Best Management Practices for Revegetation after Tamarisk Removal

In the Upper Colorado River Basin

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May this volume help facilitate information sharing between all of these groups and individuals to help us reach our shared goal of improved watershed function, use, and sustainability.

UPPER COLORADO RIVER BASIN

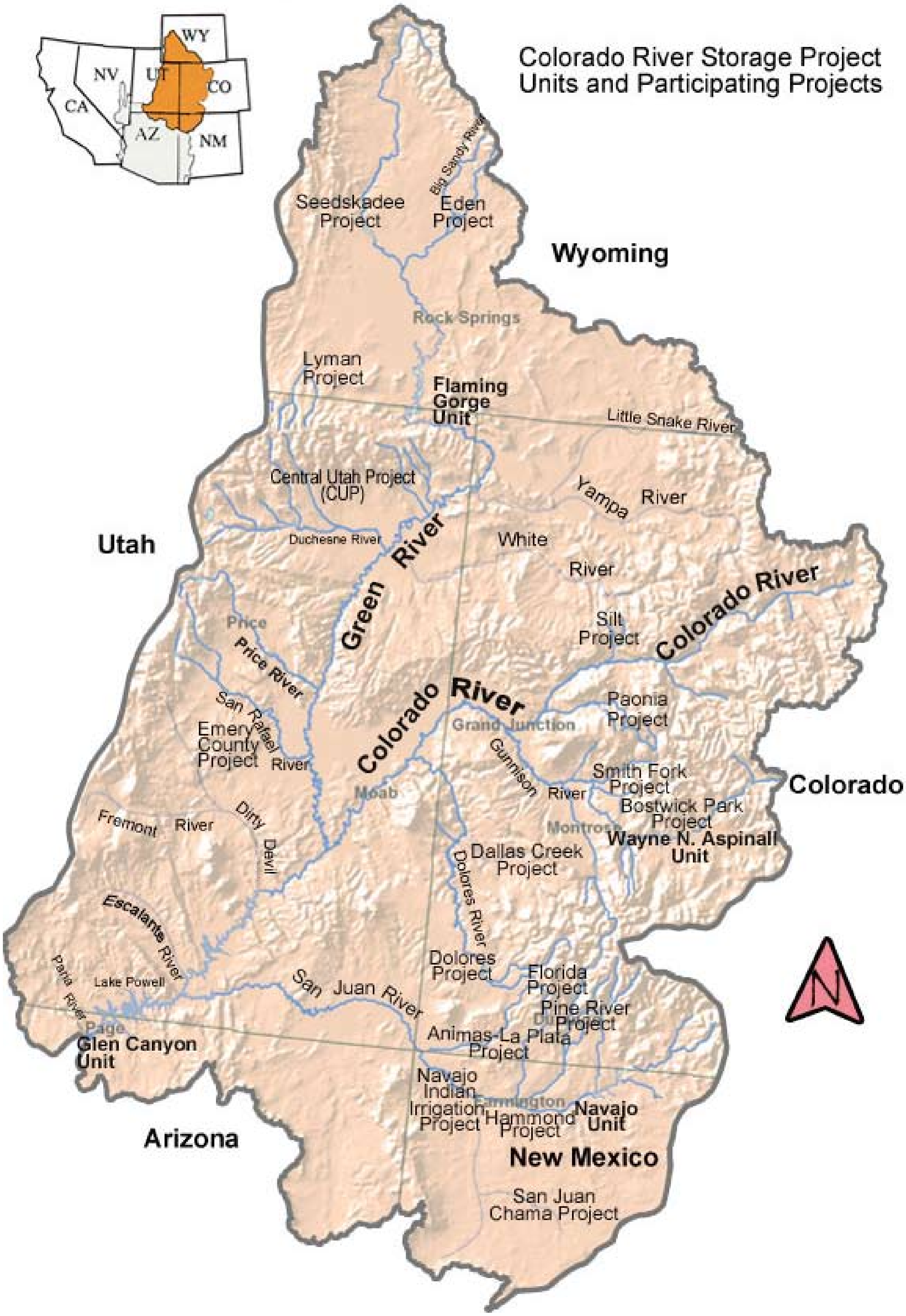

Image from Bureau of Reclamation Upper Colorado Region web site: http://www.usbr.gov/uc

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INTRODUCTION

"Controlling an existing stand of tamarisk is often relatively easy compared to restoring the site back to native species."

– Pat Arbeiter Wildlife Biologist and UCRB Project Manager

Tamarisk (saltcedar, *Tamarix* spp.) is a tree with a shrub-like growth form that has become dominant in many watersheds of the Upper Colorado River Basin (UCRB). This species has received national attention in recent years due to its non-beneficial use of water and the ways in which it changes riparian (riverbank) habitats. Although this species can play a positive role in a diverse ecosystem by providing an understory canopy used by some cup-nesting bird species, monoculture thickets of tamarisk are generally undesirable due to low overall habitat, recreation, and forage value. Tamarisk stands with thick duff are also considered a fire hazard, are associated with higher groundwater and surface soil salinity, and change surface flow morphology by trapping sediments[1]. Removing this species is therefore often a management priority; however, controlling a single species is unlikely to achieve land management goals. Revegetation, either actively through planting or passively through natural regeneration, will usually be necessary. The UCRB has particular challenges associated with soil conditions, hydrology, and site access (Figure 1). The intent of this manual is to aid the land manager seeking to conduct revegetation in association with removal of tamarisk, specifically designed for the UCRB.

This manual was developed through a synthesis of the best current research on the topic combined with experience from actual projects through site visits and interviews with land managers in the UCRB. The organization and recommendations of this manual will generally follow the 7-step process recommended for tamarisk projects in Shafroth et al. 2008 (Figure 2).

This manual is intended to assist both the experienced revegetation professional as well as a landowner new to revegetation. Appendices A-C contain worksheets and additional resources that will further explain parts of this manual. In addition, we strongly recommend to those persons new to revegetation who are contemplating working with tamarisk and revegetation on their land contact local organizations and agencies who have experience in their region. Appendix D provides a partial list of these organizations in regions of the UCRB.

"...we should be spending more money up here [in the UCRB] on tamarisk removal, not less, because we still have a reasonably functional system, and we can do restoration very inexpensively and effectively."

– Tamara Naumann, Botanist at Dinosaur National Monument Land

WHY REVEGETATION IS IMPORTANT

Restoration or rehabilitation of a drainage or other infested area should be guided by an overall management goal. Even when reestablishment of desirable vegetation is not an explicit aspect of this goal, it should be considered for the following benefits:

- Bank stabilization and erosion control
- Wildlife habitat
- Shade (e.g. for recreation, wildlife, or cattle)
- Forage for wildlife or livestock
- Aesthetics (appearance)
- Reduction of re-invasion by tamarisk and other weeds

RESTORATION VS. REHABILITATION VS. RECLAMATION

The distinction between restoration, rehabilitation, and reclamation, although somewhat academic, is important in the context of setting goals and implementing revegetation projects. It is critical to consider the entire landscape and long term objectives to effect long lasting revegetation with desirable plant species. This manual's title refers to "revegetation" with the understanding that establishing new plant material will occur in the context of a variety of goals. It is important that a land manager be clear about the objectives for a particular project, as it will clarify priorities and other aspects of planning.

Restoration, strictly defined, refers to the process by which an ecosystem is returned to a previous condition, often pre-anthropogenic (human-caused) disturbance, and including native species. While this may be perceived as the ideal, in many sites this may be impossible due to the degree of alteration of underlying conditions.

In contrast, *ecological restoration* is the intentional management of an area to promote processes that lead to the overall health and sustainability of an ecosystem (sensu Society for Ecological Restoration). In this manual, the term "restoration" refers to ecological restoration. This often involves the reestablishment of disturbance regimes (such as fire, flooding, or periodic grazing) that were associated with the maintenance of native plant communities.

Rehabilitation shares with restoration a goal of establishing a functioning ecosystem, and use of pre-existing communities as references; however, rehabilitation may not replicate the prior ecosystem.

Reclamation is defined still broader, with the primary objectives including public safety, terrain stabilization, soil quality mitigation, and otherwise returning the land to usability. This is also referred to as "enhancement" within the restoration literature.

PHOTO CREDIT: ANNA SHER

FIGURE 1: This area near Moab, Utah illustrates both how thick and extensive tamarisk infestations can be as well as how site characteristics (e.g. access issues) can make restoration in the UCRB uniquely challenging.

> "… we can't ever go back so, 'What can we manage now?' is … the way I look at it. And we try to keep it to strictly natives; at least that's my bias. Crested wheatgrass? No."
>
> – **Kara Dohrenwend** UCRB Project Manager

Restoration, rehabilitation, and reclamation all are likely to include some form of revegetation; however, each focus may result in different choices in species selection and other management decisions. Although we will be principally referring to ecological restoration in this manual, the approaches described here will generally be pertinent to any project that seeks to improve land following tamarisk removal.

Advance planning of your restoration project is the single most important element of post-tamarisk restoration. Determining the scope of intended restoration, identifying potential obstacles, estimating costs and thoroughly evaluating other feasibility issues must be considered during planning in order to improve success. See Appendix A: Land Manager Worksheet for a list of questions that will also help get you started.

"[Successful projects are those in which] people took the time to understand: what caused the damage, the nature of the damage, what are all the different resources that are damaged, and how damaged are they, and what's it going to require to get them into shape in order to sustain whatever vegetation people are wishing for."

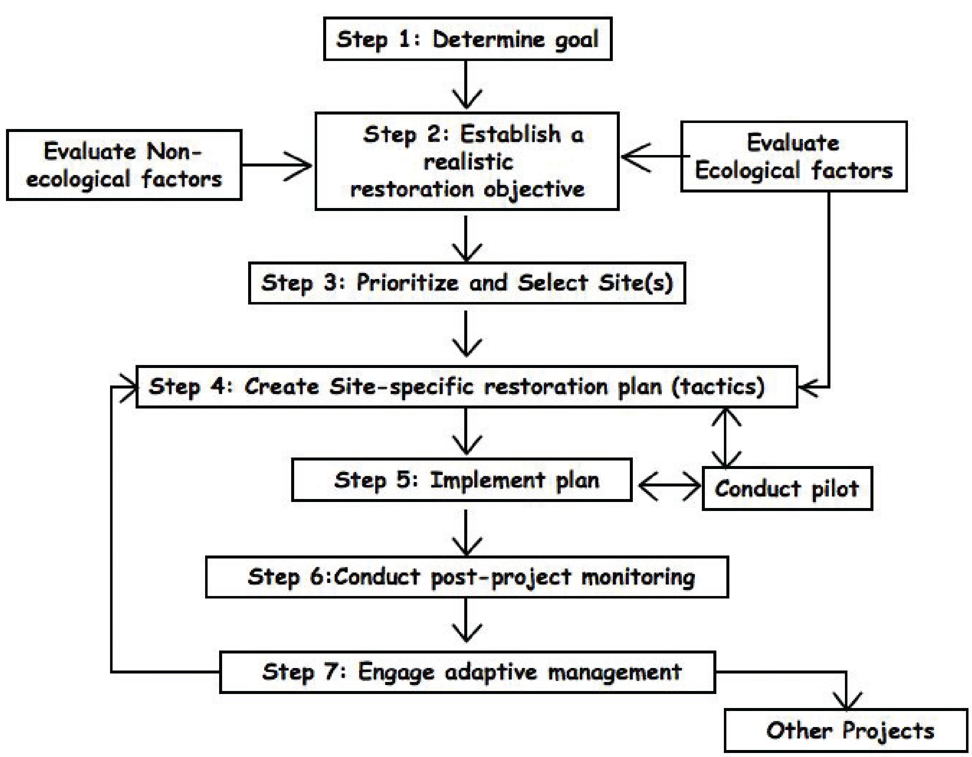
– Tamara Naumann
Botanist at Dinosaur National Monument

Figure 2 outlines the recommended planning and implementation process for revegetation following tamarisk removal as presented in this manual. However, your planning process may take a slightly different form if your site selection (Step 3 in our diagram) is predetermined by other factors such as the location of a fire last year, the land owned, or a management objective associated with a specific land unit slated for tamarisk removal. In the situation where the site is pre-determined, steps one and two become even more important. Your goal and restoration objective will still drive your future actions.

I. STEP 1: DEFINING A GOAL

"[Our] Goals: Remove the negative effects of livestock grazing, Reduce proliferation of undesirable (noxious weed) species and replace with desirable species,

FIGURE 2: A flow diagram of the steps for effective restoration after tamarisk control (adapted from Shafroth et al 2008[2]).



and improve the condition of upland buffers adjoining riparian habitats."

- Mike Francis Biologist in the UCRB

As obvious as it may seem, the first step for restoration should always be identification of restoration goals. Too often we have seen restoration projects that are so focused on the act of *Tamarix* removal that an approach is chosen that leaves the ecosystem in a state where achieving other goals may be compromised. In fact, 20% of the UCRB land managers interviewed stated *Tamarix* removal was their primary goal; however, we would encourage all land managers to consider tamarisk removal to be the means to reach a different goal: the desired future condition and use of the land, rather than merely tamarisk removal. The motivation for tamarisk removal may be any of the following: wildlife habitat creation, aesthetic improvement, recreation, other ecosystem service, etc. Which of these are the actual motivating goals and how they are prioritized will have profound consequences for the development and implementation of restoration for a given site.

Clarifying expectations with one's funding agency or governing body is also an important motivation for defining goals. It is important to note that a private landowner may be able to find assistance for both tamarisk removal and revegetation, and that defining the goal of the removal/revegetation will be essential in acquiring that assistance. In cases where the assigned task is vaguely described as *Tamarix* removal/control, it is likely that there are assumptions being made about what this will achieve that may or may not follow from a given control approach. Often, it will be too late to change trajectories once a control strategy is implemented. If it is discovered after control that the desired benefit to removing *Tamarix* will not be achieved, it will be more difficult to rectify than if the control strategy was specifically chosen with the end goal in mind.

The goal(s) will determine several fairly specific choices that must be made early in a project, including considerations of scale, location, and control method used. If the goal is to create bird habitat, clearly one should not remove all *Tamarix* from an area that has no other cover. One option is to remove tamarisk in stages with gradual replacement of other trees for habitat. Whereas, complete removal of tamarisk may be preferable with a different goal, such as reducing fire risk. If restoring native plant species is the objective, it will be paramount to choose sites where establishment of these species can be supported. In such cases also one may be advised against using an aerial application of a broad-spectrum pesticide such as imazapyr. In this manual, we will outline the relationships between control methods, site characteristics, and restoration goals.

II. STEP 2: SITE EVALUATION - ESTABLISH RESTORATION OBJECTIVES

"The collection and analysis of [soils and water] data is critical to understanding the site ecology, decision making on site preparation, planting techniques, species selection and the entire restoration process. The more variation in the site, the more data collection is warranted."

- Pat Arbeiter UCRB Project Manager

Evaluating the site conditions is a critical step to developing specific objectives for determining future revegetation actions. Skipping this step can result in time and funds lost to actions that have no hope of benefiting your site goals.

A detailed and scientific evaluation including soil testing and installing ground water wells is essential in very large diverse projects (over 40 acres), but while highly recommended, these tests may be less essential to success in smaller scale projects. At minimum a detailed site evaluation of vegetation, hydrology (based on superficial factors), site history, and non-ecological factors is essential.

This critical step has three components: evaluation of ecological factors, evaluation of non-ecological factors, and development of realistic restoration objectives as informed by these factors. This evaluation process is a general one at this stage and should be done for all areas being considered for restoration with the understanding that some sites may be excluded from further action as a result. Most projects will benefit from an evaluation that includes the following:

Non-Ecological

- How is site access?
  - Land ownership issues
  - Geographic barriers
- Resources for project
  - What is the budget? Timeframe?
  - Access to human resources
- What are the relevant policies or procedures for the site?
  - Access permits
  - Water permits
  - Restrictions on chemicals, equipment use

Ecological

- Hydrology
  - Stream perennial, intermittent, or ephemeral? Is there overbank flooding?
  - Evidence of groundwater <10′ from surface
  - Water chemistry: Conductivity (salinity), Alkalinity, Trace elements/metals? Concentration of nitrogen (NO_3^-/NO_2^-)
  - Bottomland morphology

TABLE 1: Examples of permit requirements for restoration activities (from FISRWG 1998).

<table>
<tr><td colspan="5">LOCAL/STATE</td></tr>
<tr><td colspan="3">Permits Required</td><td>Activities Covered</td><td>Administered By</td></tr>
<tr><td colspan="3">Varies- thresholds and definitions vary by state</td><td>e.g. clearing/grading, sensitive/critical areas, water quality, aquatic access</td><td>Local grading, planning, or building departments; various state departments</td></tr>
<tr><td colspan="5">FEDERAL</td></tr>
<tr><td colspan="3">Permits Required</td><td>Activities Covered</td><td>Administered By</td></tr>
<tr><td colspan="3">Section 10, Rivers and Harbors Act of 1849</td><td>Building of any structure in the channel or along the banks of “navigable waters” of the U.S. that changes the course, condition, location or capacity</td><td>U.S. Army Corps of Engineers</td></tr>
<tr><td rowspan="7">Section 404, Federal Clean Water Act</td><td colspan="2">Letters of permission</td><td>Minor or routine work with minimum impacts</td><td rowspan="7">U.S. Army Corps of Engineers</td></tr>
<tr><td rowspan="4">Nationwide permits</td><td>3</td><td>Repair, rehabilitation, or replacement of structures destroyed by storms, fire, or floods in past 2 years</td></tr>
<tr><td>13</td><td>Bank stabilization less than 500 feet in length solely for erosion protection</td></tr>
<tr><td>26</td><td>Filling of up to 1 acre of a non-tidal wetland or less than 500 linear feet of non-tidal stream that is either isolated from other surface waters or upstream of the point in a drainage network where the average annual flow is less than 5cfs.</td></tr>
<tr><td>27</td><td>Restoration of natural wetland hydrology, vegetation, and function to altered and degraded non-tidal wetlands, and restoration of natural functions of riparian areas on private lands, provided a wetland restoration or creation agreement has been developed.</td></tr>
<tr><td colspan="2">Regional permits</td><td>Small projects with insignificant environmental impacts</td></tr>
<tr><td colspan="2">Individual permits</td><td>Proposed filling or excavation that causes severe impacts, but for which no practical alternative exists; may require an environmental assessment</td></tr>
<tr><td colspan="3">Section 401, Federal Clean Water Act</td><td>Water quality certification</td><td>State agencies</td></tr>
<tr><td colspan="3">Section 402, Federal Clean Water Act National Pollutant Discharge Elimination System (NPDES)</td><td>Point source discharges, as well as nonpoint pollution discharges</td><td>State agencies</td></tr>
<tr><td colspan="3">Endangered Species Act incidental Take Permit</td><td>Otherwise lawful activities that may take listed species</td><td>U.S. Fish and Wildlife Service</td></tr>
</table>

- Soils
  - Evidence of high salinity (salt-tolerant species dominant, salt evident on surface)
  - Texture
  - pH
  - Fertility (presence of macro and micro nutrients)
  - Organic matter
- Vegetation
  - Age class, stem density, and canopy cover of tamarisk
  - Species density and diversity
  - Basal and canopy cover of desirable species
  - Potential seed source
- Site history considerations
  - Past use
  - Past management

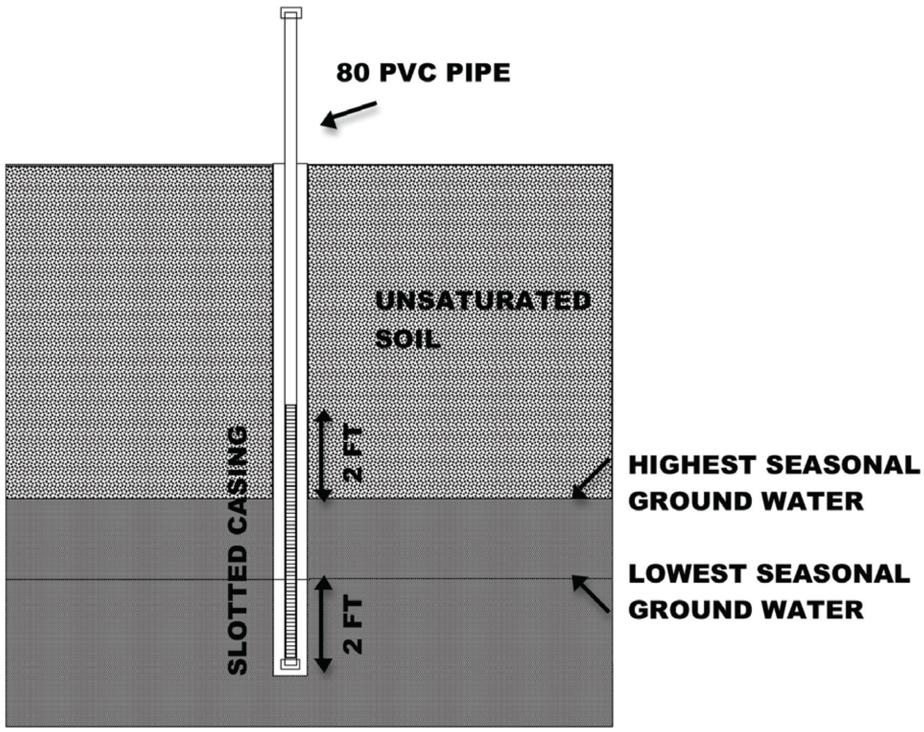
Once ecological and non-ecological site aspects have been determined, more specific objectives to achieve the goal will be identified. In some cases, the information collected at this stage can be used for baseline data (to make future monitoring in Step 6 more meaningful and useful). Note that this is not the step for a site-specific plan (Step 4).

A) Non-Ecological Evaluation: Access

Site access is important, especially when work will require the use of heavy equipment or be conducted on or adjacent to private land; working closely with the owner is advisable, and written agreements are advisable to clarify issues with affected landowners. There are many different types of access agreements (adapted from The Federal Interagency Stream Restoration Working Group (FISRWG), 1998; an NRCS publication):

- Implementation Easement: This document describes the purpose, time, and location of activity permitted.
- Access Easement: These provide permanent access, as needed for ongoing maintenance and monitoring. Usually limits (geographical or otherwise) are specified.
- Drainage easement: This is an agreement with the property owner that provides access to a specific drainage

FIGURE 3: Diagram of a piezometer using 2″ diameter standard schedule 80 PVC pipe. Total length and distance between highest and lowest seasonal ground water vary by site. Lengths shown are minimums; depth of tubing below estimated lowest seasonal ground water level should be >2′; 3-5′ preferred.



facility for ongoing maintenance, including allowing the owner to have concurrent use of the site for non-conflicting activities.

- Fee acquisition: This refers to purchase of the property. While this may also be an option, it is usually unnecessary unless no other activities can take place on the site during or after restoration.

B) Non-Ecological Evaluation: Resources Available

It is important to catalog short and long term resources available to implement and maintain the project for at least the first 3 to 5 years. Not only can this be helpful in acquiring funding for projects, but it is important to evaluate the long term commitment necessary to at least follow up initial tamarisk removal with follow up weed control and possible active revegetation. If the resources are not available for a long term commitment to the site, it may be better to not remove the tamarisk at all.

C) Non-Ecological Evaluation: Policies and Procedures

Several aspects of your project may make it prone to access and/or permitting issues. Restoration activities associated with bodies of water are subject to regulatory programs and therefore require permits. Activities on federal land, or done by or in association with federal agencies, have compliance requirements with federal legislation, such as the National Environmental Policy Act and Clean Water Act (sections 401, 402 and 404). Special permits or coordination may be necessary if the site is located in an area delineated for the National Flood Insurance Program, historic or archeological sites, or otherwise officially set aside. Table 1 provides a list to help guide efforts. Use of state or federal funding may also dictate certain aspects of your restoration plan (contact your funding representative and carefully review contracts for these).

D) Ecological Evaluation: Hydrology

Much of the hydrology of the site can be determined from a site visit with someone trained and knowledgeable of local conditions. The following questions will help to evaluate what kind of site you have to work with.

- Is the site located in a riparian or wet area, or in an arid or xeric space? If the location has not flooded in the past 25 years, the site is likely an arid site. If the site is located where overbank flooding occurs, it is important to know how often the site is flooded. A site that is flooded every 10 years has much different revegetation potential than a site that is flooded every 1 to 3 years.

- If the site is not in a regularly flooded area, is the ground water greater than 10′ deep much of the year? There are locations immediately adjacent to a river where the water table is greater than 10′ most of the year. This factor will determine a great deal about the plants that will thrive on this site with minimal maintenance.
- In sites with groundwater shallower than 10′, monitoring wells should be considered.

Groundwater monitoring

"To have a comfortable grasp of groundwater conditions for a restoration site, observation wells can be installed and monitored for seasonal fluctuations over at least one year. Two years or more would give more reliable information"

- Pat Arbeiter UCRB Project Manager

Groundwater monitoring can be easily done by auguring a hole and installing PVC with perforations. Ground water monitoring well(s) (also called piezometers or observation wells) installed simultaneous with baseline inventories and prior to treatment applications are optimal, for assessment and tracking of (as examples):

- Ground water depth
- Ground water quality
  - Conductivity (salinity)
  - pH, Alkalinity
  - Major ions (Cl-, SO4=, Ca++, Mg++, Na+, K+)
  - Trace elements/metals
  - NO3-/NO_2-.

How to create a piezometer

Monitoring wells, also called piezometers, are easy to make with standard schedule 80 PVC pipe, 2″ minimum diameter, cut into sections to reach your groundwater levels (Figure 3). Schedule 80 is a thick-walled pipe, often grey, that may be threaded. The pipe should be long enough to reach your groundwater at its estimated lowest point, plus 2-3′. The bottom section should be capped and have slots cut using a hack saw assuring that the groundwater is seeping in from the bottom of the pipe to about 2′ above the water table (depending on distance to surface). Section above the surface should not be slotted. Leave approximately 3′ of PVC pipe above the soil for ease of use and locating the well later. Top the well with a cap and mark with a fence post or some other method to be able to locate it later. For deep tables, it is easier to work with shorter pipes (e.g. 5′) with joints so that you can keep adding sections as needed. Otherwise, the longer the tubing sections, the heavier plastic you would need. There are also pre-slotted, pre-made wells available, which are usually not very expensive.

For more information about establishing wells for monitoring:

- Groundwater Monitoring Well Drilling, Construction, and Decommissioning: State of Oregon Department of Environmental Quality (DEQ) Guidance Document:

  http://www.deq.state.or.us/lq/pubs/docs/tanks/GroundwaterMonitoringWellDrilling.pdf

When and how deep should they be? To establish the wells, you must do seasonal or monthly sampling to determine what this lowest depth is. Do this with a soil auger as a pre-sample; keep digging until you hit saturated zone. Once you have determined this lowest depth in the course of a year, it is preferable to dig at this time. Using a soil auger (see Appendix B: Heavy Equipment), dig to the saturated zone and insert pipe well into that zone. Wells can also be dug by driving a steel driver rod inside of the pipe.

How many wells? One well per 2-3 acres is usually sufficient; however, this can be highly dependent upon your site and purposes. For a larger project (10-100's of acres), we recommend at least one well per 50 acres. If it is a long belt along a channel, you may wish to do more than this. Generally speaking, the groundwater depth will increase with distance from the channel. On broader floodplains, one well every 500′ should reveal the pattern of groundwater change. Dramatic changes in groundwater can occur within 100′ simply based on the alluvium, which impacts the saturated zone. If there are obvious geological breaks, above-ground management (e.g. grazing, or dramatic vegetation differences, fire histories), or terraces, a well on each is recommended.

Measuring instrument: There are several automated measuring systems on the market, including Hydrolab (by Hach) or Troll 9000 (Figure 4). These can accommodate real time measurements if you want to record continuously. These can record many different aspects of groundwater other than depth, including pH, EC, dissolved O2, turbidity. The low-tech way to measure groundwater depth is to drop a weighted measuring tape. For example, you may use a 1′ long twig attached to a stiff carpenter's tape measure. When it hits the water, record the measurement on the tape at the top of the well. Groundwater depth can then be calculated as the following:

groundwater depth = tape measure length+ length of twig above wetting line – height of PVC aboveground

Ideally, monitoring should be done before, during, and after

PHOTO CREDIT: MICHELLE OHRTMAN

FIGURE 4: Reading a groundwater monitoring well with a digital reader

PHOTO CREDIT: ANNA SHER

FIGURE 5: Soil sampling of the top foot of soil using a steel soil auger (also called a probe).

restoration in sites where you wish to establish perennial species that will be dependent on this water source. Monthly monitoring during the growing season will yield the most useful groundwater information.

Water chemistry

Once a monitoring well has been dug, evaluation of ground water can easily be conducted along with surface water. These results should be considered in the context of the soil chemical analysis for their influence on revegetation. Although only phreatophytic (deep rooted) trees will directly use ground water, elements can move vertically in the soil column, particularly if there is surface evaporation.

Bottomland morphology

The general shape ("morphology") of the land and associated stream will strongly affect vegetation growing there. Morphology will influence overbank flooding, erosion, and other aspects. Some considerations include:

- Channel pattern and shape
- Channel gradient
- Longitudinal profile
- Channel stability

A good discussion of these and other morphological considerations for riparian restoration can be found in Briggs 1996 "Riparian Ecosystem Recovery in Arid Lands" (see Appendix C for full citation).

E) Ecological Evaluation: Soils

Some aspects of soils can be determined by examining vegetation and the soil surface. Certain plants are more tolerant of highly saline or alkaline soils. Presence of these species (weedy or native) is an indicator of conditions that must be considered in planning species lists.

Soils can vary greatly on a site—especially on a hydologically active site. Soils sampling will inform decisions regarding plant species and other necessary steps needed to affect successful revegetation.

How to sample soil

Soil can be sampled either with a soil auger (2″, 3″, and 4″ are most common) or by digging a pit. Pit sampling is done when detailed information is needed for soil mapping and will allow you to see soil horizons. Pat Arbeiter recommends including a few deep soil sample pits to groundwater in association with groundwater sampling wells if extensive planting of deep-rooted woody species is planned, especially cottonwoods or large mountain willows. This will be also important if it is known that the soil has had extensive flushing or significant soil texture changes, such that deeper horizons have a dramatically different salinity or other characteristics than the surface soil[3] (see note below on soil horizons). In most restoration applications, composite samples of surface soil using an auger are sufficient (Figure 5):

- To use an auger: Take composite samples by simply pressing into the soil: first 0-6″ from the surface (place in labeled paper or plastic bag), then from same hole, 6-12″ (placed in a separate bag). This is sufficient to determine differences between surface and deep for salinity purposes. In most situations, roots are in the top 12″ for most plants, even large trees and shrubs.

- To take pit samples: Dig a hole with a vertical wall; 60″ should be sufficient. Sample soils according to horizon, noting depth of each horizon. As a general rule for most riparian revegetation applications (budget, staff and time permitting), soil sampling should be attempted at 0-6″, 6-12″, and 12-36″ (or 12″ to bedrock) increments.

- Contact your local Cooperative Extension for soil testing facilities (Appendix D). These labs generally prefer approximately 2 cups of soil per analysis; composite samples from several adjacent locations (see below under, "How many samples") are recommended to maximize likelihood of a representative sample.

How many samples? Pre-sampling at well-distributed, representative locations within a project site should provide a good indication of both salinity and texture characteristics. If budget, time, and/or staff are limited, then a minimum of 10 subsamples per affected horizon is recommended, systematically distributed across the project site to maximize representation of all site conditions. These can then be composited into one combined sample (again, per horizon) for analysis. This would result in 2-3 final composited samples per site. If there are obvious (or as determined by pre-sampling) inclusions within the site(s) that are drastically different in texture, salinity, relief, or other factor(s), particularly if repeated throughout the site(s), then these should be sampled separately. Simply put, the more sampling that can be accomplished ("higher resolution"), the greater the utility.

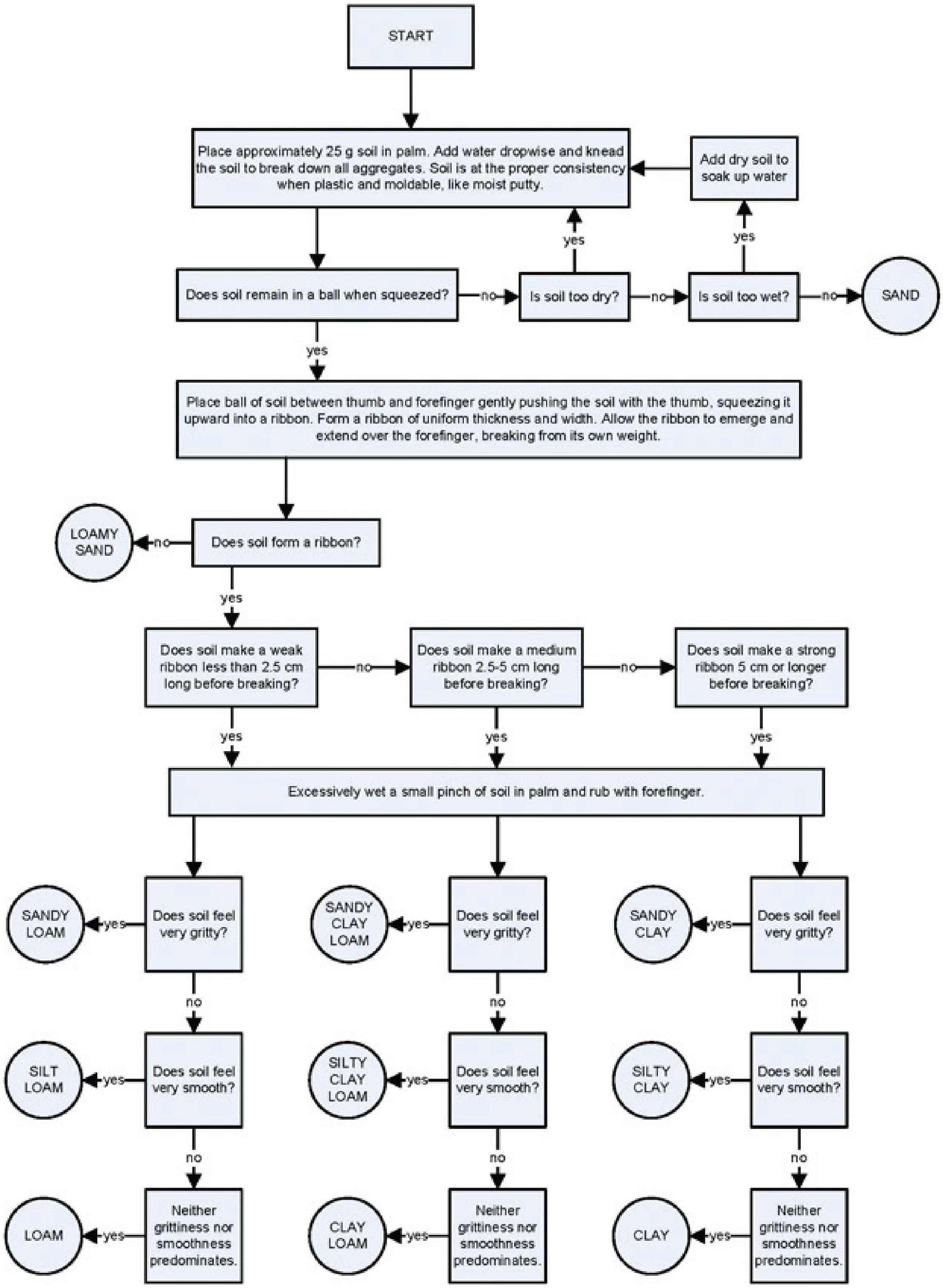
What tests to do? Table 2 shows which soil characteristics are generally of interest to a land manager assessing a site for revegetation. Which tests should be run will depend on the location; if there is remnant, desirable vegetation doing well in the site, fewer tests will be necessary. Generally speaking, if there is periodic overbank flooding, salinity (as measured in EC and SAR) should be less of a concern.

How to evaluate test results: Table 2 gives ranges of acceptable and unacceptable values for each recommended test. It is entirely possible that for a given soil, there are aspects that are "good" and others that are "poor". When faced with such

TABLE 2: Soil characteristic ranges for revegetation in the UCRB. Soil nutrient values are approximate, based on field observations. EC and SAR are measures of salinity; EC is electrical conductivity in dS/m; SAR is sodium adsorption ratio (modified from Hansen et al. 1991; Kotuby-A macher et al., 2000; Heil 1968; Brady 1974; Barber 1995[4]).

	Suitability for Promoting Native Species Revegetation			
Soil Property	Good	Fair	Marginal to Poor	Very poor
pH	6.0-8.4	5.5-6.0 or 8.4-8.8	5.0-5.5 or 8.8-9.0	<5.0 or >9.0
EC (dS/m) or (mmhos/cm)	0-4 Growth of salt sensitive species may be limited	4-8 Growth of many plants is limited	8-16 Only salt tolerant plants grow satisfactorily	>16 Only a few, very salt tolerant plants grow satisfactorily
Texture	sandy loam, silty loam, sandy clay loam	clay loam, silty clay loam, sandy clay, loamy sand	clay, silty clay, silt, sand	parent material
SAR	<6	6-10	10-15	>15
% Organic	>1	0.5-1	<0.5	0
Nitrogen (Nitrate; NO_3^-)	50-100 ppm (>0.05%)	25-50 ppm (0.025-0.05%)	12-50 ppm (0.05-0.012%) or 100-200 ppm (0.1%-0.2%)	0-12 ppm (0-0.012%) or >200 ppm (0.2%)
Phosphorus	>25 ppm (>0.1 %)	15-25 ppm (0.05-0.1%)	8-25 ppm (0.02-0.05%)	0-8 ppm (0-0.02%)

FIGURE 6: Flow diagram for determining general soil texture in the field (from NRCS, modified from S.J. Thien. 1979. A flow diagram for teaching texture by feel analysis. Journal of Agronomic Education. 8:54-55)



BOX 1: WARNING! REINVASION RISK

It is extremely important to note the presence of any noxious weeds around or in a stand of tamarisk. This will have serious implications during any removal activities, particularly those that involve large equipment. In these situations equipment must be thoroughly washed before leaving the site to minimize the risk of spreading noxious weeds to other locations.

a situation, you must determine which "marginal to poor" characters are those that you are capable of either remediating or adapting to with species selection. For example, if your soil has fair pH, fair texture, but a marginal EC, good revegetation may still be achieved by using salt-tolerant (e.g. halophytic) plant species (see "II. Plant Material Selection" in Step 4). Fertilizers or mulch can be added if nitrogen and phosphorus levels are poor (see section "E. Seedbed Preparation" under "II. Site Preparation"). Nutrient levels are generally the easiest soil characters to manipulate; soil salinity and texture the hardest.

A note on soil horizons: Relatively unregulated rivers (i.e. without dams) tend to have much more active floodplains than highly regulated rivers (e.g., the Colorado River), so texture may be highly variable (laterally and vertically) because of the fluvial dynamics still working there. Also, if you're dealing primarily with sandy soils, then there may not be definite texture boundaries or salinity thresholds. If these sites are occasionally flooded, then salts may be much more easily flushed out of the surface layers. Thus, we would expect shallow horizons to have lower salinity than deeper ones in flooded sites, but the reverse is more likely in sites with a lot of bare ground and therefore evaporation from the soil surface.

F) Ecological Evaluation: Vegetation

The vegetation present on the site prior to work beginning indicates a great deal about the site. Density, age class, and canopy cover of tamarisk before removal has many implications for revegetation success after removal.

Evaluation of vegetation at this stage can be general, using a walk through of the potential restoration sites with an individual who is knowledgeable about plant species to determine general plant assemblages and degree of tamarisk infestation. This is critical for the following reasons:

- evaluation of potential for passive revegetation (see "Choosing Active vs. Passive" in Step 3, below)
- determination of reinvasion from the seedbank or adjacent weed populations (Box 1)
- analysis of existing vegetation as an indicator of overall site quality.

This visual survey will also inform the potential for natural seed sources; if desirable species are present to some degree, they can replace or augment active seeding from outside sources. Toward this end, it will be important to view areas both up and downstream of the site as well.

Once sites are selected, it will be critical to take good, quantitative, baseline data of vegetation to be able to track progress toward your restoration goal. Methodologies and resources for vegetation sampling are discussed further in Step 6 (Monitoring and Maintenance).

G) Ecological Evaluation: Site History Considerations

Past use and management can profoundly influence your potential for revegetation, and a little research can go a long way toward avoiding frustration. A site that has flooded regularly will have different soils and available seed bank than, for example, one that was farmed or grazed. Site histories can be found from land management records, local museums, and prior landowners, ranchers, and farmers. Some of the features particularly important to note include:

- Fire and flooding history
- Agricultural use
- Grazing patterns and intensity
- Previous infrastructure
- Other past disturbances

In one extreme example, a foundation to a building had been covered by a few feet of topsoil; time was wasted attempting to plant trees in that spot before this was discovered. Locations of watering stations for livestock are notorious for being nitrogen hot-spots and having soil compaction issues for many years afterwards, only allowing some species to grow. A good knowledge of history for your site is essential for any revegetation planning.

III. STEP 3: PRIORITIZE AND SELECT SITES

"Reclamation methods will vary by degree of infestation. Reveg in areas of light infestation will clearly be easier because likely a native seed bank still exists in the soil and natives can return relatively easily, especially in wetter riparian areas."

- Mike Zeman Wildlife Technician in the UCRB

"…Now I do know, that you don't do pole plantings in silts and clays. They just die. On the south end where we did it in sand, those trees are 35 feet tall now. That's another reason I like to stop and wait."

- Kara Dohrenwend UCRB Project Manager

The prioritization of sites for restoration will be determined based on project goals and the feasibility of reaching them at a given location. For revegetation, presence of perennial flows and a groundwater depth that does not drop to more than 10 feet below the surface is of utmost importance. Water availability was the number one "factor predicting success" by the land managers we interviewed. Restoration sites in the UCRB that had surface water during the summer had more native vegetative cover and less weedy species. Thus, more mesic sites should generally be prioritized over arid. Clearly, one reason for this is the potential for passive revegetation, although as explained below, there are vegetation parameters that also must be considered.

Mesic versus Arid sites

Mesic sites

On sites where favorable soils, climate, and hydrology prevail, potential for both active revegetation and natural recovery (i.e. "passive revegetation") of native species and associated desirable wildlife habitat is great (Figure 7). Four of 21 restoration sites in the UCRB investigated for this volume fell under this category. These sites (often riparian zones) have hydrologic (shallow groundwater; < 6'), hydrographic (frequent seasonal river overbank flows), and soil salinity (electrical conductivities [EC's] less than 4) regimes necessary to promote and sustain establishment of, for example, native, phreatophytic cottonwoods (*Populus* spp.) and/or willows (*Salix* spp.).

Supplemental irrigation can often compensate for the absence of one or more of these abiotic processes, particularly in terms of fulfilling plant water demand and for dilution or leaching salts from the soil rhizosphere (see irrigation section on Step 5: Hydrology). However, carefully consider whether irrigation in lieu of natural hydrology is cost-effective and sustainable. To the extent that riparian sites approach or exhibit the favorable environmental characteristics previously described

FIGURE 7: This site at Tilman Bishop State Wildlife Area is a good example of successful woody and herbaceous revegetation at a more mesic site.

FIGURE 8: This is a restored arid site near Moab, Utah. This site was primarily impacted by vehicle traffic; the revegetation was done near the creek. Like many arid sites, there is significant cover of exotic species, however there is a good native species diversity here as well as a mix of woody species.

for soil and water resources, establishment of mesic native species (adapted trees, shrubs, forbs and grasses) in lower (moist to mesic) floodplain zones can be successfully accomplished with a high degree of confidence, within the context of sound assessment of site potential and strategic planning. Sites where surface water and/or groundwater are lacking and supplemental irrigation is infeasible are not good candidates and should be considered lower priority for restoration.

Arid to Xeric Sites

Many tamarisk-invaded sites in the UCRB fall under this category. These are more distant from the active river channel and may be occupied by longer-term tamarisk infestations, typically comprised of upper terraces exhibiting deeper water tables (> 2m), higher soil salinity (EC > 4 dS/m), and flood frequencies often exceeding 5 years. This zone corresponds to the hydrologic, hydrographic, and salinity regimes that typically support arid to xeric upland vegetation commonly characterized by non-phreatophytic shrub / forb / grass associations. As such, this complex of environmental constraints is difficult to overcome when conducting revegetation following tamarisk removal. Lack of overbank flooding will mean greater likelihood of litter accumulation, high soil salinity/sodicity, hummocky micro-relief, and nitrogen limitations.

Despite these constraints, however, there have been numerous successful restoration efforts in arid zones in the UCRB (Figure 8). Vegetative cover in xeric areas may be different, but nearly has high as in more mesic areas. The challenge is primarily favoring desirable species, which were more difficult to establish in arid sites. Thus, the most successful restoration sites either flooded occasionally or had opportunities for irrigation.

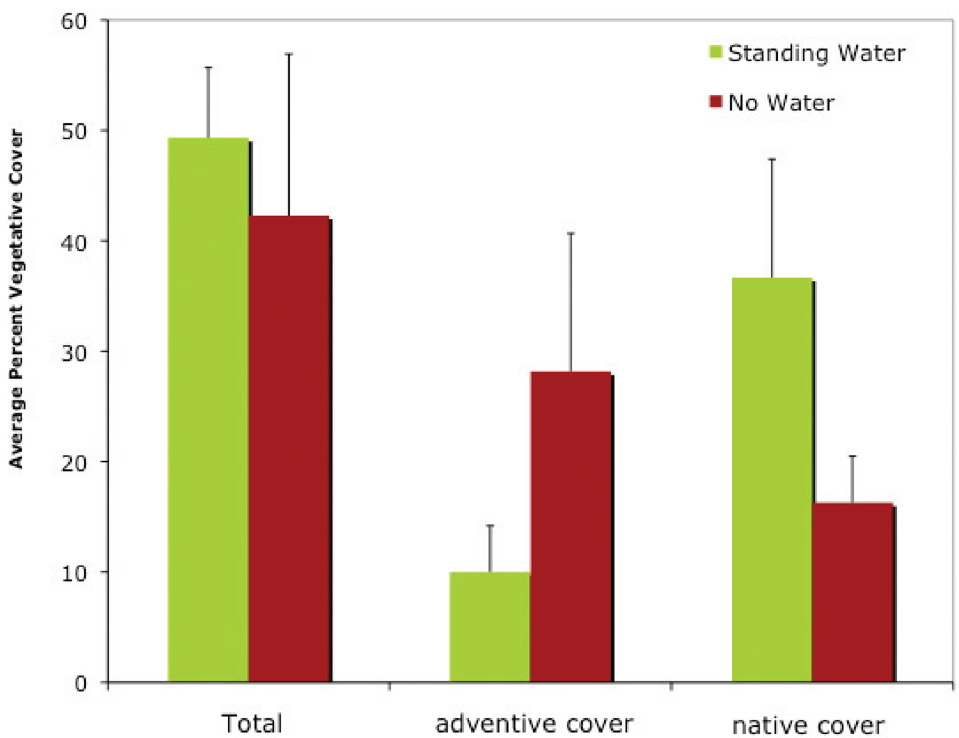
Choosing Passive versus Active Revegetation

"Frankly, I have found so many natives on so many of our sites that… if I was to be able to take a stretch of river and a side canyon, say, and just do what I think is right, what I would do is … first [remove] the invasives from really close to the natives and then let that pace of regeneration dictate the pace of removal. …Every site's different; you've got to let the site tell you what to do. You shouldn't blindly say, '"Must do reveg' unless the site tells you it needs it."

- Kara Dohrenwend UCRB Project Manager

Where possible, sites with a potential for natural revegetation ("passive revegetation") should be prioritized for restoration. Fortunately, the opportunity for passive revegetation is common in the UCRB, but should by no means be expected at all restoration sites. Passive revegetation for projects was much more common than active revegetation among the land managers we interviewed; however, this was often due to resource

FIGURE 9: Average vegetative cover (with 1 SE) measured at the 9 restoration sites surveyed in the UCRB during the summer of 2007. Presence of standing water, i.e. perennial flows, is one measure of how arid a site is. Adventive cover refers to all non-native species.



or other limitations rather than suitability for this approach. It should be noted that most of the site preparation guidelines provided in this manual for active revegetation can be used in conjunction with passive revegetation.

Determining active vs. passive should be based on the presence of a remnant community of desirable species to act as a seed source and to respond to the release from competition from the tamarisk (Figure 10). In general, based on field experience of the authors, those whom we interviewed, and literature inference, certain minimum thresholds of pre-treatment, relative plant community composition (above-ground biomass and/or canopy cover basis) should be comprised of desirable, healthy native species that remain intact (undisturbed) post-treatment, in order for natural recovery of the native species to be favored and expected over time. These suggested thresholds are:

- Wet (groundwater never < 10'): Moist to mesic riparian sites (typically lower floodplain terraces) exhibiting
  - reduced salinity and/or favorable hydrology (seasonal overbank flooding)
  - 5 to 10% remnant native plant community composition (preferably on a biomass or canopy cover basis).
- Dry (groundwater > 10'): Arid to xeric riparian sites (typically upper floodplain terraces or floodplain segments with artificial interception of surface and groundwater flows) exhibiting
  - higher salinity and/or unfavorable hydrology (infrequent or no seasonal flooding, and predominantly deeper depths to groundwater)
  - 25% remnant native plant community composition (biomass or canopy cover basis).

If candidate restoration sites do not meet these threshold criteria for natural (passive) recovery of remnant native vegetation, active revegetation will likely be required to achieve desired plant species cover. Without active revegetation, invasive weed species will likely re-encroach within 1 to 3 growing seasons.

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 10: Remnant native vegetation was left intact and facilitated passive revegetation at this restoration site in Colorado National Monument.

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 11: Tamarisk removal in Dinosaur National Monument was followed by vigorous invasion by whitetop in this area. Because this project was done in stages and the site was revisited after tamarisk control, there was an opportunity to modify the original plan and valuable resources were saved.

STEP 4:
DEVELOPING A SITE SPECIFIC PLAN FOR RESTORATION

"Let's try a little instead of planting 400 pole plantings and watching them all die, let's do a few and see what works… I tend to get really cautious."

– Kara Dohrenwend UCRB project manager

PHOTO CREDIT: HISHAM ELWAER

FIGURE 12: Baseline data collection of tamarisk cover and other vegetative descriptors such as species diversity and overall cover at this Dolores River site prior to tamarisk removal will help guide management activities and monitor success.

This is the tactical step of creating the detailed plan for the project, including both logistics and timeframe. Land managers in the UCRB strongly suggested beginning with a small scale pilot project before implementing a plan for an entire area (Figure 11). If time allows, designing a plan that includes one or two seasons to confirm effectiveness of a particular approach can conserve funds and avoid wasted time.

An important first step of your site specific plan will be the collection of baseline data (Figure 12). As the arrow between Step 2 "Site Evaluation" and this step implies (Figure 1), ecological data are important both before and after choosing your site, usually being more detailed at this stage than in Step 2. Measures of plant cover before restoration and before-vs.-after photographs are examples (see Step 2 and Step 6 for more recommendations and information on data collection, e.g. Table 9: Suggested Monitoring Data and Box 8: Plant Community Sampling Resources). There are several reasons why these types of data are important to collect at this stage:

- To design the correct restoration given existing site conditions.
- To quantify achievement of restoration goals by providing a measure of change.
- To quantify change at your site providing an important function for communication with the public and other stakeholders.
- To facilitate adaptive management (Step 7), as well as allowing future projects to benefit from prior successes and failures.

PHOTO CREDIT: TIM CARLSON

FIGURE 13: A fire stimulated regrowth in this stand of tamarisk along the Colorado River.

What follows are recommendations for developing a specific management plan after baseline data are collected:

I. TAMARISK REMOVAL

"Used Arsenal™ initially, wouldn't use it again. It is nasty; kills everything except cottonwoods and has a long half-life and [is] expensive. [Also I recommend] using the trackhoe for removal - highly recommended if terrain is right."

- Neil Guard, Land Owner UCRB

Although this manual is primarily concerned with revegetation after tamarisk removal, the mode of removal has important implications for revegetation, and thus must be considered in planning. Different methods of tamarisk control—mechanical, chemical, biological, or a combination of these—will materially affect restoration costs, methods, and feasibility. In general, the approach that is most effective for removing undesirable species while being gentle on the rest of the ecosystem is most advisable, but unfortunately often these two objectives are at odds. Below is a general review of each removal approach and considerations (Table 3)[5].

II. SITE PREPARATION

Once tamarisk is controlled at your site, you will need to consider preparation for further management. This may include removing standing dead biomass of tamarisk and/or seedbed preparations, particularly if you intend to do active revegetation.

A) Tamarisk biomass removal

Presence of dense standing dead or defoliated tamarisk biomass following non-mechanical control measures poses limitations in relation to any replanting techniques, seed interception in aerial applications, and shading impacts. An overview of approaches for handling this biomass can be found in Table 4.

Several UCRB managers favored dozing tamarisk into piles to leave on site for wildlife habitat cover (Figure 11, Figure 14, Figure 25), and the second most popular approach was mulching (Figure 15, Figure 18). Mechanical measures incorporating rotary blade or cutter-head shredding or mulching have gained popularity and extensive use for rapid, above-ground tamarisk (and/or Russian olive (*Elaeagnus angustifolia*)) biomass reduction that preclude the need to cut down stems and create a ground cover. These implements include, as examples, a Hydro-Ax™ machine or Prentice™ Site Prep Tractor mounted with a mulching head (e.g. Fecon™), the Woodgator T-5™, and mulchers by Brown Bear™ (see Appendix B for equipment overview). While this type of mechanical measure is not a stand-alone tamarisk control technique (i.e., without root removal or depletion, mechanically treated plants rapidly resprout), the above-ground biomass removal enhances surface aesthetics and enables simplified application of future measures for control of regrowth and secondary (understory) herbaceous invasives, seeding, or planting, and possibly wildlife habitat mitigation or enhancement.

TABLE 3: A review of common tamarisk control methods and their pros and cons (adapted from Gieck 2006)

Control Method	Pros	Cons
Biological	• Inexpensive • To date indicate low to negligible environmental impact • Appear to be relatively self-sustaining method • Good for areas of low accessibility	• Requires a moderately dense stand to support sustainable control agent populations • Requires several years of defoliation before mortality of tamarisk occurs, if at all • Has not established well in all areas, although much observed success in the UCRB • Costly removal of dead overstory required prior to revegetation
Manual grubbing / rogueing (pulling seedlings)	• Negligible impact to soil, water, wildlife, and other vegetation • Effective control on young seedlings • Revegetation is not impeded	• Extremely labor intensive and costly • Not advisable for anything but smallest or youngest infestations • Only possible with small (<1/4" diameter stem) plants • May stimulate other invasives by soil churning and disturbance of seed bank
Herbicidal Spot Treatment	• Highly effective control • Limits chemical impact on non-target plants	• Chemical may still persist in soil, water, and organic matter if over-applied, limiting revegetation efforts[6]. • Labor intensive and costly • Licensed applicators with special equipment required • Costly removal of dead overstory required prior to revegetation
Cut-stump, basal bark, girdling herbicidal treatment	• Highly effective control • Limits chemical impact on non-target plants	• Labor intensive, high cost per individual tree treated • Chemical may still persist in soil, water, and organic matter if over-applied, limiting revegetation efforts. • Costly removal of dead overstory required prior to revegetation
Extraction (removal of above-ground biomass and root crown with trackhoe/excavator)	• High rate of tree mortality (80-95%) • Clears ditches and other steep banks other mechanical equipment can't reach • Performed with reduced equipment movement across the landscape	• Expensive • Requires more time and heavy equipment mobilization • Soil is highly disturbed by tamarisk extraction requiring landform reshaping • Costly secondary weed control to treat resprouting tamarisk • Requires site access by heavy equipment
Burning	• May be effective control when combined with chemical treatment • Effective, low-cost biomass removal or reduction in denser stands • Easy access to resprouts	• Used without herbicide, burning can stimulate tamarisk growth (Figure 13) • Can alter soil characteristics (particularly surface salinity); reduce fertility • Air pollution constraints; may harm wildlife and habitat • Site may be prone to erosion and secondary weed invasions, especially without revegetation. • Removal of remaining overstory and roots prior to revegetation
Mowing, disking, roller-chopping, etc.	• Highly effective when combined with chemical treatment • Revegetation is not impeded due to this control method	• Requires site access by large equipment • Expensive due to specialized equipment costs • Heavy equipment may disturb soil and desired vegetation • Site is prone to secondary weed invasions, especially without revegetation.
Broadcast herbicide treatment	• Highly effective control (90-100%) • Large areas can be treated in a small amount of time • Preferable and most effective on large, contiguous, monotypic stands with little or no native understory	• May have higher potential environmental impact to soil, water, wildlife, and other vegetation. • Chemical persistence by certain herbicides (e.g., imazapyr) in soil, water, and organic matter may make revegetation difficult. • Costly removal of dead overstory and roots required prior to revegetation.

PHOTO CREDIT: KEN LAIR

FIGURE 14: A Hydro-Ax equipped with a brush rake clears tamarisk.

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 15: Mulching was done at this restoration site in the UCRB; note how close to the cottonwoods it was able to come without disturbing the desirable vegetation. Seedlings are coming up through the mulch, but there is less weed encroachment into the mulched area.

PHOTO CREDIT: KEN LAIR

FIGURE 16: A broadcast seeder is being used at this site prior to tamarisk removal.

The woody residue (shredded or mulched material) from these operations poses limitations, however, for seeding or planting techniques. Resultant mulch cover typically constrains site access and/or types of equipment used for large debris clearing and subsequent pole plantings. More importantly, heavier-duty equipment is required for ground-based broadcast seeding or aerial (helicopter) application of broadcast seeding on larger tracts must be practiced in lieu of infeasible drilled seedings.

Burning tamarisk is also a means of biomass reduction; however, this is the least common and least recommended approach (see Table 4, Figure 13). In addition to safety concerns, fires can increase soil salinity and decrease nutrient availability in these riparian zones.

If the method for handling tamarisk biomass will compromise access to the soil surface (such as mulching or shredding), broadcast seeding, soil amendment, and/or mycorrhizal inoculation may precede mechanical mulching or shredding where stands are sufficiently open to permit equipment access (Figure 16). This maximizes contact of seed and/or amendment materials with mineral soil and minimizes seed sequestration or "perching" within overlying mulch material, especially after completion of subsequent implement operations. On dense, monotypic stands with full canopy closure and/or negligible ground-based mechanical access under the canopy, broadcast seeding following mulching operations must typically be conducted. Within this context, other implements can subsequently be employed to mechanically incorporate seed, amendments and /or inoculum through the mulch and litter (duff) down to the mineral soil. These latter implements, as examples, include roller choppers (Figure 19), land imprinters, and/or heavy tandem (offset) disking (see Appendix B for list and descriptions of equipment).

B) Herbaceous Weed Management

> *"I've seen a canopy of tamarisk with solid knapweed under it. So if you're going to remove that tamarisk, you know you're going to have solid knapweed. So why reveg that until you get a little bit ahead on that knapweed?"*
>
> – **Kara Dohrenwend** UCRB Project Manager

The initial site assessment will reveal whether other weed management besides tamarisk removal will be necessary. Keep in mind that weed control methods will affect subsequent options and timetable for revegetation; for example, aerial application of imazapyr will generally kill tamarisk and herbaceous weeds in the understory[7] (Figure 17); however, herbicide residues may impede establishment of desirable species for at least two years[8]. Similarly, tamarisk removal via mechanical means such as with a Hydro-Ax™ is likely to achieve some herbaceous control, especially if the rotary head is used to till the upper layers of the soil during tree grinding and/or if a thick layer of mulch is left (Figure 18). Thus, site assessment should be on-going. In general, foliar spot spraying with a recommended herbicide for other weed control is advisable.

C) Hydrology management

> *"On low elevation mesic riparian sites, use irrigation water to mimic the natural hydrograph, since most of these native species have evolved with this moisture regime. For the first 2-3 years or until establishment (if over the bank flooding is NOT occurring), irrigate heavily at the historic high water period"*
>
> - **Pat Arbeiter** UCRB Project Manager

In many cases, tamarisk infestation has benefitted from changes in the historical hydrological regime and/or has influenced a change in hydrology itself. Hydrological changes may result from channelization, construction of drains and special-purpose diversions that lower water tables, and changes in soil and water quality (particularly salinity). Hydrology management may be a necessary adjunct to successful revegetation. More information on this topic can be found in the resources listed at the end of this volume.

One note on arid sites where overbank flooding does not occur and the water table is inaccessible: UCRB managers have had success with revegetation of these sites with correctly chosen seed mixes that germinate over time. There are also sites that are arid despite close proximity to perennial flows since they may flood only ever 25 to 50 years; this river influence should be taken into account for long term maintenance.

Flooding and water table

Periodic overbank flooding is one of the factors most associated with reestablishment of native vegetation in wet and

TABLE 4: Tamarisk biomass management at restoration sites.

Handling of biomass	Pros	Cons
Off site disposal	• Most aesthetic • Reduction of fire risk • Clears areas for active revegetation	• Generally highest cost • Lost benefit of biomass (see 'mulching' and 'piling' below)
Piling on site	• Creates Wildlife habitat • Most cost effective	• Unsightly • May be fire risk • Re-rooting or re-sprouting possible
Burning on site	• Reduces age-class of tamarisk, which may increase efficacy of herbicides and biological control • Low-cost means of rapidly reducing standing biomass	• Can adversely alter soil chemistry, making establishment of desirable species difficult • Stringent fire safety controls required • Site access not reliably safe for tires (puncture risk)
Mulching on site	• Moisture conservation • Moderation of temperature / wind extremes • Salinity remediation and reduced capillary rise of salts • Enhancement of microsite environment for seedlings • Provides weed suppression (particularly for annual / ruderal species) • Elevates C/N ratios that induce nitrogen stress over time, facilitating positive successional trajectory.	• Cost of equipment • Covers bare soil, hinders reseeding • Reduces site access for some equipment • Heavier equipment needed for planting

BOX 2: RESOURCES FOR WATER DATA

Stream gage records are published for public use (e.g. http://nwis.waterdata.usgs.gov/nwis), or can be determined by indirect means such as:

a) current velocity meters, if cross-sectional areas of the affected stream channels are known or can be obtained (see http://ga.water.usgs.gov/edu/measureflow.html; http://www.ecy.wa.gov/Programs/wq/plants/management/joysmanual/5meter.html)

b) measurement flumes or weirs (see http://waterknowledge.colostate.edu/parshall.htm; http://waterknowledge.colostate.edu/v_notch.htm)

c) observation of debris-lines from previous flooding events.

PHOTO CREDIT: STEPHANIE GIECK

FIGURE 17: Application of imazapyr was very effective at killing tamarisk at this site, but soils were effectively dead the following spring.

PHOTO CREDIT: STEPHANIE GIECK

FIGURE 18: Tamarisk mulch left by a Hydro-Ax shredder.

riparian sites. Many native species (particularly cottonwoods and willows) depend on scouring and gradual water table decline to support germination and growth. Base flows then need to be sufficient to sustain these populations. Evaluation of the low flow hydrology should be an important aspect of site evaluation.

Where possible, natural flows should be encouraged or simulated. Riparian sites exhibit limited potential for natural or artificial recovery of willow and/or cottonwood species where supplemental water (via seasonal flooding, shallow water table, or irrigation) is unavailable. On the Provo River in Utah, success with passive revegetation has been achieved by coordinating dam releases with seed dispersal of native species, particularly cottonwoods. Although this does not replicate all aspects of a natural, pre-dam flood event, the essential elements for promoting native establishment have been restored. Similar success in promoting native establishment, even in the presence of tamarisk, has been documented in the UCRB[10].

Flooding is also important because of its effect on water table levels. Water table is the other key factor for riparian plant establishment; in a survey of over 30 restoration sites across the west, having a water table that was never >10’ below the surface was highly correlated with restoration success[11], and among successful active revegetation projects, most had water table depths reported to be < 6 feet, although there were successful examples of revegetation at more arid sites[12]. Site preparation should include installing piezometers at varying distances from the channel for monitoring if they were not already established in conjunction with site evaluation (see “How to create a Peizometer” p 7) .

Channel morphology and streambank stabilization

River channel modifications may be necessary as a part of your overall restoration plan if the channel has been severely degraded and is unstable. For areas invaded by tamarisk, this is likely to include bank re-profiling and/or restoring historic meander patterns of the water channel. It should be noted that channel morphology is a complex science and should not be undertaken without consultation by those with experience in this field.

Stabilization of stream banks is also important for a healthy ecosystem and restoration success. Tamarisk was planted in many areas to secure riverbanks and trap sediment, which it does very well, but many invaded areas in the UCRB are still prone to erosion, especially if tamarisk is removed. Many tamarisk infestations in the UCRB tend to be patchy and narrow, with desirable vegetation that should not be disturbed, thus it will be less likely that complete restructuring of the channel will be either possible or desirable. Where additional stabilization is needed, plantings and/or mechanical means (e.g. with rocks and wire) may be used, but again consultation with a specialist may be necessary as correct design is critical. Also, permits are often required for this work; contact your regional Army Corps of Engineers office to check (see Appendix D). See resources listed in Appendix C for more information, particularly those of the NRCS:

"Stream Coridor Restoration Principles, Processes, and Practices", The Federal Interagency Stream Restoration Working Group, 1998. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.http://www.nrcs.usda.gov/technical/stream_restoration/

Other NRCS publications on ecosystem management: http://www.nrcs.usda.gov/technical/ecosystem.html

Irrigation

Where natural overbank flooding is not possible, irrigation is a technique used with success in revegetation. A variety of types are available and should be selected based on material planted and feasibility of irrigation, including sources, water rights, and water quality considerations (see Table 5). Where surface

TABLE 5: Types of irrigation appropriate to restoration with uses and limitations.

Type	Description	Uses	Limitations
Hand watering	Watering individual plantings using water brought in, e.g. in a pick-up truck water tank.	As an inexpensive supplement in sites without other irrigation; useful for initial establishment	Labor intensive; generally used only once or twice after planting in a drier season
Drip irrigation	Slow, localized irrigation using flexible tubing, bubblers and misters and seep tubing.	Recommended for transplants	Expensive, including maintenance and cleaning; will require eventual removal.
Impact Sprinkler systems	Stationary lines 30-40' joined by collars with multiple lines if needed. Can achieve 30-40' radius of water from each rotating sprinkler head	Impact sprinkler lines can be as long as needed. Can achieve 100% coverage.	Requires a pressured system (i.e. pump or other high pressure water source).
Big gun sprinklers	Like an oversize impact-type as long as 100' with lots of pressure resemble a traveling lawn sprinkler. Wheel mounted lines, self powered.	For seedlings or transplants.	Requires high pressure and a relatively prepared seedbed with little debris.
Surface flooding irrigation	Canal water is diverted into a head ditch or pumped into a head ditch to irrigate via a siphon tube or pump. A big sheet of water between two berms or within furrows	Graded areas where water will flow through revegetation area.	Requires extensive landform preparation to distribute water via furrows by gravity. Other irrigation infrastructure required to deliver water to site.
Surface irrigation with gated pipe. Form of flood irrigation.	6-10" diameter PVC or aluminum pipe with 2"square gates every 18-24" that can be opened into individual furrows.	Good for both seeded and transplant. Plant arrangement can be staggered to appear more natural.	Pressurized or gravity flow system required. There must be at least 2-3% grade for gravity system. Requires additional infrastructure as with surface flooding.

PHOTO CREDIT: KEN LAIR

FIGURE 19: The roller chopper shown above has been used to create surface texture after tamarisk was cleared from a site.

water or shallow groundwater is not available, early supplemental irrigation (where available) can be used to enhance germination and establishment of characteristically slowly germinating shrubs such as winterfat (*Krascheninnikovia lanata*), providing them with competitive advantage that often enables equal rates of establishment with saltbush (*Atriplex* spp.) and other competitive species. Many native plants, even in xeric environments, require only supplemental irrigation in order to establish initial and secondary (adventitious) root systems, after which adaptation and environmental "hardening off" enable further growth, vigor, and reproduction without additional irrigation. Irrigation may also help overcome salinity constraints in affected riparian soils, enabling flushing of salts below the root zone.

Irrigation should be designed to incorporate varying frequency, volume, and duration within growing seasons in response to variations in climate, hydrology, and other environmental stressors. Irrigation should reflect minimum evapotranspiration needs of the newly planted materials in order to prevent moisture stress during germination, adventitious root development, and transplant acclimation. A minimum application rate of approximately 0.25 inches (0.64 cm) per week for the duration of irrigation application (i.e., growing season) for seeded material is recommended. For transplanted material (containerized or bare root), provide limited supplemental irrigation to avoid severe stress. Transplanted stock may only require one year of supplemental irrigation if there is some precipitation. In drought conditions, a minimum 2-3 yrs may be needed. In general, try to simulate the monthly precipitation x 2 in arid areas. Sprinkler systems or drip systems may be most feasible. Where feasible due to water availability and appropriate grade, surface irrigation has been used successfully to revegetate many areas of the UCRB, particularly abandoned farmland that had become infested with tamarisk and Russian olive.

Monitoring-

Tracking soil moisture will help maximize effort of irrigation and avoid over-watering. Some of these can be automated, such as Hobo microstations, which can be read remotely. Onset Computer Corp creates a unit that is 4" square and can be mounted in the field with 4 sensors: air temp, soil moisture, radiation, wind speed and direction, etc.

D) Land form shaping and mechanical seed bed preparation

> *"Sometimes I would decide to just 'start over' with heavy equipment on a riparian site that had been altered by dense infestations of tamarisk/other weeds or intense agriculture, if the current hydrology and soils were still very viable. On other sites where the hydrology and soils were drastically altered, a cost/benefit analysis often pointed to just walking away. Thoughtful site analysis and consultation with experienced colleagues can lead to the best fit."*
>
> – **Pat Arbeiter** UCRB Project Manager

Both active and passive revegetation may be facilitated by some measure of land form shaping and/or surface manipulation, especially when these may improve water-holding capacity of the soil and/or distribution of irrigation water. Note that not all sites will require such intensive measures for passive revegetation (see above under Passive Revegetation), and disturbance of the soil can facilitate weed invasion if there is not a native seed source and suitable moisture. In semi arid restoration sites, we recommend removing the standing dead tamarisk, including stumps, with a shredder (e.g. Wood-Gator™, Hydro-Ax™/Prentice™, Brown Bear™, Fecon™,

TABLE 6: Average values, standard deviation, minimum and maximum values measured for soil characters in surface soils of 17 restoration sites in the UCRB. These are expected to be better than average measurements for UCRB soils generally. Analyses done by the Cooperative Extension Service and Experiment Station Soil, Water & Plant Testing Laboratory, Colorado State University. For categories "% lime" and "texture estimate", most common (16/17 and 9/17 sites respectively) evaluation is listed.

	pH	Salts (dS/cm)	Lime %	Texture estimate	Organic matter %	Nitrate ppm	Phosphrus ppm	Potassium ppm
average	7.9	6.4	High	Sandy Loam	2.7	13.4	10.4	306.4
st dev	0.3	6.9			1.7	16.9	7.8	193.5
min	7.4	0.3			0.4	1.0	1.8	69.0
max	8.4	27.6			6.6	61.0	31.2	824.0

Fleco™, etc.) without disturbing soil, followed by broadcast seed application and then using a land imprinter to increase contact of seed with soil and enhance germination. Broadcasting seed without the imprinter is a good practice where mulch is thin and if done in late fall.

Active revegetation of disturbed sites generally will require soil surface manipulation (i.e. some form of seedbed preparation) and, in some cases, restoration of soil microbial communities and soil:plant functional processes. Soil surface disturbance needed for adequate seedbed preparation is typically absent following fire and herbicide applications.

Mechanical treatments can be used for landform shaping, seedbed preparation, salinity remediation, placement of seed, and incorporation of soil microbial (mycorrhizal) amendments. These measures may include land imprinting, pitting, and/or heavy tandem (offset) disking. Soil surface treatments are used to

- create soil surface micro-relief (micro-catchments) to enhance precipitation capture and retention in the rhizosphere of seeded/planted vegetation (Figure 19);
- reduce, redistribute, and/or dilute salts in the upper soil profile and tamarisk leaf litter on the soil surface;
- create more spatially uniform soil texture characteristics (in both depth and lateral distribution) for improved seeded vegetation adaptation; and
- assure proper depth placement and incorporation of broadcast seed and/or mycorrhizal inoculum.

Soil manipulation is generally performed by heavy equipment that can be purchased or rented. See a list of those often associated with restoration after tamarisk removal, with uses, benefits, and limitations in Appendix B: Heavy Equipment. Some aspects to consider when using heavy equipment:

- Mechanical removal of tamarisk (including burning) is likely to leave sharp and very hard stumps or other debris. If there are stumps sticking up, land shaping implements will need to be run on tracks to avoid punctured tires.
- If you have soil horizons that should be maintained or if there is an erosion risk, surface soil should be disturbed as little as possible (see recommendation in the first paragraph of this section).
- Disturbing the soil surface can make a site vulnerable to weed encroachment. Do not leave a site tilled with no follow up management.

E) Seedbed preparation: chemical and biological

During the evaluation of ecological factors in Step 2 of your restoration planning, it may be discovered that soils require remediation. In parentheses is the problem most often found in the UCRB, although sites selected for restoration tend to be better than average (Table 6):

- Salinity (>8 dS/cm EC)
- Nitrogen soil nutrients (<5 ppm nitrate nitrogen)
- Organic matter (<2%)
- Texture ("heavy", clay soils- >25%)
- Soil microbial community (i.e. mycorrhizas reduced or depleted)

Addressing these common issues can greatly enhance establishment of species. However, it should be acknowledged that addressing some of these problems may be logistically or financially infeasible in some sites, and thus may be reason to deprioritize them for revegetation during Step 3 (site selection).

Salinity Remediation

High salinity (>8 dS/cm EC) will make establishment of many species difficult; if the dominant salinity levels are over 15 dS/cm, very little will establish (see Table 2). The primary means by which salinity can be reduced in soils is through leaching via flooding. Some salinity reduction may also be afforded by mechanical creation of micro-relief on the soil surface that will catch and hold precipitation (e.g. Figure 19). Any introduction of topographical relief even on micro-scales of less than 5 inches (12.5 cm) will provide microsites for seed germination and/or transplant establishment and survival (Appendix B). Soil salts are wicked up the side of the depressions via capillary rise of soil moisture, thereby proportionally reducing the salt content at the bottom of the depression. This is especially advantageous in non-silty, medium-textured riparian soils (e.g., sandy loam to clay loam), which retain the shape and intended function of the depressions without sedimentation (filling) over longer periods of time.

The experience of the authors suggests that in arid sites, addition of mulch (where feasible) also significantly reduces surface moisture evaporation and associated capillary rise and soil surface deposition of salts. As such, mulching can aid both passive and active revegetation. When considered in combination and interaction with the moisture retention and conservation attributes of soil surface roughening and/or mulching, the resultant seedbed is more conducive to seed germination and plant growth. This is particularly true early in the establishment phase of restoration efforts when increased moisture and lowered salinity in the rhizosphere of young plants are most critical.

Commercial soil amendments are also available that reduce salt impacts. Products most commonly used involve a) a chemical reaction, converting soluble salts to neutral or acidic compounds (e.g., gypsum/$CaSO_4 \cdot 2H_20$); or b) physical adsorption of sodium (Na^+) via colloidal attachment and sequestration (e.g., HydraHume™; distributed by Helena Chemical Company; manufactured by Horizon Agricultural Products). Humic acids in the product reduce the osmotic potential (lowering the salt index) of Na^+ by satisfying the positive charge with a humate salt, thereby colloidally sequestering Na^+ by surrounding the ion with organic acids.

The effectiveness of these products can be reduced by both cost of the higher application rates needed to be effective in higher EC soils and the need to incorporate these products for maximum efficacy, which is often infeasible in many tamarisk control scenarios (especially herbicidal and biological). Ultimately, land managers in the UCRB have found that selection and use of halophytic (i.e. salt loving) species is the best management response to restoration situations exhibiting elevated soil salinity (see Table 8).

The USDA Natural Resources Conservation Service (NRCS), through their Field Office Technical Guides and professional experience, can provide detailed recommendations for types, rates and application methods for organic matter mulches and fertilization.

http://www.nrcs.usda.gov/technical/

Nitrogen Dynamics

In most native seedings or plantings, early (establishment phase) fertilization with N is often counter-productive, enabling or enhancing greater encroachment, establishment, and vigor of ruderal weedy species, often at the expense of seeded or planted natives[13]. This is particularly true on sites disposed to invasion following disturbance (e.g., by mechanical *Tamarix* control measures and/or seedbed preparation) by high resident seed bank or prevalent seed dispersal vectors of annual grass weeds (e.g., *Bromus*/cheatgrass, *Hordeum*/foxtail barley, *Taeniatherum*/medusahead, etc.) and/or annual broadleaf weeds (e.g., *Salsola*/Russian thistle, *Kochia*/*Bassia*/burning bush, *Chenopodium*/lambsquarters, *Xanthium*/cocklebur, etc.)[14]. Effectiveness of fertilization on very coarse (sand) or very fine (clay, silt) soils will also be constrained because of limited availability for plant uptake. Generally, pre-plant or immediate post-plant fertilization holds limited potential for benefit to native species, in light of these constraints.

Nevertheless, soil nitrogen is often a dominant factor determining plant communities. Soils with a history of tamarisk domination (i.e., absence of herbaceous understory) may be severely nitrogen-limited. Conversely, younger, less dense, mixed stands exhibiting a significant broadleaf component (native or exotic) in the understory, particularly if hydrologic processes (water table, seasonal surface inundation, etc.) are favorable, will typically have sufficient nitrogen due to nutrient cycling from degradation of senescent plant material.

Analysis of soil samples from surface and subsurface (potential root zone) horizons, for macro-and micro-nutrients and organic matter, is the most accurate method for determining nutrient needs (see Soil Sampling, in Step 2: Site Evaluation). Most soil analysis labs provide fertilization recommendations focused on agronomic (i.e., crop) use of the soils, which often result in significant over-estimation of nutrient needs. If revegetation is to target native plant communities, this should be conveyed to the soil analysis lab in order to improve applicability and practicality of their recommendations, as well as land manager understanding and interpretation of those recommendations.

Upon successful suppression of ruderal weedy species, supplemental fertilization may be considered if ambient soil N levels remain low. Where nitrogen is low, augmentation may be accomplished by two methods:

a) direct addition through broadcast application of commercial or organic nitrogen fertilizer; or
b) addition of organic mulches.

Generally, native seedings or plantings on stable soils (i.e., not highly disturbed, retaining renewable soil genesis properties) need no more than the equivalent of 60 lb/ ac (67 kg/ ha) of actual applied N. Often, considerably less should be applied in order to maximize benefit to natives while minimizing extraneous losses (i.e., volatilization, other movement out of the rhizosphere).

Seed or plant mixtures containing significant percentage composition of legumes (e.g., *Prosopis, Acacia*, etc.) should not need N fertilization if properly inoculated with *Rhizobium*[15] at the time of seeding or planting because of their natural N fixing and auto-supplementation resulting from the *Rhizobium* association. Similarly, if revegetation mixture composition is primarily broadleaf (i.e., dicot), phosphorous (P) supplementation may be more important than N. **Only if mixture composition is dominated by grasses should N fertilization be considered strongly on sites exhibiting N depletion.**

Conversely, it may be possible that your site has high N (specifically nitrate, NO_3). High density of ruderal, agricultural weeds or proximity to livestock confinement areas (feedlots, corrals, dairies, etc.) may be indications of this. Sequestration of N in microbial biomass through application of organic, high carbon:nitrogen (C:N) ratio materials have been found to be effective under these conditions. Research has demonstrated that application of non-recalcitrant (rapid release), high-carbon materials (in the form of mulches, wood by-products, etc.) promotes N sequestration, orienting successional trajectory of seedings in favor of more stress-tolerant, native perennial species (as opposed to ruderal weed species)[16]. Fiber-based (woody) material sources offer slow-release, longer term impacts, whereas non-fiber sources such as common sugar provide a quick-pulse of organic carbon for rapid, short-term impact. These latter treatments must be applied repeatedly during a growing season in order to achieve desired results over the establishment period. Alternatively, blue-green algae (cyanobacteria) have also shown promise in achieving N sequestration. Although blue-green algae are capable of fixing organic N (NH_4), these microorganisms also act as unavailable sinks for N because of initial rapid uptake, metabolism, and subsequent population increase. Some firms that supply commercial mycorrhizal inoculum also have commercial sources of cyanobacteria that can be applied as a broadcast pellet.

Organic material and soil texture

Tilling additional organic material into the soil may be helpful to increase nutrient availability and soil texture, but it is important to prioritize use of mulches with species native to the UCRB. The primary reason for this being the potential for seed transfer, as well as the possible secondary benefit of the reintroduction of beneficial fungi and other microorganisms.

Incorporation of mulches also improves moisture holding capacity, nutrient retention, and organic matter cycling, especially during early establishment phases of seedings or plantings. Incorporating mulches will be difficult unless *Tamarix* biomass is removed. Surface mulches (including masticated *Tamarix* biomass) may provide significant organic matter infusion over time, in addition to other benefits of moisture, temperature, and wind buffering. However, in arid to xeric climatic regimes, where organic matter degradation is often slow, potential benefit is minimized.

Remediating high clay content soils is difficult and expensive. Importing lighter topsoil is effective but costly. Alternatively, deep ripping of soils with heavy equipment can increase infiltration. However, fractures from deep ripping are only good for that year or a couple years. **As with most soil issues, species selection may be the best response to heavy soils** (e.g. western wheatgrass, many shrubs including saltbush, greasewood, winterfat).

Mycorrhizal Inoculation

Mycorrhizas are beneficial fungi that form associations with the roots of plants to aid in moisture and nutrient absorption (particularly phosphorus).

BOX 3: ENDO VS. ECTO MYCORRHIZA

Endomycorrhiza (also referred to as arbuscular mycorrhiza, AM, or VAM) are those which actually penetrate the root, and many revegetation species are believed to take advantage of this symbiosis. In general, native herbaceous species are more likely to benefit from AM, whereas trees such as cottonwoods and willows are more likely to have symbiosis with ectomycorrhiza, a fungus that forms a fruiting body (i.e. a mushroom) at the soil surface.

Soils under tamarisk, a non-mycorrhizal species, have been found to lack spores of those mycorrhizas that are associated with healthy native plant communities. In the absence of critical mycorrhizal species, competitive species that are less dependent on mychorrhizal association may establish and dominate revegetated sites. Furthermore, one study found that arbuscular mycorrhizal inoculation decreased growth in young tamarisk in the presence of cottonwood[17]. Thus, adding mycorrhiza where tamarisk has dominated for a long time may aid in establishment of desirable species. See Table 8 for recommended mycorrhizal associations.

Mycorrhizal inoculum (using host-specific species, as determined from baseline soil samples, current research, and pertinent literature) can be obtained in two ways:

- **Raw soil**: harvest and incorporate raw soil as an inoculum from adjacent native stands. Simply transferring soil between sites is preferable because correct species of mycorrhizas for the desired vegetation is assured, and it is cost effective.
- **Commercial inoculum**: this may be purchased directly from the manufacturer or from some local garden suppliers; be sure to use the correct mycorrhizal type for the plant species you are using; see Table 8 for general recommendations. The UCRB land managers we spoke to preferred to apply these directly to the roots of transplants (Box 4). For establishment by seed, one can purchase seed that has been treated with mycorrhizal spores or commercial inoculum can be incorporated into the prepared seedbed by three methods:
  a. As a pre-plant granular or encapsulated broadcast application using an aerial or ground-based rotary fertilizer or seed spreader
  b. As a raw inoculum (powder-grade spore and hyphal material) incorporated in commercially pelletized seed coatings and applied in the same manner during broadcast seeding using prescribed seeding rates
  c. As a granular through the drill with seed where drill seeding is feasible. Mechanical treatments previously described can be used to incorporate or improve depth placement of the broadcasted inoculum.

BOX 4: TREATING SEEDLINGS WITH MYCORRHIZAS

"Prior to planting seedlings, roots may be dipped in a slurry mixture of the inoculum (live spores), water and water absorbing polymer powder (cross linked polyacrylamide). The polymer is readily available though commercial reforestation catalogues and protects the fragile rootlets during planting operations and will reduce root dessication. This technique is most valuable in areas that have been farmed, mined, or covered with dense stands of tamarisk for many years and few to no host mycorrhizas still exist. Check with your nursery to see if they have already treated seedlings.

I've done this with many 100,000's of seedlings of many species and have seen many study plots showing a marked increase in growth rates and survival rates over untreated seedlings, usually in areas that did not have native cover for many years."

– Pat Arbeiter UCRB project Manager

As an alternative on sites needing soil organic matter augmentation, an organic matter amendment such as SOILution™ or Biosol™ that incorporates mycorrhizal inoculum within the formulation may also be considered. Regardless of source, the inoculum should contain one or more species of mycorrhizas that are host-specific to the native revegetation plant species (See Table 8 for some guidelines for specific revegetation species). Typically the mycorrhizal innoculum will include one or more of the non-specific *Glomus* species, e.g. *G. intraradices, G. mosseae, G. aggregatum,* and/or *G. fasciculatus*.

Two caveats with regard to use of mycorrhizas: First, certain residual herbicides in the soil may negatively affect their colonization and association with native host plants, and thus shift competitive advantage to those species (both desirable and not) that are less dependent on mycorrhizas. Second, mycorrhizas are less likely to have a beneficial effect on wild plants (and can in fact even become parasitic) when there are abundant resources (nutrients and water). Thus, mycorrhizal inoculation finds its highest utility when:

a. No remnant native understory remains
b. The majority of key (dominant) species in the revegetation mixture are mycorrhizal-dependent (Table 8);
c. the site is amenable to mechanical inoculum spreading and/or incorporation in some way
d. it is used in concert with reasoned and thoroughly researched use of appropriate herbicide chemistry
e. environmental stress may limit availability of moisture and nutrient resources.

FIGURE 20: Species selection at this saline site in the UCRB was determined by the presence of salt-loving weeds prior to tamarisk control.

F) Fences

Where there may be a risk of herbivory, fencing during establishment is highly recommended. Browsing or grazing can mean loss of most or even all planted material, especially transplants. Some of the UCRB land managers we spoke to had problems with browsing by deer, elk, and beaver, making investment in exclusion devises advisable. Depending on the type of herbivory expected, these may range from heavy woven wire field fencing around the trunk (for beaver), or fencing around an area (electric, if possible) for deer or elk where densities of these warrant such an investment. Be careful not to fence in rabbits. We know of one project where it is likely that most plantings died because there was a population of rabbits living in the enclosure.

Fencing comes in several types, including but not limited to the following:

- *Barbed Wire:* Although it may exclude cattle, barbed wire fencing is not effective for most other herbivores. Barbed wire may effectively be used to supplement other types of fencing.
- *High Tensile Steel Wire:* If tall enough (8-10'), such wire can exclude large jumping herbivores but not burrowing ones. Bottom wire should be no more than 6" to prevent deer from crawling under. Individual wires can be electrified (see below). Use high tensile steel instead of regular steel wire fencing. High tensile will not stretch or sag, and this is the main reason deer, elk, and other wildlife become tangled and die in fencing. High tensile is initially more expensive but is less expensive to maintain.
- *Woven Wire Fences:* Strong and relatively easy to install, these can exclude both small and large herbivores and are essential if planting cottonwoods where beaver are present. A 36" woven wire fence can easily be extended to five feet by adding two or three strands of high tensile wire. Some advocate a barrier of wire mesh buried an inch or two under the ground around the outside perimeter to exclude rabbits.
- *Electric Fencing:* Effective for large herbivores, although often costly. Five-wire fences 58" tall have been used to effectively exclude deer. Requires a battery, which may be a theft risk. Electric fencing can also be used to supplement other types of fences. Tall grass and deep snow have been known to short out wires.

In general, fencing requires frequent maintenance and repair to ensure continued functioning. Fencing inspection and maintenance needs to be an important component of any post-planting implementation and long-term monitoring until no longer needed.

III. PLANT MATERIAL SELECTION AND PLANNING FOR PLANTING

> *"Our greatest challenges in riparian restoration are water issues, and this can only intensify in the future. Often I have held the vision of classic (read that historic) riparian habitat. However, water demands on our western rivers keep dramatically increasing. Global warming presents more question marks. In many areas, an emergent wetland today may well have only the hydrologic potential for a willow/cottonwood forest several years from now. The willow/cottonwood site may only have the moisture potential for scattered cottonwoods and sumac/greasewood in the near future. Planning projects that focus on* ***more drought tolerant*** *(his emphasis) riparian species can save money, save water, and help our habitats last longer for future generations"*
>
> – **Pat Arbeiter** UCRB Project Manager

Careful species selection is critical for restoration success. It is highly recommended that reference sites are identified that have similar or achievable environmental conditions (e.g. hydrology and soil type/quality) to aid in species selection. Pat Arbeiter, one of the most experienced land managers we spoke to, chooses appropriate revegetation species based on what species exist at a site pre-treatment (Figure 20). Thus, if only halophytic weeds occur on a site, he will choose desirable halophytes to replace them. For example, on semi-arid saline riparian sites, tamarisk could be replaced with grease-

TABLE 7: Most common ecosystem types found in the context of tamarisk removal and species types recommended for revegetation (adapted from Shafroth et al 2008[18]). See Table 8 for more recommended species by growth form with common names.

Type	Definition	Example revegetation composition
Predominantly mesic, less saline	Receiving sub-irrigation from seasonally shallow water tables and/or seasonal inundation from flooding	Grasses and annual / perennial forbs; reduced proportion of chenopod shrubs (e.g. *Atriplex, Sarcobatus*) and forbs (e.g. *Heliotropium, Oenothera*)
Ephemeral mesic, highly saline	Receiving periodic groundwater and/or surface flow contributions (e.g., alkali "scalds", "slicks", "sinks").	High proportion of halophytic chenopod species (e.g. *Atriplex, Sarcobatus*); minimal grasses (e.g., inland saltgrass in fringe zones)
Arid, moderately to highly saline	< 10"/yr precipitation, little to no surface flow contributions. Salinity >8 EC	Mixture of shrubs, forbs, and grasses; emphasis on more halophytic species, particularly chenopod shrubs (e.g. *Atriplex, Lycium*)
Arid, less saline	< 10"/yr precipitation, little to no surface flow contributions. Salinity <8 EC	Mixture of shrubs, forbs, and grasses; broader spectrum of adapted species (including legumes); (e.g. *Ribes, Rhus*), higher proportion of forbs and grasses

wood, halogeton could be replaced with four-wing saltbush, or poverty weed could be replaced with inland saltgrass (with consideration to other microsite parameters). Species selection will also be guided by overall restoration goals (e.g. forage, recreation, etc.). The species recommendations in Table 8 are based on the experience of the managers of the UCRB and of successful species observed on restoration sites where tamarisk had been removed. Timing of planting should also be very carefully considered and should be discussed with your seed provider (Box 5).

A) Ecological and Physiological Considerations

Successful restorations on upland floodplain terraces (i.e., arid to xeric) will be characterized by shrub/forb associations, with native grass as a minor component. These associations a) correspond to realistic capabilities on formerly infested fields and soils, reflecting current potential of altered hydrology, soils and climate; and b) approach reference native plant communities currently prevalent along fringes of the historic floodplain zones that have been recognized as desirable for wildlife, site stability, and weed suppression.

Individual seed mixtures of shrubs, forbs, and grasses, should be specifically formulated to address field conditions. These environmental constraints, however, are anticipated to occur predominantly within four generalized physiognomic regimes, based primarily on soil moisture and salinity limitations (Table 7). Species selection and mixture formulation should be suitable for prescriptions to landowners in terms of desirable traits (Box 6).

BOX 5: PLANT LATE IN THE SEASON

Timing of planting during the season was cited as an important factor by UCRB managers. In particular, late fall and winter plantings for both seeds and poles was associated with success in both arid and wet sites due to more moisture availability in the form of snow this time of year, which also helps prevent bird and ant seed consumption.

B) Seeded Species Autecology, Competition, and Seeding Strategies

"…you can seed a site and not see some seeds germinate for years. In this situation continual 'mucking about' with the site trying new things every year or

BOX 6: DESIRABLE TRAITS WHEN CHOOSING PLANT MATERIAL

- Plant/seed source
  - first priority – endemic (native) to local reach of the river. To do this, one may do your own collections or work with a local commercial nursery to transfer seed directly or propagate locally collected materials.
  - second priority – endemic to affected watershed
  - third priority – endemic to regional locale (50 miles) exhibiting similar soils, elevation, and climate
- Ease of establishment in field situations characteristic of managed tamarisk infestations
  - high germination, seedling vigor, and sustainability
  - practical seedbed preparation and seeding methods for field establishment
- Suppression of /resistance to/tolerance of weed competition
- Reproductive success (sexually: seed production; asexually: vegetative spread by tillering, sprouting, root extension)
- Favorable pollination requirements
- Insect and disease resistance
- Ease of seed harvest, cleaning, conditioning, processing, viability testing, and storage, utilizing mechanized and/or seed industry standard methods wherever possible
  - availability and quantity (commercial stocks and non-commercial harvest)

two is not a good idea. I am seeing a lot of that in tam removal sites in Moab – when if the site was just left be, it might have already revegetated by now, but the constant mucking about with it favors certain annuals (kochia and Russian thistle for a start)"

– Kara Dohrenwend UCRB Project Manager

Because plant species interact with each other through competition and/or facilitation, the order and combinations of plantings can have a significant effect on the community that results. Few of the sites we visited in the UCRB showed a species composition that matched those planted, at least in part for this reason. It also should be noted that soil disturbance generally favors weeds, hence the association between too much "mucking about" and lack of revegetation success in the quote above. The following discussion may help inform the land manager as to species selections within this context. All assumes that the site will be given time; many seeds will not germinate for years after planting, and some only after other species have established ("late seral" species).

Reducing the time for establishment of desired cover, diversity, production, and habitat values is generally a high priority. Passive revegetation often requires 10 years or more for establishment of desirable, native vegetation, with the first 1-5 years typically dominated by ruderal weedy species. These species that can establish quickly and easily on a bare substrate are considered early successional or "early seral" species. Those that are facilitated by the presence of these species, which need a more developed soil and are more competitive, are considered "later seral" species.

A prime objective should be to shorten or circumvent an extended ruderal and/or bare period by establishing diverse habitat characterized by predominance of early and late seral perennial species (i.e. those species that live for more than one year, see Table 8). This also minimizes potential for capillary rise and salt accumulation at the soil surface following tamarisk reduction and maintains lower wildfire hazard. Some sites may need initial establishment of earlier seral species in order to cope with and adapt to harsh environmental conditions until the site stabilizes (from the standpoints of organic matter recovery, energy flow, and nutrient cycling). More favorable sites may facilitate later seral species and accelerated successional strategies.

Facilitation

Facilitation refers to the condition when the presence of one plant helps establish another, a condition more common in

BOX 7: CASE STUDY- USE OF GRASSES

The need to suppress severe competition from tamarisk and/or secondary invasives following seeding may dictate species selection. For example, along the upper Pecos River in southeastern New Mexico, native grasses alone were seeded initially to assist in suppression of kochia (*Bassia scoparia*) (K. Lair and S. Nissen 2006; Bureau of Reclamation, Denver, CO, and Colorado State University, Fort Collins, CO; unpublished data). application of herbicidal and mechanical tamarisk control measures have converted riparian sites once dominated by tamarisk to monotypic kochia (*Kochia scoparia*), including apparent imazapyr-resistant kochia. Planting the grasses allowed use of a broadleaf herbicide to kill both the kochia and immergent tamarisk. Once the grasses had established and weeds controlled, the seeded plant community was augmented by subsequent inter-seeding of desirable forbs and shrubs.

arid environments. Early plantings of shrubs can facilitate the establishment of desirable later successional species by reducing surface evaporation and creating higher nutrient islands of plant debris in dry habitats with low organic content soils. Plants can also facilitate establishment of other species through soil stabilization. On disturbed sites where rapid site stabilization and erosion control are primary concerns, species selection should incorporate early- to mid-seral, "transitional", or "ecobridging" species (Table 8). This approach involves using regional natives that exhibit greater establishment potential under the harsh climatic and soil conditions on tamarisk revegetation sites. This strategy expedites site stabilization, facilitating more rapid recovery of basic plant community function and structure and restoring depleted energy, nutrient, and water cycles.

Competition

Competition is the opposite of facilitation; in a revegetation context we must be aware of species that are unlikely to be able to establish in the presence of others because of competition for light, water, or nutrients. Forbs, shrubs, and less competitive grasses may be significantly reduced when seeded in mixtures with highly competitive grasses (e.g. slender wheatgrass, thickspike wheatgrass, sideoats gramma (for natives), pubescent wheatgrass). To avoid this problem, species combinations may be seeded in sequences with timing that favors less competitive species during a given time period (e.g., sequenced seeding of forbs and shrubs prior to more competitive grasses; fall seeding to provide vernalization and release of dormancy for selected species; etc). Competition from seeded species can also be used to prevent re-invasion by tamarisk and other weeds; research has shown that tamarisk is not very competitive as a seedling against cottonwood and willow[19], and planting native grasses has been used to suppress kochia (Box 7).

C) Choosing seed versus pole or whole-root plantings

The form of plant material will affect success and progress of restoration as well as its cost. Pole/whip plantings or rooted transplants lead to fastest recovery and are associated with increases in overall plant community diversity over time. These applications are typically more expensive and labor intensive, however, and thus may be most appropriate for smaller-scale projects. Furthermore, these should not be used unless they can be planted with roots at the capillary fringe (i.e., region with both water and oxygen), or in the water table itself (for poles). Given standard auguring and/or "stinger" planting equipment, this generally means poles/whips of <8′ at time of planting, which also corresponds well with typical maximum rooting depths for phreatophytic species such as cottonwood, willow, baccharis, etc. Furthermore, planting these materials appears to work best when water table is never less than 10′ below surface, plantings are within 40′ of active flows, and there is good drainage (e.g. >3% gravel).

Current use of narrow, deep containers ("deep-pot" technology) for transplants allows existing root systems to immediately take advantage of deeper, typically lower salinity soil horizons and gain quick proximity to shallow water tables. However, saline or sodic surface layers still tend to determine seeding or planting success, even with deep-pot containers and/or irrigation. This is particularly true where water tables are deeper, containers are small, and/or the plantings have to suffice on natural precipitation or limited irrigation (e.g., upper floodplain terraces not amenable to pole or whip plantings).

Planting from seed is often less costly and easier to implement on a larger scale than poles or transplants. Our surveys have also suggested that revegetating from seed is also generally best for increasing vegetative cover and initial species diversity[20]. Seeding is often preferable with more saline and alkaline soils; however, seeding can be more risky because of vulnerability to other environmental stressors such as drought and predation. Time must be given for establishment, with success often not quantifiable for 3 years or more.

D) Species lists with planting information

The following Table can serve as a guide for appropriate revegetation species after tamarisk removal in the UCRB. Species selection and mixture formulation should be determined in cooperation and consultation with other potential stakeholders. Technical assistance may be available from the Natural Resources Conservation Service and associated Plant Materials Centers (NRCS-PMC), Cooperative Extension Service (CES), Bureau of Land Management (BLM), Fish and Wildlife Service (FWS), U.S. Forest Service (FS), National Park Service (NPS), State Fish and Game Departments (F&G), Bureau of Reclamation (BOR), landowners and managers, and local environmental organizations (see Appendix D for contact information). Local agricultural groups (including individual farmers) can also be an excellent source of information. Local knowledge on what grows successfully in a given area is invaluable.

Select non-native species are included because of their roles as potential "transitional" or "bridge" species that may fill temporal ecological niches in providing rapid site stabilization, phytoremediation of saline soil limitations, and/or site amelioration that enhances or predisposes saline riparian sites (e.g., energy, nutrient and organic matter cycling; moisture regime) for more rapid establishment of subsequently planted or co-planted native species.

TABLE 8: Suggested species for use in the UCRB with some environmental parameters for consideration. This list is not exhaustive or fully comprehensive. Basic environmental parameters are noted, including whether plants are early, mid, or late successional (E, M, or L respectively) species. Where known, associations with endomycorrhizae ("En"; i.e., growing on the inside of the roots, a.k.a VAM, or "arbuscular" type) or ectomycorrhizae ("Ec"; growing on the surface of the root) as well as the nature of these relationships are noted. See footnotes list for full keys for abbreviations.

Scientific Name [1]	Common Name	Recommended Cultivar / Germplasm	Utah Riparian Handbook Planting Zone[2]	Expanded Zone of Adaptability	Wetland Indicator [3] /Higher Soil Moisture Required(√)	Mycorrhizal Status [4]	Threshold Salinity [5] (mmhos cm^{-1})	Max Salinity [5] (mmhos cm^{-1})	Origin [6] / Life History	Succession (Seral) Status, Disturbed Sites [7]
GRASSES										
Achnatherum hymenoides	Indian rice grass	Nezpar, Paloma, Rimrock	Green Zone	Riparian arid, non-saline	UPL	M - En	4	6	N - P	E, M, L
Bouteloua gracilis	Blue grama	Hachita, Vaughn	Green Zone	Riparian arid, non-saline	NI	O - En	4	8	N - P	L
Distichlis spicata	Saltgrass*	Local ecotype(s)	Green Zone, Streambank	Riparian, saline swales, salt meadow	FAC+ √	F – En	6	12	N – P	E, M, L
Elymus canadensis	Canada wildrye	Mandan	Green Zone, Streambank	Streambank, riparian mesic	FACU √	O – En	6	12	N – P	P, E, M
Elymus elymoides	Bottlebrush squirreltail	Sand Hollow, Toe Jam Creek, Fish Creek	Green Zone	Riparian arid	UPL	M – En	4	8	N – P	E, M, L
Elymus trachycaulus	Slender wheatgrass	Pryor, San Luis	Green Zone	Riparian mesic, saline swales	FACU	O – En	10	22	N – P	P, E
Leymus angustus	Altai wildrye	Prairieland, Pearle, Eejay	Green Zone	Riparian arid, saline swales	NI	O – En	10	20	I – P	E, M
Leymus cinereus	Basin wildrye	Trailhead, Magnar	Green Zone	Riparian mesic	NI	O – En	4	8	N – P	E, M, L
Leymus multicaulis	Manystem (beardless) wildrye	Shoshone	Green Zone	Riparian, saline swales	NI	F – En	12	26	I – P	E, M
Pascopyrum smithii	Western wheatgrass	Rosana, Rodan, Arriba, Walsh, Barton	Green Zone	Alkaline flats, saline swales, riparian, salt meadows	FACU	M – En	6	16	N – P	M, L
Pleuraphis jamesii	Galletta grass	Viva	Green Zone	Riparian arid	NI	M - En	6	12	N - P	M, L
Poa secunda	Sandberg bluegrass	Canbar, Sherman, Opportunity, Mountain Home select germplasm	Green Zone	Riparian arid	UPL	O – En	4	6	N – P	E, M
Puccinellia spp	Alkaligrass	Local ecotype(s)	Green Zone, Streambank	Riparian mesic, saline swales, salt meadow	OBL √	F – En	14	30	N – P	M, L
Sporobolus airoides	Alkali sacaton	Salado, Saltalk	Green Zone	Alkaline flats, saline swales, riparian, salt meadow	FAC	O – En	14	26	N – P	P, E, M
Sporobolus cryptandrus	sand dropseed	Local ecotype(s)	Green Zone	Riparian arid; salt desert scrub	FACU-	F - En	6	8	N - P	E, M
Thinopyrum ponticum	Tall wheatgrass	Largo, Jose, Alkar	Green Zone	Riparian arid	FACU √	F – En	12	26	I – P	P, E

TABLE 8 CONTINUED

Scientific Name [1]	Common Name	Recommended Cultivar / Germplasm	Utah Riparian Handbook Planting Zone[2]	Expanded Zone of Adaptability	Wetland Indicator [3] /Higher Soil Moisture Req. (√)	Mycorrhizal Status [4]	Threshold Salinity [5] (mmhos cm^{-1})	Max Salinity [5] (mmhos cm^{-1})	Origin [6] / Life History	Succession (Seral) Status, Disturbed Sites [7]
SHRUBS										
Allenrolfea occidentalis	Iodinebush	Local ecotype(s)	Green Zone	Alkaline flats, sinks, pools	FACW	N	15	30	N – P	L
Amelanchier alnifolia	Saskatoon serviceberry	Local ecotype(s)	Green Zone	Riparian mesic	FACU-	M – En, Ec	8	12	N – P	M, L
Artemisia cana	Silver sagebrush	Local ecotype(s)	Green Zone	Riparian arid	FAC*	M - En	2	4	N – P	E, M, L
Artemisia filifolia	Sand sagebrush	Local ecotype(s)	Green Zone	Riparian arid	UPL	M - En	2	4	N – P	L
A. tridentata ssp. *vaseyana*	Mountain big sagebrush	Hobble Creek	Green Zone	Riparian mesic (higher elevation)	UPL	M - En	4	6	N – P	L
A. tridentata ssp. *wyomingensis*	Wyoming big sagebrush	Gordon Creek	Green Zone	Riparian arid	UPL	M - En	4	6	N – P	M, L
A. tridentata ssp. *tridentata*	Basin big sagebrush	Local ecotype(s)	Green Zone	Riparian arid	UPL	M - En	4	6	N – P	L
Atriplex canescens	Fourwing saltbush	Wytana, Rincon	Green Zone	Riparian arid, saline swales, alkaline flats	UPL	N	6	10	N – P	P to L
Atriplex confertifolia	Shadscale saltbush	Local ecotype(s)	Green Zone	Alkaline flats	UPL	N	12	20	N – P	M, L
Atriplex gardneri	Gardner's saltbush	Local ecotype(s)	Green Zone	Riparian arid, saline swales, alkaline flats	UPL	N	6	10	N – P	M, L
Atriplex lentiformis	Quailbush	Casa (southern)	Green Zone	Riparian arid, saline swales, alkaline flats	FAC+	N	8	20	N – P	P, E, M
Baccharis emoryi	Emory's baccharis	Local ecotype(s)	Green Zone, Streambank	Streambank, riparian mesic	FACW √	FAC - En	8	12	N – P	E, M
Dasiphora fruticosa	Shrubby (bush) cinquefoil	Local ecotype(s)	Green Zone, Streambank	Riparian mesic (higher elevation)	FACW* √	M - En	4	8	N – P	E, M, L
Ericameria nauseosa	Rubber rabbitbrush	Local ecotype(s)	Green Zone	Riparian mesic, riparian arid	FACU	M - En	4	6	N – P	E, M
Frankenia spp.	Alkali heath	Local ecotype(s)	Green Zone	Riparian arid, alkaline flats	NI	M – Ec?	8	12	N – P	M, L
Krascheninnikovia lanata	Winterfat	Hatch	Green Zone	Riparian arid	UPL	N	6	10	N – P	M, L
Lonicera utahensis	Utah honeysuckle	Local ecotype(s)	Green Zone	Riparian mesic (higher elevation)	FACU	N	2	4	N – P	L
Lycium spp.	Wolfberry	Local ecotype(s)	Green Zone	Riparian arid, saline swale	FACU	M - En	8	12	N – P	M, L
Prunus americana	American plum	Blackhawk, Hawkeye, DeSoto	Green Zone	Riparian mesic	FACU	M – En, Ec	4	8	N – P	E, M
Prunus virginiana	Chokecherry	Schubert, Canada red	Green Zone, Streambank	Streambank, riparian mesic	FACU	M – En, Ec	8	10	N – P	P to L

TABLE 8 CONTINUED

Scientific Name [1]	Common Name	Recommended Cultivar / Germplasm	Utah Riparian Handbook Planting Zone [2]	Expanded Zone of Adaptability	Wetland Indicator [3] /Higher Soil Moisture Required (√)	Mycorrhizal Status [4]	Threshold Salinity [5] (mmhos cm^{-1})	Max Salinity [5] (mmhos cm^{-1})	Origin [6] / Life History	Succession (Seral) Status, Disturbed Sites [7]
SHRUBS (Cont.)										
Quercus gambelii	Gambel oak	Local ecotype(s)	Green Zone	Riparian arid	UPL	M – En, Ec	4	6	N – P	E, M
Rhus glabra	Rocky Mtn (smooth) sumac	Local ecotype(s)	Green Zone	Riparian mesic	UPL	M - Ec	2	4	N – P	L
Rhus trilobata	Skunkbush sumac	Bighorn	Green Zone	Riparian mesic, riparian arid	NI	M - Ec	4	8	N – P	E, M
Ribes aureum	Golden currant	Crandall	Green Zone	Riparian mesic	FACW √	M - En	2	4	N – P	E, M
Rosa woodsii	Woods' rose	Local ecotype(s)	Green Zone	Riparian mesic	FAC-	M - Ec	2	4	N – P	E, M, L
Sambucus nigra	Blue elderberry	*Local ecotype(s)*	Green Zone	Riparian mesic	FACU	M – En, Ec	2	4	N – P	E, M
Sarcobatus vermiculatus	Greasewood	Local ecotype(s)	Green Zone	Alkaline flats, saline swales	FACU*	N	6	10	N – P	M, L
Shepherdia argentea	Silver buffaloberry	Sakakawea	Green Zone	Riparian mesic, riparian arid	NI	M – Ec	8	12	N – P	P to L
Suaeda spp.	Seepweed; seablite	Local ecotype(s)	Green Zone	Alkaline flats, sinks, pools	FAC+	N	12	30	N - P	M, L
Symphoricarpos longiflorus	Desert (longflower) Snowberry	Local ecotype(s)	Green Zone	Riparian mesic	NI	M - En	4	8	N – P	M, L
Symphoricarpos occidentalis	Western snowberry	Local ecotype(s)	Green Zone	Riparian mesic	NI	M - En	4	8	N – P	M, L
TREES										
Acer glabrum	Rocky Mountain maple	Local ecotype(s)	Green Zone	Riparian mesic, riparian arid (higher elevation)	FAC*	M – En, Ec	4	6	N – P	E, M, L
Acer grandidentatum	Big tooth maple	Local ecotype(s)	Green Zone	Riparian mesic, riparian arid (higher elevation)	NI	M – En, Ec	4	6	N – P	E, M, L
Betula occidentalis	Water birch	Local ecotype(s)	Green Zone, Streambank	Streambank, riparian mesic	FACW √	M - Ec	4	6	N – P	M, L
Celtis occidentalis	Common hackberry	Local ecotype(s)	Green Zone, Streambank	Riparian mesic, saline swales	NI	M - En	4	6	N – P	E, M, L
Chilopsis linearis	Desert willow	Local ecotype(s)	Green Zone	Riparian arid, tributary arroyo	FAC	O - En	4	6	N – P	M, L
Crataegus douglasii	Douglas (black) hawthorn	Local ecotype(s)	Green Zone, Streambank	Riparian mesic, riparian arid	FAC	M - Ec	4	8	N – P	M, L
Crataegus rivularis	River hawthorn	Local ecotype(s)	Green Zone, Streambank	Riparian mesic	NI	M - Ec	4	8	N – P	E, M
Forestiera pubescens	Stretchberry (New Mexico olive)	Jemez	Green Zone	Riparian arid	NI	M - En	4	6	N – P	M, L
Populus angustifolia	Narrowleaf cottonwood	Local ecotype(s)	Streambank	Streambank, riparian mesic	FAC √	M – En, Ec	2	4	N – P	P to L

TABLE 8 CONTINUED

Scientific Name [1]	Common Name	Recommended Cultivar / Germplasm	Utah Riparian Handbook Planting Zone [2]	Expanded Zone of Adaptability	Wetland Indicator [3] /Higher Soil Moisture Required (√)	Mycorrhizal Status [4]	Threshold Salinity [5] (mmhos cm^{-1})	Max Salinity [5] (mmhos cm^{-1})	Origin [6] / Life History	Succession (Seral) Status, Disturbed Sites [7]
TREES (Cont.)										
Populus fremontii	Fremont cottonwood	Local ecotype(s)	Green Zone, Streambank	Streambank, riparian mesic	FACW* √	M – En, Ec	2	4	N – P	P to L
Robinia neomexicana	New Mexico locust	Local ecotype(s)	Green Zone	Riparian arid	NI	M – Ec, En	2	4	N – P	M
Salix spp	Willow	Local ecotype(s)	Green Zone, Streambank	Streambank, riparian mesic	OBL – FACW √	M – En, Ec	2	4	N – P	P, E, M
FORBS										
Heliotropium curassavicum	Salt heliotrope	Local ecotype(s)	Green Zone	Riparian mesic, riparian arid, saline swales	OBL	N	8	15	N – P	M, L
Oenothera spp	Evening primrose	Local ecotype(s)	Green Zone	Riparian mesic, saline swales	NI	N	4	6	N – P	P, E, M
Plantago spp	Plantain	Local ecotype(s)	Green Zone	Riparian arid, saline swales, alkaline flats	UPL	FAC – En	2	6	N – P	M, L
Sphaeralcea spp	Globemallow	Local ecotype(s)	Green Zone	Riparian arid, saline swales	NI	FAC – En	4	8	N – P	E, M

Footnotes for Table 8:

1 **Species scientific and common names are according to the USDA PLANTS database** (http://plants.usda.gov).

2 **Adapted from:** Gardner, P.A., R. Stevens, and F.P. Howe. 1999.
A handbook of riparian restoration and revegetation for the conservation of land birds in Utah with emphasis on habitat types in middle and lower elevations. Pub. No. 99-38, Utah Div. Wildl. Res., Salt Lake City, UT. 48pp.

3 **Wetland indicator status and definitions from the USDA PLANTS Database** (http://plants.usda.gov), as abstracted from the following wetland reports: U.S. Fish and Wildlife Service. 1988. National list of vascular plant species that occur in wetlands. U.S. Fish & Wildlife Service Biological Report 88 (26.9).

U.S. Fish and Wildlife Service. 1993. 1993 supplement to list of plant species that occur in wetlands: Northwest (Region 9). Supplement to U.S. Fish & Wildlife Service Biological Report 88 (26.9).

Indicator Code	Wetland Type	Description
OBL	Obligate Wetland	Occurs almost always (estimated probability 99%) under natural conditions in wetlands.
FACW	Facultative Wetland	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
FAC	Facultative	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU	Facultative Upland	Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
UPL	Obligate Upland	Occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in non-wetlands in the regions specified. If a species does not occur in wetlands in any region, it is not on the National List.
NA	No agreement	The regional panel was not able to reach a unanimous decision on this species.
NI	No indicator	Insufficient information was available to determine an indicator status.

Regional Indicators express the estimated probability (likelihood) of a species occurring in wetlands versus non-wetlands in Region 8 (includes Utah). Regional Indicators reflect the unanimous agreement of the Regional Interagency Review Panel. An asterisk (*) following a regional Indicator identifies tentative assignments based on limited information from which to determine the indicator status.

4 **Mycorrhizal status:**

Association:
O = Obligate mycorrhizal
M = Strongly mycorrhizal
F = Facultative mycorrhizal
N = Non-mycorrhizal
NI = No information

Type:
En = Endomycorrhizal (arbuscular)
Ec = Ectomycorrhizal

5 **Threshold salinity** indicates the level of soil salt concentration at which plant performance begins to be observably or measurably reduced.

Maximum salinity indicates that level at which plant viability, growth and/or performance are severely or permanently curtailed.

6 **Origin / Life History Status:**

Origin:
N = Native to Continental U.S.
I = Introduced to Continental U.S.

Life History:
A = Annual
B = Biennial
P = Perennial

7 **Typical Successional (Seral) Status on Disturbed Sites:** **
P = Pioneer (newly disturbed sites)
E = Early Seral
M = Mid-Seral
L = Late Seral

[adapted from Successional Status materials and citations in the USFS Fire Effects Information System, http://www.fs.fed.us/database/feis/plants. See this site for comprehensive literature citations on this topic].

It should be noted that the seral stages listed in the table are intended to connote establishment capability and subsequent ecological niche occupation particularly on sites affected by infestation and/or removal of *Tamarix*. However, it assumes that periodic flooding does occur. Dams and reservoir systems that change the natural timing and volume of seasonal water flow may reduce recruitment and vigor of otherwise stable, mid- to late-seral species. Replacement of species may not occur under these scenarios. This may alter floodplain / riparian disturbance characteristics and associated species-specific successional dynamics, strategies, and trajectories over time. As one example, cottonwood can often assume both "climax" and "pioneer" successional roles[21]. Therefore, traditional terminology of biological succession needs to be used with caution. River hydrology (amounts, timing, frequency, and duration) is typically the driving successional force in these communities and has greatest impact upon true successional status of a given species or guild of species.

For detailed evaluation of plant characteristics (e.g., descriptions, origin and life history, site adaptation, establishment and recommended seeding or planting methods, planting timing, propagation techniques, propagule treatment and storage, available cultivars or select germplasm, commercial and/or agency availability / sources, management, wildlife and livestock forage value ratings, and further references), the reader is referred to the following references (and others listed in Appendix C):

- Conservation Plant Characteristics Tables in the USDA PLANTS Database (http://www.plants.usda.gov/characteristics.html).
- Plant Fact Sheets and Plant Guides in the USDA PLANTS Database (http://www.plants.usda.gov/java/factSheet).
- USDA Natural Resources Conservation Service (NRCS) Ecological Site Descriptions (http://esis.sc.egov.usda.gov).
- USDA Forest Service (USFS) Fire Effects Information System (http://www.fs.fed.us/database/feis/plants).
- Gardner, P.A., R. Stevens, and F.P. Howe. 1999. A handbook of riparian restoration and revegetation for the conservation of land birds in Utah with emphasis on habitat types in middle and lower elevations. Pub. No. 99-38, Utah Div. Wildl. Res., Salt Lake City, UT. 48pp.

STEP 5:
PROJECT IMPLEMENTATION

"They have a youth group from the school who removed all the trees along the shoreline. Otherwise, there are 2 people to run the area, and tamarisk control is 5% of their job."

\- **Robert Parsons** UCRB land manager

PHOTO CREDIT: KEN LAIR

FIGURE 21: A Hydro-Ax clears tamarisk on this site. This approach was selected in the context of overall restoration goals and site logistics.

Implementation is the actual removal of tamarisk and planting of desirable species. These actions are generally what is thought of as 'restoration'; however, this step should not begin until all planning steps and actions are completed (Figure 21). One exception to this could include beginning a pilot application before a final tactical plan and implementation are fully determined.

Dwight D. Eisenhower once said, "In preparing for battle, I have always found that plans are useless but planning is indispensable." You may find, when you reach actual implementation phase, that you end up doing some things very differently than you had planned; however, it should be very evident how invaluable the planning steps were to making the most of your resources, particularly with regard to the relationship between your long term goals, site characteristics, and species selection.

STEP 6:
MONITORING & MAINTENANCE

"Emphasize that non-natives cannot be eradicated, but can be kept under control. Maintenance is necessary to ongoing success."

- **Bob Wilson** President, Grand Valley Audobon Society

Revisiting a site on a regular basis for both monitoring and maintenance is the only way of assuring long-term goal obtainment. In the first years of establishment, it will be necessary to "babysit" your site to some degree to ensure survival of your investment. It may be expected that the implementing entity will consider plant mortality, hydrology reworking, etc. to be failures and not want to bring them to the attention of funders. However, this is an inaccurate and unproductive attitude. Both implementers and funders must visit and discuss site status during the post-planting phase and acknowledge and discuss both anticipated and unanticipated "failures" and glitches. This is necessary in order to

- Protect the initial investment
- Ensure funding for management and repairs
- Build and reinforce realistic expectations and assessments of "success"
- Provide information on what works and does not work, and why, to inform future projects.

Monitoring can save significant time and money in the long term by addressing a wide range of problems before they become major factors in failure of the restoration effort.

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 22: This UCRB site is an illustration that simply removing tamarisk, even when there are perennial flows, will not assure improved habitat value. Monitoring the site can lead to modifications in the restoration plan to improve likelihood of success.

I. MONITORING

Monitoring is often an overlooked step in the restoration implementation process. Photo points, at a minimum, should be set up on all project sites. Larger projects should have more intensive monitoring programs included as part of the project plan and implementation to help inform maintenance actions and to help future project managers learn from success and failure of past projects.

Most restoration projects evaluated in the UCRB did not reach peak cover and diversity until 7-9 years after tamarisk removal. Although yearly monitoring over the course of this period is ideal, we recommend intensive monitoring and maintenance for a minimum of 3-5 years will be required to maximize success. How often and for how many years this stage must continue will be highly contingent on your site, types of plantings, irrigation type (if any), weather conditions, and resources relative to acceptable loss rates. Generally speaking, frequency of site visits can taper to annual or

TABLE 9: Suggested monitoring data based upon objectives (adapted from Gieck 2006).

Objective	Data to collect before and after control (minimum)	Additional data to collect before and after control (optimal)
Reduce/eliminate tamarisk cover	• Measure canopy cover from the ground (visual estimate) • Count/density of tamarisk resprouts • Photographs at permanent reference points	• Ground or aerial photography and mapping with GIS identifying tamarisk cover (Everitt et al. 1996). Requires ground-truthing to ensure proper tamarisk vs natives identification. • Measure light under tamarisk canopy
Restore the plant community	• Measure diversity and abundance of species in the plant community using line transects and/or plot sampling (Box 8) • Photographs at permanent reference points	• Aerial photography and remote sensing identifying bare soil and cover or plant types (grasses, forbs, etc.) (Everitt et al. 1996). Required ground-truthing. • Track individuals
Restore wildlife habitat	• Measure key vegetation for wildlife survival • Direct measures of priority species (e.g. bird counts)	• Monitor key species population dynamics (demography studies)
Maintain or improve watershed health and function	• Monitor ground water and channel water levels • Monitor water quality • Monitor wetlands (plant species, water quality)	• Test for chemical residue in water and soil

biannual once plants appear well established and you can be fairly confident that they have access to the water they need going forward. Monitoring could be on an annual basis for the remaining period.

Specific data to be collected during these site visits should be guided in part by the original restoration goal. The following table with site considerations (Table 9) can be used to guide monitoring.

A) Hydrology

Monitoring water supply is important for understanding impacts to the site from external factors (e.g. water use upstream), the effect of your management on water availability, and insuring successful establishment of plantings. Monthly well measurements are ideal, as is taking advantage of data from local weather stations for precipitation and temperature fluctuations. This information will help you interpret responses in vegetation. Water quality may also be a factor, particularly the concentration of solutes (salts) and/or other potential contamination. However, regular monitoring of water quality should not be necessary unless special circumstances warrant it (e.g. significant change in land/water use upstream).

B) Success of planted and other desirable species

Vegetation should be monitored closely for establishment of desirable species. This is where careful records of species planted and locations can save a lot of trouble. New plantings should be monitored very closely for the first 1-3 months (during the growing season), and then annually at the minimum for 2-3 years (Figure 24). It will take many perennial forbs and shrubs at least two years to be considered well established. For pole plantings and whole root transplants, metal tags with embossed numbers are preferable over permanent marker, as the latter will fade, even in one year. Flagging tape is prone to

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 23: Well-established cottonwood saplings at Connected Lakes grow along-side re-sprouts of tamarisk. Follow-up control of the tamarisk will reduce competition, but the cottonwood is likely to continue to do well regardless, given water availability.

cattle herbivory. When feasible, tracking survival of individual plants will facilitate adaptive management. Seeding is best monitored using transects at regular intervals perpendicular to the drainage with either randomly placed meter-square plots or using a belt transect (see Box 8 for sources on vegetation monitoring). This can be done across the entire restoration site, or only in the seeded area, depending on goals. Measurements should include species diversity and % cover (by species is ideal, in categories of weed, native grass/forb/shrub or other meaningful categories).

Some loss of plantings or delay in seedling establishment is to be expected; remedial planting may be necessary in the first two years. Succession is also a normal process, with some species doing better initially and replaced by other species over time. This should be anticipated and planned for (see section on Seeded Species Autecology, above).

Grazing by wildlife or domesticated livestock should also be duly noted, particularly in the first two years so that protective measures can be taken where necessary (see Fencing, above).

II. MAINTENANCE

For the first few years there is likely to be maintenance required to maintain the advantage gained by the removal of the tamarisk. It is rare that a tamarisk removal project will not require maintenance for at least a few years after initial treatments. In addition to planted material losses, our survey of restoration sites in the UCRB revealed that reinvasion by noxious weeds is a significant issue and will need to be addressed at most sites, particularly in the first few years. A list of the most common weedy species in UCRB tamarisk restoration sites can be found in Table 10, the most abundant being cheatgrass. At several UCRB sites where tamarisk removal was implemented as a single cut and spray effort, most had little habitat value (Figure 22).

A) Tamarisk resprouting

Spot-spraying of resprouts will be minimal if initial control effort is done well; however, an annual check and spraying will help insure total removal. It is advisable that this occur in the fall, using a systemic herbicide such as imazapyr, so that the herbicide can translocate to the roots and kill the plant. Following mechanical control, secondary spraying of resprouting tamarisk may be necessary. However, in the Moab area they are testing for impacts of tamarisk biocontrol beetles on tamarisk resprouts; they are finding that many sites are being cut with no herbicide treatments and resprouts are minimal in the presence of the beetle.

Checking for resprouts (or regrowth from seed) should be done annually for the first 2-3 years after initial control. Note that the presence of tamarisk resprouts may not overly threaten res-

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 24: Unsuccessful plantings at one site in the UCRB. Flagging facilitated follow-up monitoring; however, wildlife will often be attracted to flags and eat them. Alternative means of marking plantings is advisable for long term monitoring, such as metal tags.

BOX 8: PLANT COMMUNITY SAMPLING RESOURCES

There are many techniques that can be used for measuring overall plant species diversity and/or percent cover. These approaches are valuable for tracking progress of ecosystem health as well as any specific goals relating to habitat or forage quality. The following resources provide detailed methodologies for sampling vegetation:

Elzinga, C.L., D.W. Salzer, and J.W. Willoughby. 1999. Measuring and Monitoring Plant Populations. BLM Technical Reference 1730-1.

Winward, Alma H. 2000. Monitoring the vegetation resources in riparian areas. RMRS-GTR-47. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 49p. http://www.fs.fed.us/rm/pubs/rmrs_gtr047.pdf

Mitchell, Wilma A. and H. Glenn Hughes. 1995. Line Intercept: Section 6.2.5, U.S. Army Corps of Engineers Wildlife Resources Management Manual, Technical Report EL-95-22, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 25 pp

The Nature Conservancy. 1995. Vegetation Monitoring in a Management Context. Handbook from a workshop coordinated by The Nature Conservancy and cosponsored by the U. S. Forest Service. June 1995.

Monitoring manual for grassland, shrubland and savanna ecosystems / by Jeffrey E. Herrick ... [et al.]. Publ Info Las Cruces, N.M. : USDA-ARS Jornada Experimental Range, [2005]

TABLE 10: A list of weedy, non-native species found on 9 UCRB restoration sites, in order of frequency. Invasive status indicates which states, if any, have an official noxious ranking. If plants are noxious elsewhere but not in the UCRB, it is noted as "None for UCRB". If there is no official ranking in any state, presence in the Weeds of The West[22] text is noted. Other than the species listed below, only one other non-native species, tall wheatgrass (*Thinopyrum ponticum* (Podp.) Z.-W. Liu & R.-C. Wang), was identified at our sites (it was not included here as it was a seeded species at our sites and is not considered a weed). Scientific names are according to USDA.PLANTS.gov.

Growth form	Life History	Species	Invasive status	Common name	Average % cover
graminoid	annual	*Bromus tectorum* L.	CO	Cheatgrass	40.7%
forb/herb	annual	*Bassia scoparia* (L.) A.J. Scott/ aka *Kochia scoparia* (L.) Schrad.	In WOTW	Burningbush, Mexican fireweed	28.6%
forb/herb	perennial	*Convolvulus arvensis* L.	CO, UT, WY, NM, AZ	Field bindweed	16.3%
forb/herb	perennial	*Carduus nutans* L.	UT, WY, NM, CO	Musk thistle	11.3%
forb/herb	perennial	*Lepidium latifolium* L..	UT, WY, NM, CO	Perennial pepperweed	10.4%
forb/herb	perennial	*Trifolium repens* L.	None for UCRB	White clover	9.3%
forb/herb	annual	*Lactuca serriola* L.	In WOTW	Prickly lettuce	6.8%
tree	perennial	*Elaeagnus angustifolia* L..	NM, CO	Russian olive	6.0%
forb/herb	perennial	*Taraxacum officinale* F.H. Wigg.	In WOTW	Dandelion	4.0%
tree	perennial	*Tamarix ramosissima* Ledeb.	WY, NM, CO	Tamarisk	4.0%
forb/herb	annual	*Salsola* L.	None for UCRB	Russian thistle	1.5%

toration success if plantings are well-established (Figure 23)[9].

B) Secondary invasion

There will always be a risk of weeds, particularly annuals, encroaching on the site or even tamarisk-reinvasion by seed if there is water available (Figure 9, Figure 23, Figure 25, Table 10). Our observations of tamarisk restoration sites across the West show that re-invasion is much less likely if the site is managed well for native plant establishment, especially if there is moisture from rain or overbank flooding. The site evaluation (Step 2) should have noted the presence of secondary weeds such as Russian knapweed or perennial pepperweed. Sites with noxious weeds present must be carefully monitored, and these weeds treated to ensure the site will revegetate with native plants. Monitoring and treatment of any secondary invasion should occur every 1-2 months (ideal) or twice a growing season (minimum).

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 25: This restoration site in Connected Lakes shows re-invasion by cheatgrass after tamarisk removal. Cheatgrass can promote fire that threatens establishing native plants and infrastructure. Although this is not the ideal land cover, the site still has habitat value, in part because the piles of dead tamarisk are used as wildlife cover.

STEP 7:
ADAPTIVE MANAGEMENT

"You don't learn anything from your successful projects, you learn a lot from your failures. ...I decided to pick a place where I could stay around long enough to learn from my mistakes, and get to know it well enough to choose a pathway that, over the longer term, results in improvement. ... it's more of a tortoise approach than a hare approach."

– **Tamara Naumann** Botanist at Dinosaur National Monument

Adaptive management is the application of the information learned in Step 6 (Monitoring and Maintenance) to the continued management of the site and to benefit future restoration efforts. Adaptive management actions are taken in a timely manner to address challenges (foreseen and unforeseen) that threaten success of restoration. Altering irrigation, fertilization, remedial planting, and invasive species control are examples of actions identified during monitoring as needed to improve restoration.

Adaptive management integrates practical and scientific information about the project in question with social and political needs to achieve restoration goals. This step is not complete until the information learned in the process of implementing the project and monitoring it is used to inform the maintenance of the site. It also is important that this information is documented and made available to others in the local area who may be contemplating beginning a tamarisk removal and ecological restoration project. This can be done through local and regional weed society meetings, publications, and web sites (see Appendix D for a partial listing).

Adaptive management in the technical sense reflects a multifaceted approach that includes all of the steps with an emphasis on hypothesis testing and iteratively adapting management approaches. For example, predictive models that are either conceptual or quantitative may be used to anticipate results of a particular restoration approach, based on data taken at other restoration sites. However, adaptive management as we intend here need not be so extensive, especially for smaller projects. What is important is that records have been kept in a careful fashion with an eye to informing future projects and that regular monitoring is done. Such practices will inevitably save time and resources.

FINAL NOTE

"Over my 30 year career, I have seen evidence over and over that one can't really determine what will be on a restored site until at least 10 years have elapsed, regardless of how intensive the management is during that period. Plant communities just take that long to work out the relationships among species, site conditions, and local climate. We need to help practitioners and their sponsors really understand and embrace this time frame."

– **Lucy Jordan** former biologist with US Fish and Wildlife

PHOTO CREDIT: MICHELLE DEPRENGER-LEVIN

FIGURE 26: Careful species selection at this high salinity site in the Tilman Bishop State Wildlife Area ensured revegetation success.

Restoration takes time and is an art form as much as it is a science. Fearless post-planting monitoring, flexibility, and willingness to learn from mistakes (i.e. adaptive management) are critical aspects of long term success. The effective UCRB land managers whom we spoke to emphasized that revegetation is possible, even on arid lands, but that good planning and frequent site visits were essential. As the technology develops and experience turns into knowledge, this document will continue to evolve. It is the authors' hope that land managers reading it will be a partner in this process.

APPENDIX A: LAND MANAGER WORKSHEET

The following questions may be used to help begin the restoration process. This sheet may be copied to be used for multiple projects.

DATE NAME OF PROJECT

NAME(S) OF PROJECT LEAD

1. **What are your goals for the restoration project, what is the desired end use of the land?** (be specific):

2. **What is your time-frame?**

3. **What resources do you have?**

   A. FUNDING

   B. EQUIPMENT (hand tools, heavy equipment, chemicals)

   C. LABOR

4. **What is your site access?** Are access roads suitable width, grade and road base material for the equipment you plan to use? What travel do they permit and when?

5. **Site assessment**:

   A. Is there water onsite/nearby?
   EPHEMERAL | INTERMITTENT | PERENNIAL

   B. Is there overbank flooding? YES | NO

   C. Is the groundwater table within 10′ of the surface?
   YES | NO

   D. What is the dominant soil texture?
   SANDY | SANDY LOAM | LOAMY | CLAY LOAM | CLAY (HEAVY)

   E. Is supplemental irrigation required? YES | NO
   If Yes, is irrigation feasible? YES | NO

   F. Are water quality issues significant and how can they be resolved?

6. **Site history**:

   A. Has there been past use of herbicides? YES | NO

   B. If yes, are they likely to still be present in the soil?
   YES | NO

   C. Has there been fire at the site? YES | NO

   D. Is there agriculture run-off or other sources of nitrogen inputs? YES | NO

7. **Is permitting necessary at your site? Other agency involvement necessary?**

8. **Landform shaping** (see Site Preparation - Landform Shaping)? Will heavy equipment be needed?

9. **How will tamarisk be removed: if using chemicals - which chemicals, if mechanical - what means, if biological - which type?**

10. **What monitoring of the restoration site is planned?** Have you allocated sufficient funding for intense monitoring (3-5 years) and long-term monitoring (10 years)?

APPENDIX B: HEAVY EQUIPMENT

TABLE 11: Description, primary areas of use, and limitations of some major seedbed preparation equipment (modified from Monsen, Stephen B.; Stevens, Richard; Shaw, Nancy L., comps.2004. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 1-294).

Equipment		Description	Primary Area of Use	Limitations
Roller chopper		Large drums with a series of longitudinally mounted blades or cutter-head with shredding or mulching capabilities that may be filled with water to increase weight. Drums may be from 24 to 60 inches in diameter and can be pulled singly, double, triple or in tandem configurations.	Can lay down standing material up to 5” in diameter (maximum), and chop smaller vegetation, while at the same time create soil surface relief.	Should not be used in overly rocky soils. Cannot control tamarisk on its own. Cannot chop any material over 2” diameter.
Land imprinter		Similar to roller chopper but use conical projections welded to a drum surface instead of blades. Comes in various sizes and types. Some can be filled with water to increase weight- 2 to 4 tons when filled and normally require a larger tractor to pull them (150 horsepower or more).	Creates depressions to collect moisture, mitigate surface conditions, and create soil compaction around seed. Will help compact soil around seed to enhance germination. Seed dispensers may be attached to frame-tow bar combination to plant in depressions. Works well on loamy or coarser soils.	Does not work well in dense shrubs, grass communities, compacted or rocky soil, or on sites where there are stumps and stems remaining. On fine textured soils, siltation will immediately fill depressions after precipitation.
Tractor outfitted with rotary blade or cutter-head		Large blades attached to a motorized wheel or drum made for shredding or mulching woody material (e.g. Fecon™ or Fleco™ mulching head mounted to a Hydro-Ax™ machine or Prentice™ Site Prep Tractor, or other mulchers by WoodGator™, Brown Bear™, etc.)	Can take down mature tamarisk trees, create mulch and in some cases do some surface tilling.	Will not kill tamarisk trees alone (see section on control).
Heavy duty tandem discs:	Disk-plow	Single gang of a few to several disks mounted on a frame. Good for seedbed prep, not tamarisk removal.	Deep plowing of rock-free and debris-free soil. Controls deep rooted plants.	Restricted to fairly rock-free and large debris-free sites. Slow speed. Large amount of power required to operate.
	Brushland plow	Pairs of disks connected to independently suspended spring-loaded arms. Arm connected to heavy duty frame with wheels.	Shallow plowing on smooth, rough, rocky, and uneven terrain. Controls grasses, forbs, and non-sprouting shrubs. Low maintenance costs.	Will not control sprouting shrubs. Difficult to transport. Operational speed is slow.
	Off-set disk	Two rows or gangs of disks set at an angle to each other.	First gang of disks turn soil and vegetation. Second gang turns soil and vegetation in opposite directions. Vegetation is cut up and broken. Works well on dry, heavy, and moderately rocky soils.	Cannot be operated in soil with large rocks and on slopes over 30 percent. Fairly slow operational speed.
Chains and Cables		Modified anchor chains that are generally pulled between two crawler tractors for the purpose of removing or thinning trees, shrubs, and grasses and for covering seed.	Commonly occurs on slopes of up to 50 percent grade (Vallentine 1980). Chaining can occur up and down or across the slope without adversely affecting watershed values.	Not recommended for tamarisk control. Only moderate soil scarification.
Rangeland pitter		Discs, tines, or scrapers used to make pits in soil. Standard rangeland pitter creates random pits in the soil 2-3’ long, 0.5’ deep.	Allows water infiltration, moisture capture. Best if done in conjunction with seeding.	Can only be used when there is a minimum of woody material, including subsurface stumps or rocks in the soil. Can stimulate weed invasion.
Contour furrows		A plow share cultivator blade or chisel points.	These can be used to create miniature terraces or berms. Rain will catch in these that are on a slope. You can pull a furrow instead of a pit on contour to achieve same effect.	Can only be used when there is a minimum of woody material, including subsurface stumps or rocks in the soil.
Root-plow		Straight or V-shaped blade attached to shanks. Shanks are attached to a trailing draft or arm or tow bar, dozer blade, or dozer frame.	Used to undercut undesirable grasses, forbs, shrubs, and small trees in soils free of large rocks. Works well in dry soils. Can be used to remove root crowns of tamarisk, thereby killing plant.	Not adapted to shallow, rocky, steep or wet areas. Cost of operation can be high. If any material is left on site, tamarisk can re-sprout from stem or root segments.

FIGURE 27: Examples of heavy equipment used in tamarisk removal and restoration.

Well-drilling rig

Pasture Aerator

Ripper/Deep Chisel Type Root Plow

Brush rake

Bladed Root Plow

Ripper/Deep Chisel Type Root Plow

Fecon™ mulching head

Bladed Root Plow

Ripper/Deep Chisel Type Root Plow

Woodgator™ masticator

Laird range drill

Ripper/Deep Chisel Type Root Plow

Woodgator™ masticator

Land Imprinter

APPENDIX C: OTHER RESOURCES

Riparian restoration publications

FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (15 Federal agencies of the US gov't). GPO Item No. 0120-A; ISBN-0-934213-59-3. SuDocs No. A 57.6/2:EN 3/PT.653. http://www.nrcs.usda.gov/technical/stream_restoration/ The most comprehensive guide available. Has detailed information about hydrologic and geomorphic processes, restoration design, and habitat recovery.

Nissen, S., A. Norton, A. Sher, D. Bean, S. Gieck, and K. Lair. *In press*. Tamarisk Best Management Practices in Colorado Watersheds. Colorado State University, Ft. Collins, CO. Most current guide on tamarisk control, with a regional focus.

Briggs, M.K. 1996. Riparian Ecosystem Reocovery in Arid Lands: Strategies and References. The University of Arizona Press, Tuscon, USA.

Monsen, S.B., R. Stevens, N. L. Shaw. 2004. Restoring Western Ranges and Wildlands, vol. 1. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 1-294 plus index

Shafroth, P. B. , V. B. Beauchamp, M. K. Briggs, K. Lair, M. L. Scott, and A. A. Sher. 2008. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16 97-112.- a peer-reviewed paper in a special edition of Restoration Ecology, devoted to tamarisk and restoration issues. Includes specific recommendations for planning restoration projects.

Revegetation publications

"Native Plant Revegetation Guide for Colorado" October 1998. Caring for the Land Series Volume III. Colorado Natural Areas Program Colorado State Parks and Colorado Department of Natural Resources.

"How To Plant Willows And Cottonwoods For Riparian Restoration" by J. Chris Hoag, Wetland Plant Ecologist USDA-NRCS Plant Materials Center, Aberdeen, Idaho. USDA-Natural Resources Conservation Service Technical Note, Boise, Idaho. January 2007. TN PLANT MATERIALS NO. 23

"A Guide for Planning Riparian Treatments in New Mexico", United States Department of Agriculture, September 2007- a printed guide from the experiences of staff from NRCS and Soil and Water Conservation Districts in New Mexico, including many useful links to detailed guides available online, such as planting depths for poles and whips.

Colorado Vegetation Classification Project: http://ndis.nrel.colostate.edu/coveg/ An interagency effort to provide landscape-level vegetation data for the state of Colorado. Is useful for its vegetation classifications list.

PLANTS Database: http://plants.usda.gov - an online database that provides detailed information on thousands of species, including native status, distribution, and uses.

Assessment/Monitoring Resources

Natural Resource Conservation Service (NRCS) publications provide help with many aspects of restoration as indicated throughout this manual, available in published (hardcopy) and digital (web-based and CD) formats. These may be acquired by contacting the county NRCS or Soil and Water (Natural Resource) Conservation District office servicing your area. Considerable information is also available via direct access to the following web sites. Contacting local NRCS staff at county or state levels, however, will provide expert assistance for use and interpretation of information, including soils data (Additional contact information for the NRCS is found in Appendix D).

Major Land Resource Area (MLRA) Locator:
http://www.nrcs.usda.gov/technical/land/mlra/

NRCS States and Regions Locator:
http://www.nrcs.usda.gov/about/organization/regions.html

Field Office (Service Center) Locator:
http://offices.sc.egov.usda.gov/locator/app

Published Soil Survey Locator:
http://soils.usda.gov/survey/printed_surveys/

Online Soil Survey Locator:
http://websoilsurvey.nrcs.usda.gov/app/

Salinity Management:

http://www.wcc.nrcs.usda.gov/salinity/

Riparian Assessment - Using the NRCS Riparian Assessment Method; Ecological Sciences - Environment Technical Note Number MT-2: http://www.mt.nrcs.usda.gov/technical/ecs/environment/technotes/envtechnoteMT2.html

Kershner, Jeffrey L.; Archer, Eric K.; Coles-Ritchie, Marc; Cowley, Ervin R.; Henderson, Richard C.; Kratz, Kim; Quimby, Charles M.; Turner, David L.; Ulmer, Linda C.; Vinson, Mark R. 2004. Guide to effective monitoring of aquatic and riparian resources. Gen. Tech. Rep. RMRS-GTR-121. Fort Collins, CO: U.S. Department of Agriculture, Rocky Mountain Research Station. 57 p. http://www.fs.fed.us/rm/pubs/rmrs_gtr121.pdf. This manual was developed primarily for monitoring resources relevant to fish, including riparian vegetation, streambank stability, water quality, and other features important for habitat.

USGS Real-time water data: http://nwis.waterdata.usgs.gov/nwis

Soil and Plant Analysis Laboratory Registry for the United States and Canada, Second Edition (March, 1999) CRC Press LLC. Boca Raton, FL. 800-272-7737, orders@crcpress.com, www.crcpress.com. This is a directory of soil labs compiled by the USDA Natural Resources Conservation Service, USDA

Cooperative Extension Service, and Council on Soil Testing and Plant Analysis. The directory lists university and private labs that perform soil, plant, and water analysis. The individual listings describe analytical procedures available.

General Guidelines for Selecting a Soils Analysis Laboratory. 2002. Waskom, R.M., J.G. Davis and J.R. Self. Colorado St. Univ. Coop. Ext. Fact Sheet No. 0.520. 10pp.
http://www.ext.colostate.edu/PUBS/crops/00520.html

Web Sites for Soil Testing and Nutrient Management
http://attra.ncat.org/attra-pub/soil-lab.html

General references

Utah State University Extension Service: http://extension.usu.edu/ See "publications" link for useful resources.

Colorado State University Extension Service: http://www.ext.colostate.edu/ See "Agriculture & Natural Resources" link for useful publications and other resources

NRCS guide to compliance: http://www.nrcs.usda.gov/technical/envicomp.html Information about national policies.

APPENDIX D: IMPORTANT ORGANIZATIONS AND AGENCIES

What follows is a partial list of organizations and agencies especially important for the land manager new to restoration. When seeking assistance or information for a project, it is important to start as local as possible.

Natural Resources Conservation Service (NRCS)

http://www.nrcs.usda.gov/
An agency of the United States Department of Agriculture (USDA) with the mission to help America's private land owners and managers conserve their soil, water, and other natural resources. Their Conservation Technical Assistance (CTA) program is an excellent resource for restoration projects, and the NRCS also provides publications and funding opportunities. See the web site for state service centers and other resources:
http://offices.sc.egov.usda.gov/locator/app

Bureau of Reclamation

http://www.usbr.gov/
A bureau within the Department of the Interior that is the primary water management agency for the Western United States. As such, they are primarily concerned with meeting water needs of people while protecting the environment. The agency is organized by watersheds, with the Upper Colorado Regional Office located in Salt Lake City. Other offices and information about programs can be found at the region web site:
http://www.usbr.gov/uc/

Cooperative Extension Service (CES) Offices

Cooperative extension is a program of the USDA to bring technical support for human, plant, and animal needs in both urban and rural areas via offices at land grant universities. They support research, education, and youth development (e.g. 4-H). One of the six program areas is in natural resources, with the mission to provide landowners with information about being land stewards, including education in water quality, timber management, composting, and recycling. Inquire with your state's extension office for classes and other resources.
http://www.csrees.usda.gov/Extension/

Tamarisk Coalition

www.tamariskcoalition.org
A not-for-profit with the mission to "provide education and coordinating support for the restoration of riparian lands." They host an annual conference that in alternate years focuses on the latest management developments with one that is more research focused. Their web site also has links to information about tamarisk management and other tamarisk-related news.
PO Box 1907
Grand Junction, CO 81502
970-256-7400

Society for Ecological Restoration International (SER)

http://www.ser.org
A not-for-profit dedicated to promoting ecological restoration "as a means of sustaining the diversity of life on Earth and reestablishing an ecologically healthy relationship between nature and culture." Web site and listserv are good sources of information about funding opportunities. The journal "Ecological Restoration" is a publication of this group, and many important papers relevant to restoration after tamarisk removal are published there, including a special issue devoted to the topic in 2008.

Center for Invasive Plant Management (CIPM)

http://www.weedcenter.org/
"The Center for Invasive Plant Management is a regionally focused Center based at Montana State University. We work in partnership with county, state, and federal agencies, tribes, nongovernmental organizations, private industry, commodity groups, and academic institutions." This organization is a good source for grants and training opportunities, including online seminars.

Utah Weed Control Association

http://www.utahweed.org/
This group was formed "in order to bring weed control issues into a greater light and to provide a forum to address ways to improve weed control in the state." This group holds meetings, provides information about grants, and otherwise is a good source of information about Utah's weed laws and other weed resources.

Cooperative Weed Management Areas (CWMA's)

These are multi-stakeholder groups joined to coordinate weed control and share expertise and resources. They often function under a

mutually developed MOU and governed by a steering committee. Many exist throughout the UCRB. A map of CWMA's can be found on the web site of the National network of Invasive Plant Centers:
http://www.invasiveplantcenters.org/cwmamap.cfm
Contact information for Utah CWMA's:
http://www.utahweed.org/cwma.htm

Colorado Weed Management Association

http://www.cwma.org/
"The mission of CWMA is to provide education, regulatory direction, professional improvement, and environmental awareness to preserve and protect our natural resources from the degrading impacts of invasive species (terrestrial and aquatic vegetation) in Colorado and surrounding states." This is a very active group that provides information, including an annual conference, trainings, and events such as restoration site visits.

Wyoming Weed Management Association

http://www.wyweedmgmt.org/
"The mission of the WWMA is to promote and facilitate collaboration and education on weed management issues among all interested parties in Wyoming." This organization hosts an annual conference and scholarship, among other activities.

U.S. Army Corps of Engineers (ACE)

http://www.usace.army.mil
This federal agency is responsible for the technical aspect of water management throughout the US, including dam building. They strengthen our security because they build and maintain America's infrastructure at home and also for military servicemembers at home and abroad. The Regulatory Program administers and enforces Section 10 of the Rivers and Harbors Act of 1899 (RHA) and Section 404 of the Clean Water Act (CWA). The UCRB is a part of the South Pacific Division, in the Sacramento District. You may need to contact ACE for permits to alter channel morphology, for Environmental Impact Statements, to discuss dam releases upstream from a restoration site, or other water-related concerns.

Executive Office
U. S. Army Corps of Engineers, Sacramento District
Colonel Thomas C. Chapman, District Engineer
1325 J Street
Sacramento, CA 95814
(916) 557-7490
http://www.spk.usace.army.mil

Public Affairs Office
CESPK-PA
spk-pao@usace.army.mil
(916) 557-7461

WATER DISTRICTS

These are special districts with the responsibility to supply water and sewer needs to a particular region or community. They can provide seminars and grants relevant to the management of river and reservoir systems. Some associated with the UCRB are the following:

Central Utah Water Conservancy District

"The purpose of the CUP is to enable the State of Utah to beneficially use a substantial portion of its allotted share of the Colorado River water under the Colorado River Compact."
http://www.cuwcd.com/

Colorado River Disrict

The mission is "to lead in the protection, conservation, use and development of the water resources of the Colorado River basin for the welfare of the District, and to safeguard for Colorado all waters of the Colorado River to which the state is entitled."
http://www.crwcd.org/

Colorado River Municipal Water District (CRMWD)

http://www.crmwd.org/
The mission of the Colorado River Municipal Water District is to maintain an adequate supply of the best quality water possible, at a reasonable cost, for its service area in West Texas.

Utah Division of Water Rights

http://www.waterrights.utah.gov/
This is an agency of the Utah State Government that administers the appropriation and distribution of the state's water resources. The web site has valuable information about purchasing water rights and well digging relevant to Utah state law.

Utah Division of Water Resources

http://www.water.utah.gov
"One of seven agencies of the Utah Department of Natural Resources and is the water resources authority for the state of Utah." Their web site has stream condition links, including real-time water data for Utah. There are also down-loadable brochures, including summaries of Utah state water plans.

Fish and Wildlife Service

http://www.fws.gov/
A bureau within the Department of the Interior with the mission to protect animals and plants for the benefit of the American people. In addition to managing refuges, the agency is a resource to the public. There are permit and policy information, grants (use search term "grants"), and other information available on the web site.
See the following link for state offices:
http://www.fws.gov/offices/

National Fish and Wildlife Foundation (NFWF)

http://www.nfwf.org
A not-for-profit organization devoted to preservation and restoration of wildlife habitat. Although not technically a government agency, it was created by the US Congress to direct public conservation funds to individuals, foundations, government agencies, nonprofits and companies in support of conservation activities. See web site for more information about grant programs.

FOOTNOTES

1 Zavaleta, E. S. (2000). The economic value of controlling an invasive shrub. Ambio 29(8): 462-67

2 Shafroth, P. B. , V. B. Beauchamp, M. K. Briggs, K. Lair, M. L. Scott, and A. A. Sher. 2008. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16 97-112.

3 Emphasis in terms of seeded or planted material adaptation and tolerance has always been to prioritize the top 0-12". This is the germination and initial root development zone during early (year 1) establishment. Since many riparian revegetation efforts often target plant composition that strongly favors forbs, shrubs and trees, salinity in deeper horizons is also important for later vigor and productivity. However, enabling or facilitating establishment within the 0-12" layer is much more critical; deeper root extension and salinity tolerance in year 2 and beyond usually is accommodated by better moisture, nutrient and salinity regimes typical of deeper soil horizons in stable alluvial situations. However there are exceptions; Pat Arbeiter notes that in one recent restoration site in Utah, the A horizon was 8-10" deep and had a "nasty" EC of 3-5, but increased to 15-18 above the capillary fringe.

4 Barber, S. A. 1995. Soil nutrient bioavailability: a mechanistic approach (2nd ed.). John Wiley & Sons, Inc., New York. 414pp.

Brady, N. C. 1974. The nature and properties of soils (8th ed.). MacMillan Publ. Co., Inc., New York. 639pp.

Heil, R. D. 1968. Colorado State University fertilizer recommendations for non-irrigated crops. Pamphlet No. 90, Department of Agronomy, Colo. St. Univ., Fort Collins, CO. 2pp.

Hanson, D. E. 1991. Russian knapweed interference with corn VA mycorrhiza, western wheatgrass, and smooth brome. M.S. thesis, Colorado State University, Fort Collins.

Kotuby-Amacher, J., R. Koenig, and B. Kitchen. 2000. Salinity and plant tolerance. Utah State University Cooperative Extension Publication AG-SO-03. Logan.

5 At time this BMP went to press, a manual focused on tamarisk control was also in final stages of development. All new releases of tamarisk publications will be announced with contact information on the Tamarisk Coalition web site: www.tamariskcoalition.org

6 Gieck, S. 2006. Restoration of Tamarisk (*Tamarix* spp.) invaded lands. Masters Degree Thesis. University of Denver. Denver, CO.

7 Sher, A. A., S. Gieck, B. Brown, and S. Nissen. 2008. First-year responses of cheatgrass following tamarisk control and restoration-related disturbances. Restoration Ecology 16:129-135.

8 Gieck, S. 2006. Restoration of Tamarisk (*Tamarix* spp.) invaded lands. Masters Degree Thesis. University of Denver. Denver, CO.

9 Sher, A.A., D.L. Marshall, and J. Taylor. 2002. Spatial partitioning within southwestern floodplains: patterns of establishment of native *Populus* and *Salix* in the presence of invasive, nonnative *Tamarix*. Ecological Applications 12:760-772.

10 Shafroth, P. B., G. T. Auble, J. C. Stromberg, and D. T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18:577-590.

11 Bay, R. F., and A. A. Sher. 2008. Success of active revegetation after *Tamarix* removal in riparian ecosytems of the southwestern United States: A quantitative assessment of past restoration projects. Restoration Ecology 16:113-128.

12 Success at sites with groundwater deeper than 6.5' was contingent on species selection and the passage of time. See "Species selection and planting strategies" for more information.

13 Shafroth, P. B. , V. B. Beauchamp, M. K. Briggs, K. Lair, M. L. Scott, and A. A. Sher. 2008. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16 97-112.

14 The most common weeds we observed in our UCRB surveys and their life history (annual/perennial) can be found in Table 10.

15 This is the bacterial mutualist that associates with some plant species roots, making them "nitrogen fixers"—plants capable of converting atmospheric N into plant-usable forms. Legumes are typically associated with *Rhizobium*, and so planting them is often associated with increasing overall N levels in the soil. Also note that the bacteria *Rhizobium* should not be confused with the fungal mycorrhizal symbionts that can increase a plant's nutrient and moisture uptake.

16 E.g. Redente, E. F., and C. W. Cook, Eds, 1986. Structural and functional changes in early successional stages of a semiarid ecosystem. Progress Report to U.S. Department of Energy. Department of Range Science, Colorado State University. Fort Collins. 07 pp.

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17 Beauchamp, V. B., J. C. Stromberg, and J. C. Stutz. 2005. Interactions between *Tamarix ramosissima* (Saltcedar), *Populus fremontii* (Cottonwood), and Mycorrhizal Fungi: Effects on Seedling Growth and Plant Species Coexistence. Plant and soil 275:221-131.

18 Shafroth, P. B. , V. B. Beauchamp, M. K. Briggs, K. Lair, M. L. Scott, and A. A. Sher. 2008. Planning riparian restoration in the context of *Tamarix* control in western North America. Restoration Ecology 16 97-112.

19 Sher, A.A., D.L. Marshall, and J. Taylor. 2002. Spatial partitioning within southwestern floodplains: patterns of establishment of native *Populus* and *Salix* in the presence of invasive, nonnative *Tamarix*. Ecological Applications 12:760-772.

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

21 Johnson, R. Roy; Bennett, Peter S.; Haight, Lois T. 1989. Southwestern woody riparian vegetation and succession: an evolutionary approach. In: Abell, Dana L., technical coordinator. Proceedings of the California riparian systems conference: Protection, management, and restoration for the 1990's; 1988 September 22-24; Davis, CA. Gen. Tech. Rep. PSW-110. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 135-139. [13515].

22 Whitson, T.D. (ed.) et al. 1996. *Weeds of the West*. Western Society of Weed Science in cooperation with Cooperative Extension Services, University of Wyoming. Laramie, Wyoming. 630pp

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