

Other sections in this document include: conclusions, recommendations, next steps, and numerous appendices that provide additional technical information.

**Task 1: Evapotranspiration by Riparian Vegetation**

Rivers anchor the society, economy, and ecology of the arid American West. Their stewardship is central to the region’s long-term future. Restoration of rivers and riverbanks could generate many benefits, but the question remains whether increased water savings would be among them.

A panel of experts was convened in November 2008 to try to answer this question. The report focuses on ten specific questions on the current knowledge about tamarisk and Russian olive effects on water availability. The Panel assembled to complete the report was asked to address whether TRO water use, or evapotranspiration, is sufficiently understood to reasonably predict the water savings associated with TRO removal and native species restoration. The panel was also asked to detail where and how future research and demonstration projects could best contribute to tamarisk and Russian olive management and its role in the stewardship of Western rivers.

Although tasked with evaluating both tamarisk and Russian olive, the panel concluded that very little information exists about Russian olive. The report therefore addresses tamarisk almost exclusively.

The full ET Peer Panel’s report titled, *Independent Peer Review of Tamarisk & Russian olive Evapotranspiration Colorado River Basin* is included in Appendix C attached as a Data-DVD. Appendix C also includes audio PowerPoint presentations by Panel members.

**Question 1: What does existing research tell us about the use of water by TRO in different ecological settings?**

A key conclusion of the panel is that *native vegetation can use either more or less water than tamarisk*, depending on the identity of the native species, stand densities, and environmental and site conditions such as depth to groundwater and salinity. Panel members expressed two distinct
perspectives on how ET rates can be predicted or extrapolated from one site to another: 1) ET depends on several factors that vary by site, making extrapolation relatively complex; and 2) ET is relatively well-predicted from canopy characteristics and reference ET (ET$_o$) for the site in question.

It is unreasonable to expect or to use a single value for ET from TRO systems. It is possible, however, to express water consumption in relatively narrow ranges for specific classes of vegetation stand characteristics and site conditions. To normalize across sites with different weather and climate, ET or water consumption measurements should not only be reported in terms of absolute units, such as mm or acre-feet, but should also be normalized for climatic evaporative demand by dividing by a reference ET (ET$_o$).

**Question 2:** Can ET measurements from lower latitude states be used to infer potential ET rates in higher latitude states? What about elevation differences?

ET rates can reasonably be re-scaled to new latitudes and elevations by expressing tamarisk ET as a fraction of reference ET (ET$_{OF}$) for each site. This would be very useful as most studies to date on ET rates have taken place in the Lower Basin states of the Colorado River.

**Question 3:** What is known about ET rates for replacement vegetation, both riparian and upper terrace floodplain species? What is an appropriate palette of replacement species for each ecosystem within the Colorado River watershed?

Generally speaking, ET rates for replacement vegetation are not as well studied as for tamarisk. It is clear that replacement species exhibit a very wide range of ET values, from values typically higher than tamarisk to values significantly lower. In the riparian zone phreatophytic tree communities (e.g., mainly cottonwood-willow (Populus-Salix) vegetation) which are appropriate for shallow groundwater and low salinity areas, exhibit ET rates comparable to tamarisk at maturity and full canopy closure. Some replacement species (e.g., shrubs and grasses) that have been studied exhibit lower ET rates. Replacement of tamarisk with these diverse facultative or non-phreatophytic plant types that are adapted to upper floodplain terraces may reduce ET, depending on the density of the removed tamarisk and the availability of water. However, few studies are available where tamarisk and replacement species ET were measured at the same time and place. These studies sometimes show equal or greater ET rates by possible replacement species, typically on a per-plant basis. Where replaced tamarisk stands are dense with high canopy cover, however, native replacement vegetation comprised predominately of facultative or non-phreatophytic species will seldom achieve similarly high densities or cover (and by inference, ET values) on a stand or community basis. The choice of appropriate replacement species can be based on three driving factors at nested scales: climate (regional-scale), hydrology / water table characteristics (reach-scale), and salinity (site-scale). Figure 1 illustrates a cottonwood / shrub / grass plant community typical of some river sections within the Colorado River Basin.
Salinity is a pervasive challenge in the Lower Basin, and revegetation and restoration of highly saline, xeric sites may be extremely difficult. Panel members had divergent views about the practicality, feasibility, and cost of trying to restore infested areas on such sites in the Lower Colorado River Basin. Native plant community restoration is technically achievable on many of these sites, but economic feasibility rests with value of the restored habitat as perceived or assigned by the managing agency or landowner. In comparison, several areas in the Upper Basin will likely experience passive revegetation after tamarisk control because infestations are less dense, there is good presence of native vegetation, and periodic over-bank flooding occurs.

**Question 4: What role does infestation density play in overall ET rates?**

ET rates for all vegetation species vary positively with amount of canopy cover for similar age class and ecological setting. It is probably sufficient to treat canopy cover categorically; i.e., high, medium, and low categories within broad size classes and types of ecological setting that can be used to assign ET rates or ranges to particular stands.

**Question 5a: Can the Panel agree on a narrower range of TRO ET than is described in the literature?**

Based on all available evidence, the Panel reached consensus that the typical range of tamarisk ET on western rivers is 0.7 to 1.4 meters per year, (ET$_o$F of 0.3 to 0.7, centering on a mean value of 0.5). The extremes of this ET range occur in distinct settings. In the southwestern US along the Colorado River, a healthy, dense tamarisk forest well supplied with groundwater can use up to 1.4 meters of water per year over a 300 day growing period (ET$_o$F of 0.7). A similar stand experiencing water and salinity stress, such as on upper floodplain terraces, would likely have significantly lower evapotranspiration. Insufficient knowledge exists about Russian olive to estimate its range of ET rates.
King and Bawazir (2003) reinforced this conclusion on the paucity of ET research for Russian olive. They note that there are few ET studies reported in literature on Russian olive. One recent U.S. Geological Survey (USGS) study in Nebraska provides some information that indicates that evapotranspiration averages for Russian olive were similar to those of tamarisk (Irmak et al. 2005, 2009).

**Questions 5b and 5c: Can a range of water savings per acre be agreed to? Can a relative range of water savings between TRO and replacement plant communities be agreed to?**

The range of water savings is large and depends on site ecology, hydrology, and the identity of replacement vegetation. Water savings requires the replacement of tamarisk with species that require less water. This can only occur on sites appropriate for more xeric replacement vegetation.

**Figure 2: Eddy Covariance instrumentation used to measure ET on the Rio Grande in New Mexico (Photo courtesy of Salim Bawazir, New Mexico State University).**

In general, potential water savings will range from 50-60% to less than zero (if replacement vegetation uses more water than tamarisk). Water salvage will typically occur only for a few years (during early growth) in areas where riparian species such as cottonwood and willow are the appropriate replacement vegetation for tamarisk. For other replacement vegetation, potential water savings are higher but vary among species and depend strongly on site factors. The greatest opportunity for meaningful water savings will occur on upper terraces located within the floodplain. However, the greatest opportunities for recovery of other ecosystem service values may occur in the mesic riparian fringe where water savings are lower.
**Question 5d: Is there potential for saving water and increasing stream flows in the Colorado River system by implementing TRO control and restoration actions?**

Most panel members agreed that the potential exists for saving water and increasing stream flows in the Colorado River system, through appropriate and well-planned TRO control and restoration measures which include:

- Revegetation as a critical component of restoration.
- Replacement vegetation for tamarisk on upper floodplain terraces composed of more xeric native species suitable for site-specific precipitation, soils, salinity, and groundwater depths.
- Long-term maintenance of the restoration action.

Panel members agreed that water salvage should not be expected in areas where the appropriate replacement vegetation is willow-cottonwood and where restoration therefore necessarily revegetates with these species. Considerable areas in both the Upper and Lower Colorado River Basin (range by river reach or tributary: 20-90%) are likely suitable for restoration to species more xeric than cottonwood and willow.

More conclusive and quantitative answers to the questions of whether and how much water savings will likely occur are not yet available. Well-planned restoration experiments coupled with good ET and hydrologic monitoring and modeling would help provide a more conclusive and quantitative answer. Whether water makes it to the channel and increases surface flow or enters groundwater depends on the hydrology of the system.

**Question 6: If climate change occurs, what might be the implications for ET rates from TRO as well as potential replacement vegetation? Change in range expansion?**

The Panel has high confidence of a region-wide rise in temperatures throughout the year due to climate change. Temperature increases could drive higher ET by increasing the driving force for evapotranspiration and/or increasing photosynthetic rates. Increased temperatures could lead to higher ET rates by extending the growing season and regional extent of tamarisk. However, temperature, drought, and biological control stress could lower ET rates or leave them unchanged. Other factors of uncertainty include precipitation rates and forms (i.e. snow versus rain) and increased CO₂ concentrations.

**Question 7: What are the implications of active biological control in the Upper Basin? Implications for the Lower Basin?**

At its current rate of expansion, the tamarisk leaf beetle (*Diorhabda elongata*) will spread throughout the Upper Colorado River Basin by September 2010. The long term impact on tamarisk density remains a matter of speculation, but a 50% reduction in green tamarisk biomass seems likely across the Upper Basin within the next five years.
The northern ecotype beetles released in the Upper Basin will very likely continue to move slowly southward as they evolve to cope with southern environmental conditions. The Crete (southern ecotype) beetle population will likely make it to the Lower Basin from California. It is likely that within 5 to 10 years the beetles will be in the lower Colorado River system from either/or the Upper basin populations or the California populations. It is possible that large scale defoliations could occur soon (within 2-3 seasons) after Crete beetles reach or are introduced into the Lower Basin.

The beetles will continue to assist tamarisk control indefinitely, as they can respond to evolved resistance by the tamarisk (which herbicides cannot do). However, they need to be accompanied by active monitoring, restoration, and in some cases additional control measures to achieve desired outcomes for ET and other values.

**Question 8: What are the potential benefits or impacts if TRO management within the Colorado River Basin states does not occur?**

Proactive management has time and again produced better results, for lower costs, than reactive steps taken in crisis mode. It is reasonable to expect that without TRO management, both species will continue to expand – tamarisk especially in the Upper Basin, and Russian olive especially in its understory. These expansions into new areas will most likely increase ET.

The other critical point is that tamarisk management is already occurring – as described above, an effective bio-control agent for tamarisk has been released and is spreading on a regional scale within the Upper Basin. At this stage, we must consider what benefits and impacts will accrue if bio-control proceeds without any additional management measures. First, bio-control by itself will not finish the job of controlling tamarisk. Second, the chance to reclaim and restore tamarisk-invaded sites controlled by beetles is best when it is proactive rather than reactive. Finally, bio-control will reduce ET in the short term by reducing tamarisk ET. However, monitoring after bio-control will be essential for adaptive management responses such as the need to control secondary invasions.

Most Panel members view tamarisk as a negative component of the system overall, one whose continued spread will be a detriment to the river system and whose control is desirable regardless of whether water savings can be demonstrated.

One Panel member disagrees that removing or controlling tamarisk will be beneficial or that expansion into new areas will most likely increase ET.

**Question 9: Can modeling be used to clarify potential water savings resulting from TRO management?**

Water savings due to TRO management can be assessed using three general modeling approaches: 1) a comparison of modeled and remotely sensed ET rates, among locations with and without TRO stands; 2) a comparison of modeled ET rates from TRO stands before and after
stand removal; and 3) an integrated hydrologic model that simulates or predicts ET as a function of vegetation type, vegetation density, and climate. A hydrologic model can be used to predict if reductions in ET will be converted to groundwater storage or streamflow. These models can also indicate optimal management scenarios that maximize water savings by focusing TRO management on areas that provide the greatest benefit. A surface energy balance application has the best chance of detecting relative differences in ET rates.

**Question 10: Future Research needs?**

The Panel identified specific recommendations for developing quality research/demonstration sites in both the Upper and Lower Basins and the importance of establishing consistent protocols for data collection. Sites should be located on river reaches or in watersheds with well-defined boundaries, geology and surface and subsurface flows so that entire water budgets can be modeled over time. An interdisciplinary team to establish such protocols and to vet demonstration proposals should include at least one expert from each of the following areas: ecology, hydrology, remote sensing, ET modeling, direct ET measurement, restoration, and bio-control.

**Figure 3: Tamarisk biological control monitoring, Colorado River near Moab, Utah.**

A number of critical issues were also identified that would greatly benefit from additional research. These include:

1. All aspects of the invasive species Russian olive;
2. Various approaches to improve ET measurement methods and to better parameterize ET models;
3. ET rates of halophytic and xeric replacement species;
4. Ecosystem response to and effectiveness of biological control;
5. Ascertain the Upper Basin’s need for active revegetation;
6. Identify the implications of TRO removal – especially on streambank erosion and stabilization; and
7. The effectiveness of soil manipulation.

In all situations, the Panel encourages all TRO ET measurement systems and programs to receive extensive peer review by communities of experts to reduce experimental biases and pitfalls and to promote effective expenditure of public dollars.
Task 2: TRO Management – state-of-the-science

In order to assess TRO distribution, the state-of-the-science, and the range of information available on impacts, the Tamarisk Coalition extensively reviewed literature, conducted interviews and compiled information on the following:

- Rate of TRO infestation and mechanisms of spread.
- Extent of TRO infestations including a detailed distribution map based on existing data.
- Wildlife habitat and biodiversity impacts especially as they relate to endangered and threatened species; specifically the Southwestern willow flycatcher and the four endangered Colorado River fish species.
- Sediment deposition and transport impacts.
- Salinity and soil chemistry impacts.
- Wildfire threat.
- Cultural resources impacts.
- Recreation impacts.
- Ecosystem response to widespread tamarisk biological control by the tamarisk leaf beetle (*Diorhabda elongata*).
- Biomass utilization.

Mechanisms of Spread

Tamarisk Reproductive Biology

Di Tomaso (1998) provides a review of tamarisk (see Figure 4a and 4b) ecology and much of the information summarized here is discussed in more detail in his paper. Tamarisk has many characteristics typical of an early successional species. Because it requires bare, wet ground for colonization, it is dependent on disturbance such as floods; however, heavy rainfall or irrigation water could also create suitable conditions. Seedlings are often found on recently deposited or scoured riparian substrates. Tamarisk produces many small, lightweight seeds which are dispersed by wind, aided by a hair tuft, or may be carried by water. Larger tamarisk trees can produce as many as 500,000 seeds each year and may bloom across almost the entire growing season, giving it a much broader window of opportunity to colonize available substrates. Seeds are only viable for about 5 weeks, and the site of germination must remain moist for 2-4 weeks or seedlings will die. At the same time, seedlings must not be inundated for 4-6 weeks following germination, and large floods even two years after germination may lead to plant mortality (Birken and Cooper 2006). Once established, seedlings can grow up to 3-4 meters (m) (approximately 10-14 ft) per year and may begin reproducing at the end of their first year.

Tamarisk’s Rate of Spread

A timeline of tamarisk introduction and spread is detailed in Di Tomaso (1998). Tamarisk was introduced on the east coast of North America, where it was sold by plant nurseries in the early
Western nurseries began selling tamarisk in the mid-1850s and it was planted to prevent erosion, provide shade and windbreaks, as well as for its ornamental value. Tamarisk was found to provide some form of erosion control, bank stability, and sediment deposition; thus, reducing sediment loads to reservoirs (Brotherson and Field 1987, Campbell 1970). Soon tamarisk began escaping cultivation and was recognized as a problem species as early as the 1920s. Tamarisk’s spread was rapid – an approximately 3-4% increase in acreage per year. An estimated 4,000 hectares (ha) (9,900 acres) were covered in the 1920s compared with approximately 470,000-650,000 ha (1.2-1.6 million acres) in 2000 (Zavaleta 2000). Researchers at Colorado State University (CSU) have used data on the pattern of spread of tamarisk (and Russian olive) to develop a model that predicts where infestation is likely to occur in the future. For more information on this model please see the Mapping Summary in Appendix D.

The invasion of tamarisk roughly coincided with the advent of major anthropogenic changes in western rivers as well as climatic conditions (i.e., droughts and wet periods) that may have favored the spread of tamarisk (Birken and Cooper 2006). As rivers were dammed and regulated and water was diverted for irrigation and other uses, conditions in riparian areas changed in ways that may have favored tamarisk over native species such as cottonwood and willow. These anthropogenic and climatic conditions generally reduced flows, the frequency and intensity of flood events, and may have increased drought conditions as well as the salinity of riparian soils (Di Tomaso 1998, Glenn and Nagler 2005). Like tamarisk, cottonwoods and willows are dependent on flood events for seedling establishment, so all three species would be negatively impacted if flood events became more infrequent. However, because tamarisk is more tolerant of drought and high salinity than are cottonwood and willow, it gained a competitive advantage under these conditions (Glenn and Nagler 2005).

However, researchers are not in agreement regarding the conditions under which tamarisk can invade native riparian communities. Some researchers argue that tamarisk is only able to outcompete native riparian species under these stressful conditions (high salinity and drought) because, in part, river regulation conserves water in reservoirs thus limiting overbank flows that can tend to flush away surface salts (Glenn and Nagler 2005). Proponents of this view conclude
that restoring more natural flow regimes to western rivers will reduce tamarisk’s competitive advantage under stressful conditions and allow native trees to establish and coexist with tamarisk (Glenn and Nagler 2005). Other researchers point out that tamarisk invaded some rivers before they were dammed (such as the lower Green River) and is invasive on other rivers that have never been regulated (such as the Virgin River) (Birken and Cooper 2006). Proponents of this view argue that river regulation is not the primary force driving tamarisk invasion and therefore restoring more natural flow regimes will not reduce its spread. In their view, more natural flow regimes, with high water (flood) years followed by low water years, may even encourage the establishment of more tamarisk (Birken and Cooper 2006).

Whether or not the restoration of more natural flow regimes will reduce the invasiveness of tamarisk is a complex question and is not within the scope of the TRO Assessment. For the purposes of the TRO Assessment it is assumed that the current flow regime, regulated for flood control, power generation, and water supply will continue. Figure 5 illustrates tamarisk along the Lower Colorado River while Figure 6 provides the mapped tamarisk infestations within the Colorado River Basin based on all available mapping and inventory data (see Appendix D for details).

Figure 5: Lower Colorado River near Blythe, California (Photo courtesy of Bureau of Reclamation).
Figure 6: Mapped tamarisk infestations in the Colorado River Basin.
Russian Olive Reproductive Biology
Katz and Shafroth (2003) provide a comprehensive review of Russian olive (*Elaeagnus angustifolia*) (Figure 7a) biology and much of the information summarized here is discussed in more detail in their review. Contrary to tamarisk, Russian olive has the characteristics of a late successional species. The tree produces large seeds contained in a fruit (Figure 7b) that are 1-1.5 centimeters (cm) (approximately 0.4-0.6 inches) long and dispersed primarily by birds and other vertebrates. Seed dispersal occurs primarily during the fall and winter with seeds remaining viable for 1-3 years. Russian olives do not reach reproductive maturity until approximately 10 years of age. A critically important feature of Russian olive biology is its shade tolerance. Russian olive grows more quickly than cottonwood in shaded conditions (Shafroth et al. 1995) and is able to establish in undisturbed herbaceous vegetation (Katz 2001). This is important because it means that unlike most invasive species, such as tamarisk, Russian olive is not dependent on disturbance to establish.

![Russian olive tree and seeds](image)

Figure 7: a. Russian olive tree and seeds (b.)

Russian Olive’s Rate of Spread
There is far less information available on the rate of spread or invasive characteristics of Russian olive. Compared to tamarisk, Russian olive spreads more slowly as it is a late successional species that is not adapted for rapid reproduction and dispersal. The species was introduced to the Western U.S. in the early 1900s when it was planted as a shade tree, windbreak, and in hedgerows. Russian olive was not common outside of cultivation until 20-50 years following its introduction to the West. Despite the fact that it is now recognized as an invasive species, it was widely promoted and states subsidized plantings through the 1990s for wildlife habitat and erosion control. It is still sold as a horticultural plant in many states. Russian olive is now invasive in 17 western states, but there is no accurate estimate of the number of infested acres. Within the Colorado River Basin it is found primarily in the Upper Basin in certain areas such as the White River (see Figure 8), but also occurs in the Little Colorado watershed, as well as the
Salt and Gila Rivers in the Sonoran Desert. Figure 3 in Katz and Shafroth (2003) is a map summarizing distribution of Russian olive. The predictive model in development at CSU, referred to in the discussion of tamarisk, will also predict potential future infestations of Russian olive. For more information about this project please see the Mapping Summary in Appendix D.

Figure 8: Russian olive on the White River near the Utah / Colorado state line.

Perhaps because of Russian olive’s slow rate of spread, it has generated much less concern than the more aggressive tamarisk. However the very characteristics that make it slow to spread may make it a more difficult problem in the long run. Its shade-tolerance enables it to invade under woody canopies, and a larger seed size conveys a competitive advantage on its seedlings, allowing them to establish within herbaceous groundcover. This means that Russian olive may be able to invade established native riparian communities, whereas tamarisk must wait for physical disturbance to open up bare ground. However if cottonwood forests cannot replenish themselves by recruiting seedlings, Russian olive may continue to invade and eventually come to dominate these riparian forests.

Figure 9 provides the mapped Russian olive infestations within the Colorado River Basin based on all available mapping and inventory data (see Appendix D for details).
Figure 9: Mapped Russian olive infestations in the Colorado River Basin.
Mapping and Inventory Results

As a component of the TRO Assessment, the Tamarisk Coalition created comprehensive databases and maps characterizing tamarisk and Russian olive infestations throughout the entire Colorado River Basin. Appendix D, provided as a Data-DVD, details how the maps were developed and includes:

- Geographic Information Systems (GIS) data
- Display maps of TRO infestations
- Reports describing the condition of TRO infestations in specific areas
- Spreadsheets outlining infested acres, treatments and associated costs
- Website resources for ongoing data collection and updates

The data package is designed to provide users with multiple pathways to:

- Explore GIS and non-GIS data in the database
- View TRO infestation on a broad or focused scale
- View attribute data for specific data sets
- Create and export maps containing TRO data
- Print GIS maps on many scales with preferred map details included

The goal of this effort was to enhance the user’s understanding of the TRO infestation within the Colorado River Basin. Table 1 presents information on the overall inventory of TRO within the Colorado River Basin from all available data sources (see Appendix D). Acreage figures for aerial extent and calculated full canopy cover acreage of TRO are listed when the data configuration allows for this calculation. Due to many different types of mapping protocols being utilized to gather this inventory data, it is not possible to calculate areas of infestation for certain data sets. These data sets are generally composed of point data only; i.e., TRO location is noted with no area extent (polygon) identified. For data sets made up of polygons, acreage estimates are provided in the Table 1. These calculated figures are then totaled at the bottom of the table for the data available in polygon form only. The folder in Appendix D that contains the instructions for accessing these polygons is found in the file entitled “TRO Mapping Data Package and Instructions for Use.”

In the Colorado River Basin, mapped tamarisk accounts for a total stand acreage (aerial extent) of approximately 250,000 acres. This value must be considered low because a significant amount of the data is point data with no actual acreage assigned to this information. Thus, it must be concluded that the acreage totals represent only a portion of the entire mapping data set. Additionally, the differences in these data formats underscore the importance of universally adopted mapping protocols for TRO in order to produce a more homogenous mapping data set for the entire Colorado River Basin. Suggested mapping protocols are described in Appendix D. Figure 10 shows the importance of groundtruthing (i.e., visual confirmation of remote sensed data) coupled with high resolution photos to estimate aerial extent, canopy cover, the riparian / upper terrace ratio of tamarisk within the floodplain.
Implications for Water Savings
Both Russian olive and tamarisk can be expected to continue to spread in the Colorado River Basin if they are not managed. These species may use more water than native vegetation when they are replacing upland species rather than riparian species (see the Tamarisk and Russian Olive Evapotranspiration Peer Panel summary.) If the spread of TRO is halted and reversed, there is potential for water savings. The greatest opportunity for meaningful water savings will occur on upper terraces located within the floodplain.

Conclusions
Tamarisk and Russian olive have different mechanisms of spread. While tamarisk is adapted to aggressively colonize bare patches of soil, Russian olive is shade tolerant and is able to invade established communities of native plants. Both species can be expected to continue to spread in the Colorado River Basin. Russian olive, because of its shade-tolerance and larger seed size, may enable it to eventually come to dominate these riparian forests where soil conditions are favorable.
<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Tamarisk / Russian Olive</th>
<th>Type of Data</th>
<th>Type of Mapping</th>
<th>Aerial Extent (acres)</th>
<th>Full Canopy Cover (acres)</th>
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<td>Tamarisk</td>
<td>GIS-polygon</td>
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<td>GIS-point</td>
<td>Ground surveys, Aerial photo-interpretation, and remote-sensing techniques</td>
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Table 1, continued

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<th>Type of Data</th>
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<th>Aerial Extent (acres)</th>
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<td>N/A</td>
</tr>
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</table>

| Totals-Tamarisk (estimated):                                           | ~250,000                                      | ~160,000                  |
| Totals-Russian Olive (estimated):                                      | ~42,000                                       | ~40,000                   |

**Notes:** Data received as of January 7, 2009. The majority of the GIS data is in point form rather than polygons and therefore it is not possible to calculate actual areas of infestations.
Wildlife and Sensitive Species

It is commonly assumed that invasive plant species are detrimental to wildlife because they displace native plant species on which animals depend. This is true in many cases, especially when an animal has specialized on a native plant for food or shelter. It is also possible that an invasive will serve as an acceptable substitute for the native plant it displaces and thus have little to no direct or immediate effects on the animal species. (However, if an invasive impacts ecosystem functionality at a landscape level, the animal species may be exposed to indirect effects). Facilitative interactions are also common (Rodriguez 2006) and may occur when the invasive modifies habitat in a manner beneficial to an animal or serves as a food source. Effects of invasive plants on wildlife are diverse and depend on the species considered.

There has been considerable debate regarding the wildlife habitat value of tamarisk and Russian olive (Olson and Sferra 2009; Paxton et al. 2009; Dudley et al 2009 and Longland 2009). As with other invasive plants, the habitat value of tamarisk and Russian olive will depend on the wildlife species being considered. In addition, the effect of TRO on wildlife will depend on the native plant species that they are replacing. In some areas, TRO may provide better habitat for certain wildlife species than did the native plants that previously occupied the area. However, for many other wildlife species in the same area, replacement of native plants by TRO may prove detrimental (Longland 2009).

This review focuses primarily on the interaction between *Tamarix* spp. and wildlife. Because Russian olive spreads more slowly than tamarisk, many have viewed it as less of a threat and there has been little research on its effects on wildlife. In the past, Russian olive was promoted as beneficial to wildlife because many birds and small mammals feed on its fruits (Zouhar 2005). However, Hansen et al. (1995) report that it has poor food value for mule deer and only fair value for white-tailed deer and elk. Though this study occurred in Montana, outside of the Colorado River Basin, it is unlikely that the nutritional value of Russian olive will vary significantly.²

Knopf and Olson (1984) have shown that Russian olive stands tend to support less bird species diversity than did stands of native vegetation; however, this effect was not statistically significant. Stoleson and Finch (2001) found that some species of songbirds preferentially placed their nests in Russian olive, however when Southwestern willow flycatchers (*Empidonax trailli extimus*, SWFL) did so, they were more likely to be parasitized by Brown-headed cowbirds (*Molothrus ater* - a brood parasite). When Russian olive has invaded areas that previously did not support trees, it may provide a nesting substrate for avian nest predators such as magpies. However, Gazda et al. (2002) did not see a significant reduction in duck nest predation rate following Russian olive removal. Given that Russian olive invasion alters the structure of riparian vegetation, and its fruits are a food resource for some animals, it is clear that more research on the interaction between native wildlife and Russian olive is needed.

² General note on research references used in the TRO Assessment – Some studies referenced, although the research occurred outside the Colorado River Basin, were considered to be appropriate to use as they reflected conditions that occur within the Basin.
Birds

Riparian habitat is critical for many taxa, including birds. Riparian areas support significantly greater numbers and diversity of birds than do surrounding uplands, especially in the arid West. In addition, riparian corridors are critical stop-over points during the migration of many birds. Invasive plants, such as tamarisk, are predicted to dominate southwestern riparian ecosystems in 50-100 years if they maintain their current rate of spread (Howe and Knopf 1991). This trend has raised concern among wildlife managers and bird researchers that bird populations may be negatively impacted. Because of this concern, there has been more research on the impact of tamarisk on birds than any other wildlife taxa. It is often assumed that tamarisk provides poor habitat for birds. However, research has shown that the impact of tamarisk varies between bird species and depends on the native habitat that is being replaced. Two papers by Sogge et al. (2008) and van Riper et al. (2008) recently addressed this issue.

For many birds the structure of vegetation is thought to be the most significant characteristic (Hausner et al. 2002, Jones and Bock 2005). Vegetation structure, i.e. height, density, branching patterns, etc. determines in part, its suitability as nesting habitat and foraging habitat. For instance, a cavity nester, like a woodpecker, will not build a nest in a stand of willow shrubs, but will use a dead cottonwood branch. Similarly a red-tailed hawk cannot hunt small mammals concealed beneath a dense tamarisk thicket; rather it hunts over open grassland. When tamarisk structure mirrors that of native vegetation, it may serve as a suitable substitute. For instance, young tamarisk plants are structurally similar to native willow shrubs and are a suitable nesting substrate for many birds that nest in willows. It should be noted, however, that tamarisk structure can vary and thus the quality of habitat it provides will vary. While young tamarisk shrubs resemble willows in having many whip-like stems, older tamarisk are tree-like and may have trunks greater than 12 inches in diameter with a dense canopy of branches. Tamarisk monocultures provide relatively little structural diversity. It is important to note however that riparian obligate species, such as the SWFL and Yellow-billed Cuckoo, are tied to riparian habitats primarily because of the food resources and vegetation structure in these areas. They are not associated with these habitats because of a preference for or habitat value of tamarisk specifically.

Structure is not the only important vegetative characteristic however, and several studies have shown that bird species composition is closely associated with the species composition of the plant community (Walker 2006, Fleishman et al. 2003). Plant species vary in value as a food resource as some produce edible seeds, berries or nectar-rich flowers. Different species of plants may also host different species of insects. The relative importance of plant species composition vs. vegetation structure may depend on the geographical scale being considered (Fleishman et al. 2003).

Many birds are insectivores, thus the insect communities supported by tamarisk will in part determine its ability to support bird populations. Studies comparing insect populations in tamarisk versus native vegetation have yielded varying results in large part due to the collection methods used, vegetation types adjacent to the study area and varying degrees of tamarisk dominance in the tamarisk invaded sites (i.e. monoculture vs. mixed tamarisk-native). In general, tamarisk appears to support an equal, and in some circumstances a greater abundance of insects than native vegetation (Durst et al. 2008). Types of insects supported by the two types of
vegetation may vary, but not in a manner expected to affect bird populations. However, Wiesenborn and Heydon (2007) found that tamarisk stands had fewer predaceous insects than did native willow stands. Predaceous insects contain more nitrogen and may have greater nutritional value. Wiesenborn and Heydon’s examination of SWFL fecal samples suggests that SWFL in tamarisk dominated sites may supplement their diets with insects caught in other vegetation types.

When tamarisk is intermixed with native vegetation and does not form a monoculture, it may be beneficial for many species of birds. On the Lower Colorado River, Van Riper et al. (2008) saw a significant increase in the number of birds present as the percentage of native vegetation in these mixed stands increased from 20-40%. The positive response in bird numbers leveled off at around 60% native vegetation. This is described as a “threshold effect” by the authors, who suggest that the most cost effective way to increase bird diversity and abundance in large tamarisk monocultures would be to create a mixed stand by increasing the percentage of native vegetation to 20-40%. However, mixed native-tamarisk stands (created via natural processes or restoration) may not be climax communities. If tamarisk continues to colonize and out-compete native plants, these mixed stands may become tamarisk monocultures in the future.

The bird species that has received the greatest amount of study in relation to tamarisk is the Southwestern willow flycatcher (*Empidonax traillii extimus*, SWFL, Figure 11). This bird was listed as endangered in 1995 primarily due to loss of habitat. The U.S. Fish and Wildlife Service (USFWS) has identified its critical habitat as that in Figure 12. This critical habitat is located in Apache, Cochise, Gila, Graham, Greenlee, Maricopa, Mohave, Pinal, Pima, and Yavapai counties in Arizona; Kern, Santa Barbara, San Bernardino, and San Diego counties in southern California; Clark County in southeastern Nevada; Grant, Hidalgo, Mora, Rio Arriba, Socorro, Taos, and Valencia counties in New Mexico; and Washington County in southwestern Utah (USFWS 2005).

The SWFL breeds in “young” riparian habitat (Paxton et al. 2007) and while historically such habitat was dominated by willow (*Salix* spp.), tamarisk is now extensive in the SWFL’s range. Approximately 25% of SWFL now breed in mixed native-tamarisk habitat and 25% breed in tamarisk dominated habitats (Durst et al. 2006). There is no evidence that SWFL breeding in tamarisk-invaded habitat suffer physiological stress (Owen et al. 2005), reduced productivity or survivorship (Sogge et al. 2006).

Tamarisk provides habitat for the SWFL, and those concerned with the survival of this species fear that tamarisk control efforts will hinder the recovery of the SWFL. Biological control of tamarisk with the tamarisk leaf beetle (*Diorhabda* spp.) has been particularly controversial. In
March of 2009, the Center for Biological Diversity sued the U.S. Animal and Health Inspection Service (APHIS) and the USFWS for failing to reinitiate Endangered Species Act consultation regarding potential threats to the SWFL resulting from tamarisk biological control (USDCA 2009). When APHIS consulted with USFWS during the tamarisk leaf beetle approval process they assured USFWS that no beetles would be released within 200 miles of SWFL habitat, and that the tamarisk leaf beetle could not become established within the flycatcher’s range due to their photoperiod requirements.

Figure 12: Southwestern Willow Flycatcher (Empidonax traillii extimus) critical habitat (USFWS 2005).
In 2006, the City of St. George, Utah (which is within the range of the SWFL) released tamarisk leaf beetles along the Virgin River and they are now established and spreading in SWFL habitat (Olson and Sferra 2009). There have been anecdotal reports that SWFL nests have already failed as a result of tamarisk defoliation by the tamarisk leaf beetle. The Center for Biological Diversity requests that: 1) spread of the tamarisk leaf beetle is monitored, 2) native plants are restored in areas of SWFL habitat where tamarisk has been/may be defoliated, and 3) there be no further introduction of tamarisk leaf beetle within the SWFL’s range (Silver 2008). The lawsuit increases the urgency of the need for further research and revegetation efforts. In response to this lawsuit, on June 5, 2009 APHIS at the recommendation of U.S. Department of Agriculture (USDA)’s Office of General Council temporarily suspended current permits and will not issue new permits for interstate beetle distribution. For more information on the tamarisk leaf beetle see the Biological Control section presented later in the TRO Assessment.

The Tamarisk Coalition is aware of only four bird-monitoring efforts being done specifically in the context of biological control. One project, in Dinosaur National Monument, is being done by the Rocky Mountain Bird Observatory with funding from the Bureau of Reclamation and the National Park Service. At present, three years of data have been gathered. Two other bird monitoring efforts began in spring 2009, one spanning Western Colorado and Eastern Utah is being performed by the Rocky Mountain Bird Observatory and the Tamarisk Coalition with funding from the Walton Family Foundation. Another study, on the Virgin River, is being done by Tom Dudley and Michael Kuehn of the University of California Santa Barbara and collaborators (Dudley and Kuehn, pers. comm. 2009). In 2009 the Utah Division of Wildlife Resources will also be monitoring the SWFL and impacts from biological control on the Virgin River.

Many other riparian bird species besides the SWFL have been observed to nest in tamarisk. Among these is the Yellow-billed cuckoo (Coccyzus americanus), which unlike the SWFL, prefers mature riparian woodland and historically nests in cottonwood stands (Hughes 1999). The western U.S. population of this species is a candidate for federal endangered species listing due to habitat loss. Sogge et al. (2008) lists eleven other species of birds that have been observed to nest in tamarisk dominated habitats and may experience local declines following tamarisk removal. This list includes several species on the USFWS Birds of Management Concern list and the Partners in Flight Priority Species list such as Summer tanager (Piranga rubra), Bell’s vireo (Vireo bellii) and Lucy’s warbler (Vermivora luciae).

Reptiles and Small Mammals
As discussed above, tamarisk will impact different species of wildlife in different ways depending on their habitat requirements and preferences. The effect of tamarisk replacing native habitat on small mammals and reptiles has not been extensively studied, and conflicting results of existing studies make it difficult to draw general conclusions. A study by Ellis et al. (1997) showed no reduction in species richness of small mammals associated with tamarisk. In contrast, several studies have shown that reptile densities and diversity are lower in tamarisk habitat than in native vegetation (Jackle and Gatz 1985, Jones 1988, Lovich and DeGouvenain 1998). Recent work by Bateman et al. (2008) on the Middle Rio Grande showed that tamarisk control efforts may benefit some lizard species and do not appear to affect snakes or toads. Foraging by bats appeared to increase in areas where tamarisk was controlled, while the abundance of another small mammal, the shrew, was not affected.
Fish
Relative to terrestrial wildlife, much less is known about the impact of tamarisk on aquatic animals. In the upper Colorado River Basin, it has been suggested that tamarisk control may benefit several endangered fish species including the Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*). These species shown in Figure 13 are endangered in part due to changes in the river’s flow regime that have reduced the availability of backwaters, side channels, and bottomlands that are critical habitat (Van Steeter and Pitlick 1998). As discussed elsewhere in this document, these changes in flow regime may promote tamarisk establishment. Tamarisk in turn, further reduces the number of side channels and backwaters by stabilizing banks, and increasing sedimentation and channelization of the river (Graf 1978). The results of these studies suggest that removal of tamarisk may improve habitat for the endangered fish species in the Upper Colorado River Basin.

![Fish images](image)

**Figure 13:** a. Colorado pikeminnow (*Ptychocheilus lucius*)  b. Razorback sucker (*Xyrauchen texanus*) (photos courtesy of U.S. Fish and Wildlife Service).

The river and the riparian vegetation bordering it are linked via evapotranspiration, nutrient cycling and leaf litter input (Gregory et al. 1991). Leaf litter is an important source of food and habitat for many aquatic macroinvertebrates, which in turn are an important food source for fish. The Bailey et al. (2001) study comparing macroinvertebrate communities on tamarisk leaf litter to those on native cottonwood leaf litter showed significantly fewer and less diverse macroinvertebrates on tamarisk. The authors suggest that this difference may be due to higher tannin content of tamarisk and the narrow structure of the leaves. How this difference between tamarisk and native leaf litter will scale up the trophic levels is unknown. However, it is possible that if tamarisk is the major source of leaf litter for the river, food resources for fish may be reduced relative to rivers with more native leaf litter. Kennedy et al. (2005) documented an increase in the density of native pupfish in a Nevada desert stream following tamarisk removal. The authors attributed this effect to a reduction in stream shading which promoted growth of algae on which the pupfish feed. These studies demonstrate the cascading effects of tamarisk across trophic levels.

To date there have been no studies directly examining the impact of tamarisk and tamarisk management on fish in the Colorado River Basin. The Kennedy et al. (2005) study occurred outside of the Colorado River Basin, and its results may not be generalizable as the habitat and fish species studied were unique. To our knowledge, the relationship between tamarisk’s ability to alter the structure of stream channels and its effect on fish has not been studied directly. However as many large scale tamarisk control projects are planned it will be advantageous to examine the impact of these efforts on fish and other aquatic organisms.
Lower Colorado River Multi-Species Conservation Program

One organization that is intimately involved in tamarisk management efforts in the Basin is the Lower Colorado River Multi-Species Conservation Program (LCR MSCP). The LCR MSCP was developed between 1996 and early 2005 as a long term (50-year) endangered species compliance and management program for the historic floodplain of the Lower Colorado River (see Figure 14). The program coordinates stakeholders in Arizona, California and Nevada with the goals of:

1. Conserving habitat and working for recovery of threatened and endangered species as well as reducing the likelihood of additional listings.

2. Accommodating present water diversions and power production as well as optimizing opportunities for future power and water development.

3. Providing the basis for incidental take authorizations.

The program can be viewed at [http://www.lcrmscp.gov/](http://www.lcrmscp.gov/) and covers 27 plant and animal species (see Table 2) including five federally endangered species, one federally threatened species, two candidate species, as well as species that are protected under California, Arizona or Nevada law. In addition, the program covers several species that have the potential to be listed by state or federal government during the term of the LCR MSCP. Of the species covered by the LCR MSCP, four species of birds, two species of bat and one species of butterfly utilize tamarisk for breeding and/or foraging (Olson and Sferra, 2009).
Table 2: Species covered by the Lower Colorado River Multi-Species Conservation Program.

<table>
<thead>
<tr>
<th>Species name</th>
<th>Taxa</th>
<th>Conservation Status¹</th>
<th>Observed to use tamarisk as habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuma clapper rail</td>
<td>bird</td>
<td>FE</td>
<td></td>
</tr>
<tr>
<td>Southwestern willow flycatcher</td>
<td>bird</td>
<td>FE</td>
<td>✓</td>
</tr>
<tr>
<td>Bonytail</td>
<td>fish</td>
<td>FE</td>
<td></td>
</tr>
<tr>
<td>Humpback chub</td>
<td>fish</td>
<td>FE</td>
<td></td>
</tr>
<tr>
<td>Razorback sucker</td>
<td>fish</td>
<td>FE</td>
<td></td>
</tr>
<tr>
<td>Desert tortoise (Mojave population)</td>
<td>reptile</td>
<td>FT</td>
<td></td>
</tr>
<tr>
<td>Yellow-billed cuckoo</td>
<td>bird</td>
<td>FC, ASC, CE</td>
<td>✓</td>
</tr>
<tr>
<td>Western red bat</td>
<td>mammal</td>
<td>ASC</td>
<td>✓</td>
</tr>
<tr>
<td>Western yellow bat</td>
<td>mammal</td>
<td>ASC</td>
<td>✓</td>
</tr>
<tr>
<td>Desert pocket mouse</td>
<td>mammal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colorado River cotton rat</td>
<td>mammal</td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td>Yuma hispid cotton rat</td>
<td>mammal</td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td>Western least bittern</td>
<td>bird</td>
<td>ASC, CSC</td>
<td></td>
</tr>
<tr>
<td>California black rail</td>
<td>bird</td>
<td>ASC, CT/CFP</td>
<td></td>
</tr>
<tr>
<td>Elf owl</td>
<td>bird</td>
<td>CE, NP</td>
<td></td>
</tr>
<tr>
<td>Gilded flicker</td>
<td>bird</td>
<td>CE</td>
<td></td>
</tr>
<tr>
<td>Gila woodpecker</td>
<td>bird</td>
<td>CE</td>
<td></td>
</tr>
<tr>
<td>Vermillion flycatcher</td>
<td>bird</td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td>Arizona Bell’s vireo</td>
<td>bird</td>
<td>CE</td>
<td>✓</td>
</tr>
<tr>
<td>Sonoran yellow warbler</td>
<td>bird</td>
<td>CSC</td>
<td>✓</td>
</tr>
<tr>
<td>Summer tanager</td>
<td>bird</td>
<td>CSC</td>
<td>✓</td>
</tr>
<tr>
<td>Flat-tailed horned lizard</td>
<td>reptile</td>
<td>CSC</td>
<td></td>
</tr>
<tr>
<td>Relict leopard frog</td>
<td>amphibian</td>
<td>FC, ASC, NP</td>
<td></td>
</tr>
<tr>
<td>Flannel mouth sucker</td>
<td>fish</td>
<td>ASC</td>
<td></td>
</tr>
<tr>
<td>MacNeil’s sootywing skipper</td>
<td>insect</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Sticky buckwheat</td>
<td>plant</td>
<td>NEP</td>
<td></td>
</tr>
<tr>
<td>Threecorner milkvetch</td>
<td>plant</td>
<td>NEP</td>
<td></td>
</tr>
</tbody>
</table>

¹FE= Listed as endangered under the Federal Endangered Species Act (ESA)
   FT= Listed as threatened under the Federal ESA
   FC= Candidate for listing under ESA
   ASC= Arizona wildlife of special concern
   CE= Listed as endangered under the California Endangered Species Act (CESA)
   CSC= California species of special concern
   CT= Listed as threatened under the California Endangered Species Act (CESA)
   CFP= Fully protected under the California Fish and Game Code
   NP= Nevada protected
   NEP= Nevada critically endangered plant

The LCR MSCP was implemented in 2005 and is currently in the 4th year of the 50 year permit. According to the LCR MSCP "Final Implementation Report, Fiscal year 2010 Work Plan and
Budget, Fiscal Year 2008 Accomplishment Report”, the program has created or restored 2,508 acres of habitat critical to the species covered by the LCR MSCP and augmented the Lower Colorado River with 86,627 razorback sucker and 29,102 bonytail fish. As part of the programs monitoring and research goal, two important documents were produced in 2008: “Species Accounts for the Lower Colorado River Multi-Species Conservation Program” and “Final Five Year Monitoring and Research Priorities for the Lower Colorado River Multi-Species Conservation Program: 2008-2012.” These documents are available as technical reports on the LCR MSCP homepage http://www.lcrmscp.gov/. In addition, over $7.7 million have been put into Conservation Area Development and Management. This represents significant progress towards the program goals of 8,132 acres of new habitat, augmentation with 660,000 razorback sucker and 620,000 bonytail and a $25 million investment in projects that protect and maintain habitat to the covered species. The LCR MSCP requires funds of $20,729,810 for FY 2010 which will aid progress towards program goals over the next 45 years. Funding for this program has been committed by states and the federal government for the duration of its 50 year permit. The program incorporates an active adaptive management component which assures that conservation measures will evolve in response to new research, technology and cost assessments.

**Upper Colorado River Endangered Fish Recovery Program**
Established in 1988, the Upper Colorado River Endangered Fish Recovery Program is a partnership of public and private organizations working to recover four endangered fish species while allowing continued and future water development. The program is working to recover the Colorado pikeminnow, razorback sucker, humpback chub and bonytail that once thrived in the Colorado River system. Dam installation and the introduction of nonnative fish changed the river environment and put these fish at risk. Program partners include federal, state and private organizations and agencies in Colorado, Utah and Wyoming. Recovery strategies include conducting research, improving river habitat, providing adequate stream flows, managing non-native fish, and raising endangered fish in hatcheries for stocking. [http://www.fws.gov/coloradoriverrecovery/](http://www.fws.gov/coloradoriverrecovery/)

**San Juan River Basin Recovery Implementation Program**
The San Juan River Basin Recovery Implementation Program is designed to help recover the Colorado pikeminnow and the razorback sucker while allowing water development to continue in the San Juan River Basin. Partners include federal, state and Tribal governments. The main program elements include protection of genetic integrity, management and augmentation of populations; protection, management, and augmentation of habitat; water quality protection and enhancement; interactions between native and nonnative fish species; monitoring and data management. [http://www.fws.gov/southwest/sjrip/index.cfm](http://www.fws.gov/southwest/sjrip/index.cfm)

**Implications for Water Salvage**
While there are no direct connections between wildlife and water savings, any TRO management that occurs in an effort to save water will need to abide by state and federal laws protecting sensitive species where applicable. Minimizing negative impacts of TRO management on species that utilize TRO habitat is an important consideration.

**Conclusions**
With regard to all three of the programs described above, there are opportunities for cooperative efforts which meet the goals of both the Basin States and the program sponsors. For the two fish
recovery programs, the effect of potential Basin States’ tamarisk management is positive especially as it relates to habitat improvements. For the LCR MSCP, a carefully designed and implemented program can be consistent with the goals of the LCR MSCP to enhance habitat for many species, both riparian and upland terrace animal communities.

Tamarisk removal is often undertaken in part as a means to improve wildlife habitat. While this is certainly true in some cases, a review of the available research and reports indicate that benefits of tamarisk control depend on the extent and density of tamarisk infestation, infestation location, and the wildlife species being considered. Clearly, more research is desirable as a better understanding of the interactions between tamarisk and wildlife would allow managers to make more informed decisions.

Tamarisk management will almost always benefit wildlife in the long term when it includes revegetation, either passive or active. Denuded areas rarely support much wildlife, and unless tamarisk is replaced by vegetation of equal or greater habitat value, wildlife will not benefit from control efforts and may in fact be negatively affected. In cases where site characteristics or funding limitations make revegetation impracticable, it may be in the best interest of wildlife to leave tamarisk in place. When control is undertaken, timing control efforts to minimize disturbance to wildlife is an important consideration. In addition, selective removal of patches of tamarisk may afford wildlife some suitable tamarisk habitat while areas where it was removed are being restored. Regularly assessing the impact of restoration work on wildlife both during and after a project will allow managers to adjust their current efforts and plan future efforts so as to benefit or minimize detriment to wildlife.

If TRO management does not occur, it can be speculated that as infestations expand in the future some species may adapt and do fairly well in a TRO dominated floodplain. Other species, both terrestrial and aquatic, may suffer.

**Salinity and Soil Chemistry**

**Soil Salinity and Moisture Stress**
As the salinity of soil water around a plant’s root system increases, greater osmotic pressure is required on the part of the plant to extract water molecules from the soil (Hem 1967). When a plant cannot generate enough osmotic pressure to separate water molecules from salt and other dissolved solids, it will succumb to drought stress and desiccation. Drought (moisture stress) and elevated levels of soil salinity trigger similar physiological responses in many species of plants; i.e., low soil water potential triggers stomatal closure and reductions in growth, transpiration, photosynthesis, and other metabolic processes (Pataki et al. 2005, Singh et al. 1999).

**Competitive Advantages: Salt and Drought Tolerance**
Soil salinity has become elevated in the floodplains and bottomlands of southwestern rivers where human activities have resulted in diminished water quality and altered natural flooding regimes (Shafroth et al. 2008). Historically, overbank flooding on unregulated rivers leached salts and other ions from riparian and floodplain soils, but reductions in flooding frequency and magnitude have created drier, more saline soils (Glenn and Nagler 2005). Evaporation of
agricultural irrigation runoff has also contributed to elevated soil salinity in these areas. Tamarisk does not require a saline environment for establishment and growth, but can thrive in soils where other types of vegetation are inhibited by elevated salinity (Hem 1967). As a facultative halophyte (salt-tolerant plant), tamarisk has a competitive advantage over many native woody riparian plant species (Wiesenborn 1996, Shafroth et al. 1995), particularly on regulated rivers.

Different studies have reported different ranges of salt tolerance for tamarisk, collectively these values range to as high as 30,000 milligrams per liter (mg/l) (DiTomaso 1998, Brotherson and Winkel, 1986, Carmen and Brotherson, 1982, Glenn et al. 1998). Conversely, growth of many native woody plant species, such as willow and cottonwood, is inhibited by saline conditions. In a greenhouse-based study of eight riparian tree and shrub species salinity tolerances, Jackson et al. (1990) reported that cottonwood (Populus fremontii) and willow (Salix gooddingii) did not tolerate salinity over 1,500 mg/l of soil water. In their analysis of seedling growth and survival, Jackson et al. (1990) report that tamarisk and two species of mesquite (Prosopis spp.) achieved 100% survival up to 36,000 mg/l. Extremely high levels of salinity did eventually impact tamarisk seedlings. Shoot growth and biomass were significantly lower when irrigated with solutions of 36,000 and 60,000 mg/l (Jackson et al. 1990). Glenn et al. (1998) conducted a greenhouse study of tamarisk and five other native tree and shrub seedlings on a salinity gradient. They reported that tamarisk seedlings had a significant advantage in growth rate and transpiration over cottonwood and willow seedlings at elevated levels of salinity.

Tamarisk is also more salt-tolerant than Russian olive, which occurs on soils with low to medium concentrations of soluble salts (Carman and Brotherson 1982). In a north-central Utah field study of soil and vegetation characteristics on tamarisk-invaded sites versus Russian olive-invaded sites, tamarisk occurred on soils with salt concentrations ranging from 700 - 15,000 mg/l, while salt concentrations at Russian olive sites ranged from 100 - 3,500 mg/l (Carman and Brotherson 1982). Accordingly, plant species associated with Russian olive-invaded sites were described as “typical of mesic meadows”, whereas species associated with tamarisk-infested sites were “characteristic of halophytic (plant) communities” (Carman and Brotherson 1982).

Tamarisk’s competitive advantage on altered soils extends to post-fire regeneration. Following fire, soils tend to be dryer and more saline. Deposits of ash on the soil surface contain elevated concentrations of phytotoxic boron (see Wildfire Threat section). Salt glands in tamarisk foliage concentrate and excrete salt, boron, and various other substances, while native riparian plant taxa may be more susceptible to salts and heavy metal toxicity (Busch and Smith 1993).

**Tamarisk’s Contribution to Soil Salinity**

Salts and other elements are absorbed by tamarisk roots from deep within the soil profile, and redistributed to the soil surface via leaf litter. Salt glands occur on tamarisk leaf surfaces and on the stems of new growth. “Collecting cells” accumulate high concentrations of salt which are then secreted as crystals onto leaf surfaces (DiTomaso 1998, Jackson et al. 1990), along with other ions, such as potassium, nitrate, calcium, magnesium, sulfur, phosphorus, bicarbonate, chloride, molybdenum, boron, copper, manganese, aluminum, zinc, and various additional trace elements, depending on what is present in the root environment (Storey and Thomson 1994, DiTomaso 1998). The diversity of ions secreted by tamarisk glands suggests that the glands as
well as the root system have a low level of selectivity to uptake of ions, and that tamarisk can regulate the ionic composition of its cells by secreting a range of elements, allowing it to survive on a wide range of soil types (Storey and Thomson 1994). It is believed that, over time, senescent deciduous tamarisk foliage containing elevated concentrations of salt and other ions accumulates on the soil surface (Figure 15), increasing salinity and inhibiting the germination and growth of other species of riparian vegetation (DiTomaso 1998, Wiesenborn 1996). It should be noted that there is some debate over the extent to which tamarisk contributes to soil salinity. Some researchers argue that altered river conditions are largely responsible for elevated soil salinity, and halophytic tamarisk now occupies areas too saline for other native species to survive.

**Figure 15: Salt accumulation on surface soils, Colorado River near Moab, Utah.**

Research indicates that tamarisk stand attributes, such as stand age and density, may be related to levels of soil salinity. Ohrtman et al. (2009) analyzed soil salinity associated with tamarisk stand age and density along a reach of the Middle Rio Grande River. The highest soil salinity occurred in middle-aged tamarisk stands (approximately 15 years of age), while lower levels of salinity occurred in older stands (Ohrtman et al. 2009). This may be due in part to greater foliar outputs from mid-aged trees (with branching foliage present across most of their vertical profile) than from mature trees with well-developed trunks and foliage occurring primarily up in the crown (Sher 2009). Ohrtman et al. (2009) further reported that tamarisk density did influence salinity levels, but not heavily; and suggested that surface evaporation, especially in un-shaded areas prone to soil capillary action, was also contributing to elevated soil salinity. Study areas subject to overbank flooding had lower levels of soil salinity than areas where flooding was eliminated by a levee (Ohrtman et al. 2009, Sher 2009). In some riparian and floodplain vegetation communities where tamarisk is the dominant overstory species, salt-tolerant species such as native saltgrass (*Distichlis spicata*) become well-established in the understory (Brotherson and Winkel 1986).

**Salinity Remediation and Ecological Restoration**

Some researchers believe that tamarisk only has a competitive advantage over native riparian plants under conditions of drought and increased soil salinity (Glenn and Nagler 2005). These researchers advocate overbank flooding as a mechanism for re-establishing native riparian species. Overbank flooding leaches salts out of riparian and floodplain soils and scours away organic litter; preparing the seedbed, providing soil moisture, and reducing soil salinity (Ohrtman et al. 2009, Sher 2009, Bay and Sher 2008). A reduction in soil salinity would negate tamarisk’s
competitive advantage under high salinity conditions, and flooding would further reduce its advantage because tamarisk is less tolerant of inundation than some native species (Vandersande et al. 2001).

Levels of riparian and floodplain soil salinity vary greatly across the Upper and Lower Basins of the Colorado River watershed. In the context of ecological restoration, soil salinity is an important site factor to evaluate in advance of revegetation (Shafroth et al. 2008). Many native riparian species may not be able to tolerate the elevated salinity levels now present and remediation may be necessary for successful revegetation. Where overbank flooding is not an option, other treatments exist for soil salinity amelioration. Mechanical surface soil treatments may be used to reduce or redistribute salts in leaf litter or surface soils, and commercial soil amendments which convert salts to neutral or acidic compounds are available (Shafroth et al. 2008). Caplan et al. (2001) document a soil restoration project in New Mexico that used mechanical soil mixing treatments as well as a gypsum soil amendment. Though this project was successful in restoring native grasses, the technique is quite expensive and may not be practicable in many areas.

Saline conditions on regulated rivers favor the growth and establishment of certain salt-tolerant native species, including saltbush (Atriplex spp.), arrowweed (Pluchea sericea) and the extreme halophyte iodinebush (Allenrolfea occidentalis), all of which can excrete salt and/or penetrate saline surface soils and utilize less saline groundwater from deeper in the soil profile (Glenn and Nagler 2005). While cottonwood is not generally considered a salt-tolerant species, a study by Rowland et al. (2004) documents genetic variability in salt-tolerance among different families of Rio Grande cottonwood (Populus deltoides var. wislizenii). This variation could be used to benefit restoration if stock from salt-tolerant families were chosen for revegetation in sites with higher salinity. A summary of the salt tolerances of grass, forb, shrub, and tree species frequently used in revegetation projects is available in Shafroth et al. (2008) Planning Riparian Restoration in the Context of Tamarix Control in Western North America.

Implications for Water Savings
There are no direct connections between soil salinity and water savings. However, tamarisk management undertaken with a goal of saving water may involve revegetation and soil salinity will play a large part in determining which plant species should be used in revegetation (a list of salt-tolerant plants are included in Appendix E). Some researchers advocate using over-bank flooding to reduce soil-salinity levels. If this technique is used, water savings may not occur if overbank flooding reduces channel efficiency and thus increases water conveyance losses.

Conclusions
Levels of riparian and floodplain soil salinity vary greatly across the Upper and Lower Basins of the Colorado River watershed. Tamarisk does not require a saline environment for establishment and growth, but can thrive in soils where other types of vegetation are inhibited by elevated salinity. Research indicates that soil salinity levels may be related to tamarisk stand attributes, such as stand age and density. Although many native plants cannot tolerate high salinity levels, many other native plants can be used for revegetation materials (see Appendix E for a listing of salt tolerant species).
Sedimentation

This review focuses on the role of vegetation in sedimentation, bank stability and erosion processes, and TRO establishment as it relates to channel narrowing. Sedimentation refers to the behavior of particles suspended in river water, how they move and settle, and what external factors affect this behavior. Channel response and potential erosion impacts resulting from TRO management are also reviewed.

Braided, meandering and complex channel morphology represents the natural state of river systems in which vegetation and wildlife have adapted. Significant ecological, hydrologic, and geomorphic changes have occurred during the 19th and 20th centuries along many large floodplain rivers in the American Southwest (Birken and Cooper 2006). Many factors that contribute to these changes include climatic factors such as drought, construction of large dams, trans-basin diversions, and non-native vegetation invasion (Allred and Schmidt 1999). Tamarisk now dominates most floodplain ecosystems in the West (Birken and Cooper 2006).

Tamarisk can provide some form of erosion control in riparian areas (Brotherson and Field 1987). The extensive tamarisk root system makes the bank area more stable and resistant to erosion than prior to establishment. The channel stabilization and increased sediment deposition then reduces sedimentation of reservoirs further downstream (Campbell 1970); thus, some reservoirs may not have experienced the anticipated sediment loads that were included in designs. In 1926, tamarisk was introduced to the Rio Puerco, New Mexico to control erosion and slow the amount of sediment filling the Elephant Butte Reservoir (Friedman et al. 2009). A study to investigate causes of channel narrowing and incision in Canyon de Chelly National Monument, found that the effects of root reinforcement provided by TRO had a significant impact on bank stability and bank-failure frequency (Pollen-Bankhead et al. 2009).

The development of heavily vegetated floodplains composed primarily of tamarisk, often within the active channel, has caused many rivers to narrow (Birken and Cooper 2006). Vegetation contributes to channel narrowing by increasing sediment deposition and bank stability (Schumm and Lichty 1963, Friedman et al. 1996). Griffin et al. (2005) present ideas about how channels with and without vegetation impact the hydraulics of the river which in turn impact sedimentation. According to their research, the morphologies of natural stream channels are determined by the interactions of flow, sediment, and riparian vegetation. The establishment of vegetation in the active channel may facilitate the vertical accretion or build-up of sediment and reduce channel capacity by increasing hydraulic roughness and increasing sediment deposition rates (Merritt and Cooper 2000). An example of channel capacity reduction due to tamarisk infestation is documented in a USGS study of a reach of the Arkansas River near the town of Las Animas, Colorado. There, the USGS’ hydraulic modeling indicated a potential to increase channel capacity by 55,000 cubic feet per second, a 69% increase above existing capacity, through the elimination of a dense stand of tamarisk in a leveed reach of the river (USGS, Pueblo, CO 8/7/2006 written communication to CWCB).

The amount of sediment deposited depends on many factors including the rate at which the water is flowing. The higher the flow velocity, the greater the sediment loads being carried. When the water slows, sediments are deposited. Channel narrowing begins (see Figure 16) as dense woody
vegetation on the floodplain slows the overbank flow, forms drag on the stems and reduces the stream’s power or ability to carry sediment on the floodplain to less than the amount of force needed for erosion of the cohesive material on its surface. This results in deposition of fine sediment on the floodplain rather than transport of the sediment back into the river (Griffin et al. 2005).

Figure 16: Purgatoire River, near Trinidad, Colorado.

In a properly functioning river system, the channel form adjusts to handle increases in runoff with minimal disturbance of the channel and associated riparian plant communities. The channel is constantly adjusting itself to the water and sediment load that is present. If a channel is down-cut or incised and flows can no longer access the floodplain, the stream system can no longer provide important hydrologic functions such as sediment disposition and periodic flooding of vegetation. Riparian areas with incised channel conditions with a limited or nonexistent floodplain lack the ability to retain water (Prichard et al. 1998).

Riparian vegetation has the ability to establish within and near the channel, which increases channel stabilization (Pollen-Bankhead et al. 2009). It has been hypothesized that channel narrowing is initiated by establishment of vegetation on the channel bed during a period of relatively low flows that lasts several years (Friedman et al. 1996). Subsequent higher flows deposit sediment around the vegetation, forming a new stable surface adjacent to a narrower channel (Schumm and Lichty, 1963). Riparian vegetation can only facilitate sediment deposition when flows are high enough to bring the newly established vegetation in contact with flowing sediment, but not so high as to remobilize the channel bars (and hence remove the vegetation itself) (Allred and Schmidt 1999). Similar processes have been proposed to explain channel narrowing following introduction of non-native shrubs (Friedman et al. 1996).

The establishment of tamarisk impacts channel ability to shift morphology from single-thread meandering to braided. This is attributed to the fact that tamarisk stands have a higher stem density than native vegetation which allows it to be more resistant to removal by large floods (Pollen-Bankhead et al. 2009). Tamarisk stems change the landscape properties of gravel and cobble islands and bars, as well as those of adjacent channels, by slowing the flow velocities and increasing the force required to remobilize the channel bed, while woody roots increase the bed resistance to mobilization (Cooper et al. 2003). Figure 17 provides a characterization of changes...
in morphology from a wide braided channel to a narrow, reduced width incised channel as tamarisk is established.

Figure 17: Characteristic changes in channel morphology and vegetation as tamarisk is established.

Tamarisk is able to colonize in areas of debris fans and gravel bars exposed at very low flows where no native species are established (Cooper et al. 2003). Tamarisk has facilitated vertical sediment accretion that can lead to bar enlargement, and subsequent channel narrowing (Allred and Schmidt 1999). These processes are evident in both regulated (Lodore Canyon) and unregulated (Yampa Canyon) study areas, showing that tamarisk can change channel and floodplain sediment storage and vegetation patterns along both unregulated and regulated rivers (Cooper et al. 2003).

Channel narrowing along the Green River has been attributed to hydrologic alteration which happened at the same time as the proliferation of tamarisk (Allred and Schmidt 1999). The majority of tamarisk establishment and Green River channel narrowing occurred long before river regulation by Flaming Gorge Dam. Tamarisk initially colonized bare in-stream sand deposits (e.g., islands and bars), and most channel and floodplain changes followed the establishment of tamarisk (Birken and Cooper 2006).

Another impact of tamarisk establishment related to channel narrowing is the simplification of secondary channels. Allred and Schmidt (1999) found that many of the small islands originally included in their study reach on the Green River became attached to the banks at most discharges because the secondary channels that once surrounded these islands had become constricted and/or completely filled with sediment. They found that surface area of secondary channels
decreased by over 50% between 1938 and 1993. Van Steeter and Pitlick (1998) identified similar trends toward channels becoming less complex in some reaches of the Colorado River near Grand Junction, Colorado.

**Tamarisk and Russian olive management**

The specific effects of TRO management on sedimentation and erosion have only been explored by a few. More documentation of erosion following tamarisk management is needed (Hilldale 2007). Specifically, land managers need to understand the impacts of tamarisk management and sedimentation on small reservoirs and other water resources infrastructure (Friedman et al. 2009).

Large-scale TRO management, when it is a dominant riparian species, can lead to extreme erosion if revegetation is not accomplished (Friedman et al. 2009). Erosion following tamarisk management should be considered, but not be assumed, because the potential for erosion depends on many factors including soil type, bank height, treatment method and revegetation, morphology of the channel, slope, presence of geologic control, hydrology (controlled or uncontrolled river), and timing of a flood after revegetation (Hilldale 2007). Although TRO management may cause additional sediment load to a river system, the actual impact to a downstream reservoir may be no different over the life of the reservoir; i.e., sediment loads discharged as pulses may be no different than the cumulative sediment loading that would have occurred if TRO had not been established.

Pollen-Bankhead et al. (2009) suggest that TRO management along the entire riparian corridor in Canyon de Chelly, Arizona may lead to the introduction of significantly more sediment to the system through bank widening processes, although it is not known whether this change alone would be sufficient to cause a shift in channel morphology to the wide-braided channels that were once characteristic of the canyon.

Protecting bank vegetation can reduce the risk of erosion in TRO management projects. Erosion following herbicide application is likely to be greatest along flood-prone rivers with sand banks (Friedman et al. 2009). In addition, when TRO mortality is abrupt due to mechanical or chemical control techniques, TRO root stability can decrease quickly (Hilldale 2007). Tamarisk biological control (see Biological Control section) may provide the greatest bank protection. This is because slow mortality of tamarisk in response to beetle defoliation maintains root viability, continuing to provide increased soil strength as other plants colonize under defoliated tamarisk, providing added erosion protection (Hilldale 2007). However, the sediment impacts could be negative if revegetation of the area is not completed (Friedman et al. 2009). Similarly, in New Mexico, the Interstate Stream Commission notes that land disturbance initiated by removal of tamarisk, even while undergoing transition to native plants can result in significant head-cutting along tributary arroyos. Thus, in areas of sandy/silty soils that occur in much of the Basin, it would seem likely that additional sediment loading will be experienced (Groseclose pers. comm. 2009). When implementing tamarisk management, Friedman suggests avoiding river systems susceptible to erosion; applying herbicide to one small reach at a time; keeping bank vegetation intact, especially willow; and completing quick revegetation of the area.
Implications for Water Savings
Riparian areas with incised channel conditions with a limited or nonexistent floodplain lack the ability to retain water (Prichard et al. 1998). A functioning riparian area, where TRO management has been successful, may have implications for water savings by improving floodwater retention and ground-water recharge. From a different perspective, TRO removal can destabilize river banks and reestablish overbank flooding resulting in a broader water surface exposed to increased transportation losses as has been experienced on the Pecos River in New Mexico (Groseclose pers. comm. 2009).

Conclusions
TRO establishment has played a role in the sedimentation process and morphology of western river systems. TRO management may cause additional sediment load to the Colorado River system. However, over time, this may not be any different than the cumulative sediment loading that would have occurred if TRO had not been established. Methods of TRO management need to be carefully evaluated to determine potential impacts to sedimentation and inputs to water resources infrastructure prior to implementation (Friedman et al. 2009). A properly designed and implemented project can minimize potential sedimentation impacts.

Wildfire Threat

Tamarisk and Wildfire Regimes in Southwestern Riparian Systems
Little information is available on historic fire regimes in southwestern floodplains and riparian areas. No reports of riparian zone fires occur in historical fire accounts of the southwestern U.S. (Zouhar et al. 2008). Dams and diversions, groundwater pumping, agriculture, urban development, and the displacement of native vegetation by invasive exotic vegetation have all contributed to a shift in disturbance regimes on southwestern rivers. Fire has replaced flooding as the major disturbance regime on many southwestern floodplains and riparian corridors (Zouhar 2003, Busch 1995, and others). Multiple sources report that while fire remains uncommon in tamarisk-free riparian areas, fire frequency has increased in many low-elevation riparian ecosystems where tamarisk has become established (Zouhar 2003, Busch and Smith 1993). Increases in fire frequency have been reported for tamarisk-infested riparian areas across the southwest (DiTomaso 1998), including portions of the Colorado, Little Colorado, Bill Williams, Gila, and Virgin rivers (Busch 1995), and the Middle Rio Grande Valley (Stuever 1997). Wildfire intensity can be extreme regardless of the time of year (Drus 2009) or greenness of the plant. The costs to fight wildfires can be significant if occurring in urban or other high value areas as experienced near Phoenix in 2008 (see Figure 18) and can result in mortality to many native plants such as cottonwoods.

There is a need for further research on the relationship between tamarisk, Russian olive and wildfire in southwestern riparian systems. It is unclear whether the presence of tamarisk or Russian olive creates conditions which are conducive to fire, or whether dry conditions and altered disturbance regimes on regulated river systems increase fire risk. In all likelihood, multiple conditions, including flood suppression, water stress, and the replacement of native riparian vegetation by tamarisk and other invasive species, increases the occurrence of fire in southwestern riparian ecosystems (Zouhar 2003). Wildfire impacts include diminished water
quality, altered flood regimes, and drier and more saline floodplain environments. Multiple sources note that increased human presence in riparian areas has resulted in increased sources of ignition. Pre-European settlement sources of ignition, i.e. lightning and burning by Native Americans, are now augmented by untended campfires, debris burning, cigarettes, fireworks, equipment, railroads, and fire in surrounding uplands.

**Tamarisk Adaptations to Fire**

Canopy connectivity in dense stands, the growth form of individual trees, and rapid post-fire recovery have been identified as characteristics that make tamarisk a more “fire adapted” species than native cottonwood or willow. As opposed to open stands of native vegetation, tamarisk can form dense stands of trees with multiple stems, each retaining dry leaf litter and dead branches. This flammable material creates a “fuel ladder” up into the tree crowns of tamarisk (Zouhar 2003) and other tree species present in a mixed stand. It is likely that proximal upland areas (adjacent to river floodplains) also carry an increased risk of fire due to tamarisk, especially those areas where tamarisk has replaced lower-density native vegetation.

While living (fresh) tamarisk foliage does contain volatile oils, it is not considered highly flammable due to its high salt and moisture content (Zouhar et al. 2008, Zouhar 2003, Busch 1995). However, buildup of dry leaf litter can increase fire frequency along river corridors and floodplains where flow regimes have been altered (Ellis 2001). Natural flooding scours away buildup of dry fuels and debris in riparian areas. Reduced flooding in riparian areas may result in accumulation of a thick layer of combustible material, which can increase wildfire frequency, intensity, and severity (Zouhar 2003, Ellis et al. 1998). Ellis et al. (1998) report that periodic surface moisture from flooding or precipitation increases the rates of decomposition of both cottonwood and tamarisk leaf litter on the soil surface.

![Figure 18: Gila River tamarisk wildfire June, 2008](https://example.com/image.png)

Other, highly-flammable, exotic, invasive species of vegetation spreading aggressively in southwestern riparian ecosystems include giant reed (*Arundo donax*), red brome (*Bromus madritensis*), and cheatgrass (*Bromus tectorum*).
Response to Fire: Tamarisk vs. Native Vegetation

Data is needed on the responses of both native and exotic plant species to fire in southwestern riparian systems (Ellis 2001). We are unaware of any data available for riparian forests in the Colorado River Basin. However, a study of riparian forest along the Middle Rio Grande Valley is relevant as it addresses similar species. This study (Stuever 1997) revealed high rates of cottonwood mortality in response to fire. Stuever (1997) suggests that Rio Grande cottonwoods evolved in an environment where wildfires were absent or of light intensity, and that traits such as stump sprouting and thick bark evolved in response to stressors other than fire. Native cottonwood (Populus spp.) and willow (Salix spp.) have the ability to re-sprout from stumps post-fire, but not as quickly as tamarisk recovers by re-sprouting from root crowns (Glenn and Nagler 2005, Zouhar 2003, Ellis 2001). McDaniel and Taylor (2003) reported prolific tamarisk re-sprouting from buried root crowns after a 1986 wildfire in Bosque del Apache National Wildlife Refuge, which resulted in a uniform stand of tamarisk regrowth.

The competitive advantage of tamarisk over cottonwood post-fire is augmented by differences in the timing of seed production. While tamarisk produces large quantities of seed throughout the growing season, the reproductive period for cottonwood is limited to a brief period in the spring, and is dependent on spring flooding for seedling establishment (Zouhar et al. 2008, Glenn and Nagler 2005). Coupled with the reduced frequency of natural flooding on regulated rivers, tamarisk seeding is more likely to coincide with favorable (moist) germination conditions at some point during the growing season than cottonwood seed (Zouhar 2003).

Tamarisk is better adapted to post-fire conditions than many native species. Tamarisk is better able to utilize limited soil moisture, and is more tolerant of elevated levels of salt and mineral nutrients in the soil. Post-fire soil analyses by Busch and Smith (1993) on the Colorado River and Bill Williams River floodplains indicated dryer surface soils, increased soil salinity, as well as elevated levels of phytotoxic boron. While tamarisk can tolerate higher concentrations of boron, other species of vegetation are more sensitive to heavy metal toxicity and elevated soil salinity (Busch and Smith 1993). Predictably, tamarisk and halophytic, drought-tolerant, fire-tolerant shrub species such as saltbush (Atriplex spp.) and arrowweed (Pluchea sericea) have replaced cottonwood and willow in repeatedly burned, low-elevation riparian plant communities (Zouhar 2003, Busch 1995). Along the Colorado River, stands of cottonwood which covered over 5,000 acres in the 1600s were reduced to less than 500 acres by 1998 (Zouhar 2003).

Fire as a Management Tool
Tamarisk is one of the only species for which fire has been utilized as a management tool in riparian areas (Zouhar et al. 2008), most often in combination with other control measures. Where tamarisk and native species are present in mixed stands, survival of native species and revegetation are important components of management plans. Due to cottonwood susceptibility to fire, Stuever (1997) argues that where management objectives call for the preservation of cottonwoods, fire should be excluded or carefully managed. As noted earlier, tamarisk can resprout vigorously into monotypic stands after fire; thus, fire alone is never recommended – it must be used in combination with either mechanical, chemical, or biological control.

In the context of ecological restoration, dense stands of tamarisk can prevent soil treatments, seedbed preparation, and equipment access (Shafroth et al. 2008). Removal or reduction of
woody tamarisk biomass is typically required to facilitate revegetation measures (Shafroth et al. 2008). Prescribed fire is used in the Lake Mead area, for example, in order to reduce above-ground tamarisk biomass and surface litter (Zouhar et al. 2008). Research indicates that tamarisk is most susceptible to fire during periods of moisture stress. Although they are likely to be most effective during the summer months, Lake Mead area burns are typically conducted in the fall to avoid negative impacts to populations of nesting birds (Zouhar et al. 2008). Following controlled burning along the Green River (Ouray National Wildlife Refuge, Utah) Provenza (1982) reported that burning treatments conducted in July prevented 64% of tamarisk from resprouting, while September/October fires prevented resprouting in less than 10% of the plants. Ongoing research is underway to determine the optimal phenological stage(s) at which to burn tamarisk, to achieve the greatest reductions in canopy, density, and fuel loads (Zouhar 2003).

Controlled burning can be utilized in combination with herbicide, mechanical, and biological control treatments. McDaniel and Taylor (2003) reported that herbicide treatment followed by a broadcast burn three years later resulted in 93% tamarisk mortality six years after the original herbicide application. Comparison treatment, mechanical removal, and burning of slash piles at years one and three, resulted in 97% mortality at year six. It is important to note that although both treatments resulted in greater than 90% mortality, the costs associated with the mechanical treatment were over five times higher than those of the herbicide-burn treatment (McDaniel and Taylor 2003). Detailed information on fire as a tamarisk control treatment, tamarisk response post-fire, and integrated management combinations of fire, mechanical, and chemical treatments, is available online through the U. S. Department of Agriculture (USDA) Forest Service Fire Effects Information System (Zouhar 2003). Work by Drus et al. (2009) demonstrates that fire following biological control may be an effective way to kill tamarisk and reduce standing biomass. However timing of this treatment is important. It must be done in the summer when tamarisk are not dormant, otherwise the plant’s energy stores are below in the roots, and are not consumed in the fire (Drus pers. comm. 2009).

**Russian Olive and Fire in Southwestern Riparian Systems**

Russian olive alters the structure of invaded communities by increasing vertical and horizontal canopy density, increasing fuel continuity, and creating volatile fuel ladders (Zouhar et al. 2008, Katz and Shafroth 2003). Russian olive established along the Middle Rio Grande floodplain is described by Caplan (2002) as forming dense, fire-prone thickets that develop into monospecific stands because of vigorous root-sprout growth following fire.

In the USDA Forest Service Fire Effects Information System review of Russian olive, Zouhar (2003) states that there is a scarcity of literature addressing Russian olive fire adaptations and post-fire regeneration. Observational evidence, however, indicates re-sprouting from trunk, roots, and root crown in response to dead or damaged above-ground portions of the tree (Zouhar et al. 2008, Zouhar 2003, Katz and Shafroth 2003, Caplan 2002, and others).

The seeds of Russian olive remain viable longer (up to three years), and germinate under a wider range of conditions than those of cottonwood and other native plant taxa (Katz and Shafroth 2003, Shafroth et al. 1995). In comparison, cottonwood seeds are short-lived, produced in one springtime pulse, and germinate under a narrow range of conditions. Further, Russian olive
seeds are bird and animal-dispersed. These characteristics may give Russian olive an advantage in colonizing burned areas.

**Implications for Water Savings**

Given that tamarisk is fire adapted, wildfires may increase its dominance in riparian areas and thus its water use. Given the effectiveness of fire as a management tool, it can be concluded that removal of tamarisk biomass in this manner in combination with traditional mechanical, chemical, and biological control techniques could provide for water savings when revegetation includes plant species that use less water.

**Conclusions**

Increased fire frequency and intensity favor tamarisk re-establishment over less fire-adapted native riparian species, such as willow and cottonwood, which are slower to re-sprout post-fire (Zouhar 2003). Alteration of natural flow regimes (changes in timing, frequency and intensity of overbank flooding) and drier, more saline riparian environments reduce opportunities for recruitment of new cohorts of native cottonwood (Zouhar 2003). It is likely that these factors, in combination, favor the replacement of native southwest riparian vegetation by tamarisk.

Russian olive alters the structure of invaded communities by increasing vertical and horizontal canopy density, increasing fuel continuity, and creating volatile fuel ladders (Zouhar et al. 2008, Katz and Shafroth 2003).

Controlled burning can be useful in combination with herbicide, mechanical, and biological control treatments for tamarisk. By itself, fire is a poor management approach for tamarisk because it is better adapted to post-fire conditions than many native species. Although burning may be an effective way to control small Russian olive seedlings, burning alone is not an effective treatment for mature trees, which will vigorously re-sprout following treatment (Tu 2003).

**Biological Control**

**Background**

The USDA Animal and Plant Health Inspection Service (APHIS) began to look for potential tamarisk biological control agents in the 1980s. Insects that naturally eat tamarisk in its native ranges throughout China, Kazakhstan, Uzbekistan, Tunisia, Greece, and other countries were studied to evaluate their appropriateness. The tamarisk leaf beetle, or *Diorhabda* spp., was eventually identified in 1992 and the USDA then began an extensive testing process in quarantine. The primary goal of this testing process was to ensure that the beetle would feed exclusively on tamarisk and not harm native plants. Beetles were offered a varied selection of native plants and crop species and subjected to extensive host range testing (Bean 2009). Host range testing determines the list of hosts, or plants, upon which an organism can complete its lifecycle.

Tests revealed that the beetles are highly specialized on tamarisk, preferring tamarisk to all native plants. *Diorhabda* spp. will seek out additional tamarisk after defoliating a tamarisk stand.
instead of searching for different food sources nearby, and will starve in the absence of tamarisk (see Figure 19).

**Figure 19:** Tamarisk defoliated (brown) by tamarisk leaf beetle and non-damaged native vegetation (green), Colorado River in Canyonlands National Park, Utah.

The beetle larvae were able to feed on four North American species of the small xeric shrub frankenia (*Frankenia* spp.). However, the larvae inflicted minimal damage on these plants and the adult beetles did not feed on them at all. It was determined that the impact to the genus *Frankenia* was not significantly detrimental (Bean 2009).

Following these laboratory tests, APHIS approved the tamarisk leaf beetle for field testing in 1999. Beetles were released in outdoor cages at ten sites in six states including California, Nevada, and Utah. These trials confirmed the beetle’s host specificity and it was approved for open releases in 2001. Populations were introduced at seven sites in six states, four of which experienced 2,000-hectare defoliation events by 2006. Ongoing monitoring efforts at the 2001 Lovelock, Nevada beetle release site have documented population expansion throughout the Humboldt Basin that periodically defoliates approximately 30,000 hectares of tamarisk (Bean 2009).
These large area defoliations may have been an initial response to the massive tamarisk infestations in the Humboldt Basin. Now, seven years after the initial release, 75% of tamarisk trees in and around the release site are dead. Yet, tamarisk mortality of only 5% or less can be expected one to four kilometers away from the release. This may indicate that the huge beetle population explosions that are being recorded are merely the beetle’s initial response to an overabundance of tamarisk and that their influence may lessen over time (Dudley et al. 2009).

Since the initial releases, 180,000 adult tamarisk leaf beetles have been distributed in the time period from 2005 to 2008. Fifty beetle outdoor nurseries in ten states have been created, half of which harbor significant populations. Ten of these locations maintain populations large enough to facilitate collections which will support in-state redistributions in 2009 (Hansen and Usnick 2009). Currently, beetle populations are spread across Western Colorado, eastern to central Utah (Jamison and Bean 2009), and a small northwestern plot in Arizona (Dudley pers. comm. 2009).

**Beetle Characteristics**

Very recently the taxonomy of *Diorhabda* beetles has been revised to divide *Diorhabda elongata* into five distinct species within a “*Diorhabda elongata* species group” (Tracy and Robbins 2009.) Four of these species, *D. elongata*, *D. carinata*, *D. sublineata*, and *D. carinulata* have been introduced for tamarisk biological control in the U.S. (see Figure 20); the fifth species *D. meridionalis* is not being used for biological control (Tracy and Robbins 2009). The beetles originating in Kazakhstan and China, which have established in the Upper Colorado Basin, are now designated as *D. carinulata*, but until May 2009 were identified as a sub-species of *Diorhabda elongata*. They are still commonly referred to as *D. elongata* and are referred to as such throughout the majority of this document to reduce confusion.

**Figure 20:** Home Range of tamarisk leaf beetle ecotypes that have been released in the United States: i.e., *Diorhabda carinulata* from Chilik, Kazakhstan and Fukang, China; *Diorhabda elongata* from Crete; *Diorhabda carinata* from Uzbekistan; and *Diorhabda sublineata* from Tunisia (Bean 2009).
**Diorhabda carinulata**

- **Current Range:** Jamison and Bean (2009) found *D. carinulata* populations throughout an estimated 4,000,000 ha (10 million acres) of the Northern Colorado Plateau and Colorado’s Western slope in 2008 (see Figure 21).

- **Postulated Range:** Bean postulates that this population will spread through the entire Upper Colorado River Basin where tamarisk is growing by September of 2010 (Bean 2009). No tamarisk biological control agent has been introduced by APHIS in the Lower Colorado River Basin. However, the beetles are slowly making their way further south. Originally, it was thought that *D. carinulata* would be unable to successfully reproduce and establish populations below 38° north, roughly 75 miles north of the southern borders of Colorado and Utah. This limitation is due to day length requirements that trigger the beetle’s reproductive diapause (a state similar to hibernation) and determines how many generations can occur during a summer. As a result, below 36°-20’N (approximately 45 miles below the southern border of Utah and Colorado) shorter day lengths will trigger premature diapause in *D. carinulata* and beetles will generate only one generation each year (Bean et al. 2009). This reproductive limitation will greatly curtail successful establishment in the Lower Basin (Bean et al. 2007, Lewis et al. 2003). North of 38° N, where summer day lengths are longer, *D. carinulata* are able to produce multiple generations per summer, which greatly aids in their establishment. At latitudes between 38° N and 36°-20”N, beetles will exhibit an intermediate response (some beetles may produce multiple generations per summer) and populations may have some difficulty becoming established (Bean pers. comm. 2009). For instance, a population of *D. carinulata* collected in Delta, Utah was transferred by Utah weed managers to the Virgin River drainage (which lies in this intermediate latitude). This population has exhibited multiple generations per summer, become established and since moved south into northern Arizona (Dudley pers. comm. 2009, Bean pers. comm. 2009).

**Diorhabda elongata**

- **Current Range:** Currently being released in Texas and Coastal California (Carruthers et al. 2006, Bean 2009)

- **Postulated Range:** This species, which originates from Crete and is adapted to more southerly latitudes, may move into the Lower Colorado River Basin. It is more likely that the *D. elongata* being released in coastal California along or near Colorado River drainages will move into the Lower Basin, as opposed to those released in Texas (Bean 2009). It is possible that large scale defoliations could occur soon (2-3 seasons) after Crete beetles reach or are introduced into the Lower Basin.

**Diorhabda carinata**

- **Current Range:** Successfully established in Seymour, north Texas (DeLoach et al. 2009).

- **Postulated Range:** Modeling by Tracy et al. (2009) predicts that this species may do well in grasslands and northern desert areas.
**Diorhabda sublineata**

- **Current Range:** Has been released in southern Texas but establishment is uncertain.

- **Postulated Range:** Modeling by Tracy et al. (2009) suggests that this species may establish well in the Mojave, Sonoran and Chihuahuan deserts.

**Figure 21: Colorado River Basin distribution of *D. carinulata* beetle in 2009.**

Lower Colorado River Basin Dispersal of *Diorhabda* Species

Tamarisk leaf beetles may establish and spread in the Lower Basin via two avenues. *D. carinulata* may evolve and adapt to shorter day lengths enabling them to establish populations farther south. Alternatively, the more southerly adapted species (*D. elongata*, *D. carinata* and *D. sublineata*) may move into the Lower Basin from their release sites in California and Texas. For example, *D. carinulata* populations that have been in the field for eight years have decreased their day length requirement for reproduction by twenty minutes. If these *D. carinulata* populations do move into the Lower Basin it would take at least five years (Bean 2009); it is more likely that the southerly adapted species will spread into the Lower Basin.

**Beetle Distribution Prediction**

Tracy et al. (2009) are applying a Stacked Environmental Envelope Model (SEEM) to five beetle ecotypes to predict appropriate geographical ranges for the beetles based on 59 climatic...
environmental components. The China and Kazakhstan ecotypes are predicted to do well in the northern deserts (Great Basin Shrub Steppe, Colorado Plateau Shrublands, Wyoming Basin Shrub Steppe, Snake/Columbia Shrub Steppe, the Northern Short Grasslands, Northern Western Short Grasslands, western Mojave Desert, and northern tip of Chihuahuan Desert). The Crete ecotype was best suited for the Californian coast Mediterranean and grassland biomes and southern Western Short Grasslands as well as Central and Southern Mixed Grasslands. The Uzbekistan ecotype is predicted to do well in the Central and Southern Mixed Grasslands, the Colorado Plateau Shrublands, Great Basin Shrublands, and the southern interior and coast of California. The Tunisian ecotype is predicted to do well in the Mojave, Chihuahuan, and Sonoran Deserts. This latter ecotype may be problematic for the SWFL because the Tunisian beetle’s predicted distribution overlays most of the bird’s critical habitat in the Lower Basin.

One other ecotype which is from Iran is predicted to survive in southern deserts but has not been released (Tracy et al. 2009). The SEEM results may help to predict beetle population successes in the future. Figure 22 presents the predicted distribution of these four ecotypes of the tamarisk leaf beetle as well as monitored areas of beetle activity. Appendix D contains individual predicted distribution maps for each of the four ecotypes.
Figure 22: Predicted range of tamarisk leaf beetle ecotypes based on 59 climatic environmental components: *Diorhabda carinulata* (Chilik, Kazakhstan and Fukang, China), *Diorhabda elongata* (Crete); *Diorhabda carinata* from Uzbekistan; and *Diorhabda sublineata* from Tunisia (Tracy et al. 2009).
**Ecosystem Response**

Due to the distribution efforts discussed above, other undocumented dispersals, as well as natural dispersal, tamarisk leaf beetle populations are already widely dispersed in the western United States. Despite the testing processes described above, little is known regarding the ecosystem response to the introduction of *Diorhabda* spp. Indirect interactions and food-web subsidies (the beetle being an additional food resource) created by the introduction of the beetle will likely impact non-target species (Pearson and Callaway 2003) and tamarisk biological control experts encourage efforts to study the indirect ecological impacts of *Diorhabda* spp. Many beetle release site managers are working to incorporate ecosystem response information. This is evidenced by the many insectary sites that have collected pre- and post- release vegetation data (Hansen and Usnick 2009). Yet studying the intricate interactions in ecosystems on such a massive scale is a daunting task.

A coordinated, cooperative approach among scientists, land managers, and stakeholders will be necessary to ensure that beetle-induced tamarisk mortality results in water savings. A preliminary effort by several universities, federal agencies, The Nature Conservancy, and the Tamarisk Coalition is currently attempting to achieve riparian restoration (a related goal) by combining research, implementation, and monitoring to address time-sensitive questions about the ecosystem response to tamarisk biological control. The research questions addressed by this project are listed below along with descriptions of current research on *Diorhabda* spp. (Dudley 2009).

**Monitoring the Tamarisk Leaf Beetle** – One of the most important initial steps in understanding *Diorhabda* spp. ecosystem impacts is to monitor its life cycles and reproductive dynamics, population size variations, dispersal patterns, defoliation trends, and potential genetic changes (Dudley 2009). In 2007, the Colorado Department of Agriculture (CDA) and Tamarisk Coalition partnered to conduct large-scale, on-the-ground monitoring work to record the dispersal and establishment of *D. elongata*, to measure the efficacy of the beetle in controlling tamarisk, to monitor the rate of tamarisk mortality, and to ascertain the impacts of this biological control agent on riparian native and non-native plant ecology and wildlife habitat. These efforts have found that beetles released in three Southeastern Utah locations in 2004 have rapidly expanded and were found throughout an estimated 4,000,000 ha (10 million acres) of the northern Colorado Plateau and Colorado’s Western Slope in 2008 (Jamison and Bean 2009).

Another method of obtaining information on a large scale about beetle dispersal and tamarisk defoliation is satellite remote sensing. Dennison et al. (2009) reported that 15 meter spatial resolution Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) data can be used to reliably indicate tamarisk defoliation by *D. elongata*. However, the large time intervals between productions of this imagery prohibit frequent monitoring of defoliation trends. Moderate Resolution Imaging Spectroradiometer (MODIS) data, at a 250 meter spatial resolution, is available often enough to compile useful information but is more coarse than the ASTER data. Dennison et al. (2009) determined that MODIS remote sensing data is adequate to monitor tamarisk defoliation in large stands and may also be appropriate to estimate potential water savings due to tamarisk defoliation.
Pattern and Extent of Tamarisk Mortality – *Diorhabda* spp. induced tamarisk mortality is achieved through a series of defoliation/refoliation cycles, in which a tamarisk stand completely refoliates following a defoliation event. At least six such events must occur over the course of three growing seasons to kill tamarisk and mortality is never 100% (Bean 2009). A better understanding of the timing and spatial patterns of these cycles would greatly aid land managers attempting to balance tamarisk control with other responsibilities (Robinson et al. 2009). It would also aid in prioritizing sites for active revegetation or secondary invasion control.

As the extent, seasonal timing, and frequency of defoliation cycles are a function of *Diorhabda* spp. natural history, it is essential that scientists continue to study the biology of this organism. Recent discoveries include a shift in host plant acceptance to another tamarisk species (*Tamarix parviflora*) (Thomas 2009) and a decreased critical day length (by twenty minutes) in the Chinese ecotype (Bean 2009).

Riparian Vegetation Restoration – Little is known about native vegetation response to tamarisk biological control. It has been suggested that tamarisk should be actively replaced with native plant species. The ability of natural processes to promote passive revegetation versus the need for active revegetation is unknown. Likewise, it is uncertain whether tamarisk biomass left standing after beetle defoliation (dead branches) must be removed to promote native plant establishment (Dudley 2009). These questions need to be considered to ensure that areas where tamarisk is removed via biological control can be restored with native vegetation.

One study examining the effect of tamarisk biological control on ecosystem nutrient dynamics found that leaves dropped by *Diorhabda* spp. herbivory have a higher nutrient content and decompose faster than unaffected tamarisk leaves that dropped during senescence (Uselman et al. 2009). Such leaf litter may increase nutrient availability in soil and perhaps aid in revegetation efforts.

Secondary Invasion – The control of tamarisk would be less successful in the event of secondary invasions by species as such Russian olive, knapweed, perennial pepper weed, and thistles. Reduced competition following tamarisk control could promote the proliferation of other invasive species. Management techniques to prevent secondary invasion by weeds must be studied and implemented (Dudley 2009).

Currently, a project on the Dolores River is examining the likelihood of Russian knapweed encroaching as tamarisk declines due to biological control. This research is also addressing the impacts if such an invasion should occur (Hultine et al. 2009). Additionally, a *Diorhabda* spp. monitoring effort conducted by the Tamarisk Coalition and the CDA covering much of the Upper Colorado River Basin is noting the presence and abundance of native plants as well as secondary weed species in proximity to declining tamarisk stands.

Erosion and Hydrological Changes – Riparian vegetation, including tamarisk, provides bank stability. Dudley (2009) suggests that it is important to understand how biological control induced tamarisk dieback will affect channel morphology, bank stability, and sedimentation regimes.
A study conducted by Friedman et al. (2009) found that the large-scale control of a dominant riparian species could result in severe erosion events. Aerial herbicide tamarisk control along 12 kilometers of the Rio Puerco, New Mexico in 2003 eliminated all riparian vegetation, including a strip of sand bar willow (*Salix interior*) running along the channel. A 2006 flood event eroded 680,000 cubic meters of sediment from the channel banks. In theory, replacement of aerial herbicide with biological control in this instance would have resulted differently as the sand bar willows lining the channel would have remained and biological control would have result in a more gradual, and less uniform die off of tamarisk (Bean 2009). It is important to recognize the potential for erosion events following biological control. For more information on tamarisk’s influence on stream morphology see the Sedimentation section.

Furthermore, potential water savings and stream flow shifts due to defoliation-altered evapotranspiration rates should be explored (Dudley 2009). A remote sensing study monitoring tamarisk defoliation recently began concurrent estimation of evapotranspiration. Preliminary findings indicate that this method may produce reasonable estimates however the error terms on these estimates are relatively large (Dennison et al. 2009).

**Wildfire Risk** – Some concerns have been raised about increased risks of wildfire due to fuel loads of defoliated leaf litter and dead branches. It is unclear how this litter will affect the wildfire regime. Though beetles do cause an increased fuel load in the short term, there is evidence that defoliated litter will decompose more rapidly than senesced leaves (Uselman et al. 2009). As tamarisk decline, the fuel load may be further reduced as the standing surface area to biomass volume ratio declines and leaf litter decreases. Thus, another question to answer is: Does tamarisk leaf beetle-induced mortality shift wildfire risk over time (Dudley 2009)?

A tamarisk control study examining beetle induced defoliation combined with wildfire led to a hypothesis that the beetles may actually decrease fuel loads (Drus pers. comm. 2007). A study will test this hypothesis using a combustion chamber to determine tamarisk fuel traits when green and at various stages of defoliation and mortality (Drus pers. comm. 2009). Fire behavior models will then be constructed using energy content and ignition traits (Dudley pers. comm. 2009). Land managers and fire crews would benefit from more research in this area.

**Soil Salinity** – Soil salinity levels are generally thought to increase in tamarisk stands due to salt excreting glands on the leaves (Di Tomaso 1998, Wiesenborn 1996). Though not all scientists agree on how significant a contribution tamarisk makes to surface soil salinity, a good practice would be to gauge the impact that tamarisk leaf beetle herbivory has on soil salinity values, organic litter horizons, and the potential affects to native plant recruitment (Dudley 2009). Currently, there are no known studies of this issue though the Tamarisk Coalition and CDA will begin testing soil salinity as part of its regional-scale beetle monitoring effort.

**Wildlife Abundance and Diversity** – For a more detailed discussion of the effect of biological control of tamarisk on wildlife see the Wildlife and Sensitive Species section. It is important to monitor the shifts in wildlife abundance and diversity in response to tamarisk leaf beetle presence and resulting tamarisk defoliation and mortality. Important questions to answer include whether wildlife use will vary among sub-habitats (i.e. terrestrial and aquatic) and if tamarisk leaf beetles will provide an important food source (Dudley 2009). Also, how will defoliation and
Tamarisk mortality affect the quality of wildlife habitat in both the short and long term? Just as biological control of tamarisk may affect wildlife, wildlife may affect the success of biological control. Multiple studies indicate that pressure on tamarisk leaf beetles from invertebrate predators (such as ants) can inhibit population establishment (Knutson and Muegge 2009, DeLoach et al. 2009, Dudley 2009), and that beetle populations can increase predator numbers (Dudley et al. 2009). Such information could have implications for the larger trophic system.

Another study assessed the effect of tamarisk leaf beetle presence on another trophic level, small mammals. This research revealed little to no impact. One survey that compared small mammals captured in a site undergoing tamarisk defoliation to a control site in the same timeframe found no difference in rodent abundance or species composition. Other studies comparing small mammal populations in tamarisk stands before and after tamarisk leaf beetle introduction found only minor disparities that were likely linked to annual abundance variation (Longland 2009).

Small-Scale, General Ecosystem Response Studies – In addition to specific studies discussed in the section above, there are several Diorhabda spp. monitoring and ecosystem data collection projects underway. These studies provide preliminary data of ecosystem responses to the issues discussed above. Some aspects of these studies have already been discussed. They are described below.

The Kazakhstan ecotype of the tamarisk leaf beetle released in Grand County, Utah in 2004 is being monitored on a large-scale by the Tamarisk Coalition and the CDA. It is also being closely followed by local county weed managers. In 2007, a USDA APHIS based protocol was initiated to record the condition of and extent of beetle presence upon marked trees throughout the area. This study focuses on the timing of defoliation, re-foliation, and re-colonization to help land managers better understand mortality rates of tamarisk and to plan restoration actions accordingly. While such studies do not directly address the ecosystem response to biological control, the information they obtain can be combined with more detailed results of other studies to gain even more knowledge for scientists and land managers (Robinson et al. 2009).

Another site specific monitoring effort documents the Crete ecotype released in 2004 on Beals Creek in Texas. Monitoring efforts at this site have recorded beetle expansion of 6.4 miles as of 2008. Other information collected includes tamarisk mortality rates, native plant response, predator and competitor insect response, beetle life cycles, as well as beetle aggregation and dispersal data. Researchers are also beginning a study to compare plant and bird diversity before and after biological control. Initial results indicate that native grasses and forbs began recovering beneath tamarisk after two years of defoliation (DeLoach et al. 2009). Information collected at several other release sites indicate that the Uzbekistan ecotype may thrive in north Texas and that the Crete ecotype may struggle to establish on the Rio Grande (DeLoach et al. 2009).

Another study in Clark County, Nevada where no tamarisk leaf beetles have been released simulates defoliation with a topical application of low-dose chemical defoliants. Over the course of two years the study will record changes in tamarisk condition, changes in associated vegetation, changes in soils and implications for revegetation, structural habitat trends, as well as species associations, including birds. Invertebrate sampling and, potentially, some herpetofauna
sampling, will also be completed during the course of the study. A secondary component will examine the potential for biological control to reduce wildfire risk. Vegetation structure data will be combined with information discovered about the fuel traits of healthy and dry tamarisk foliage and results will inform a fire behavior model (Dudley pers. comm. 2009).

A consortium of scientists is also researching tamarisk and biological control on the Dolores River at Entrada Ranch, Utah. Studies at this location include basic tamarisk biology studies, biomass estimation, ground water, and salinity studies. A large portion of the research, however, focuses on the impacts of the beetles on tamarisk and various aspects of the ecosystem. Cameras are recording time sequenced physical tamarisk (defoliation and refoliation) response to the beetle. Physiological response data including plant sugar and nitrogen content of tamarisk are being collected, and avian habitat quality is being monitored. Tamarisk mortality is being examined on a regional scale using the carbon isotopes in tree rings (Hultine et al. 2009, Nagler pers. comm. 2008). Additionally, the response of other invasive species to tamarisk defoliation and decline is being examined. For example, the potential impacts of secondary invasion by Russian knapweed, a deep rooted weed, following the decline of tamarisk are being studied. This group is also conducting a large-scale, remote sensing project monitoring tamarisk defoliation and estimating changes in evapotranspiration discussed above (Hultine et al. 2009, Dennison et al. 2009).

Pollutants and tamarisk leaf beetle – As well as interacting with wildlife and plants, the tamarisk leaf beetle may interact with natural or anthropogenic pollutants that have accumulated in tamarisk. A recent study found that the growth of tamarisk leaf beetle larvae was significantly reduced by selenium (Se) concentrations in tamarisk biomass. The study also found that of the four contaminants examined, perchlorate, selenium, manganese, and hexavalent chromium, hexavalent chromium accumulated at greater concentration in the beetles than in their food source (Sorensen et al. 2009). One implication of this research is that tamarisk biological control may not be successful in controlling selenium contaminated stands. A second possible implication is a potential mobilization of these contaminants through the food chain, especially if the beetle becomes a significant food source for local wildlife species.

Implications for Water Savings
Biological control of tamarisk may lead to a gradual reduction in the amount of tamarisk in the Colorado River Basin. As tamarisk uses more water than the upland native vegetation it replaces on the upper terraces of floodplains, biological control, similar to other management methods, may lead to water savings depending on site-specific conditions such as availability of groundwater.

Conclusions
The primary goal of the tamarisk biological control program is to reduce tamarisk and its impacts to riparian lands. Biological control of tamarisk may also result in water savings and aid in the restoration of riparian lands. For these goals to be achieved more must be understood about the ecosystem response to tamarisk biological control. However, the multifaceted nature of an ecological system creates a network of interrelated issues requiring multiple fields of expertise and thus significant collaborative effort. Integrating research with implementation actions and
monitoring protocols while engaging a diverse array of scientists, land managers, and stakeholders will aid in addressing these issues effectively.

**Cultural Resources Impacts**

Non-native, invasive plants such as tamarisk and Russian olive alter the vegetative composition of a landscape. This change affects not only ecosystem processes, but also the cultural practices that interact with these processes. Unfortunately, there is little documentation of the impact of invasive species on culture, including impacts of tamarisk and Russian olive. This area of study could greatly benefit from further research that could help define culturally based restoration needs, scope, and goals.

**Background**

The Society for Ecological Restoration’s Foundation Documents state that: “A cultural landscape or ecosystem is one that has developed under the joint influence of natural processes and human-imposed organization.” They go on to state: “Perhaps all natural ecosystems are culturally influenced in at least some small manner, and this reality merits acknowledgement in the conduct of restoration” (Society 2004 p5).

While all landscapes have been impacted by human culture, most contemporary societal practices, ceremonies, and livelihoods in the western United States do not directly depend on their immediate natural surroundings. There is little information describing the cultural impacts that TRO inflict on mainstream culture. For more information on the interactions between people and TRO see the Recreation section. The majority of this discussion will focus on gathering of plant materials (for artistic or practical purposes), as well as Native American, agricultural, or transient populations that are more directly dependent upon or interested in their natural environment.

Little research has been conducted to discover and document any impacts of TRO on culture in part due to the difficulty of assigning quantitative values to cultural practices or to the ease with which they are conducted (Scott-Small pers. comm. 2008). According to Pfeiffer and Voeks (2008), there are three ways that an invasive species can impact cultural practices: a user group is culturally impoverished when native species and their associated cultural practices are reduced or lost; culturally enriched when cultural practices include the invasive species in lexicons, narratives, foods, pharmacopoeias, etc; or culturally facilitated when the invasive species provides continuity and reformulation of traditional ethnobiological practices.

**Gathering of plant materials**

The literature and conversations that informed this discussion generally depict TRO as culturally impoverishing species; however, in some cases it may be culturally facilitating. For example, Triassic Stone, an artisan guild in Moab, Utah that specializes in collecting their own source material in a sustainable way, uses both tamarisk (*Tamarix ramosissima* and *T. chinensis*) and Russian olive in various woodworking projects. Products include bowls, serving trays, chop sticks and tongs. The owner of Triassic Stone finds that while tamarisk wood is beautiful, it is very hard to work with as it cracks significantly when drying during the creation process. He
recommends that it only be used for smaller projects such as spoons or cutting boards and even then with caution. Russian olives, being generally larger trees, are easier to work with and can be used for such tasks as flooring, though it is not ideal wood for the task. The wood works easily and is light-weight but strong and durable (Anderson pers. comm. 2009). Other species of tamarisk, *T. aphylla* and *T. gallica*, are listed as plants habitually used by Native Americans. *T. aphylla* serves as fuel wood in the winter and *T. gallica* is an important source of wood and building material (Moerman 1998).

Figure 23: a. Tamarisk Bowl, b. Russian olive tongs (photos – Triassic Stone).

**Native American Impacts**

More often, TRO are considered culturally impoverishing species as, “Invasive plants reduce the abundance and health of culturally important native plants by invading sacred landscapes, displacing native plants in traditional gathering sites, and stunting or reducing native plant growth or development” (Pfeiffer and Ortiz 2007 p7). Robin Powell, the Nevada Director of Bird Conservation for the Audubon Society who has worked extensively with the Pyramid Lake Paiute Tribe, explains: “the known ecological impacts are transferred to the assumption that invasive plants negatively impact the plant-based cultural resources and cultural practices such as basket making, gathering, medicine, etc.” These statements generalize the TRO realities experienced by the Crow, Hopi, and Navajo Nations.

**Crow Nation:** The Crow Nation is located on the lands surrounding Crow Agency, Montana and is not within the Colorado River Basin but is included here because it is a rare example of documented cultural difficulties with Russian olive. Scott-Small (pers. comm. 2008) is conducting her doctoral research on the cultural impacts of Russian olive growing along the Little Big Horn River within the Crow Nation. She has found that as Russian olive encroaches, locals have to travel further to collect culturally significant native species such as cottonwood, willow, choke cherry, and buffalo berry. Russian olive’s hindrance of cottonwood recruitment is especially detrimental to cultural practices as this narrows the range of cottonwood sizes and structures that are required for significant Crow ceremonies (Scott-Small pers. comm. 2008).

**Hopi Nation:** The Hopi Nation is located in the northeast corner of Arizona and is completely encompassed by the Navajo Reservation. Tamarisk infestations are displacing culturally significant native species on Hopi lands as well. The wetlands of the Hopi Reservation provide water, promote the survival of eagles and hawks, and are necessary for Hopi ceremonial life. However, cottonwoods and willows used in ceremonies are being replaced by tamarisk (Bindell
According to Enrique Salmon, in response to the cultural impacts of tamarisk infestation, Hopi tribal elders are removing stands and revegetating with sand reed (*Calamovila gigantea*), willow, and yucca (*Yucca* spp.). This work is being completed near reservation lands where proximity to the population ensures that the restoration work can be effectively maintained (Pfeiffer and Ortiz 2007, Pfeiffer and Voeks 2008). Hamann, a graduate student at Northern Arizona University, is exploring similar work in ephemeral and perennial washes on Hopi lands. He is currently studying the ecological and social benefits as well as the economic feasibility of tamarisk removal and biomass utilization (Hamann and Kim 2009).

**Navajo Nation:** The Navajo Nation is located at the corners of Colorado, Utah, New Mexico, and Arizona, with the majority of its tribal lands lying in Arizona. The Navajo TRO story is very similar to that of the Hopi. These invasives are choking sources of running water which exacerbates drought conditions and can affect livestock. The majority of Navajo people keep livestock, and any strain on water resources greatly affects the health of those animals. If water becomes scarce, more time and energy must be spent to haul water to those animals. Additionally, in Canyon de Chelly TRO negatively affect corn, a crop that has great cultural significance for the Navajo. TRO control efforts in Canyon de Chelly have encouraging results as willows are making a strong comeback (Hill pers. comm. 2009). However, while TRO management can improve cultural aspects of the Navajo Nation there is also some concerns about the impact of TRO management on potential increases in bank erosion rates in these areas (Pollen-Bankhead et al. 2009).

There is much discussion throughout the Navajo Nation about how tamarisk removal should be approached. Local tribal chapters are very interested in addressing the invasive weed issue and a Navajo volunteer group is currently working to create a strategic weed management plan to mitigate negative impacts. However, as the Navajo Nation covers a very large area and many diverse environments that require site specific restoration approaches the plan will not be a simple one. The plan must also strive to work in concert with Hopi TRO removal efforts as Hopi lands are adjacent to Navajo lands. For instance, the Hopi often use cottonwoods in their cultural practices, so the Navajo are considering that in their restoration plans. These restoration efforts must avoid allowing herbicide to contaminate water that Hopi consider sacred. There is interest in tamarisk biological control, *Diorhabda elongata*, as a means of avoiding this issue. Yet, many individuals are seeking herbicide permits to begin control work and the local tribal chapters already have herbicide applicators (Hill pers. comm. 2009).

**Other Tribes:** Other major tribes and Pueblos in the Colorado River Basin may suffer similar TRO induced cultural impacts. These should be considered in restoration actions and would benefit from additional research.

**Ancient Indigenous Art:** It is important to note that removing tamarisk may also have culturally impoverishing impacts. Many historically and culturally significant petroglyph and pictograph sites along southwestern river waterways are partially protected from high human traffic by dense stands of tamarisk. Some land managers are concerned that if tamarisk stands are removed in these locations, these sites may suffer damage. However, there are many highly visited, culturally significant river sites that have been well preserved. Interpretive signs and
impact education will be necessary at these sites if tamarisk stands are removed to limit potential negative effects.

Another impact of TRO management can be the exposure and/or damage of archeological sites if bank erosion and head-cutting occurs. This could affect the costs for the preservation of these sites.

**Agriculturalists**

Agriculturalists that depend on water quality, quantity, and accessibility for their crops and livestock have a large stake in riparian health. It is apparent that their relationship with TRO is not a simple one as the species alternately impoverish, facilitate, and perhaps enrich their way of life. As such, the impacts to these communities, cultural or otherwise, are important and deserve recognition in the context of restoration needs.

It has been suggested by many that TRO can negatively affect crop cultivation. TRO clog irrigation ditches, decreasing their efficiency and water output. These invasives also occupy lowland floodplain areas that could be used for crop production.

As mentioned above tamarisk and Russian olive can decrease the availability of water for livestock (Hill pers. comm. 2009). TRO have also been known to form dense barriers limiting livestock access to larger water resources such as rivers or ponds. However, tamarisk stands do provide some cover for livestock (Kearney et al. 1960) and Russian olive are used for windbreaks and erosion control (Christensen 1963, George 1953a, George 1953b, Hays 1990). TRO can also serve as browsing material. Though the leaves of tamarisk are generally thought to be unpalatable (Stephenson and Calcarone 1999), cattle and sheep will graze seedlings and mature trees in open stands (Hansen et al. 1995). The nutritional value of tamarisk is not well known and livestock seem to prefer native plants such as cottonwood and willow, giving tamarisk a competitive advantage (Dick-Peddie 1993, Stromberg 1997). Russian olive seedlings can also be browsed by livestock (Borell 1971) and have moderate caloric and protein value (Hansen et al. 1995). Mature Russian olive trees, however, are unpalatable (Katz and Shafroth 2003).

TRO are both a source of nectar and pollen for honey bees. Southwestern beekeepers rely on tamarisk for its nectar and pollen as well as for a refuge from cropland insecticides (Horton 1974). Russian olive are also used for their nectar by honey bees (Katz and Shafroth 2003) but are not as widely known for this use.

**Transient Populations**

Dense tamarisk thickets can serve as shelter for transient populations. This is an especially prominent phenomenon in urban areas. Often the presence of transients in tamarisk discourages the general public from recreating in and around tamarisk stands due to safety concerns. While these concerns are legitimate and as such should be considered when planning removal activities, consideration must be paid to the transient populations dwelling in tamarisk.
Implications for Water Savings
There are no direct connections between water savings and the cultural impacts of TRO. However, any water savings that occur following TRO management will likely benefit the cultures discussed here as all are dependent on water.

Conclusions
Cultural impacts of TRO are clearly varied. While TRO generally impede native plant and water related cultural practices they do provide some benefit in the form of raw wood material, protective barrier, livestock cover, and honey bee nectar/pollen. These issues deserve consideration in TRO management planning and could benefit from more research.

“What makes ecological restoration especially inspiring is that cultural practices and ecological processes can be mutually reinforcing” (Society 2004 p2). In some cases, societies are so closely and reciprocally tied to their landscape that preserving or restoring cultural practices may help to preserve or restore ecological health to the system in a sustainable way (Society 2004). This is a powerful example of approaching restoration work at the level of local partnership and investment to sustain ecosystem health in the long term. As a result, restoration projects that reflect local cultural values could be some of the most effective for sustainable restoration.

Recreational Impacts
Tamarisk is often decried for inhibiting recreational activities in the riparian corridor and degrading aesthetics (Dudley et al. 2000, Haase 1972, Horton and Campbell 1974). However, tamarisk is known to benefit some recreationalists. Russian olive is also known as a physical barrier to many outdoor enthusiasts but is generally thought to be an ornamental that is attractive. Although there is little to no known scientific literature supporting these claims, the experience of many researchers, land managers, river runners, fishermen, hunters, hikers, and bird watchers combined define the impacts of TRO, both good and bad, to humans in the outdoors. These impacts are important to consider in restoration projects (Burke pers. comm. 2009).

The most commonly cited benefit of tamarisk to recreationalists is the shade that it provides (Hamilton pers. comm. 2009). Tamarisk’s ability to thrive in saline soils (Hem 1967; Wiesenborn 1996; Shafroth 1995); its elevated drought tolerance (Di Tomaso 1998); its ability to quickly resprout following wildfires that remove native species (Glenn and Nagler 2005, Zouhar 2003, Ellis 2001); and its extended seed production (Zouhar 2003) often mean that it is the only plant of shade producing size for miles. In the Southwest shade can drastically change the quality of any outdoor experience. This benefit seems to be especially important to river runners, who compete to find shaded campsites, tie their boats to tamarisk trunks on the shore, and who travel through areas where rapids force high flows to scour native vegetation to a greater extent. Recreationists in the Lower Colorado River Basin (downstream of Lee’s Ferry, Arizona) rely heavily on tamarisk shade. River regulation and more arid conditions have promoted tamarisk growth and have more stringently limited native recruitment on the Lower Colorado River.
Many tamarisk removal projects take amount of shade into account when working in high human use areas such as campgrounds or boat launches. Mitigation methods include: 1) leaving some tamarisk standing to provide shade, though this increases potential for reinvasion; 2) timing revegetation efforts to allow native vegetation to establish before removing all tamarisk from the area; 3) revegetating with trees, generally cottonwoods, that have larger caliber trunks and that will grow to shade the area more quickly; and 4) building structures to provide shade. Such measures make it possible to thin or control tamarisk stands while maintaining the recreational value of a site. Russian olive trees also provide shade. Monotypic Russian olive stand removal efforts in popular areas should also consider the above options. However, along much of the Colorado River Russian olive growth co-occurs with tamarisk invasion. It has been suggested to remove all tamarisk and leave some larger Russian olives until native vegetation reaches shade producing size as Russian olive are slower invaders than tamarisk.

The negative impacts of TRO to recreationalists are more varied. The dense and widespread growth patterns of tamarisk create physical barriers within the riparian corridor, often completely restricting access to waterways such as rivers, springs, ponds, and lakes. These thickets can also limit access from the water to river banks or side canyons, such as those surrounding Lake Powell. This limited mobility greatly curtails the activities of recreationalists such as fishermen, hunters, river runners, hikers, bird watchers, and boaters (see Figure 24).

These bank invading tendencies have also allowed tamarisk to impede access to or, in some cases, eliminate popular campsites along the river by greatly reducing the number and size of beaches. Many recreationalists have cut camping niches throughout such dense tamarisk stands, in some cases enjoying the extensive shade. However, the area will support fewer campers and presents an alarming risk of wildfire (Invasion on the Colorado…[updated 2009]). Dense stands of tamarisk may also facilitate dangerous interactions with wildlife. According to anecdotal reports, dense growth can limit visibility and allow people moving through tamarisk to surprise recreationalists (Lauck pers. comm. 2009).
potentially dangerous animals such as black bears (Lauck pers. comm. 2009) or rattlesnakes (Lair pers. comm. 2008). Hiking through thickets of this dusty and scaly plant can be a difficult and unpleasant experience.

Though not as common throughout the Colorado River system, Russian olive stands can reach densities comparable to tamarisk. These thickets create even more fearsome barriers as their long, sharp thorns make bushwhacking nearly impossible. The trees may create another barrier in the form of irritating allergies. Many locals on the western slope of Colorado complain of strong Russian olive allergies (Swett pers. comm. 2009). The trees are listed by the Allergy Associates of Utah as a springtime allergen (Rogers and Carroll…[updated 2009]).

Though TRO do not universally decrease wildlife abundance and diversity, areas where these species dominate may offer fewer fishing, hiking, camping, hunting, or wildlife viewing opportunities. This is especially true for dense stands where limited visibility inhibits activity and the enjoyment of spectacular western vistas (Dudley et al. 2000, Haase 1972, Horton and Campbell 1974). Though fewer studies have been conducted on the recreational impacts of Russian olive, it is likely they are capable of similarly degrading riparian areas. For an in-depth discussion of TRO wildlife impacts (see Wildlife and Sensitive Species section).

Aesthetic impacts are more difficult to gauge due to the subjectivity of the topic. Tamarisk were brought to the United States in part to serve as ornamental species (Cronquist et al. 1997, Tamarix spp…[updated 2009]). Many people, especially those that have no memory of the river system prior to severe invasions, think these plants are beautiful. Even more popular is Russian olive, a tree many enjoy for its fragrant yellow flowers and sage-like hue. Such realities are especially important for tourism based economies to consider, e.g. Moab, Utah. Tamarisk lines much of the Colorado River that flows by this community and Russian olives line one of its major tributaries, Mill Creek. It is a difficult task for the town to educate a visiting public enjoying the strip of green riverside vegetation about the intricacies of the tamarisk issue. Residents and visitors can be informed of the importance and purpose of TRO management and that negative aesthetic effects can be mediated by planting native species.

The more objective aesthetic realities are the homogenizing, obstructive affects of dense TRO stands. In some areas these plants are the only species for acres and grow so densely that they can completely hide the Colorado River even when it is flowing yards away. Therefore, it is less a debate of species aesthetics, and more a question of the vegetative composition and viewsheds on a larger scale. In these cases, most people agree that TRO degrade aesthetics.

**Implications for Water Savings**

There are no direct connections between water savings and recreation. However if water is saved via TRO management, there is some cumulative potential for larger flows in rivers which may enhance recreational activities such as rafting. For some river segments, there may be a downside to TRO management if bank destabilization occurs and the river becomes wider and/or more braided resulting in decreased water depths that could hinder some activities such as rafting. River bank access may also return as an issue if the replacement vegetation eventually becomes as thick as the tamarisk it replaces.
Conclusions
TRO do provide some recreational benefit in the form of shade in the absence of native vegetation. However, tamarisk’s dense, monotypic growth patterns can block access to waterways, create hazards for river runners, invade popular camp sites, and facilitate dangerous wildlife encounters. Likewise, dense Russian olive growth curtails recreationalists’ mobility and may exacerbate allergies. Both species impacts on wildlife, birdlife, fish, and aesthetics directly affect outdoors enthusiasts as well. The outdoor community and industry provides revenue through tourism and retail outfitters. Additionally, healthy and inviting natural landscapes can create community pride in the river system. Management efforts should consider both potential impacts to recreationalists and potential methods to engage this active community in any management plan.

Biomass Utilization

TRO management often results in large quantities of biomass that must be either disposed of or used in some way. Typically, tamarisk biomass is mulched, stacked for wildlife habitat, or burned; and in rare instances, thrown into the river. Uses of tamarisk, such as biomass for energy and wood product materials, have been discussed on a small scale and researched in some instances. This review discusses disposal methods and what is known about alternative uses for tamarisk biomass. Consideration of what to do with removed tamarisk biomass is an important component of TRO management programs. An example is described as a recommended action in the Kansas Water Plan (2009 p. 2): “Determine the potential value of tamarisk biomass for various value-added products such as ethanol, bedding, fiberboard, and fuel pellets, or if not suitable for alternative uses, determine how to dispose of dead plant materials.”

Choosing among the disposal methods for TRO is a function of site use, vegetative density, control methods used, and landowner restrictions, such as fire bans. Removal of dead tamarisk tree skeletons may be important after mechanical root crown removal, biological control, or foliar herbicide control if densities are moderate to high. Biomass reduction under these conditions assists planned revegetation efforts, restores aesthetic values, and reduces the wildfire potential of dead biomass in moderately to highly infested areas. The removal of dead trees can be accomplished using mechanical mulching equipment or fire.

Mechanical mulching transforms the dead material into mulch. Properly mulched areas can support native growth, provide organic material, reduce moisture loss, and limit weed propagation. However, if a large amount of biomass is mechanically mulched and piled, the thickness of the layer produced may actually impede or prevent revegetation. Reducing biomass with fire may require the construction of adequate fire breaks in sensitive riparian areas to safely burn the slash. Fire is an option that must be carefully coordinated with land managers and county air quality personnel. It should only be used for biomass reduction on dead plants, because live tamarisk will flourish after fire.

For many areas with light to moderate infestations, the dead biomass can be left standing without any actual physical biomass reduction actions. Standing dead biomass in these situations probably does not significantly impede natural or planned revegetation, affect aesthetics, or
support high wildfire potential. Stacking biomass into brush piles is a common practice to provide cover for small mammals and birds. This approach works well in light to moderate infestations, but heavy infestations result in an excess of piles.

Disposing of biomass into a river is a less common practice that is only known to be used at Dinosaur National Monument. This method is particularly interesting as it introduces terrestrial carbon into the river system. Modeling by Zeug and Winemiller (2008) identified terrestrial carbon of riparian origin as the primary carbon source supporting the consumers in the main channel of their study reach. Human activity (dams and diversions) has removed significant amounts of natural debris from the river system which can affect biodiversity, specifically aquatic invertebrates that depend on coarse wood debris (Naumann pers. comm. 2009).

At Dinosaur National Monument crews remove tamarisk and cut the large diameter stems (approximately 3-6 inches) into 18 inch sections to stack for firewood for rafters. The smaller diameter material is cut into lengths under eight feet and stacked with the cut ends facing the river to enable volunteers to break apart the piles after they have dried. Drying takes approximately one year. During the spring runoff season, the piles are broken up and each stem is thrown into the river separately to ensure boater safety. Russian olive is not put in the river because of its thorns. Where there are large amounts of biomass and access for equipment, the biomass is chipped and used as mulch in public use areas (Naumann pers. comm. 2009).

Burning was tested at the Monument as a method for disposing of TRO biomass before deciding the river method was more appropriate. Burning raised concerns in two areas: 1) on sandbars, firefighters were hired to monitor the fire and large amounts of diesel or other fuel were needed to ignite the fire making the process labor and cost intensive; and 2) on floodplain terraces, the fire incinerates microbes and native plants in the soil under the slash pile, making the soil less fertile, and the process is time intensive. They also found that other weeds can invade post-fire sites (Naumann pers. comm. 2009). While these concerns may not be the same in all slash pile situations, they are important to consider.

The various methods of TRO biomass disposal discussed here may benefit site needs, wildlife habitat, or, potentially, aquatic habitat. However, these benefits are difficult to document and even more difficult to assign a value. Better documentation and evaluation of TRO biomass disposal could benefit future projects.

The advantages of utilizing TRO biomass for commercial gain could provide motivation to complete projects and fund removal efforts. The numerous efforts aimed at utilizing the lodgepole pine beetle-kill biomass in the central Rocky Mountain region are examples of ingenuity creating opportunities for productive biomass use.

Due to the potential benefits of biomass utilization to offset some portion of TRO management, much interest has been expressed in biomass studies though relatively few studies have been attempted. Suggestions for utilization have focused on tamarisk and include sources of solid (e.g. charcoal, for wood burning power plants, or fuel pellets) or liquid (e.g. ethanol) fuels, bedding, pallets, general carpentry, or for cultural and artistic uses. The Next Earth Foundation (2007) reviewed the possibility of utilizing tamarisk in wood fuel pellets or as fire logs. While
there are no specific examples of tamarisk pellets, they found that that wood pellets can be made from nearly any kind of wood. With appropriate drying techniques, tamarisk could be a viable resource to use in pellets. The group also suggests that it may be feasible to repackage wood pellets for cat litter, composite filler or fiber, dust abatement, wood siding, and biomass for energy. Overall, they found that extensive research is necessary in order to determine cost effective approaches and the best harvest sites.

Using tamarisk biomass for other types of energy has also been explored. There is a possibility that tamarisk can be utilized in gasifiers, combined heat and power systems, or other “burn” systems (Next Earth 2007). Tamarisk burns at about the same Btu (British thermal units) as pine or fir after it has dried an adequate amount of time (Anderson 2009). Tamarisk has approximately an 8,000 Btu/lb. heating value which is similar to the average for other woody biomass (LeVan as sited in Next Earth 2007). Much more research is needed to determine if tamarisk biomass could efficiently be utilized for energy.

The 2002 South Mittry Biomass Utilization Project is an example of a biomass to energy pilot project. The Bureau of Land Management (BLM) office in Yuma, Arizona cooperated with Colmac Energy, a biomass plant in Mecca, California, to utilize chipped tamarisk from an 80 acre tamarisk control project implemented by BLM. The result of the effort was not conclusive as the wood was generally too dirty to generate energy. In addition, the material was expensive to transport and the cost of chipping the material to the appropriate size was significant (Next Earth 2007).

The costly nature of harvesting and transporting biomass is being addressed by a grantee of the U.S. Forest Service Woody Biomass Utilization Grant Program. Mt. Taylor Machine LLC, Milan, New Mexico is using this funding to develop an efficient harvesting and transporting system in order to use tamarisk in wood pellet production (LeVan–Green and Benisch 2008).

A study by Clemons and Stark (2007) found that it is technically feasible to make wood-plastic composites out of tamarisk. Wood-plastic composite lumber is used to make decking, guard rails, pedestrian bridges, signs, etc. The composites are popular because of their durability (Winandy et al. 2005). Wood-plastic composites are made when wood flour is added to plastic (rather than inorganic fillers) to improve performance or reduce cost. Issues such as moisture removal and low thermal stability need to be addressed when working with wood flour fillers (Clemons and Stark 2007). A study completed by a different group also showed that composites such as particleboard, sign materials, and Americans with Disabilities Act accessible playground equipment could be made using tamarisk. These composites are all wood-based and would substitute tamarisk for other wood fibers on a small scale (Winandy et al. 2005).

The economic feasibility of using TRO will depend on many factors including harvest and transportation costs, and manufacturing and market values. Clemons and Stark (2007) recommend that there are ways to possibly increase market opportunity for the tamarisk wood-plastic composites. They suggest that land managers could partner with manufacturers to make composite lumber from their invasive species for use on their land.

In order for land managers, researchers, companies and individuals to assess the feasibility of using tamarisk commercially, it is important to understand and predict the amount of tamarisk
biomass that could be potentially used. A study to find a reliable method for estimating biomass was completed by Colorado State University’s (CSU) Natural Resource Ecology Lab (NREL) and the USGS’s National Institute of Invasive Species Science (NIISS) (Evangelista et al. 2007). This group worked to develop models to predict above-ground *Tamarix ramosissima* biomass using height and canopy cover area (see Figure 25). Note that the biomass estimates by CSU-NREL and USGS-NIISS represent measurements made in only the Arkansas River ecosystem for one species of tamarisk (*Tamarix ramosissima*). Climate, age, water availability, species of tamarisk may affect growth and lead to different results in biomass predictions (Evangelista et al. 2006). No similar model exists for Russian olive.

**Figure 25: Relationship between *Tamarix ramosissima* canopy area (m²) and predicted total oven-dry aboveground biomass (TAGB; kg) (Evangelista et al. 2007).**

Another study to determine biomass availability was sponsored by the National Invasive Species Council to estimate the amount of biomass available for potential commercial uses in the Colorado River and Rio Grande Watersheds. Eleven discrete river sections were identified as having significant acreage of tamarisk infestation and relatively good access to support potential biomass harvesting. Based on land management estimates of acreage and average height, this information was fed into the CSU-NREL and USGS-NIISS model (described above) and resulted in an estimated 21 million dry weight tons from approximately 580,000 acres. Biomass estimates ranged from 14 to 47 dry weight tons per acre based on tamarisk density and height (NISC 2006). This work provides a basic understanding of the biomass potential within these two watersheds but doesn’t represent any findings of potential economic benefit in using this biomass for any purpose. For the Colorado River Basin, approximately 15 million dry weight tons were estimated as potentially available for biomass utilization. Actual biomass from other species (i.e., *Tamarix chinensis* and *Tamarix* hybrid) which are common to the Colorado River Basin, different geography, and different climate from that in the Arkansas River system may influence these very preliminary estimates.

Interest has been expressed in using cellulosic biomass for production of ethanol. This research being conducted by scientists at numerous universities, federal agencies, and energy companies is at the early stages of lab experiments using bacteria, enzymes, and/or catalysis techniques. Much of the research is being closely held because of the economic value of proprietary processes and patents. Thus, any prediction of the potential for TRO biomass conversion is only speculative at this time and beyond the scope of this TRO Assessment report. USBR’s assessment of the TRO throughout the West may develop more detail on this issue. The appropriate federal agencies to evaluate this potential are the National Renewable Energy Laboratory in Golden, Colorado and the Forest Products Laboratory in Madison, Wisconsin.
A number of smaller scale uses of tamarisk biomass have been attempted as well. These have less of an economic focus and more of an educational, artistic, or cultural convenience focus that incorporates tamarisk into local cultures. An example of an educational use is a tamarisk pencil that is sold highlighting the invasive species issue. Numerous artisans use both tamarisk and Russian olive to create small woodworking articles (sculpture, bowls, utensils, flooring or cutting boards) (Anderson pers. comm. 2009). None of these represent a significant biomass use.

In 2009, Senate Bill 1713 was introduced and a similar bill (H.R. 2170) was introduced in the House of Representatives. The proposed legislation mentions tamarisk and one of its purposes is to remove excess biomass of species which cause harm to water resources. The legislation develops a loan program through the Departments of Interior or Agriculture to guarantee loans by private institutions for the construction or acquisition of facilities for the production of biochar, establish biochar demonstration projects, and develop biochar technology and markets.

**Implications for Water Savings**

There are no direct connections between biomass utilization and water savings, however TRO management in an effort to save water will be costly, and biomass utilization may help to offset those costs.

**Conclusions**

Overall, there are some proven and some potential uses of TRO biomass. The question that land managers and others need to consider is the economic viability of biomass utilization. The end use of the tamarisk will depend on restoration goals, economics, and cost effectiveness. Additional research will need to determine whether TRO biomass can have commercial value.

**Best Management Practices**

Two best management practices guides for land managers will be available as working documents in 2010. The first, entitled *Tamarisk Best Management Practices in Colorado Watersheds*, primarily concerns methods of removal and project planning specifically for projects in Colorado. Topics include Integrated Pest Management, chemical and mechanical control, biological control and developing a management strategy. This work is being done by researchers at Colorado State University, Colorado Department of Agriculture, Denver Botanic Gardens, University of Denver and the Bureau of Reclamation. A placeholder has been set as Appendix F to this document. The report will be provided and appended when it is complete.

The second, entitled *Best Management Practices for Revegetation after Tamarisk Removal in the Upper Colorado River Basin Handbook*, is a guide for restoration, planning and revegetation after tamarisk removal for projects in the Upper Basin. Topics include planning, site evaluation, site preparation, plant material selection, tamarisk re-sprouting, secondary invasion, and hydrology. This work is being performed by researchers at Denver Botanic Gardens, University of Denver, and HT Harvey and Associates Environmental Consulting. A placeholder has been set as Appendix G to this document. The report will be provided and appended when it is complete.
Task 3: Programmatic Issues and Economics of TRO Management

Costs of TRO management compared to potential water savings

To gain an understanding of the overall costs of TRO management and how that compares to the value of water saved it requires that all the components of a restoration be analyzed. This includes site specific land, surface water and ground water characteristics; infestation characteristics, and restoration vegetation objectives. Over the past four years the Tamarisk Coalition has been collecting cost, efficacy and appropriateness data from TRO control and restoration projects that have occurred throughout the West and Plains States. This information has been updated for this report and is included as Appendix H, Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction, and Revegetation. All currently available technologies were evaluated; however, not all are applicable for a given location. To determine overall costs of managing TRO, five basic components are included with developed cost algorithms: 1) planning and design, 2) control, 3) biomass reduction, 4) revegetation, and 5) long-term monitoring and maintenance. Without considering all five components it is unlikely that TRO management projects will result in long-term success. Restoration is not a quick process and restoration plans may span 10 years or more.

Components for these five relevant TRO management components are detailed in Appendix H and outlined below:

1. **Planning and design** refers to the professional design of a restoration plan informed by accurate inventory and mapping efforts. This would include vegetation soil testing (e.g., salinity, pH, texture), GIS information, plant material lists, irrigation needs, design drawings, specifications, etc. sufficient to implement a restoration plan. For the cost algorithms that follow, inventory and mapping efforts to define the TRO problem as well as land manager agreements and permitting are not considered part of planning and design costs. Any specialized activities such as detailed land surveys, water rights, utility relocations, permitting, etc. would be additional costs that are not included within these cost algorithms.

2. **Control** refers to the methods for causing mortality to tamarisk and Russian olive using hand, herbicide, mechanical, or biological methods. Monitoring during the implementation phase and control of resprouts is considered part of control costs. These costs typically include equipment rental, labor, fuel, herbicide, mobilization, project administration, etc.

3. **Biomass reduction** is the removal of dead biomass through mechanical methods, natural decomposition, or controlled fire. Potential offsetting income from uses of the biomass material are not included in this analysis.

4. **Revegetation** refers to the reestablishment of native grasses, shrubs, forbs, wetland species, and trees on disturbed areas through seeding, planting, or enabling natural regeneration to occur. Components include: plant materials, plant protection, nutrient additions, and irrigation if required. For large projects costs could include development of nursery stock. Monitoring of restoration progress and establishment of the desired
plant community as well as herbaceous weed control during the establishment period is included as part of revegetation. Land or water costs are not included.

5. **Long-term monitoring and maintenance** refers to the annual post-restoration efforts that are required once the desired plant communities are established and sustainable with relatively little outside intervention. These post-restoration efforts include development of the monitoring plan, annual monitoring, weed control, and reseeding if needed. Since the implementation phase is intended to provide a sustainable plant community, there should not be the need for continued irrigation or other special maintenance needs. This approach is similar to road construction in which the right of way is seeded with grasses suited for the road location’s specific climate and soils; thus, after establishment relatively little maintenance is required.

**TRO Control Techniques**

TRO can be controlled using a variety of weed management techniques, including chemical, mechanical, and biological techniques. All of the following TRO control techniques are appropriate, but each must be selected based on local conditions; i.e., “Integrated Pest Management.” Integrated Pest Management (IPM) is the “toolbox” from which land managers select techniques tailored for a project in a specific setting.

The IPM toolbox includes prevention, cultural management (land stewardship), mechanical or physical removal, biological control, herbicide treatments, and revegetation techniques. Appendix H provides photos and detailed comparison of each of these major control technologies as well as other methods. It should be noted that there are many hybrids of these technologies that fall within the general understanding of tamarisk control. Actual costs and applicability may vary for each site. The basic approaches are summarized below:

- **Hand cutting with herbicide application** – This method is referred to as the “cut stump” approach in which the tree is cut or scored with chainsaws, handsaws, or axes, and the stump is treated with an herbicide within a few minutes of cutting. This approach is considered to be appropriate for: difficult to access areas; areas of special concern; areas in close proximity to valuable native vegetation, historic and archeological sites; campgrounds; and efforts involving volunteer support.

- **Mechanical removal** – This approach uses heavy equipment to physically remove TRO. This is accomplished in one of two ways: root crown removal or cutting with herbicide application. These methods require road access in order to get equipment to the site.
  
  - **Root crown removal** is the extraction of the root crown by either root plowing accompanied by root raking to remove the root crown from the soil or by extraction of the entire plant. These approaches do not use herbicide.
    
    - **Root plowing and raking** is extremely disruptive to the soil, native plants are destroyed, and the intense soil disturbance would support weed viability. It essentially removes all vegetation in a manner that would be similar to preparing
land for intense agricultural production. Large equipment (Cat D-7 or larger) is necessary for and is most appropriate for sandy silty soils.

- **Extraction** approaches using a large tracked excavator (Cat 325 or larger) is appropriate for some areas, especially those areas that have steep banks such as ditches and river banks and along roadway embankments. This approach results in high levels of soil disturbance and thus may require significant revegetation efforts. The removed biomass may also require disposal or additional treatment such as mulching. Russian olive extraction should not be used on trees over 3 inches in diameter because broken roots will regenerate.

  - **Mechanical Cutting with herbicide application** is the mechanical removal of above ground biomass accompanied by herbicide treatment of the cut-stump. This approach is used with either equipment that cuts and mulches the trees or grabs and cuts the trees for removal.

- **Mulching** uses newly developed, specialized mulching equipment followed by herbicide application to the cut stumps (see Figure 26). The resulting mulched materials can reduce soil disturbance, and provide a good seed bed for native plant recruitment if the mulched materials are not too thick while discouraging establishment of noxious weeds. Tracked mulching equipment provides a lighter footprint pressure than those with wheels and thus causes less soil disturbance.

- **Grab & cut-stump** equipment developed for the forest products industry combines a grabbing or holding device that attaches to a tree while a shear or circular saw blade cuts the tree near ground level. Herbicide is then applied to the cut stump. This equipment is commonly called a “feller buncher” and unlike the extraction technology, this approach can be used to remove Russian olive as well as tamarisk.

  - **Aerial herbicide application** – In larger infestation areas such as in Texas and New Mexico, helicopter and fixed wing aircraft are being used to apply foliar herbicide where monotypic stands of tamarisk exist. This approach may be appropriate where: 1) monotypic infestations are dense and include enough acreage to make this approach economically
feasible and 2) significant native vegetation is not present because aerial spraying will cause mortality among many of these species.

- **Biological control** – This method for invasive plant control uses specific organisms to control an undesirable organism. For tamarisk, two biological control agents have been identified – grazing by goats and the tamarisk leaf beetle described earlier. Both organisms work to control tamarisk by repeated defoliation of the plant over several years.

**Biomass Reduction**

Removal of dead tamarisk tree skeletons may be important after mechanical root crown removal, biological control, or foliar herbicide control if densities are moderate to heavy. Biomass reduction under these conditions assists planned revegetation efforts, restores aesthetic values, and reduces the wildfire potential of decomposing litter in moderately to highly infested areas. The removal of dead trees can be accomplished using mechanical mulching equipment or fire.

Mechanical mulching, by its nature manages the dead material by transforming it into mulch. However, if a large amount of biomass is mechanically mulched and piled the thickness of the layer produced may actually impede or prevent revegetation. Reducing biomass with fire may require the construction of adequate fire breaks in sensitive riparian areas to safely burn the invasive plants. In addition, air quality may be a concern for large-scale burns as carbon sequestered in the tamarisk will be released instantly. As presented earlier, controlled burning can be successfully utilized in combination with herbicide, mechanical, and biological control treatments to result in high tamarisk mortality above 90% (McDaniel and Taylor 2003). Fire is an option that must be carefully coordinated with land managers and air quality management agencies. It should only be used for biomass reduction on dead plants, because live tamarisk will flourish after fire. As shown in Figure 27, fire breaks and professional fire fighting staff are critical because of the intensity that tamarisk fires exhibit.

For many areas with light to moderate infestations, the dead biomass can be left standing without any actual physical biomass reduction actions. Standing dead biomass in these situations probably does not significantly impede natural or planned revegetation, affect aesthetics, or support high wildfire potential.

**Figure 27**: Controlled fire used for dead tamarisk at the Bosque del Apache NWR, New Mexico 2004 (photo courtesy of USFWS).
Revegetation

Successful revegetation can be a complex undertaking especially in areas of high soil salinity, low precipitation and herbaceous weed infestations. As a result, implementing revegetation projects following the removal of invasive species is an inherently site-specific task. It is therefore recommended that local revegetation specialists, State Cooperative Extension type organizations, Natural Resources Conservation Service (NRCS), and comprehensive revegetation and restoration texts be used to develop a course of action for individual projects. As stated earlier, the University of Denver is currently preparing a “Best Management Practices” handbook for revegetation that will be made available as Appendix G. There are also many excellent sources presently available to inform revegetation actions, principally from the NRCS Plant Material Centers. The Colorado River Basin has three centers that provide expertise on the many ecotype specific areas within the Basin: Los Lunas, New Mexico; Meeker, Colorado; and Tucson, Arizona (see http://plant-materials.nrcs.usda.gov/centers/).

A comprehensive plant list is provide as Appendix E as a starting point for revegetation planning, keeping in mind the importance of knowing specific site characteristics before choosing plants for revegetation purposes. Revegetation efforts may require labor, seed, plant materials, amendments such as fertilizer and mycorrhizal inoculants, equipment rental, weed control, and water. Specialized planting techniques may also be necessary as illustrated in Figure 28.

**Figure 28: Techniques for revegetation of riparian areas (NRCS).**

Requirements for revegetation have a direct relationship to density of infestation and width of infestation. In some areas, especially those with light tamarisk infestations, active revegetation may not be necessary as pre-existing native plants will be able to colonize patches where tamarisk has been removed. In other areas, such as tamarisk monocultures, intensive revegetation will be necessary. For narrow widths (generally less than 50 feet) natural revegetation may occur more easily because of close proximity to native plant and seed sources. However, these areas may still incur minor to moderate costs because of soil disturbance and the need for weed control. For broader widths (greater than 50 feet) costs will be higher because less native plant/seed will be able to reach the interior areas of the infestation (K. Lair, 2008 pers. comm.). Other site conditions also influence...
revegetation such as surface and ground water dynamics, soil chemistry and texture, density of
propagules of desired revegetation species, etc. Whether passive or active, a plan for
revegetation and necessary funding should be established before tamarisk control begins
(Shafroth et al. 2008).

In planning for revegetation it is important to recognize the ecological requirements and natural
history of the plant species that are being established. In some areas, revegetation with the plant
species that historically occupied the site may be challenging. The Colorado River’s flow
regime has changed radically in the last 120 years due to the construction of dams and diversions
for flood control, and irrigation and municipal water. Some ecologists suggest that some
Colorado River riparian areas may not be able to support native species like cottonwoods and
willows unless flood pulses are re-established (Glenn and Nagler 2005, Stromberg 1998).

In some regulated river systems, including the Bill Williams River (Shafroth et al. 1998), the
Colorado River delta (Nagler et al. 2005), the Truckee River, Nevada (Christensen 1996), and
the Oldman River, Alberta, Canada (Rood et al. 1998), researchers and water managers have
shown it is possible to manage for pulse high flows in order to successfully germinate and recruit
native cottonwood-willow vegetation, even with existing tamarisk infestations (Sher and

The magnitude and timing of seasonal high flows plays a driving role in establishing (and
maintaining) native riparian vegetation, in determining the successional trajectory of native plant
communities and thus in promoting and renewing landscape level diversity in vegetation and
habitat throughout the Colorado River Basin (Merritt and Cooper 2000, Richter 1999). For
instance, in order to successfully germinate and establish, cottonwoods need the bare moist
sediment (Sher et al. 2002, Sher and Marshall 2003) that pulsed flows provide and be within two
meters of the water table (Mahoney and Rood 1998).

Specifically, appropriately timed periodic high flows (i.e. pulsed flows) function in several ways
to establish, maintain and diversify native riparian vegetation. Periodic high flows help to
maintain lower salinity levels by flushing accumulated salts out of the soil (Busch and Smith
1995), and refreshing nutrient levels in the floodplain by supporting decomposition (Molles et al.
1998). Periodic high flows promote channel migration and the movement and deposition of
coarse sediments to higher levels in the floodplain, thus periodically creating and recreating
appropriate sites for cottonwoods and willows to germinate and recruit (Richter 1999, Salo et al.
1986; Stromberg 1998a as cited in Shafroth 2000, Shafroth 2000), and promoting landscape
heterogeneity (Richter 1999). Finally, periodic high flows can help control the re-establishment
of tamarisk by scour and/or burial of seedlings (Shafroth et al. 2009).

Most of the same considerations that apply to revegetating areas where tamarisk has been
removed will apply when revegetating areas where Russian olive has been removed. However,
the seeds of Russian olive remain viable longer (up to three years) than tamarisk and germinate
under a wider range of conditions than those of cottonwood and other native plant taxa (Katz and
Shafroth 2003, Shafroth et al. 1995). These characteristics may give Russian olive an advantage
in colonizing disturbed and burned areas, or recolonizing areas where Russian olive has been
removed and must be considered in revegetation efforts.
Special considerations for wildlife are important in revegetation efforts. Just as the impact of tamarisk invasion will vary with the wildlife species and the area considered, so too will the impact of TRO management. For instance, a recent study by Bateman et al. (2009) found that birds nesting in mid-story vegetation were negatively affected by tamarisk control, but other bird species were not affected. The long-term effect of TRO management on wildlife will depend heavily on what species replace TRO once it is removed. If active revegetation does not occur, the disturbance caused by TRO control may favor the establishment of other invasive species that may be undesirable (Shafroth et al. 2008).

The process by which control and revegetation occur will also affect wildlife. Timing is important for all aspects of TRO management. Wildlife populations may be most vulnerable if reproduction is disrupted. If TRO control can occur outside of the breeding or nesting season, it may be less disruptive. Similarly, the timing of revegetation must also be considered. In most cases, plants used in revegetation will take several years to establish, mature and provide suitable habitat. There will be a considerable lag time between tamarisk removal and when the habitat is again suitable for many species, leading to a short-term loss of habitat. In some situations, such as a large tamarisk monoculture, it may be advisable to control tamarisk and revegetate in patches i.e., staged revegetation (Fleishman at al. 2003). When this strategy is used, wildlife will still have tamarisk habitat available while replacement vegetation is establishing in the areas where tamarisk was removed.

**Long-term Monitoring**

For riparian restoration activities, “monitoring” is the act of observing changes that are occurring or expected to occur with, or without, remediation actions. The purpose of monitoring is to provide information in response to objectives, to make informed decisions to initiate, continue, modify, or terminate specific actions, remediation activities or programs – better known as “adaptive management.” While discussed at length as critical for successful TRO management, there are not good examples of how best to perform either long-term monitoring or maintenance. The University of Denver is intending on completing a third Best Management Practices manual for these two areas to complement that being produced for tamarisk management and revegetation (Appendices F and G). Recognizing this lack of good examples, Appendix I provides templates and protocols for both long-term monitoring and maintenance. For the purposes of this report the term *template* defines what actions should be taken, and the term *protocol* defines how the actions could be performed.

Scale and ownership are two considerations important to gauge success. In general there are two divisions in each of these elements: large-scale versus small-scale projects; and public ownership versus private ownership. For the purposes of this discussion it is assumed that parcel sizes large enough to support large-scale projects are usually located on public lands and that small-scale projects are located primarily on private lands. Coordination between private land owners and public land managers is essential to gain access to private lands, create a standard monitoring protocol, and to develop and execute training in monitoring methods. Depending on the objectives of each restoration site, varying combinations of monitoring approaches may be designed based on intensity of restoration, site specifics, or capability of partners.
Large-scale monitoring on public lands allows policy makers, land managers, and the public to evaluate the potential impacts of remediation on water resources, vegetation, wildlife habitat, biodiversity, economic health, society, and culture. These are essential considerations for determining what level of funding should be committed to management efforts by local, state, and federal agencies. Pre-restoration monitoring is important to establish baseline data to determine if goals and objectives are being achieved on the landscape scale.

Small-scale monitoring on private lands provides useful information on the effectiveness of control and restoration activities. This information allows for modifications, if necessary, to achieve the restoration goals. In general, small-scale monitoring criteria should consist of simple and inexpensive monitoring techniques based on meeting management objectives.

**Long-term Maintenance**

Long-term maintenance is a dynamic management process, carried out over years to decades to achieve social, economic, and ecological goals associated with a watershed. The process of management encompasses the strategic implementation of actions to identify, maintain, remediate, improve, and monitor the ecological processes of the watershed. Actions, and the tools required to accomplish them, are chosen because they are consistent with and likely to achieve the watershed goals, and because they address the results of monitoring.

Monitoring is related to maintenance in that it is the act of observing changes that are occurring with, or without, restoration actions. Monitoring provides information for making informed decisions to ensure “maintenance” will continue to remediate or improve the ecological processes of the watershed. For TRO management these measures are important for effective control on a long-term basis and that the desired outcomes of revegetation and prevention of other noxious weed infestations are successful.

**Cost Analysis of TRO Management**

Costs for TRO Management are based on cost algorithms developed in Appendix H. These cost algorithms are a function of the density or canopy cover of the TRO infestation (Light density (D\text{L}) for 20% or less canopy cover, Moderate density (D\text{M}) for >20% to 50% canopy cover, and High density (D\text{H}) for >50% density) and accessibility (Low difficulty of access (A\text{L}), Moderately difficult to access (A\text{M}), and Highly difficult to access (A\text{H})). Planning, design,
implementation phase monitoring and maintenance costs during the initial five to ten years of TRO management efforts have not typically been considered in developing cost estimates. However, these components are critical to understand and should be included in the budgeting processes. Costs for these components increase proportionately as the TRO canopy cover increases due to added complexity for design, revegetation, and vegetation monitoring and establishment. Costs for these elements for light infestations are calculated at 20% of the control, biomass reduction, and revegetation combined costs. Moderate infestation costs are estimated at 25% of these same cost components, while heavy infestations have an estimated cost of 30%.

Appendix H provides focus to the appropriateness of control technologies, need for biomass reduction, and degree revegetation would be needed. From this information and using regression analysis total TRO management cost curves and equations are developed. Table 3 represents a compilation of each technology and its applicability to different density and access situations. Details for each control technology are provided in Appendix H. It is important for the reader to understand that costs developed throughout this document represent planning level values that must be adjusted for local conditions; e.g., revegetation costs for similar infestation levels can be dramatically different because of water availability, soil conditions, replacement vegetation, etc.

Long-term monitoring and maintenance costs following restoration actions (not to be confused with implementation phase monitoring and maintenance) are not included within these cost algorithms. For planning level purposes, annual ongoing monitoring and maintenance after TRO management has been completed is estimated at two percent of the total TRO management costs. Note that while control and biomass reduction will have fairly uniform costs throughout the West, the cost algorithm presented in Table 3 represents an average cost for riparian revegetation in the 17 western and plains states and is extremely sensitive to availability of water, width of infestation, soil characteristics, native plant seed bank, depth to ground water, etc. For these reasons costs could vary by an order of magnitude up or down from those presented in this table. This would be possible in sections of the Lower Colorado River below Hoover Dam where soils exhibit high salinity characteristics and there is low annual precipitation (Figure 29). Other areas such as headwater locations where soil conditions may have less salinity, more precipitation is received, native seed sources are nearby, and/or native plant materials are present (Figure 30), revegetation costs would likely be lower.
Figure 29: Colorado River near Blythe, CA (photo courtesy of Bureau of Reclamation).

Figure 30: Colorado River near Moab, UT (photo courtesy of John Dohrenwend).
### Table 3: Cost Equations for TRO Management Technologies as described in Appendix H.

<table>
<thead>
<tr>
<th>Control Approach</th>
<th>Access</th>
<th>* Applicability of Control Approach</th>
<th>Biomass Reduction Approach</th>
<th>Revegetation Approach</th>
<th>** Cost (y) Equations based on Density (x) as Percent Cover (Year 2009 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand cut-stump with herbicide</td>
<td>A&lt;sub&gt;M&lt;/sub&gt;, A&lt;sub&gt;H&lt;/sub&gt;</td>
<td>D&lt;sub&gt;L&lt;/sub&gt;</td>
<td>Not required</td>
<td>Minimal – natural revegetation anticipated</td>
<td>( y = -0.068x^2 + 100.9x ) Tamarisk and/or Russian olive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire as secondary</td>
<td>Revegetation required because of soil disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical extraction w/o herbicide</td>
<td>A&lt;sub&gt;L&lt;/sub&gt;, A&lt;sub&gt;M&lt;/sub&gt;</td>
<td>D&lt;sub&gt;L&lt;/sub&gt;</td>
<td>Not required</td>
<td>Some minor reseeding required because of soil disturbance</td>
<td>( y = 0.125x^2 + 26.10x ) Tamarisk only NOT appropriate for Russian olive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire as secondary</td>
<td>Revegetation required because of soil disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical root plowing &amp; raking</td>
<td>A&lt;sub&gt;M&lt;/sub&gt;, A&lt;sub&gt;H&lt;/sub&gt;</td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt;</td>
<td>Fire</td>
<td>Major revegetation required because of soil disturbance is extreme.</td>
<td></td>
</tr>
<tr>
<td>Mechanical mulching with herbicide</td>
<td>A&lt;sub&gt;L&lt;/sub&gt;, A&lt;sub&gt;M&lt;/sub&gt;</td>
<td>D&lt;sub&gt;L&lt;/sub&gt;</td>
<td>Not required</td>
<td>Some minor reseeding required because of soil disturbance</td>
<td>( y = 0.074x^2 + 28.13x ) Tamarisk and/or Russian olive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire as secondary</td>
<td>Revegetation required because of soil disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical grab &amp; cut-stump with herbicide</td>
<td>A&lt;sub&gt;L&lt;/sub&gt;, A&lt;sub&gt;M&lt;/sub&gt;</td>
<td>D&lt;sub&gt;L&lt;/sub&gt;</td>
<td>Not required</td>
<td>Some minor reseeding required because of soil disturbance</td>
<td>( y = 0.086x^2 + 29.34x ) Tamarisk and/or Russian olive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire as secondary</td>
<td>Revegetation required because of soil disturbance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerial herbicide application</td>
<td>A&lt;sub&gt;L&lt;/sub&gt;, A&lt;sub&gt;M&lt;/sub&gt;, A&lt;sub&gt;H&lt;/sub&gt;</td>
<td>D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire secondary</td>
<td>Significant revegetation required. Limited native plant availability under conditions associated with aerial herbicide application</td>
<td>( y = 0.102x^2 + 21.43x ) Tamarisk and/or Russian olive</td>
<td></td>
</tr>
<tr>
<td>Biological control with tamarisk leaf beetle (Diorhabda spp.)</td>
<td>A&lt;sub&gt;L&lt;/sub&gt;, A&lt;sub&gt;M&lt;/sub&gt;, A&lt;sub&gt;H&lt;/sub&gt;</td>
<td>D&lt;sub&gt;L&lt;/sub&gt;</td>
<td>Not required</td>
<td>Minimal – natural revegetation anticipated</td>
<td>( y = 0.146x^2 + 13.54x + 110 ) Available only for Tamarisk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D&lt;sub&gt;M&lt;/sub&gt;, D&lt;sub&gt;H&lt;/sub&gt; Mulching as primary with fire as secondary</td>
<td>Revegetation required because of soil disturbance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Access and Density definitions are located above on page 75.

** Costs include planning and design, TRO control, biomass reduction, revegetation, and monitoring and maintenance during the implementation period. Costs not included are long-term monitoring and maintenance requirements which are estimated at 2% of the TRO management costs.
On a site specific basis, these cost algorithms can be used to develop estimated costs for restoration. How this equates to the value of potential water savings is a function of replacement vegetation. For instance, a restoration scenario that has most of the TRO infested site revegetated with cottonwoods and willows will have very little if any water saved; thus, the cost per acre-foot of water saved would be very high. A site in which only ten percent of the site is revegetated with cottonwoods and willows with the remaining ninety percent revegetated with more xeric plant species could potentially save a valuable amount of water at a relatively low cost per acre-foot. Also, in sites in the Lower Basin with high density TRO, costs per acre-foot could be less because of the relative amount of water that can potentially be salvaged. The average site within the Colorado River Basin probably lies somewhere in between and is considered representative of many Basin situations, the calculated cost per acre-foot of water potentially saved for the different TRO management technologies are estimated in Table 4. An example spreadsheet analysis is provided in Appendix J for a mechanical control approach. Although the costs vary for each management technique, these techniques can be equally effective with regard to potential water saved. The method used depends on the site characteristics and the land-managers’ restoration criteria.

**Conclusions**

Costs for TRO management vary strongly based on site conditions, restoration goals, infestation characteristics, accessibility, control techniques used, revegetation goals, and availability of water. Costs for planning, design, and monitoring and maintenance during the implementation phase range between 20 to 30% of the costs for control, biomass reduction, and revegetation based on TRO canopy density. Annual long-term monitoring and maintenance is estimated to be 2% of the total of all other costs.

It is evident from field surveys of sites throughout the Colorado River system that several of these alternative TRO management approaches will be needed on many individual sites and; thus, the overall costs for restoration probably falls somewhere between the extremes. Cost estimating is compounded by site characteristics such as high soil salinity which increases revegetation costs. Common errors that are often made in estimating TRO management costs and water savings benefits are: 1) using only costs associated with control, 2) not identifying TRO canopy density, 3) not identifying replacement vegetation and these plant species’ water use compared to that of TRO, and 4) not identifying specific site conditions such as soil salinity and availability of groundwater.

TRO management that could provide a savings in water within the Colorado River Basin can be difficult to compare with other augmentation alternatives principally because natural processes (i.e., ET, surface groundwater interaction) are far more complex systems than physical processes (e.g., desalination). Natural processes can be modeled but can be difficult to measure unlike physical processes that can provide “end of pipe” water flow measurements. Recognizing that these evaluation complexities exist, the water augmentation cost estimates developed by the Basin States (SNWA 2008) and presented in Table 5 should be viewed with this understanding when compared with TRO management costs in Table 4.
Table 4: Comparison of different TRO management technologies including control, associated planning/design, biomass reduction, revegetation, and long-term monitoring and maintenance. Note: Costs do not include land purchase, the value of water saved or habitat benefits.

**Assumptions:** 60% tamarisk canopy cover, 25% of area suitable for replacement with cottonwood and willows with no difference in water usage, 75% of area would be revegetated with xeric vegetation with a potential 1.2 foot differential in water usage (see ET Peer Panel report conclusion #5 for the low range of tamarisk ET).

<table>
<thead>
<tr>
<th>Control Technology</th>
<th>$\text{Capital Cost per acre ($/acre)}$</th>
<th>$\text{Annual Long-term Monitoring and Maintenance ($/acre)}$</th>
<th>$\text{Potential Water Saved (acre-feet/acre)}$</th>
<th>$\text{Normalized Unit Cost of Water Saved over 30 years. ($/acre-foot)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand cut-stump with herbicide</td>
<td>$5,800</td>
<td>$120</td>
<td>0.54</td>
<td>$1,150</td>
</tr>
<tr>
<td>Mechanical extraction w/o herbicide</td>
<td>$2,020</td>
<td>$40</td>
<td>0.54</td>
<td>$400</td>
</tr>
<tr>
<td>Mechanical root plowing &amp; raking</td>
<td>$2,110</td>
<td>$40</td>
<td>0.54</td>
<td>$420</td>
</tr>
<tr>
<td>Mechanical mulching with herbicide</td>
<td>$1,950</td>
<td>$40</td>
<td>0.54</td>
<td>$390</td>
</tr>
<tr>
<td>Mechanical grab &amp; cut-stump with herbicide</td>
<td>$2,070</td>
<td>$40</td>
<td>0.54</td>
<td>$410</td>
</tr>
<tr>
<td>Aerial herbicide application</td>
<td>$1,650</td>
<td>$30</td>
<td>0.54</td>
<td>$330</td>
</tr>
<tr>
<td>Biological control with <em>Diorhabda</em> spp.</td>
<td>$1,450</td>
<td>$30</td>
<td>0.54</td>
<td>$290</td>
</tr>
</tbody>
</table>

**Notes:**

- a Capital costs include planning and design, some permitting, planning/design, TRO control, biomass reduction, revegetation, and monitoring and maintenance during plant establishment over the first 5 years. Costs are rounded to nearest $10 per acre. Costs not included are long-term monitoring and maintenance requirements which are estimated at 2% of the TRO management costs.

- b Normalized unit costs are based on the following assumptions developed by the Basin States in their evaluation of options for long-term augmentation options using the “Financial Cost Method” analysis: 1) Discount rate is 5%, 2) Amortized period is 30 years, and 3) annual ongoing monitoring and maintenance is estimated at 2 percent of TRO management costs (SNWA 2007).

- c Potential water saved is estimated to be (area that is suitable for xeric vegetation)(percent TRO canopy cover)(estimated differential in ET of TRO and replacement xeric vegetation). Thus, using the low range of the ET Panel’s estimate of tamarisk ET (2.3 to 4.6 feet per year) the calculation is (.75)(.60)(1.2) = 0.54 acre-feet/acre annual water savings.

- d Costs rounded to nearest $10 per acre-foot.

- e Capital costs for TRO management were assumed to be spread out over a period of 5 years and water yield assumed to start in year 5.

- f Long-term monitoring and maintenance begins after the initial 5 years needed to establish replacement vegetation.
Table 5: Augmentation alternatives for the Basin States. (SNWA 2008).

<table>
<thead>
<tr>
<th>Augmentation Alternative</th>
<th>Quantity of Augmentation Evaluated (acre-feet/year)</th>
<th>Annualized Cost ($/acre-foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brackish water desalination</td>
<td>4,000 to 50,000</td>
<td>$700 to $2,000</td>
</tr>
<tr>
<td>Coalbed methane produced water</td>
<td>3,000 to 20,000</td>
<td>$900 to $4,600</td>
</tr>
<tr>
<td>Conjunctive use or “water banking”</td>
<td>8,000 to 40,000</td>
<td>$400 to $700</td>
</tr>
<tr>
<td>Ocean water desalination</td>
<td>20,000 to 100,000</td>
<td>$1,100 to $1,800</td>
</tr>
<tr>
<td>Reduction of power plant consumptive use</td>
<td>1,500 to 160,000</td>
<td>$1,000 to $4,000</td>
</tr>
<tr>
<td>Reservoir evaporation control</td>
<td>0 to 270,000</td>
<td>$500 to $2,000</td>
</tr>
<tr>
<td>River basin imports</td>
<td>30,000 to 700,000</td>
<td>Costs need more refinement</td>
</tr>
<tr>
<td>Stormwater storage</td>
<td>0 to 100,000</td>
<td>$600+</td>
</tr>
<tr>
<td>Water imports using ocean routes</td>
<td>10,000 to 300,000</td>
<td>$1,400 to $4,000</td>
</tr>
<tr>
<td>Water reuse</td>
<td>20,000 to 800,000</td>
<td>$900 to $1,700</td>
</tr>
<tr>
<td>Weather modification</td>
<td>150,000 to 1,400,000</td>
<td>$20 to $30</td>
</tr>
</tbody>
</table>

**Future Impacts**

Impacts associated with TRO management versus impacts that could occur if no action is taken can be subjectively evaluated based on historic evidence, research cited in earlier sections, and from the ET Peer Panel’s report. The “No Action” Alternative does not mean conditions will remain status quo if restoration decisions are not made. “No Action” most likely means increasing infestation of TRO. Table 6 provides a comparison of these two future scenarios.

A question asked of the ET Panel that directly relates to the No Action Alternative was . . . If climate change occurs, what might be the implications for ET rates from TRO as well as potential replacement vegetation? The Panel responded that it has high confidence of a region-wide rise in temperatures throughout the year due to climate change. Temperature increases could drive higher ET by increasing the driving force for evapotranspiration and/or increasing photosynthetic rates. Increased temperatures could lead to higher ET rates by extending the growing season and regional extent of tamarisk. However, temperature, drought, and biological control stress could lower ET rates or leave them unchanged. Other factors of uncertainty include precipitation rates and forms (i.e. snow versus rain) and increased CO₂ concentrations. This information is not factored into this preliminary planning analysis.
<table>
<thead>
<tr>
<th>Issues</th>
<th>TRO Management Impacts</th>
<th>No Action Alternative Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRO water consumption</td>
<td>The potential exists for water savings if TRO is replaced on floodplain terraces with xeric vegetation.</td>
<td>Increased water usage by TRO will likely occur as TRO distribution increases and infilling occurs. Climate change may or may not lead to higher ET losses.</td>
</tr>
<tr>
<td>TRO Mechanisms of Spread</td>
<td>TRO could be reduced to a point that either of the species no longer has a significant negative impact on native plant species. With appropriate monitoring and maintenance these conditions can be sustained.</td>
<td>Tamarisk will continue to spread within tributaries and along major river systems, except in those areas already fully occupied by TRO within the floodplain. This spread and infilling will be aided by more frequent fires and climate change. Russian olive will gradually take over some areas tamarisk currently occupies because of its shade tolerance and it could become the dominant species.</td>
</tr>
<tr>
<td>Wildlife and Sensitive Species</td>
<td>Some species may suffer habitat loss in the short term until revegetation efforts are successful. Habitat for many other terrestrial and aquatic species will benefit.</td>
<td>Some species may fair well in a TRO dominated floodplain. Other species, both terrestrial and aquatic may suffer.</td>
</tr>
<tr>
<td>Salinity and Soil Chemistry</td>
<td>Surface soil salinity would gradually decrease due to precipitation flushing. Where no overbank flooding is possible and capillary soil characteristics leave salt residues due to evaporation, soil salinity will remain a problem.</td>
<td>Surface soil salinity will likely increase as distribution and infilling of TRO takes place. This increase can drive vegetation communities to ones that restrict many plants in favor of more salt tolerant species.</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Erosion and transport could occur if revegetation does not consider this factor.</td>
<td>Stream morphology will likely continue to change with narrower and deeper channels.</td>
</tr>
<tr>
<td>Wildfire Threat</td>
<td>Fire frequency and intensity would be reduced.</td>
<td>Fire frequency and intensity would increase.</td>
</tr>
<tr>
<td>Biological Control</td>
<td>If biological control is accompanied by revegetation efforts, river system ecology should generally improve.</td>
<td>Biological control is occurring in the Upper Basin and will likely continue to spread into the Lower Basin as the tamarisk leaf beetle evolves or different ecotypes are introduced. Without native vegetation reestablishment, many species of wildlife including the endangered SWFL could lose habitat.</td>
</tr>
<tr>
<td>Cultural</td>
<td>Cultural impacts would improve with reestablishment of native plant communities. Short-term loss of shade for livestock. Possible archeological damage due to bank erosion.</td>
<td>Overall, negative cultural impacts would increase.</td>
</tr>
<tr>
<td>Recreational</td>
<td>Generally, recreational impacts would improve with reestablishment of native plant communities. There would be short-term loss of shade for river users. Some types of river use may be impacted if rivers become wider and shallower because of bank destabilization.</td>
<td>Overall, negative recreational impacts would increase.</td>
</tr>
</tbody>
</table>
Zavaleta (2000) demonstrates that a program of tamarisk control and revegetation would have clear economic, social, and ecological benefits. With an aerial extent of between 470,000 to 650,000 hectares (1,150,000 to 1,600,000 acres) and marginal water losses estimated between 3,000-4,600 cubic meters per hectare (1.0 to 1.5 acre-feet per acre) per year, it is estimated that tamarisk costs the western United States 1.4 to 3.0 billion cubic meters (1,100,000 to 2,400,000 acre-feet) of water per year. She estimates that the annual costs to the western United States total $280-450 per hectare ($115 to $185 per acre) due to impacts to increased water use and sedimentation which leads to increased frequency and severity of flood damage. Zavaleta also estimates that eradication and restoration with native species would cost approximately $7,400 per hectare ($3,000 per acre) and that recovery of the benefits would conservatively occur in as few as 17 years after which the benefits of restoration would continue to accrue.

Other Programmatic Issues

There are other programmatic issues that are interrelated, especially with regard to biological control activities, and are therefore discussed together. These include: 1) planning and permitting constraints, 2) potential habitat mitigation requirements and consistency of TRO management activities with other environmental programs and concerns, and 3) long-term management and funding.

Planning and Permitting

The following list of planning and permitting issues is an attempt to discuss some of the actions that could be needed to move both research and restoration forward. This list is based on a review of known requirements. However, this list should not be considered as complete as some unknown very local and site-specific requirements could be important for some projects.

- Comprehensive planning can provide a sound footing for developing a partnership with land managers, both public and private, on the best approach for TRO management. There are a number of plans that have been completed that are now being used to garner funding and support. Most are in the Upper Basin. A critical component of each is good mapping and inventory data so that the TRO problem can be well defined and appropriate solutions identified.

- Project sites that are located on federal lands, funded by federal dollars or have any other federal nexus, are subject to the National Environmental Policy Act (NEPA).

- Most federal agencies have developed NEPA documentation that covers weed control and usually this includes TRO management.

- All seven states have environmental compliance laws which may have oversight and permitting requirements when working in riparian areas; e.g., the California Environmental Quality Act (CEQA).

- Although not always required, consultation with the state’s wildlife management office should be considered.
If actions involve federal funding or are carried out on federal lands timing of restoration and management may require consultation with the U.S. Fish and Wildlife Service (e.g., if management actions could interfere with sensitive species). This is especially important and a discernable cost factor when listed species are present.

A U.S. Army Corps of Engineers, Clean Water Act Section 404 permit may be necessary if TRO management or restoration is being conducted anywhere within waters of the United States.

Compliance with the National Historic Preservation Act may be necessary in areas of archeological or historic significance.

Fire permits may be required, and appropriate safety precautions should be followed.

Research permits are may be required on federal and Tribal lands.

Tribal agreements may need to be in place for management and active restoration.

Compliance with herbicide application requirements, state requirements may differ.

TRO management should be coordinated with existing weed management programs to ensure the best results.

Consistency with the management plans of the area or management unit in which activities would occur, for example on National Wildlife Refuges.

Potential habitat mitigation requirements and consistency of TRO management activities with other environmental programs and concerns.

Currently, the major environmental programs in the Colorado River Basin are the Lower Colorado River Multi-Species Conservation Program, the Upper Colorado River Endangered Fish Species Recovery Program, the San Juan River Basin Recovery Implementation Program, and the recovery goals established by the Fish and Wildlife Service for the Southwestern willow flycatcher. These programs are discussed in the Wildlife and Sensitive Species section of this report. TRO management throughout the Basin that includes revegetation efforts meets and supports the goals of these programs, with one exception. The biological control program has the potential to reduce tamarisk habitat in locations the Southwestern willow flycatcher has been observed to use (see Wildlife and Sensitive Species section). The Center for Biological Diversity requests that: 1) spread of the beetle is monitored, 2) native plants are restored in areas of flycatcher habitat where tamarisk has been/may be defoliated, and 3) there be no further introduction of beetles within the flycatcher’s range (Silver, 2008). To many in the scientific community these requests seem appropriate in order to mitigate the possible loss of habitat that the beetles may cause.
Long-term Management and Funding

It is clear that if resources are spent only on riparian restoration with no cohesive approach to long-term monitoring and maintenance, the potential for successful riparian restoration as part of a plan to create water savings is limited. The challenge is coordinating an acceptable restoration approach across many political boundaries. In any one watershed there will be private and public lands with the latter being represented or owned and managed by multiple cities, counties, states, tribes, and federal agencies.

Research should be conducted to identify models that can apply to the Basin. They could be patterned after existing approaches, such as the Chesapeake Bay Watershed Program and U.S. Environmental Protection Agency’s *Community Based Watershed Management: Lessons from the National Estuary Program* (2005) (see [http://www.epa.gov/twg/](http://www.epa.gov/twg/)) but other approaches could be entirely innovative in scope and design. Technical, political, and financial steps that support the maintenance of riparian restoration projects are difficult to implement. Management and funding models should be evaluated based on their effectiveness and efficiency at different levels of watershed complexity, such as:

- Watershed that is wholly within one state; e.g., San Rafael River in Utah
- Watershed encompassed within two states; e.g., Dolores River in Colorado and Utah
- Watershed within multiple states; e.g., San Juan River (Arizona, Colorado, New Mexico, and Utah) or the Virgin River (Arizona, Nevada, and Utah)
- The Upper Basin and the Lower Basin
- The entire Colorado River Basin

Public Law 109-320 specifically identified this issue, long-term management and funding, as an important research effort that needed to be addressed (see Appendix B).

Sources of Funding

Appendix K, *Grant Opportunities Available for Addressing Tamarisk Issues* provides a listing of possible grant opportunities available for addressing tamarisk issues and riparian restoration in the seven Colorado River Basin States. The sources of funding include federal, state, corporate, non-profit foundations and Congressionally-chartered foundations. This information was compiled by the Tamarisk Coalition in 2007 and recently updated to include individual state grant opportunities.

This list of grant opportunities has been compiled as a tool to be used as a starting point for grant funding research. This list is not exhaustive and is designed only to provide an overview of available grants. For more detailed information, visit the funding sources website, or contact the funding source directly.

The activities funded by the grantors include the following categories to aid in selecting appropriate grants:

- **Advocacy** includes activities associated with communicating about tamarisk issues such as organizing community meetings or distributing public education materials.
• **Education** involves direct education programs to a targeted group.

• **Policy** is defined as activities related to influencing and/or developing environmental policies.

• **Direct Action** includes activities such as volunteerism, control, revegetation, and other direct implementations.

• **Research** is defined as planning and implementing basic scientific research.

• **Start Up** is defined as funds for a new project (“seed money”) or funds for a new organization.

Please note that grants and grantors are subject to change at any time for a variety of reasons. It is critical that the funding sources are contacted for the most current information before any type of grant submission.

**Planned and Ongoing Projects and Research**

The following project and research information was submitted to the Tamarisk Coalition through February 2009. Project information forms were distributed via email to over 2000 contacts within the Tamarisk Coalition database including local, state, and federal agencies; universities; nonprofit organizations; Native American tribes; and individuals. The following list represents voluntary responses from organizations and individuals conducting research or implementing projects within the Colorado River Basin. The Tamarisk Coalition would like to recognize that this is a partial list of projects and there are more projects that were not reported.

Unless otherwise indicated, the projects are currently in progress. Project descriptions are summarized for the purpose of this report. For information on other collaborating organizations and funding sources for each project, please contact the corresponding contact person or the Tamarisk Coalition. Permission was granted from all project contacts to be included in this report.

The following table is organized by Lower and Upper Colorado River Basins. Projects within each basin are organized alphabetically by organization.
<table>
<thead>
<tr>
<th>Basin</th>
<th>Organization</th>
<th>Project Description</th>
<th>Geographic Area</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Arizona State University Polytechnic</td>
<td>Research – Bio-control of <em>Tamarix</em> and native herpetofauna</td>
<td>Virgin River, NV</td>
<td>Heather L. Bateman</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:Heather.L.Bateman@asu.edu">Heather.L.Bateman@asu.edu</a></td>
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<tr>
<td>Lower</td>
<td>Canyon Country Cooperative Weed Management Area</td>
<td>Tamarisk control (mechanical, chemical, cut-stump), spring 2009</td>
<td>East Fork Virgin River, UT, NV, AZ</td>
<td>Carl Gurr, Kane County Weed Department</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:weeds@kane.utah.gov">weeds@kane.utah.gov</a></td>
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<tr>
<td>Lower</td>
<td>DuPont</td>
<td>DuPont Land Management Russian Olive and Salt Cedar Test Sites (foliar spray)</td>
<td>CO, AZ, WY, UT, CA and other sites outside of CO River Basin</td>
<td>John Cantlon, DuPont Government Resource Manager</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:john.d.cantlon@usa.dupont.com">john.d.cantlon@usa.dupont.com</a></td>
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<tr>
<td>Lower</td>
<td>Fish and Wildlife Service</td>
<td>Tamarisk control (cut-stump, foliar spray)</td>
<td>Imperial National Wildlife Refuge (NWR) and Cibola NWR, AZ</td>
<td>Brenda Zaun</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:Brenda.Zaun@fws.gov">Brenda.Zaun@fws.gov</a></td>
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<tr>
<td>Lower</td>
<td>Forest Service, Gila National Forest Reserve District</td>
<td>Tamarisk control (cut-stump and chemical)</td>
<td>13 miles of the San Francisco River, north and south of Reserve, New Mexico</td>
<td>Jerry Turner, Reserve District Range Technician</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:jerryturner@fs.fed.us">jerryturner@fs.fed.us</a></td>
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<tr>
<td>Lower</td>
<td>Kane County Weed Department</td>
<td>Tamarisk bio-control release and monitoring</td>
<td>Johnson Canyon and The Buckskin Wash, Kane County, UT</td>
<td>Carl Gurr</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td><a href="mailto:weeds@kane.utah.gov">weeds@kane.utah.gov</a></td>
</tr>
<tr>
<td>Lower</td>
<td>Las Vegas Wash Coordination Committee</td>
<td>Tamarisk control, native plant restoration, heavily maintaining the site for a minimum of two years and annually site monitoring.</td>
<td>Clark County Wetlands Park boundary, Clark County, NV</td>
<td>Nick Rice</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><a href="mailto:nick.rice@snwa.com">nick.rice@snwa.com</a></td>
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Table 7: Planned and Ongoing Projects and Research activities.
<table>
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</thead>
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<tr>
<td></td>
<td></td>
<td>Park (NM), Grand Canyon National Park (NP), Hubbell Trading Post National Historic</td>
<td>Site, Lake Mead National Recreation Area, Montezuma Castle NM, Mojave NP,</td>
<td>Rita Beard, Invasive Plant Coordinator</td>
</tr>
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<td></td>
<td></td>
<td>Park, Tumacacori National Historic Park (NHP), Tuzigoot NM, Zion NP, and other</td>
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<td>[email protected]</td>
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<tr>
<td></td>
<td></td>
<td>sites outside of the Colorado River Basin</td>
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<tr>
<td>Lower</td>
<td>Northern Arizona University</td>
<td>Research - Economic Feasibility of Tamarisk Utilization in Northeast Arizona</td>
<td>Northeast AZ, tributary washes northeast of Little Colorado: Moenkopi,</td>
<td>Kevin L Hamann, Yeon-Su Kim</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dinnebito, Oraibi, Polacca, Jeddito</td>
<td>[email protected]</td>
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<tr>
<td>Lower</td>
<td>University of Utah</td>
<td>Research - Remote Sensing of Tamarisk Defoliation</td>
<td>Colorado River Basin</td>
<td>Philip Dennison [<a href="mailto:dennison@geog.utah.edu">dennison@geog.utah.edu</a>]</td>
</tr>
<tr>
<td>Upper</td>
<td>Bureau of Land Management</td>
<td>Tamarisk control (cut, chemical)</td>
<td>Montrose, Delta, San Miguel Counties, CO</td>
<td>Lynae Rogers [<a href="mailto:lynae_rogers@blm.gov">lynae_rogers@blm.gov</a>]</td>
</tr>
<tr>
<td>Upper</td>
<td>BLM, Farmington Field Office</td>
<td>TRO control (mechanical, chemical and cut-stump), mulch debris and/or utilize for</td>
<td>San Juan River, New Mexico</td>
<td>Sarah Scott [<a href="mailto:sarah_scott@blm.gov">sarah_scott@blm.gov</a>]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fuel wood, some active restoration, starts fall 2009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>BLM, Farmington Field Office</td>
<td>TRO control (mechanical, chemical and cut-stump), mulch debris and/or utilize for</td>
<td>Largo Canyon, New Mexico</td>
<td>Sarah Scott [<a href="mailto:sarah_scott@blm.gov">sarah_scott@blm.gov</a>]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fuel wood, some active restoration, starts spring 2009</td>
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<td>Basin</td>
<td>Organization</td>
<td>Project Description</td>
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<tr>
<td>Upper</td>
<td>BLM, Farmington Field Office</td>
<td>TRO control (mechanical, chemical and cut-stump), mulch debris and/or utilize for fuel wood, some active restoration</td>
<td>San Juan River, New Mexico</td>
<td>Sarah Scott <a href="mailto:sarah_scott@blm.gov">sarah_scott@blm.gov</a></td>
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<tr>
<td>Upper</td>
<td>BLM, Glenwood Springs Field Office</td>
<td>TRO inventory and control (cut-stump, chemical) on two major rivers and associated drainages</td>
<td>GSFO boundaries: Colorado River, De Beque to State Bridge; Roaring Fork River, Aspen to Glenwood Springs, CO</td>
<td>Dereck Wilson <a href="mailto:dereck_wilson@blm.gov">dereck_wilson@blm.gov</a></td>
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<tr>
<td>Upper</td>
<td>BLM, Kremmling Field Office (KFO)</td>
<td>Tamarisk infestation monitoring, education/outreach program on invasives</td>
<td>KFO boundaries, Colorado River from the Gore Canyon to State Bridge, Wolford Mountain Reservoir, Muddy Creek CO</td>
<td>Mandy Scott, Natural Resources Specialist <a href="mailto:amanda_scott@blm.gov">amanda_scott@blm.gov</a></td>
</tr>
<tr>
<td>Upper</td>
<td>BLM</td>
<td>Tamarisk biological control</td>
<td>Upper Dolores River near Bedrock, CO; Lower Gunnison River above Escalante Creek</td>
<td>Lynae Rogers <a href="mailto:lynae_rogers@blm.gov">lynae_rogers@blm.gov</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Bureau of Reclamation</td>
<td>Tamarisk control (mechanical, chemical and possible biological)</td>
<td>Fruitgrowers Reservoir, Delta County, CO</td>
<td>Deb Boggess <a href="mailto:dboggess@uc.usbr.gov">dboggess@uc.usbr.gov</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Bureau of Reclamation, Grand Junction Area Office</td>
<td>TRO control and revegetation</td>
<td>3 miles east of Grand Junction, CO along Colorado River</td>
<td>Terry Stroh <a href="mailto:tstroh@uc.usbr.gov">tstroh@uc.usbr.gov</a></td>
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<tr>
<td>Basin</td>
<td>Organization</td>
<td>Project Description</td>
<td>Geographic Area</td>
<td>Contact Information</td>
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<tr>
<td>Upper</td>
<td>Colorado State University, Ft. Collins, CO</td>
<td>Research - Tamarisk biological control monitoring and site effects on tamarisk and</td>
<td>Echo Park, Dinosaur National Monument, CO</td>
<td>Dr. Andrew Norton</td>
</tr>
<tr>
<td></td>
<td></td>
<td>established vegetation</td>
<td></td>
<td><a href="mailto:Andrew.Norton@colo.state.edu">Andrew.Norton@colo.state.edu</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Delta County Weed Program/BLM</td>
<td>Tamarisk and noxious weed removal since 2002, monitoring and maintenance, revegetation</td>
<td>Gunnison River for 23 miles below Black Canyon of the Gunnison National Park, CO</td>
<td>Webb Callicutt</td>
</tr>
<tr>
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<td><a href="mailto:wcallicutt@deltacounty.com">wcallicutt@deltacounty.com</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Department of Energy</td>
<td>Remediation, invasive weeds control, yearly bio-control monitoring</td>
<td>Old Atlas Minerals Mill Site, Moab, UT</td>
<td>Ed Baker</td>
</tr>
<tr>
<td></td>
<td></td>
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<td><a href="mailto:ebbaker@energysolutions.com">ebbaker@energysolutions.com</a></td>
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<tr>
<td>Upper</td>
<td>Dolores Tamarisk Action Group (DTAG), Dolores</td>
<td>TRO control, utilizing Southwest Conservation Corps, revegetation, training/education</td>
<td>Upper McElmo Creek Drainage, Primarily small tributaries feeding McElmo Creek, CO</td>
<td>Steve Miles</td>
</tr>
<tr>
<td></td>
<td>Soil Conservation District</td>
<td>program</td>
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<td><a href="mailto:rainmaker@velocitynetdsl.com">rainmaker@velocitynetdsl.com</a></td>
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<tr>
<td>Upper</td>
<td>Douglas Creek Conservation District</td>
<td>TRO control (biological, chemical), revegetation, and monitoring program</td>
<td>Lower White River, Rangely Area of Rio Blanco County, CO</td>
<td>Kelly Osborn</td>
</tr>
<tr>
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<td></td>
<td></td>
<td><a href="mailto:Kelly.Carpenter@co.net">Kelly.Carpenter@co.net</a></td>
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<tr>
<td>Upper</td>
<td>DuPont</td>
<td>DuPont Land Management Russian Olive and Salt Cedar Test Sites (foliar spray)</td>
<td>CO, AZ, WY, UT, CA and other sites outside of CO River Basin</td>
<td>John Cantlon, DuPont Government Resource Manager</td>
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<td><a href="mailto:john.d.cantlon@usa.dupont.com">john.d.cantlon@usa.dupont.com</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Eagle River Watershed Council, Inc.</td>
<td>Tamarisk control (cut-stump, chemical), revegetation, monitoring program</td>
<td>Confluence of the Eagle and Colorado Rivers at Dotsero, CO</td>
<td>Timm Paxson</td>
</tr>
<tr>
<td></td>
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<td></td>
<td><a href="mailto:timmpaxson@comcast.net">timmpaxson@comcast.net</a></td>
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<td></td>
<td>David Fulton</td>
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<td><a href="mailto:fulton@erwsc.org">fulton@erwsc.org</a></td>
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<tr>
<td>Upper</td>
<td>Forest Service, Uinta-Wasatch-Cache National</td>
<td>Tamarisk inventory and control</td>
<td>Heber-Kamas Ranger District Strawberry Reservoir, UT</td>
<td>Patricia Musser</td>
</tr>
<tr>
<td></td>
<td>Forest Service, Uinta-Wasatch-Cache National</td>
<td></td>
<td></td>
<td><a href="mailto:pamusser@fs.fed.us">pamusser@fs.fed.us</a></td>
</tr>
</tbody>
</table>
### Table 7: Planned and Ongoing Projects and Research activities.

<table>
<thead>
<tr>
<th>Basin</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>Garfield County, CO</td>
<td>TRO control (cut-stump, areal spray, chemical)</td>
<td>New Castle to Rifle in Garfield County, CO; Colorado River, Alkali, Divide, Dry Hollow and Mamm Creeks</td>
<td>Steve Anthony - County Vegetation Manager</td>
</tr>
<tr>
<td>Upper</td>
<td>Garfield County/South Side Conservation District</td>
<td>Tamarisk control (chemical and cut-stump), secondary invasives control, and restoration assistance</td>
<td>Mamm Creek, Dry Hollow, Divide Creek, Garfield County, CO</td>
<td>Steve Anthony <a href="mailto:santhony@garfield-county.com">santhony@garfield-county.com</a></td>
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<tr>
<td>Upper</td>
<td>Grand Valley Audubon Society</td>
<td>TRO control, restoration</td>
<td>Between the Colorado River and the Redlands Tail Race, Grand Junction, CO</td>
<td>Robert W Wilson <a href="mailto:bluebirdbob@gmail.com">bluebirdbob@gmail.com</a></td>
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<tr>
<td>Upper</td>
<td>Manti-LaSal National Forest and Price Field Office BLM</td>
<td>Tamarisk control (cut-stump, chemical)</td>
<td>Emery County, UT</td>
<td>Karl Ivory, Natural Resource Specialist <a href="mailto:Karl_ivory@blm.gov">Karl_ivory@blm.gov</a></td>
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<tr>
<td>Upper</td>
<td>National Park Service</td>
<td>TRO control (cut-stump, chemical, whole plant removal), studying best methods of removal for both species</td>
<td>Canyon de Chelly National Monument, AZ</td>
<td>Dr. David J. Cooper <a href="mailto:dcooper@warnercnr.colostate.edu">dcooper@warnercnr.colostate.edu</a></td>
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<tr>
<td>Upper</td>
<td>National Park Service</td>
<td><em>TRO inventory and treatment fiscal years 2007, 2008 and 2009: Arches NP, Bandelier NM, Canyon De Chelly NM, Canyonlands NP, Capitol Reef NP, Chaco Culture NHP, Colorado NM, Dinosaur NM, and other sites outside of Colorado River Basin</em></td>
<td></td>
<td>Rita Beard, Invasive Plant Coordinator <a href="mailto:rita_beard@nps.gov">rita_beard@nps.gov</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Natural Resources Conservation Service</td>
<td>Tamarisk control (cut stump, root crown removal when possible), revegetation</td>
<td>Gunnison River below confluence near Delta, CO</td>
<td>Tanya Banulis <a href="mailto:tanya.banulis@co.usda.gov">tanya.banulis@co.usda.gov</a></td>
</tr>
<tr>
<td>Upper</td>
<td>Ouray National Wildlife Refuge</td>
<td>TRO control (cut-stump, chemical and biological)</td>
<td>UT, 16 mile stretch of Green River</td>
<td>Diane Penttila <a href="mailto:diane_penttila@fws.gov">diane_penttila@fws.gov</a></td>
</tr>
<tr>
<td>Basin</td>
<td>Organization</td>
<td>Project Description</td>
<td>Geographic Area</td>
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</tbody>
</table>
| Upper | Painted Sky Resource Conservation & Development Council | Tamarisk control (biological, chemical as needed), revegetation | Delta County, CO | Richard Harding, President/Executive Director  
painted_sky@sopris.net |
| Upper | Rocky Mountain Bird Observatory | Research - Tamarisk biological control monitoring and site effects on tamarisk and established vegetation | Echo Park, Dinosaur NM and Horsethief Canyon, CO | Glenn Giroir  
glenn.giroir@rmbo.org |
| Upper | San Juan County Weed Department, UT | Tamarisk biological control monitoring of natives and Russian olive revegetation | Monticello, UT | Jim A. Eberling, San Juan County Weed Supervisor  
jimaebcrling@frontier.net.net |
| Upper | San Juan Institute of Natural and Cultural Resources, Fort Lewis College | TRO control, revegetation, monitoring (bird and mammal pellet surveys, and invertebrate sampling – comparison with mature willow stand sites) | Shiprock, New Mexico | Catherine Ortega  
ortega_c@fortlewis.edu |
| Upper | The Nature Conservancy | TRO and Siberian elm control (120 river miles), completed | San Miguel Watershed, CO | Peter Mueller  
pmueller@tnc.org |
| Upper | The Nature Conservancy | Tamarisk control, riparian restoration and best management practices, starts fall 2009 | Dolores River Watershed, CO & UT | Peter Mueller  
pmueller@tnc.org |
| Upper | The Nature Conservancy | TRO control focus on firebreaks and resprouts, revegetation | Scott M. Matheson Wetlands Preserve, Moab, UT | Linda Whitham  
lwhitham@tnc.org |
| Upper | University of Denver | Development of best management practices manual for revegetation after tamarisk removal | Upper Colorado River Basin | Dr. Anna Sher  
anna.sher@du.edu |
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<tr>
<td>Upper</td>
<td>University of Utah</td>
<td>Research - Remote Sensing of Tamarisk Defoliation</td>
<td>Colorado River Basin</td>
<td>Philip Dennison</td>
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<td></td>
<td></td>
<td><a href="mailto:dennison@geog.utah.edu">dennison@geog.utah.edu</a></td>
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<tr>
<td>Upper</td>
<td>Utah Association of Conservation Districts</td>
<td>Tamarisk control (cut-stump and possible bio-</td>
<td>Bear River Drainage, UT</td>
<td>Nathan Daugs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>control)</td>
<td></td>
<td><a href="mailto:nathan.daugs@ut.nacd.net.net">nathan.daugs@ut.nacd.net.net</a></td>
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<td>Upper</td>
<td>Utah Division of Wildlife Resources</td>
<td>Tamarisk control (cut-stump)</td>
<td>Browns Park Waterfowl Management</td>
<td>Lowell Marthe</td>
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<tr>
<td></td>
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<td></td>
<td>Area, Browns Park, UT</td>
<td><a href="mailto:lowellmarthe@utah.gov">lowellmarthe@utah.gov</a></td>
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<td>Upper</td>
<td>Utah Division of Wildlife Resources</td>
<td>Tamarisk control (mechanical, biological),</td>
<td>San Rafael River, UT</td>
<td>Kenneth Breidinger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>revegetation</td>
<td></td>
<td><a href="mailto:kennybreidinger@utah.gov">kennybreidinger@utah.gov</a></td>
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<tr>
<td>Upper</td>
<td>Wayne County Weed Department</td>
<td>Tamarisk control</td>
<td>Fremont River Drainage, Cainville,</td>
<td>Rex Thomas Griffiths</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>UT</td>
<td><a href="mailto:rtg@wco.state.ut.us">rtg@wco.state.ut.us</a></td>
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Research Needs

The Tamarisk Coalition identified the following research needs during the process of compiling this report. These needs were derived from the ET Peer Panel report, literature review, and through personal communication with resources. Additionally, some of the research needs were identified from presentations and discussions at the Tamarisk and Russian Olive Research Conference, held February 18-19, 2009 in Reno, Nevada. Research needs are assigned to categories and given a category code. This coding is used subsequently in the discussion of potential demonstration sites. As many of the research needs overlap two or more categories, effort was made to place them in the most relevant category. Research needs are not listed in any particular order of priority, however, research needs particularly relevant to the Basin States with regard to water savings are identified with an asterisk.

Evapotranspiration (ET): Within the ET Peer Panel’s report there are numerous research needs that the reader should review. The Panel recommended three specific actions when performing ET research as well as other research efforts:

1. Reference ET, ET₀, is a standardized representation of climatic evaporative demand at a given site. ET by a particular species such as tamarisk, when expressed as a fraction of reference ET, or an ET₀F, are more transferrable across latitude, altitude and climate.
2. The Panel stressed the importance of establishing consistent protocols for data collection at the outset of an integrated research program. An interdisciplinary team to establish such protocols and to vet demonstration proposals should include at least one expert from each of the following areas: ecology, hydrology, remote sensing, direct ET measurement, restoration, and bio-control. This team can also guide initial site evaluation for appropriate hydrological characteristics.

3. It is recommended that all TRO ET measurement systems and programs receive extensive peer review by communities of experts to reduce experimental biases and pitfalls and to promote effective expenditure of public dollars.

Research needs identified below represent a compilation of needs identified in the ET Panel report.

- **ET-1**: ET rates of halophytic (salt-tolerant) and xeric (drought tolerant) native species that might replace TRO.

- **ET-2**: ET rates of secondary invasive plants.

- **ET-3**: ET rates for Russian olive.

- **ET-4**: Study of the relationship between canopy density and ET rates, and stand age and ET rates, for both TRO and natives.

- **ET-5**: Study of how to better extrapolate and apply reference ET to riparian areas.

- **ET-6**: Develop hydrologic models to predict if reductions in ET will be converted to groundwater storage or streamflow. These models can also indicate optimal management scenarios that maximize water savings by focusing TRO management on areas that provide the greatest benefit. Because models, such as GSFLOW, can provide predictions of hydrologic response, various scenarios can be considered to account for uncertainties in future climatic conditions and TRO management options.

- **ET-7**: For both bare soils and vegetative covered soils, compare evaporation between floodplain terraces with soils that are susceptible to capillary action and areas that lack this characteristic.

- **ET-8**: In order to compare TRO ET rates to ET rates of important native species, ET rates in the Upper Basin need to be calculated for riparian native vegetation such as willow and cottonwood.

- **ET-9**: Follow the effects on ET of cutting tamarisk down to the stump and allowing it to regrow to learn about how regrowth rates affect ET.
ET-10 Develop an experiment that consists of only cutting back tamarisk and evaluate the change in ET.

ET-11 ET estimates for both TRO and natives would be improved by study of the relationship between ET rates and canopy density as well as stand age.

ET-12* Similarly, ET estimates would be improved by study of how to better extrapolate and apply reference ET to riparian areas, with their lower temperature, wind speed and higher humidity than surrounding areas more typically addressed by this type of extrapolation.

ET-13 In the Upper Basin, more research is needed on whether and where active revegetation will be an important component of successful restoration of TRO invaded sites.

ET-14 Research is needed on plant stomatal behavior under water stress conditions (high temperature, drought) and how it affects 24-hour estimates of ET.

ET-15 Energy balance methods, such as Bowen ratio and eddy covariance, rely strongly on assumptions about vertical vapor and heat transfer over stands. To accurately measure ET, further research is need on how to account for advection and how advection influences dynamics at different types of sites.

ET-16 Scaling up ET measured for small samples or sampled areas to represent ET of larger areas.

ET-17 Scaling up transpiration measured by sap flow to ET that includes evaporation from soil and intercepted precipitation as well as transpiration from understory vegetation.

Tools (T)

T-1* In general, Russian olive infestation is mapped to a lesser degree than is tamarisk, and better mapping of this species will improve our ability to predict its future spread as well as assess its current impact.

T-2* Many areas in the Colorado River Basin have little or no mapping of TRO and in other areas existing mapping efforts need to be expanded. The Mapping Summary section lists 16 specific river reaches where additional mapping efforts are required.

T-3 Coordinate future inventory and mapping with USGS efforts to establish a national on-line database conforming to the North American Weed Management Association’s weed mapping standards. The Mapping Summary details specific attributes that should be included in this database.
T-4* Estimate potential water savings/salvage/generation/differential use by comparing modeled and remotely sensed ET rates among locations with and without TRO stands.

T-5* Estimate potential water savings/salvage/generation/differential use by comparing modeled ET rates from TRO stands before and after stand removal.

T-6* Develop an integrated hydrologic model that simulates or predicts ET as a function of vegetation type, vegetation density, and climate.

T-7 Improve inventorying technique, particularly density and mass.

T-8 Develop a standard protocol for testing herbicide effectiveness.

T-9 Improvement in prediction of future infestations.

Mechanisms of Spread (MoS)

MoS-1 Develop a model that predicts the rate and breadth of the spread of TRO.

Salinity (Sal)

Sal-1 To what extent does tamarisk foliage contribute to soil surface salinity? Can tamarisk management reduce salinity loads into the Colorado River system?

Sal-2 Can heritable variation in salinity tolerance among cottonwoods be exploited to restore cottonwoods in riparian areas where salinity has increased?

Sal-3 Can cost-effective methods be developed to reduce salinity and restore?

Sal-4 Can cost-effective methods be developed to improve revegetation success under high salinity and low precipitation conditions?

Sal-5* Research is needed to assess effectiveness of techniques to restore soil processes on xeric sites with dense monotypic infestations, to include tamarisk litter dispersal or incorporation, improved seed contact with mineral soil, reduced surface salinity, mycorrhizal inoculation, and nitrogen manipulation.

Sedimentation (Sed)

Sed-1* How does TRO management including biological control affect sedimentation and erosion in river channels?
**Sed-2** How would potentially increased erosion impact water resource infrastructure in the wake of TRO management?

**Sed-3** Do sediment loads pose other threats such as mobilization of pollutants?

**Sed-4** Do different control methods produce different rates of potential erosion?

**Sed-5** Because streambank erosion and stabilization can be a concern following tamarisk removal, research is needed on phased approaches to control and revegetation that maintain stable vegetative protection and bank armoring over time.

**Wildfire Threat (WF)**

**WF-1** Can historic fire regimes be reconstructed for southwestern floodplains? Knowledge of fire frequency and intensity under historic as well as future restored conditions will improve the ability to sustain restored native riparian communities.

**WF-2** Do TRO infestations increase fire frequency and intensity or are dry conditions, human-caused fires and/or altered disturbance regimes responsible for the increased frequency of fires in riparian areas?

**WF-3** More data is needed on the response of both native and non-native riparian plant species to fire.

**WF-4** When fire is used as a tamarisk management tool, what is the optimal phenological stage(s) at which to burn tamarisk to achieve the greatest reductions in canopy, density, and fuel loads?

**WF-5** How is Russian olive adapted to fire and what are its post-fire regenerative abilities?

**WF-6** How does fire as a management tool affect potential erosion rates?

**Wildlife and Sensitive Species (WL)**

**WL-1** More data is needed on the interaction between native wildlife and Russian olive.

**WL-2** Mixed tamarisk-native plant communities may be beneficial for birds; however, it is not known whether these mixed-communities will remain stable or eventually progress to tamarisk monocultures which are generally detrimental to wildlife.

**WL-3** Biological control of tamarisk is very different from other control measures in its timing, pattern, and potential for indirect effects. There is a need for research on the
impacts of biological control on wildlife, in particular the Southwestern willow flycatcher.

**WL-4** Can staging and patterning of tamarisk management and revegetation minimize impacts, or maintain and improve habitat for wildlife that utilizes tamarisk as habitat?

**WL-5** Study the effects of TRO management on other vertebrates as there is relatively little information on the impacts of TRO and TRO management on species other than birds.

**WL-6** Very little is known about the impact of TRO on aquatic animals. Study the effect of TRO given the linkages between aquatic environments and the terrestrial vegetation that borders them, as well as tamarisk’s ability to influence channel structure.

**WL-7** Assess the need for active revegetation in the Upper Basin.

**Biological control (BC)**

**BC-1** Expand existing monitoring of the population dynamics of the tamarisk leaf beetle in the Upper Basin and begin monitoring in the Lower Basin to establish baseline conditions.

**BC-2** How well does native vegetation recruit in areas affected by tamarisk biological control? Is active revegetation necessary or will natural processes lead to the passive recovery of native plants?

**BC-3** Will Russian olive or herbaceous invasive weeds out-compete native revegetation after biological control defoliates tamarisk?

**BC-4** Can water savings be expected as a result of biological control?

**BC-5** As biological control leads to desiccation and mortality of tamarisk, what is the wildfire threat?

**BC-6** How will tamarisk mortality due to biological control affect soil salinity?

**BC-7** More data is needed on both direct and indirect effects of biological control on invertebrate and vertebrate riparian animals.

**BC-8** How does biological control effectiveness change when combined with other control measures such as cutting and herbicide spraying?

**BC-9** How can revegetation be initiated while tamarisk is declining?
Cultural (Cul)

Cul-1 Document native plant and water related impacts (negative and positive) of TRO on Native American cultures.

Biomass Utilization (BU)

BU-1 Determine if conversion of TRO biomass to energy is an efficient and viable use of biomass.

BU-2 Conduct a study to estimate the amount of Russian olive biomass, similar to tamarisk study conduct by CSU and USGS.

BU-3 Determine if TRO biomass has a commercial value and market.

Other Research Needs (OR)

OR-1* The development of acceptable restoration approaches for the Basin that includes long-term monitoring and maintenance structure(s) across many political boundaries is needed. This research need is unique in that it is appropriate for the political science field rather than biological and/or physical sciences, or engineering fields. However, it is considered to be single most important research effort required.

OR-2* What are the potential impacts from climate changes on tamarisk establishment, water usage, fire, floods, and other related events?

OR-3 Is the distribution of heavy metals, such as selenium, a concern when tamarisk is consumed by biological control beetles or mulched following removal?
Task 4: Demonstration Sites

This section of the report integrates the results of the preceding sections to develop a list of potential Demonstration Projects for TRO management in the Colorado River Basin for submittal to USBR for federal funding consideration pursuant to Public Law 109-320. It also provides the basis for preparation of a prioritization framework which would evaluate potential sites and assist in making decisions on which projects to implement.

In the Tamarisk Coalition’s discussions with the Science Advisor to the Secretary of the Interior and with Congress, the fundamental concept of the large-scale demonstration projects identified in PL 109-320 was not simply to fund TRO projects, but rather to use control and restoration of specific TRO problems as research platforms to address critical issues that are outstanding. These research questions addressing evapotranspiration, mapping, mechanisms and rate of spread, salinity, sedimentation, wildfire threat, wildlife, impacts of biological control, cultural, biomass reduction, and other research needs are identified in the Research Needs section.

For future research, a representative suite of sites should be considered that builds on existing research and can test long-standing questions about restoration potential in TRO-invaded sites. To represent the full range of situations in which TRO occur, study sites could include those with a range of:

- Infestation acreage and densities /canopy
- Potential native vegetation types
- Elevations
- Locations in both the Upper and Lower Basins
- Presence and absence of bio-control insects and defoliation
- Groundwater depths
- Degrees of difficulty to achieve restoration / restoration potential
- Salinities
- Hydrologic conditions (free-flowing and controlled reaches with and without flooding)

Sites should also be located on river reaches or in watersheds with well-defined boundaries, geology and surface and subsurface flows so that entire water budgets can be modeled over time⁴. Ideally, sites should be selected in pairs and established as paired control and restoration sites to provide more accurate information about the effects of TRO removal on water savings and other ecosystem services. Eight sites were identified that might be appropriate for large-scale demonstrations – four in the Upper Basin and four in the Lower Basin. There may be other potential sites. Sites were identified through interviews with land managers and researchers, the ET Peer Panel discussions, and from interaction at the 2009 Tamarisk & Russian Olive Research Conference. Potential research sites are listed alphabetically below for the Upper and Lower Basins (see Figure 31). The following list should not be considered as inclusive, as there are other sites which could also be appropriate.

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⁴ A number of specific hydrological issues need to be addressed before any site is included, such as whether significant deep percolation is likely and whether a river reach is gaining from groundwater or losing to groundwater.
Figure 31: Potential Demonstration sites for TRO management and associated research.
Upper Basin Sites:

- **Colorado River in Utah** from Green River confluence to Colorado/Utah state line. This section of the river (132 miles) has had the most biological control activity of any location within the Upper Basin. The area around Moab has significant Russian olive infestations. An active partnership with the National Park Service, BLM, state agencies, USGS, and numerous non-profit organizations are working together on restoration efforts. Inventory and mapping is complete for this section of the watershed.

- **Dolores River in Colorado and Utah.** The entire river and its tributaries from McPhee Reservoir to the Colorado River confluence (183 miles). This river is unique in the Upper Basin in that only a few Russian olive trees are present in the watershed. This site is entering its second year of biological control along its entire length. This relatively small watershed crosses through five counties and two states and is managed by five federal agencies, four state agencies, numerous private landowners, and several water and conservation districts. An active partnership headed by The Nature Conservancy is underway to initiate restoration action. Other partners include several large nonprofit foundations, the Tamarisk Coalition, BLM, USDA, USGS, several universities, and a major energy company. Inventory and mapping is complete for the entire watershed.

- **San Juan River.** This river system is one of the major tributaries to the Colorado River system. An active partnership exists among the Four Corner’s states and four tribes that the San Juan River traverses. The watershed has equal problems with both tamarisk and Russian olive below Navajo Reservoir and biological control is active on the northern fringe of the watershed.

- **San Rafael River in Utah.** This is a relatively small river system that flows into the Green River. The upper end has both tamarisk and Russian olive infestations while the lower end is dominated by tamarisk. Biological control is active in this area and through a partnership with Utah Division of Wildlife Resources. Active restoration is being initiated.

Lower Basin Sites:

- **Bill Williams River in Arizona.** Significant research by USGS and numerous universities is ongoing in this river section. Major topics include tamarisk control and cottonwood and willow recruitment following controlled releases from Alamo Reservoir.

- **Cibola National Wildlife Refuge.** This area is located in Arizona within in the floodplain of the Lower Colorado River and is surrounded by a fringe of desert ridges and washes. The refuge encompasses both the historic Colorado River channel and a channelized portion constructed in the late 1960s. The site has high salinity problems on the floodplain terraces and has been used by numerous researchers for endangered species studies and revegetation efforts. Over the past several decades an abundance of control and restoration work has been done at this site. There is a history of collaboration with many other agencies and organizations. The site is currently hosting an array of current research on ET and restoration. Numerous studies are also underway as part of the Lower Colorado River Multi-Species Conservation Program.
• **Other Lower Colorado River mainstem sites.** Other sites on the Lower Colorado River system that have potential attributes that lend themselves to addressing many research questions as part of large-scale demonstrations. These include Havasu NWR, Grand Canyon National Park, Imperial NWR, and above Laguna Dam. Many of these sites are included within the Multi-Species Conservation Program and therefore should benefit the overall goals of this program. There are also sites on tributaries to the Colorado River which may have the right combination of factors where a small scale demonstration project could be implemented which would provide evidence of water recovery.

• **Virgin River system in Arizona, Nevada and Utah.** The Virgin River system is a relatively small watershed and represents an essentially free flowing river system with minimal impoundments. Currently, this is the only known area in which biological control is occurring in the Lower Basin and within the Southwestern willow flycatcher critical habitat. An active partnership with state and federal land managers is underway in this system to initiate restoration actions coupled with biological control. Currently, a research project is proposed to conduct remote sensing of a tamarisk dominated floodplain before episodic defoliation by the tamarisk leaf beetle by the University of California-Santa Barbara, USGS, University of Utah, and Utah State University.

Table 8 displays the relationship between each of these potential demonstration sites and the research needs identified to assess water savings as previously identified. Table 9 displays all other research needs that would also be appropriate to each demonstration site. This is the first attempt to identify appropriate sites for demonstrations and associated research that could be carried out at the sites. From these tables it is apparent that not all sites are good for certain research activities. This information provides a starting point for the Basin States to refine and narrow the research topics that are most important to the Basin States.
Table 8: Potential Demonstration Sites and their relative capability to address important water saving research needs.  

<table>
<thead>
<tr>
<th>Potential Demonstration Sites</th>
<th>Evapotranspiration (ET)</th>
<th>Tools (T)</th>
<th>Salinity (Sal)</th>
<th>Sedimentation (Sed)</th>
<th>Biological control (BC)</th>
<th>Other Research (OR)</th>
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1 Note: Numbers represent research codes by category as described in the Research Needs section and summarized below:

ET-1* ET rates for halophytic (salt-tolerant) and xeric (drought tolerant) native species.
ET-3* ET rates for Russian olive.
ET-6* Develop hydrologic models to predict water savings and water recovery potential.
ET-7* ET rates for bare soil and soils with capillary action.
ET-12* Extrapolate and apply reference ET rates to other areas.
T-1* and T-2* Tamarisk and Russian olive mapping.
T-4*, T-5*, and T-6* Use modeling and remote sensing to predict ET.
Sal-5* Assess effectiveness of techniques to restore soils on xeric sites.
Sed-1* and Sed-4* How does TRO management affect bank stability and erosion.
Sed-2* How does TRO management affect water resources infrastructure.
Sed-5* Phasing TRO management to limit sedimentation.
BC-4* Impacts of biological control on potential water savings.
OR-1* Develop long-term monitoring and maintenance approaches across many political jurisdictions.
OR-2* Potential impacts of climate change to TRO distribution, water use, etc.
Table 9: Potential Demonstration Sites and their relative capability to address important research needs other than water savings. ¹

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¹ Note: Numbers represent research codes by category as described in the Research Needs section.
Next Steps in Developing Demonstration Projects

Demonstration Projects that are submitted for federal funding allow for large-scale management of TRO and are essentially research platforms that are to be used to help answer the questions raised in the preceding section. The primary research questions that are the focus for the Basin States are the documentation of potential to save water lost to ET, and to identify where this saved water would occur in the system. Secondary objectives include: preventing re-infestation of TRO in managed areas; testing the efficacy of revegetating upland areas with xeric non-phreatophytic species, focusing on areas with saline soils, and developing long-term management and funding structures. Other concepts include: testing the relative success between Upper Basin natural revegetation and Lower Basin active revegetation; implementing projects in areas of high TRO density and easy access, and; focusing on gaining reaches of the river where the water table and the TRO infestations that depend on it are both wide.

One critical component that must be addressed as part of any demonstration project is the identification of the non-federal funding source(s) required as a match to federal funding.

As an integral part of the TRO Assessment the ET Peer Panel provided the following specific recommendations for future research activities:

That pairs of sites be selected for Demonstration Projects. ET measurements need to be comparable across sites. To achieve this, the ET Panel stressed that it is more important that multiple methods be used to estimate ET at each site than that the same methods be used at each site. The best measurement approaches depend on site characteristics, but ideally every site would involve at least one direct method of measuring ET such as flux towers (micrometeorological approaches), sap flow, or isotope tracer methods. The Panel noted that micrometeorological approaches are inappropriate for canyon areas and for narrow stands of riparian vegetation; and that sap flow may be the preferred direct approach for Russian olive at all sites since it generally occurs in mixed stands.

In all situations, the Panel encouraged that all TRO ET measurement systems and programs to receive peer review by communities of experts to reduce experimental biases and pitfalls and to promote effective expenditure of public dollars.

The Panel recognized that hydrologic modeling can be used to predict if reductions in ET will be converted to groundwater storage or streamflow. These models can be applied to demonstration sites to indicate optimal management scenarios that maximize water savings by focusing TRO management on areas that provide the greatest benefit.

Biological changes, such as biodiversity responses and plant succession, need to be monitored consistently across sites. The Panel stressed the importance of establishing consistent protocols for data collection at the outset of an integrated research program. An interdisciplinary team to establish such protocols and to vet demonstration proposals should include at least one expert from each of the following areas: ecology, hydrology, remote sensing, direct ET measurement, restoration, and bio-control. This team should ensure that methods across a range of variables are comparable and mutually compatible and that all proposed sites are compatible with all
identified measurement needs. This team can also guide initial site evaluation for appropriate hydrological characteristics.

The Panel recommended that data collection at sites start as soon as possible as the first of three research phases. First, to accurately gauge the effects of restoration and other treatments, multiple years of data should be collected before the treatments are implemented at study sites. This phase includes basic site characterization – automated weather stations should be installed as soon as possible at all sites, and their hydrology characterized (e.g. surface flux, control volumes). Second, when treatments are initiated, they should begin at only one of each pair of study sites so that effectiveness can be compared to a control site for multiple years. Finally, if treatments are effective based on comparisons with before-treatment data (within sites) and with control sites (within years), then treatment can be fine-tuned and applied to the sites that served as controls.

For the eight potential sites identified, all would benefit from full funding of $7,000,000 per site authorized under the federal legislation (PL 109-320, see Appendix B). It is proposed that a subset of the ET Panel of scientists (3 to 4 members) work directly with the Basin States to: 1) narrow the number of identified demonstration sites to those that can best answer the critical questions associated with the potential for water savings, and 2) develop the scope of research activities most appropriate to address these critical questions.

**Consideration for design of the Demonstration Projects**

The ET Panel recommended the inclusion of certain study designs to address long-standing questions about TRO removal, restoration, and water savings.

- In the Upper Colorado River Basin, the panel recommends studies that use remotely sensed estimates of ET to compare areas actively and passively revegetated following beetle defoliation or other TRO removal methods. Remotely sensed estimates allow inclusion of sites within narrow canyons and with other topography that limits use of flux towers or other micrometeorological ET approaches.

- In the Lower Colorado River Basin, the panel recommends the inclusion of a high-salinity, xeric site or sites to test whether restoration is possible under these circumstances.

- In parts of one or more sites, it would be useful to follow the effects on ET of cutting tamarisk and then allowing it to regrow. There is little known about the effects of tamarisk regrowth and regrowth rates on ET through time.

- In parts of one or more sites, it would also be useful to test or demonstrate staged tamarisk control and revegetation in a way that maintains and improves habitat throughout the project. This type of restoration approach will be particularly critical in areas where tamarisk currently supports wildlife of concern, such as the SWFL.

- At one or more sites, it is recommended to study or demonstrate the potential economic and beneficial uses of harvested tamarisk biomass.
• In at least some sites with active biological control beetles, it is recommended to study how the biological control process interacts with other control measures such as herbicide spraying and cutting; how active revegetation can best be initiated while tamarisk is declining; and how the beetles affect resprouting and resprouts.

Conclusions

The purpose of this TRO Assessment is to provide enough information for the Basin States to make informed decisions about the potential desirability and cost-effectiveness of large-scale TRO management to save water lost to evapotranspiration and thus potentially augment water flow in the Basin’s river systems.

The methodology used to perform this analysis included using existing data and information sources to assess: TRO evapotranspiration use; distribution; the state-of-the-science; the range of information available on impacts; TRO management techniques; restoration; potential sources of funding; and gaps in current knowledge where additional research is appropriate. Programmatic issues such as economics, permitting, and monitoring were considered, and an independent panel of experts was convened to address the ET issue.

1. The information in this report provides the basis for the further expenditure of funds to continue to investigate large-scale TRO management, address further research questions, or begin pilot management projects. Final costs and potential water savings are strongly dependent on site specific factors. Based on sites selected for TRO management, infestation characteristics, conditions, and revegetation goals there is opportunity to save water within the Colorado River system at a reasonable cost per acre-foot.

2. The ET Peer Panel was a diverse collection of scientists brought together to arrive at a common ET value for planning purposes. A task of the Panel was to identify ET rates that account for differences in climate, elevation, and latitude. The ET Panel noted that rates from the same tamarisk species can vary widely under the same general climatic conditions due to wide variation in vegetation density, soil type, vegetation health, height and age, nature of understory vegetation, salinity, access to ground-water, geology, and stream-ground-water interactions (hydrologic connectivity).

3. Based on all available data, the basin-wide function that was developed, and the views of the Panel, the Panel reached consensus that the typical range of tamarisk ET as a basin-wide average is 2.3 to 4.6 acre-feet per acre per year. This range is considered conservative. Because the largest concentration of tamarisk infestations occur in the Lower Basin where ET rates would tend to be higher, the mean value for tamarisk ET for the entire Basin should tend towards the upper limit of 4.6 acre-feet per acre. Under similar site conditions, ET rates for the Upper Basin will tend towards the lower rate as will replacement vegetation ET rates tend to be lower than the same species found in the Lower Basin.
4. The greatest potential for water savings is by managing TRO on upland sites adjacent to rivers. In these areas the TRO would be controlled and depending on conditions, sites would either be managed to allow natural recruitment of native species or would be revegetated with upland, xeric species. Although strongly dependent on site factors, based on the species used for revegetation and conditions such as seasonal groundwater depth variability, in general potential water savings would range from 50-60% of the value of tamarisk ET. For a representative site within the basin that has 60% tamarisk canopy cover, of which 75% of the area would be revegetated with xeric vegetation, it is estimated that approximately 1 acre-foot can be saved for each 1.85 acres of TRO managed, or 0.54 acre-feet per acre.

5. In the Colorado River Basin, mapped tamarisk and Russian olive accounts for a total stand acreage (aerial extent) of approximately 250,000 and 40,000 acres, respectively. These values must be considered low because a significant amount of the data is point data with no actual acreage assigned to this information. It is reasonable to expect that without TRO management both species will continue to expand in both the Upper and Lower Basins.

6. At its current rate of expansion, the biological control agent for tamarisk (the tamarisk leaf beetle, *Diorhabda* spp.) will spread throughout the Upper Colorado River Basin by the end of 2010. It is almost certain that within 5 to 10 years the beetles will be in the Lower Colorado River system expanding from either the Upper Basin populations or beetle populations introduced in California and/or Texas.

7. Each of the TRO management methods, when used appropriately for specific site conditions can be effective in controlling TRO. The choice of which one to implement is a function of many site conditions such as the level of difficulty of site access, density of infestation, and availability of replacement vegetation.

8. Effects of invasive plants on wildlife are diverse and depend on the species considered. The endangered Southwestern willow flycatcher is of greatest concern in the Lower Basin. Tamarisk provides suitable habitat for this bird, and some are concerned that tamarisk control efforts might slow its recovery. Biological control of tamarisk with the tamarisk leaf beetle has been particularly controversial. In the Upper Basin, it has been suggested that tamarisk management may benefit several endangered fish species including the Colorado pikeminnow and razorback sucker.

9. Planning level estimates of the cost per acre-foot of water saved by TRO management in the Colorado River Basin have been developed. The costs for this TRO management effort and subsequent water savings are competitive with other augmentation approaches the Basin States are evaluating. Normalized unit costs of water saved by TRO management for a representative site within the Basin range from $260 to $1,050 per acre-foot. Using a suite of available and common techniques, TRO management costs are estimated to be less than $400 per acre-foot. Other benefits will generally result to aquatic and terrestrial habitats, wildfire threats, and cultural and recreational uses. Sedimentation and bank erosion issues are complex and can be viewed as either a beneficial or negative impact. The value of the saved water is dependent on the ability to measure and/or model the savings.
10. Although it is possible to identify that water can be saved in the Colorado Basin by means of TRO management, the amount of water that can be recovered (salvaged) cannot be predicted. Demonstration projects coupled with groundwater and surface water measurement and modeling are needed to predict where in the system this saved water would become available.

11. A list of potential Demonstration Projects for TRO management in the Colorado River Basin was developed as a starting point for possible future submittal to USBR for federal funding consideration pursuant to Public Law 109-320. Eight potential sites are identified for large-scale demonstrations – four in the Upper Basin and four in the Lower Basin.
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database[Internet]


Appendix A

Memorandum of Understanding

Colorado River Basin
Tamarisk and Russian Olive Assessment

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Appendix B

Public Law 109-320 Salt Cedar and Russian Olive Control Demonstration Act

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Appendix C

Independent Peer Review of Tamarisk & Russian olive Evapotranspiration Colorado River Basin

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Appendix D

TRO Mapping Data Package and Instructions for Use

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Appendix E

Plant Materials List for Revegetation Appropriate for the Colorado River Basin

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Appendix F

Tamarisk Control Best Management Practices in Colorado Watersheds

[Reserved awaiting document publication]

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Appendix G


[Reserved awaiting document publication]

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Appendix H

Riparian Restoration Assessment of Alternative Technologies for Tamarisk Control, Biomass Reduction, and Revegetation

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Appendix I
Long-term Monitoring and Maintenance Templates and Protocols

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Appendix J
Example of TRO Management Present Worth Analysis

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Appendix K
Grant Opportunities Available for Addressing TRO Issues

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