TECHNICAL EVALUATION OF OPTIONS FOR LONG-TERM AUGMENTATION OF THE COLORADO RIVER SYSTEM

VEGETATION MANAGEMENT TO AUGMENT RUNOFF AND WATER YIELD
TECHNICAL MEMORANDUM

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Final: June 2007
Released: March 2008

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EXECUTIVE SUMMARY

Purpose

The Seven Colorado River Basin States (Seven States) have authorized Colorado River Water Consultants (CRWC) to provide a Technical Evaluation of Options for Long-Term Augmentation of the Colorado River System (Project). This Technical Memorandum (TM), one of a series of TMs being prepared as part of the Project, presents results of an evaluation of Vegetation Management to Augment Runoff and Water Yield (Vegetation Management) Option.

Scope

The TMs are the second step in an iterative process to develop, screen, and evaluate long-term water supply augmentation options. The TMs build upon and expand preliminary studies developed during the initial weeks of the evaluation process. Saltcedar (or tamarisk) is an invasive plant that grows along rivers and streams throughout the Project area. It is an aggressive species that by some estimates could account for up to 1 million acre-feet (AF) of water consumption in the Colorado River Basin (Basin), an amount that could increase dramatically if saltcedar growth continues unchecked.

This TM expands on the White Paper to further explore the relationship of non-native species to Colorado River declining flows; saltcedar occurrence, spread, and control; cost estimates of control; true water savings of control measures; and the sustainability of controls. The upland forest management option was determined to be less practicable and is not addressed in this TM.

Findings

The key findings of the saltcedar control assessment are summarized in Table ES-1.

Conclusions

- Saltcedar control could yield 1-4 AF of water per year (AFY), or 3.0 AFY on average per controlled acre.
- Measurement of surface water yield needs to consider complex hydrologic factors, including increased groundwater withdrawal, rates of groundwater recharge, and climatic variation.
- Water rights resulting from increased surface flows must be identified and addressed.

- Two action scenarios for saltcedar control were evaluated and determined that:
    - Along the Virgin River in Arizona and Nevada (Scenario 1), a total of 8,611 acres (ac) of saltcedar could be eradicated and revegetated with native species, for a total water yield of 17,222 AFY, at a total initial cost of just over $24 million, and continuing maintenance cost of $301,000/yr. Annualized cost per AF of water yield is estimated to be $100/AF for the Virgin River.
    - Along the Lower Colorado River (LCR) from Hoover Dam to the international boundary with Mexico (Scenario 2), a total of 57,167 ac of saltcedar could be eradicated, for a total water yield of 154,351 AFY, at a total initial cost of $31.5 million, and continuing maintenance cost of $3 million/yr. Annualized cost of water yield is estimated to be $30/AF.
- Current saltcedar distribution in the Basin (based on 2001 data) covers approximately 300,000 acres. If no action is taken to control saltcedar, it is expected to spread by about 3-4 percent annually, resulting in a future Basin distribution of about 600,000 ac by the year 2022.

Table ES-1. Summary of Findings Related to the Vegetation Management to Augment Runoff and Water Yield Option	
Parameter	**Vegetation Management by Saltcedar Control**
Location of Supply	Location of water yielded from tamarisk control would consist of shallow groundwater in the vicinity of controlled stands. Saltcedar which could be controlled is widely distributed throughout riparian forests and adjacent land in the Project area. Example management scenarios are described for the Virgin and Lower Colorado rivers.
Quantity of Water Potentially Available	Estimated to be 3.0 AFY per controlled acre. Management of saltcedar is estimated to yield gains of 17,400 AFY at the Virgin River and 154,000 AFY at the LCR. If saltcedar is uncontrolled, Basin-wide losses could total 1,186,000 AFY by 2022.
Water Quality	Variable, dependent on saltcedar control methods; similar to shallow groundwater.
Technical Issues	Measurement of water yield is complex and uncertain. Selection of saltcedar removal method depends on spatial scale and progress in biological control. Accessibility to infested areas influences method and effectiveness of control. Long-term control requires consistent follow-up maintenance.
General Reliability of Supply	Reliability of water yielded from tamarisk control is dependent upon depth to shallow groundwater, and degree to which saltcedar roots effectively explore available soil water.
Environmental Issues	Substantial long-term benefits to biological resources, recreation, and fire management; short-term water quality and special status species concerns during removal efforts; cultural resources concerns.
Permitting Issues	Generally limited to environmental issues (e.g., wetland fills for access; protected species).
Cost	Management of saltcedar could cost from $30/AF at the LCR to $100/AF at the Virgin River.

1.0 INTRODUCTION

1.1 Overview

This section describes Project objectives, briefly discusses the program framework within which the evaluation of long-term augmentation options is proceeding, and presents overall Project methodology. Also provided is a brief description of how this TM is organized, a list of abbreviations and acronyms used, and information about the references cited herein.

1.2 Project Rationale (Objectives)

Separate studies and investigations have projected an increase in demands for Colorado River system water and a reduction in long-term runoff of the Colorado River. As part of their proactive response to this scenario, the Seven States have authorized CRWC to provide a technical evaluation of long-term augmentation options. The States will supplement the technical evaluations with legal, administrative, and/or institutional considerations. All phases of the evaluation are being conducted in close coordination with the States and with the two regional offices of the U.S. Bureau of Reclamation (Bureau).

1.3 Other Ongoing Water Management Efforts

The evaluation of long-term options focuses on both previously identified concepts and applications of new technology or management options. The evaluation was begun in parallel with the Bureau's development of Lower Basin Shortage Guidelines and Coordinated Management Strategies for Lake Powell and Lake Mead Under Low Reservoir Conditions. It also should be noted that each of the Seven States has comprehensive water management programs. Concepts being developed under these independent programs will not be evaluated through the Seven States process.

1.4 Methodology

Evaluation of options is an ongoing and iterative process. In the first phase of the evaluation, White Papers were developed for 12 potential long-term augmentation options developed by CRWC in concert with the Seven States. In parallel with White Paper preparation, the CRWC team met with representatives of each State, the Bureau's two regional offices, and other interested parties. A password-protected Project Website was developed, an Expert Panel was convened, and a workshop was held with the Project's Technical Committee. The workshop focus was on the 12 White Paper options and three additional options suggested by the Expert Panel. Grouped by the purpose they achieve and the benefit provided, the initial options were:

- Firm up supply/reduce shortages. Conjunctive use, reservoir evaporation control, vegetation management, weather modification, stormwater storage, and additional storage.

- New supplies. Basin imports/exports, brackish water desalination, coal bed methane, seawater desalination, and water imports using ocean routes.

- Increase water use efficiency/exchange. Reduction of power plant consumptive use, agricultural and urban water reuse, agricultural and urban transfers, and accelerated urban water conservation.

During the workshop with the Technical Committee and a subsequent meeting with the Project Principals, six options were selected for more detailed evaluation at the TM level: brackish water desalination, conjunctive use, ocean water desalination, river imports and exports, stormwater management, and vegetation management. This TM describes the Vegetation Management Option.

1.5 Technical Memorandum Organization

This TM is organized as follows: Section 1 provides the context for the Vegetation Management Option, and a roadmap to this TM; Section 2 provides a technical evaluation of the Vegetation Management Option, including implications of saltcedar ecology on water yield, complexities of evaluating potential water yield, considerations for vegetation management, and results of three vegetation management scenarios; and Section 3 provides cost opinions.

1.6 Abbreviations and Acronyms

Common abbreviations and acronyms used in this TM are:

ac	acre
ADWR	Arizona Department of Water Resources
AF	acre-feet
AFY	acre-feet per year
Basin	Colorado River Basin
BLM	Bureau of Land Management
Bureau	Bureau of Reclamation
CDWR	California Department of Water Resources
CRCF	Colorado River Citizens Forum
CRWC	Colorado River Water Consultants
ET	evapotranspiration
ft	feet
ft/yr	feet per year
GAP	Gap Analysis Program
gpm	gallons per minute
LCR	Lower Colorado River
Mech.	Mechanical
mi	mile

Seven States	Seven Colorado River Basin States
SNWA	Southern Nevada Water Authority
TM	technical memorandum
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USGS	Geological Survey

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2.0 EVALUATION OF THE VEGETATION MANAGEMENT OPTION

2.1 Overview

This section discusses technical issues for increasing water yield through vegetation (i.e., saltcedar) management. The discussion addresses:

- Initial findings of the Vegetation Management White Paper
- Relationship of saltcedar to water flows in the Colorado River
- Saltcedar distribution, invasiveness, and spread
- Historical case studies to estimate water yield from saltcedar control
- Evaluating water yield potential by saltcedar control
- Implementing saltcedar management and control
- Scenarios evaluation of three example projects for testing the potential water yield from saltcedar control.

2.2 Initial Findings

The Vegetation Management White Paper found that saltcedar is widely distributed throughout near-stream forests in the Colorado River system (Gorham, *et al*. 2006). If replaced by native vegetation, saltcedar control could reliably yield 1.0-4.0 AF of water per controlled acre, or 0.6-3.2 million AF if implemented system-wide. In addition to increasing water yield, saltcedar control benefits biological resources, recreation, and fire management; while raising concerns for short-term water quality, special status species, and cultural resources. The potential to increase water supply while delivering added social benefits contributes to this option's appeal. However, uncertainty about the efficacy and cost of available control methods, as well as the challenge of accessing remote thickets in difficult terrain, suggest a cautious approach to this water yield option.

2.3 Relationship of Saltcedar to Water Flows in the Colorado River

2.3.1 Saltcedar Adaptations for Finding Water

Saltcedar is a large shrub that grows in moist sites at seeps, streams, and along river banks and roadsides. It can draw water from underground sources, but once established it can survive without access to groundwater. Saltcedar's primary root can grow to a depth of 100 feet (ft) or more, and roots grow laterally by as much as 165 ft when they reach the water table (CWMA 2006; Glenn and Nagler 2005). Water use peaks when the water table is within 6 ft of the soil surface and decreases rapidly at water table depths greater than 17-20 ft (Ryan 2006; Van Hylckama 1974). (Cottonwood and willow are generally unable to access groundwater deeper than 7-10 ft below the surface, whereas mesquite can access groundwater as deep as 33 ft [Shafroth, *et al.* 2000; Glenn and Nager 2005].) Where present, saltcedar outcompetes native riparian vegetation for available water. Saltcedar is more tolerant of low soil moisture than native species and tends to dominate sites with relatively infrequent surface flow and relatively deep groundwater (Shafroth, *et al.* 2005). Also, it has greater resiliency to wildfire (Ryan 2006). Soil salinity is a major determinant of competitiveness—saltcedar is more tolerant of increases in salinity than native riparian vegetation. In addition, saltcedar contributes to increases in salinity, as it concentrates and secretes salt in leaves (Frost 2005; Ryan 2006). A positive feedback cycle may result, with saline conditions favoring saltcedar, and saltcedar itself increasing salinity once established.

As a result, saltcedar occupies a much broader range of habitats than native riparian vegetation, extending to drier upper floodplain terraces as far as 500 ft from stream channels. Among pure saltcedar stands along the LCR, only 10 percent is suitable for cottonwood-willow vegetation, whereas 45 percent is suitable for mesquite, and 45 percent for saltbush (Bureau 1995). The degree to which saltcedar occurs in dense, solid stands, versus small patches within a vegetation mosaic, often indicates its relative competitive advantage.

2.3.2 Evapotranspiration and Water Use by Saltcedar

Evapotranspiration (ET) rates for saltcedar range from 2.5 to 4.8 ft/yr (Shafroth, *et al.* (2005). Ryan (2006) robustly estimated saltcedar ET rates on the order of 4.3 ft/yr. (Estimates of cottonwood use range from 3.3 to 3.9 ft/yr, and dry riparian shrub use ranges from 1.3 ft/yr to 3.3 ft/yr.) Although ET rates may be similar on a per leaf area basis, total water use by saltcedar may exceed cottonwood by about 50 percent in natural conditions because saltcedar stands have a greater amount of transpiring leaf surface area (Bawazir 2000).

2.4 Saltcedar Distribution, Invasiveness and Spread

2.4.1 Saltcedar Distribution

For this TM, saltcedar cover in the Basin (excluding the Wyoming portion) was estimated to be about 287,875 ac—Arizona 121,075 ac; California 9,946 ac; Colorado 18,773 ac; Nevada 18,533 ac; New Mexico 6,786 ac; and Utah 112,716 ac. (State acreages do not add due to state pixel overlap.) It should be noted that much of the saltcedar acreage is along otherwise dry watercourses, particularly in Arizona. Management of the saltcedar along these watercourses results in minimal increases in streamflow as any gain would be lost in transit. The U.S. Geological Survey's Gap Analysis Program (GAP) data was used to estimate the distribution of the saltcedar infestation. GAP maps vegetation from satellite images, with saltcedar stands typically distinguished in isolation or categorized with Russian olive, another non-native. Figure 2-1 shows the distribution of saltcedar throughout the Colorado River Basin (data are unavailable for Wyoming).

High resolution saltcedar distribution was obtained for the LCR (Figure 2-2). This mapping was compiled from detailed typing performed by the Bureau in 1998 of vegetative polygons on large-scale true color and color infra-red aerial photographs procured in 1997, ground-truthed using a stratified field sampling method (CH2M HILL 1999). There are 57,167 ac of saltcedar mapped along the LCR. (Using this same study area, GAP data identified 44,212 ac of saltcedar.) Assuming the Bureau data methods are more accurate (e.g., large-scale aerial photo-interpretation versus satellite image analysis), the GAP data appear to underestimate saltcedar distribution by about 29 percent. This proportion establishes an approximate index of errors of omission on saltcedar mapping with GAP satellite data. Applying this error factor to the GAP estimate, the distribution of saltcedar in the Basin States may be closer to 371,000 ac (based on 2001 sampling and excluding Wyoming, for which no data were available).

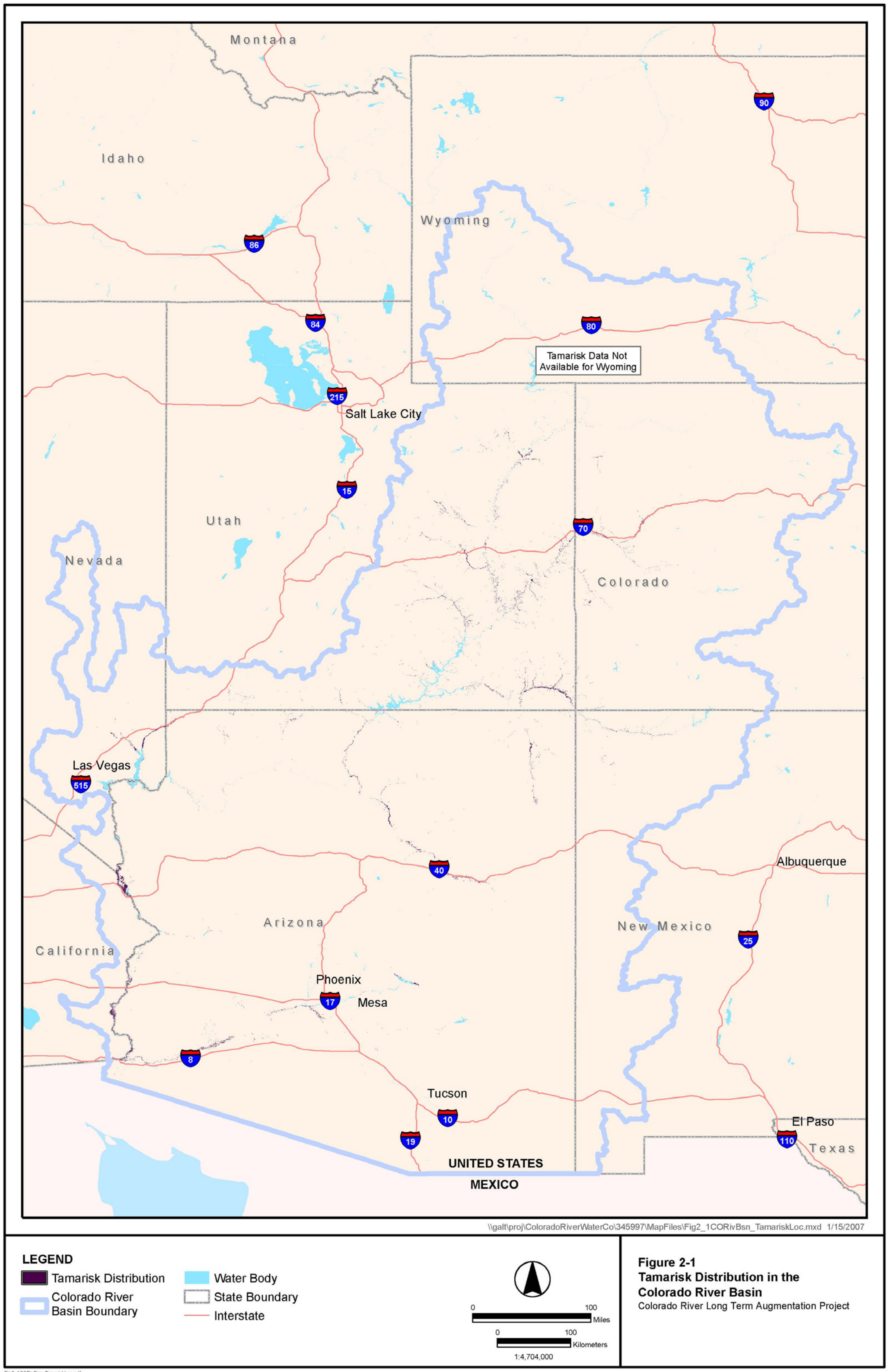

Figure 2-1
Tamarisk Distribution in the Colorado River Basin
Colorado River Long Term Augmentation Project

Fig2_1CORivBsn_TamariskLoc.pdf

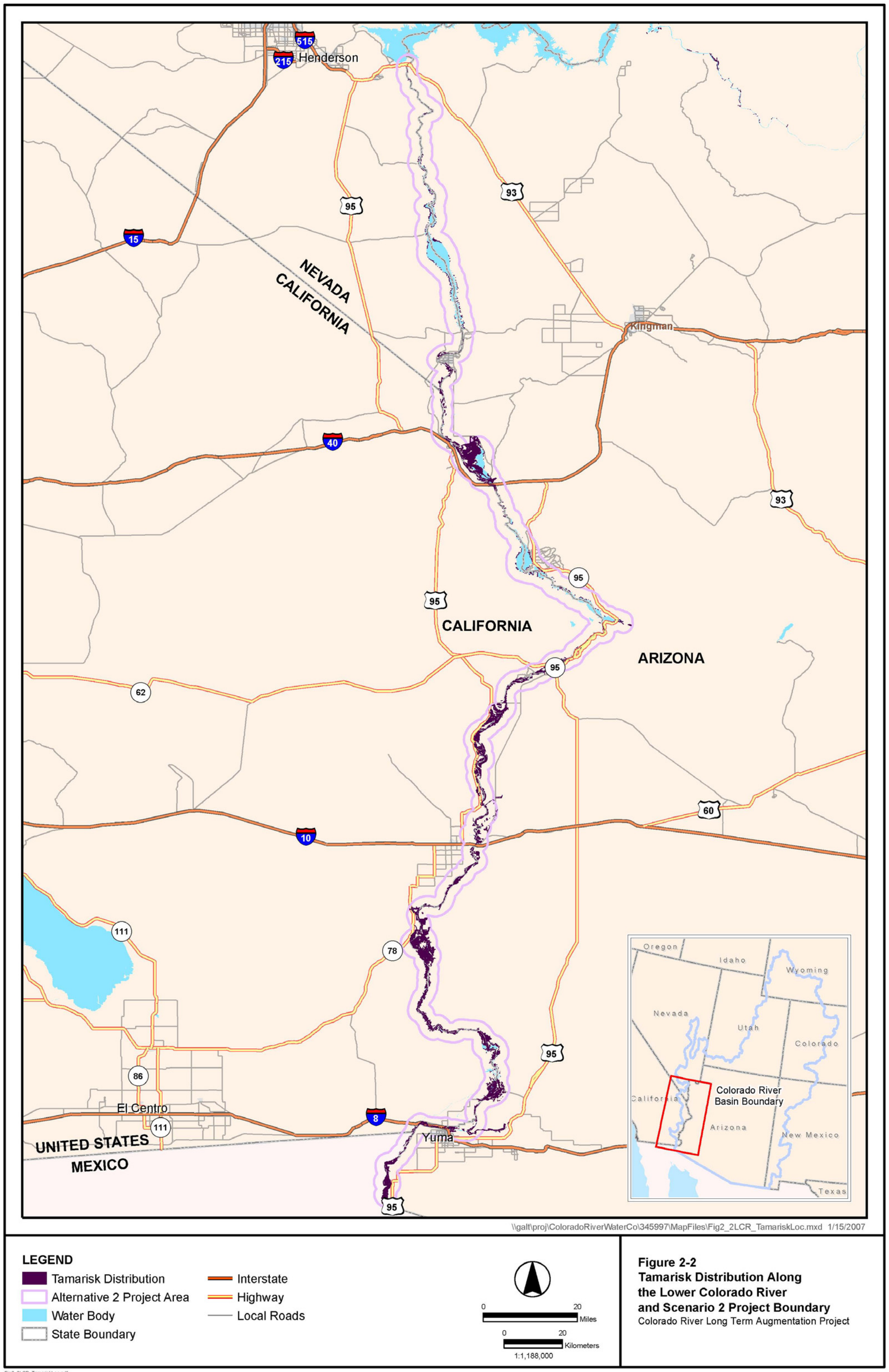

Figure 2-2
Tamarisk Distribution Along the Lower Colorado River and Scenario 2 Project Boundary
Colorado River Long Term Augmentation Project

Fig2_2LCR_TamariskLoc.pdf

2.4.2 Saltcedar Invasiveness and Spread

The rate of spread of saltcedar is about 3-4 percent per year—it nearly doubled in acreage during the last 20 years (DiTomaso 1998). In addition to physiological competitive advantages discussed above, most dense and extensive saltcedar invasions are thought to have been facilitated by disturbance, including river management that has altered natural hydrologic and geomorphic processes, or by land uses such as livestock grazing, land clearing, and groundwater pumping (Shafroth, *et al.* 2005; Ryan 2006). Based on assumed habitat suitability, saltcedar could spread to approximately 1-2 million ac within the Basin if left uncontrolled (NASA 2006; Morisette, *et al.* 2006).

2.5 Historical Case Studies To Estimate Water Yield from Saltcedar Control

The potential for water savings from saltcedar control has been evaluated extensively, but the scientific literature is inconclusive. Technical reports generally describe one of the following scenarios: (1) evaluation of saltcedar ecophysiology (e.g., ET rates) at a local scale and comparison between saltcedar and native vegetation—with the implication of potential water savings; (2) anecdotal information about local drainage or spring flow changes apparently corresponding to saltcedar removal; and, rarely, (3) watershed-wide saltcedar removal and studies of corresponding water yield. Table 2-1 summarizes case studies to estimate water yield.

Table 2-1. Summary of Historical Case Studies to Estimate Water Yield from Saltcedar Control			
Case Study/ Source	**Treatment**	**Method**	**Finding**
Gila River, AZ/ Culler, *et al.* 1982	Eradicated 5,400 ac of saltcedar and mesquite during 1967–71	Residual of a water budget equation after measuring water inflows and outflows; actual water yield or increase in surface flows were not reported.	ET declined from 4.66 ft/yr to 1.18-2.17 ft/yr; however, post removal conditions were predominantly bare ground and the substantial decreases in ET probably were temporary.
Pecos River, NM/ Bureau 2006; Welder 1988; Weeks, *et al.* 1987	Removed 19,000 ac of saltcedar during 1967-75	Estimated differences in water use between saltcedar and replacement vegetation and calculated a theoretical water yield; lack of measurable baseflow presumed due to: evaporation; climatic variation; groundwater pumping; groundwater recharge/storage; or error/lack of sensitivity in stream flow measurements.	Saltcedar used ~1.0 ft/yr more water than replacement vegetation, indicating that 10,000-20,000 AF of water could have been salvaged; however, no significant baseflow increases were observed in the Pecos River.
Pecos River, TX/ Hart, *et al.* 2005	Controlled 10,084 ac (200 river miles) of saltcedar using aerial application of arsenic-based herbicides during 1999-2003; initial cost of $1.9 million	Groundwater monitoring was conducted at control and test plots before and after treatment; surface water quantity was monitored through release and delivery data, consisting of reservoir water releases and deliveries to irrigation districts along the river; data were collected from weirs at the reservoir and at each irrigation turnout point on the river; historical data are available as a comparative baseline. Ultimately, release and delivery data from pretreatment years will be compared to post-treatment years to determine if control of saltcedar decreases the loss of water during the irrigation period. However, no water was released from the reservoir during 2002-03 because of drought conditions, and subsequent results have not been reported.	Pre-treatment total water loss per year was 5.64 ft/yr at the untreated control and 9.71 ft/yr at the treatment plot. Post-treatment water loss at the control location remained fairly constant at 6.36-6.66 ft/yr, but dropped at the treatment plot to 0.56-0.13 ft/yr; effects of saltcedar control on water salinity were inconclusive.

Table 2-1. Summary of Historical Case Studies to Estimate Water Yield from Saltcedar Control			
Case Study/ Source	**Treatment**	**Method**	**Finding**
Lower Colorado River/Bureau 1995; Ryan 2006	Modeled ~44,000 ac of saltcedar control (removal never implemented)	Based on estimates of ET rates for plant communities along the LCR from Desert Research Institute (DRI) data. Subsequently, the Colorado River Board concluded that the DRI's ET rates underestimated actual rates and did not adequately represent actual conditions within the LCR riparian corridor—problems include: (1) the inability of the energy balance method to incorporate the effect from an influx of thermal radiation due to winds blowing from the surrounding desert; (2) significant data gaps resulting from significant problems with the measurement equipment and a wildfire; and (3) poorly documented "heavy filtering of data."	A total water yield of 20,000 AFY could be realized by replacing saltcedar where suitable with mesquite. Little savings was projected if saltcedar is replaced by saltbush because DRI reported relatively high saltbush ET rates, which are refuted by some researchers. Data were unavailable for cottonwood-willow ET.
Small Scale Projects: Thousand Palms Oasis, Coachella Valley/Barrows 1996; **Eagle Borax Spring, NM**/Hart, *et al.* 2005; **Spring Lake, AZ**/Hart, *et al.* 2005; Ryan 2006	Control of saltcedar by controlled burn at 1-ac Eagle Borax Works Spring, NM. Eradication of saltcedar with herbicide at 13-ac Spring Lake, NM.	Observation of water table; anecdotal evidence indicates that controlling saltcedar on a local level adjacent to historical or existing springs may result in the return of surface flows or an increase in flows.	At Eagle Borax Works Spring, the historical pond reappeared within 8 weeks of saltcedar removal. Spring Lake, NM nearly disappeared after the invasion of saltcedar, but 34 months after eradication, the water table rose to the soil surface from a depth of greater than 19.7 ft, even though the area had experienced a mild drought during the same period.

2.6 Evaluating Water Yield Potential by Saltcedar Control

2.6.1 Challenges in Modeling Water Yield

Estimating potential water yield from saltcedar removal or management is complex and challenging. Modeling groundwater yield from vegetation management must accurately account for plant ecophysiology and habitat complexity. Determination of water yield is further complicated by the fact that visible surface water is only one of many components of the hydrologic system. Surface water, water in the vadose zone, and the groundwater aquifer combine to form a continuous hydrologic system and models must account for all.

Many researchers have evaluated ET differentials to determine water yield from saltcedar removal; that is, by determining the amount of water being transpired by the vegetation and combining that with evaporation from soil and surface water, the amount of water available for utilization through removal of the vegetation can be determined.

Methods of calculating ET include the Bowen ratio, eddy covariance, micro-meteorological data, evapotranspirometer, non-weighing lysimeter tanks, sap flow, stem-heat-balance, and groundwater monitoring well data (Hays 2003).

Van Hylckama (1974) suggested that saltcedar stand density is a parameter needed to predict water use in combination with other stand attributes. Others suggested that comparative studies of water use by different riparian communities are needed to develop accurate models, as well as an evaluation of how parameters such as leaf area index, aerial extent, and plant species composition relate to water use particularly in single-species stands of deep-rooted plants like saltcedar. Other factors include depth to water table, salinity, evaporative demand, and total leaf area (Moore 2006).

The evaporative component of ET has proven to be the most difficult parameter to estimate, particularly as it is modified under different light regimes. For example, evaporation would be expected to change under a saltcedar stand as the canopy is removed and more light reaches the soil and water surface. A general theory, and hence a practical model, that addresses soil evaporation under changing light and vegetative canopy conditions has not been developed (Shafroth, *et al.* 2005). Physical and chemical properties of the soil, such as texture and salinity, further complicate the prediction of evaporation.

Other issues with predicting water yield from ET using traditional approaches include:

- Inability to decouple evaporation from transpiration;
- Inclusion of depth to groundwater, plant density, plant vigor and age, limits of water tolerance, and soil salinity in the model;

- Shape of the typical ET curve does not account for the relationship between groundwater elevation and transpiration rates;

- Assumption that ET rate is the same for every unit area of a particular stand; and,

- ET rates differ among varying land elevations within a stand.

2.6.2 Challenges in Realizing Water Yield

Challenges in actually realizing or claiming a water yield, assuming a yield results from ET differentials, are discussed in this section.

Identifying Water Yield. To date, no research has documented a surface water base flow increase in a controlled vegetation management experiment (Moore 2006). Most studies examined base flow changes post-removal and attribute them to changes in vegetation (although annual climate flux also causes these changes and may not be fully accounted for). As discussed in the preceding section, the hydrologic stream system includes surface water, water in the vadose zone, and the groundwater aquifer. The water yield from vegetation removal will most likely be groundwater, not surface flow. Unless the stream system is a gaining stream, this salvaged groundwater may not be available for measurement or diversion. As additional groundwater becomes available from saltcedar control, other demands on groundwater may increase, such as groundwater pumping

(Shaforth *et al.* 2005), increased uptake from adjacent plant communities (Hart 2004), or aquifer recharge (Carlson 2006).

Claiming the Water. It is difficult to identify who or what is using the salvaged water and whether there is any available for downstream users because it is difficult to determine how much groundwater has been salvaged. In instances where a stream is a gaining stream and additional water rises to the surface, it is difficult to claim a water right if it is not possible to definitively quantify the increased water quantity available from salvage. Finally, surface users with senior rights may challenge the use of groundwater by more junior rights because surface and groundwater are connected. The case may be made that the groundwater users are restricting the ability of the senior surface users to claim their full right.

2.6.3 Expectations on Water Yield

As discussed above, estimating potential water yield from saltcedar removal or management is difficult, but nevertheless, researchers have attempted to generate estimates of water yield. Based on ET differentials, on average, saltcedar stands were found to transpire 1.0-1.5 ft/yr more than the native vegetation they replace, conceivably translating to 1.0-1.5 AFY water yield (Ryan 2006). Water savings potential may be highest where saltcedar removal occurs on the high floodplain where replacement is likely to be upland scrub or grassland (Devitt, *et al.* 1998; Hart 2004). One study estimated that conversion from saltcedar to sparse cottonwood, mesquite, xeric shrubs, or grassland may decrease ET by 1.0-3.3 ft/yr, conceivably translating to 1.0-3.3 AFY (Shafroth *et al.* 2005). Empirical measurements after saltcedar eradication along the Pecos River showed that groundwater loss decreased by as much as 9.2 ft/yr; however, replacement vegetation had not yet established (Hart, *et al.* 2005).

Using these data, Ryan (2006) suggests that water savings by saltcedar removal can amount to approximately 1.0 ft/yr in the riparian areas that support cottonwood-willow forests, and 4.0 ft/yr in the upland areas that would normally support shrub or herbaceous vegetation. He suggests that an appropriate proportion of the native replacement communities for existing saltcedar may be one-third riparian and two-thirds upland shrub.

The water yield analysis presented in this TM (see subsection 2.7, Scenarios Evaluation), takes a more conservative approach, assuming that saltcedar replacement by cottonwood-willow would not yield a water savings, but that replacement by a percentage of floodplain supporting dryland riparian shrubs, would save 3.0 ft/yr, or conceivably 3.0 AFY Bureau (1996) data were used for the LCR (Scenario 2) analysis; they show cottonwood-willow replacement on only 10 percent of the floodplain, with the remaining 90 percent replaced by dryland riparian shrubs or arrowweed. For the Virgin River (Scenario 1) analysis, Ryan's proposed vegetative mix of one-third cottonwood-willow and two-thirds dryland riparian shrubs was used to calculate water yield.

2.7 Implementing Saltcedar Management and Control

2.7.1 Management Methods

Saltcedar control has been accomplished using a broad array of mechanical, chemical, and biological methods (Tamarisk Coalition 2005). Control methods for saltcedar include: (1) hand cutting with herbicide application; (2) mechanical removal; (3) hand herbicide application; (4) aerial herbicide application; (5) biological control; and (6) skeleton removal.

Hand Cutting with Herbicide Application. This very effective process involves cutting of saltcedar stems with chainsaws and subsequently applying herbicide directly to the cut stems or stumps. Costs range from approximately \$1,500/ac to \$5,000/ac, depending on vegetation density (Tamarisk Coalition 2005).

Mechanical Removal. Mechanical removal of saltcedar is accomplished by either root crown removal or mulching. Root crown removal is accomplished with bulldozers, root plows, and root rakes. Root crown removal ranges from \$150 to \$800/ac with a mortality rate of 80-95 percent. Mulching involves use of specialized machinery to rapidly clear a swath of vegetation, with subsequent application of herbicides to cut stumps. Mulching can cost \$200-\$700/ac, with a mortality rate of typically 85 percent.

Hand Herbicide Application. Plants can either be treated by spraying foliage with the herbicide imazapyr or by removing surface growth (e.g., using chainsaws) and then applying the herbicide triclopyr mixed with vegetable oil to the cut surface. This method results in 60-85 percent mortality, but costs are high in dense infestations, averaging $1,620-2,430/ac.

Aerial Herbicide Application. Larger-scale chemical control typically consists of spraying imazapyr or a glyphosate/imazapyr mixture from fixed-wing aircraft onto saltcedar monocultures in late summer. When applied to large expanses of solid saltcedar, costs are approximately $200-$250/ac when applied to areas on the order of a thousand acres, achieving mortalities up to 95 percent (Tamarisk Coalition 2005).

Biological Control. Biological control for defoliation of saltcedar includes use of goats and release of leaf beetles. Herds of goats have been shown to defoliate saltcedar, but nontarget vegetation must be fenced off to prevent unwanted herbivory; no reliable cost or effectiveness estimates are available. After years of overseas and quarantine testing, the United States Department of Agriculture (USDA) Animal Plant Health Inspection Service recently approved release of leaf beetle (*Diorhabda elongata*) to control saltcedar. In about three years, repeated defoliation can result in approximately 65 percent or more saltcedar mortality. Leaf beetles can completely defoliate thousands of acres at costs as low as $10/ac (Tamarisk Coalition 2005).

Skeleton Removal. After saltcedar has been killed by above methods that do not involve cutting or removal of aboveground growth, tree skeletons can be removed by prescribed burning or mechanical mulchers. Costs range from $50-$150/ac for controlled burns to $200-$400/ac for mechanical mulching.

2.7.2 Revegetation

Revegetation with native species after saltcedar removal can sustain saltcedar control by making the site less attractive to recolonization. Bare, high-light environments left after saltcedar removal are also the most attractive for reestablishing the pioneering saltcedar. Without native revegetation, sites may become completely or partially recolonized by saltcedar, or be recolonized by other undesirable plants (Shafroth, *et al.* 2005).

Revegetation following saltcedar removal may require planting cottonwood or willow cuttings, or container stock of native shrubs, temporary irrigation, and weed control until plants become established. Success may depend on site conditions prior to planting or remediation of unsuitable growing conditions, such as high salinity or soil compaction. Cost of revegetation can range from $500/ac to over $25,000/ac (Shafroth, *et al.* 2005; CH2M HILL unpublished data). Costs may include site preparation, temporary irrigation, cuttings or container stock procurement and installation, plant mulching, herbivory protection, hydroseeding to enhance container stock or cutting density, and ongoing monitoring and maintenance.

Revegetation of dryland riparian plants is appropriate for higher floodplain areas where saltcedar is removed—and most challenging. The most successful approach is by installing container stock with supplemental irrigation. Seeding also can work, but successful seedling establishment requires either supplemental irrigation or appropriately timed rainfall, which is infrequent and unpredictable in the Southwest. Costs for hydroseeding with native seed range from $2,500 to $4,000 per acre (CH2M HILL unpublished data).

To reduce the high potential cost of revegetation, large-scale saltcedar removal efforts have rather relied on natural revegetation, with mixed results (Culler, *et al.* 1982; Hart, *et al.* 2005).

2.7.3 Ongoing Maintenance

Most removal efforts result in about 85-90 percent saltcedar mortality. Additional treatments will be required to ensure complete eradication and ongoing monitoring and retreatment will ensure that saltcedar will not reestablish in force. Ongoing maintenance effort will increase without implementing revegetation to establish native vegetation. While complete eradication will reduce seed sources in the area eradicated, it may not be necessary where the objective is reducing water demand.

2.7.4 Environmental Requirements

Environmental constraints on saltcedar removal are limited because removal of the species is an ecological benefit.

2.7.5 Permitting

Permitting requirements for saltcedar removal are expected to match the types of environmental impacts associated with revegetation and maintenance activities. Examples of permits that may be required include:

- Permit for aerial herbicide application.
- Incidental take permit under the federal Endangered Species Act for potential impacts to listed species, such as southwestern willow flycatcher.
- Air quality management district approval for prescribed burns.

2.8 Scenarios Evaluation

To determine how the Vegetation Management Option will salvage water that is usable, the TM team developed three conceptual vegetation management scenarios for increased water yield. The scenarios, based on technical data previously presented in this section, are project examples for testing the potential water yield from saltcedar control. Because of the many technical challenges in identifying, realizing, and claiming water yield from saltcedar removal, these scenarios were developed at a preliminary level only. The three scenarios are: (1) saltcedar control at the lower Virgin River, which represents a single, smaller watercourse where the location and yield primarily would be in Nevada; (2) saltcedar control at the LCR, a large, regional project with substantial implications for multiple states; and (3) a no action scenario, which evaluates potential increased spread of saltcedar with implications on Basin water yield.

2.8.1 Scenario 1 - Lower Virgin River

Scenario 1 would involve the removal of extensive stands of saltcedar along the Virgin River from approximately Littlefield, AZ to Lake Mead, NV, a distance of about 40 miles (mi). Figure 2-3 shows the proposed Scenario 1 project area and the distribution of saltcedar along this reach of river from Bureau mapping. No comprehensive saltcedar removal efforts have been implemented on this reach of river, although the Bureau of Land Management (BLM), Clark County, Nevada, and other groups have been implementing limited removal or restoration efforts, and have formed the Virgin River Tamarisk Work Group. In 1998, a wildfire burned about 330 ac of saltcedar here.

Since then, most of the burned area has resprouted with saltcedar. However, the BLM has implemented riparian restoration on about 30 ac of this area.

Potential Water Yield. Based on available mapping data, about 8,611 ac of saltcedar stands are present in the Scenario 1 area. Under this scenario, saltcedar would be completely eradicated and replaced by native riparian woodland (cottonwood-willow) over one-third of the floodplain area and by upland native scrub, such as saltbush or greasewood, over the remaining two-thirds of the removal area. Based on the Section 2 analysis, the riparian woodland replacement would not yield a significant amount of water; however, the upland native scrub would yield 3.0 AFY per acre treated. Using these parameters, a total of 17,222 AFY of water could be salvaged for the entire Scenario 1 area.

Technical Issues: Removal, Revegetation, and Maintenance. The most effective and proven methodology for saltcedar removal is aerial spraying with helicopter; this would be implemented per methods described by Hart, *et al.* (2005). Controlled burns and/or mulching would be implemented to remove standing dead vegetation. Revegetation would be designed to maximize planting success while minimizing costs. The riparian woodland zone would be planted with cuttings of cottonwood and willow, and hydroseeded to provide additional cover. The upland zone would be hydroseeded only. No irrigation would be installed. On-going saltcedar spraying would be implemented until native vegetation was well established to limit reinvasion.

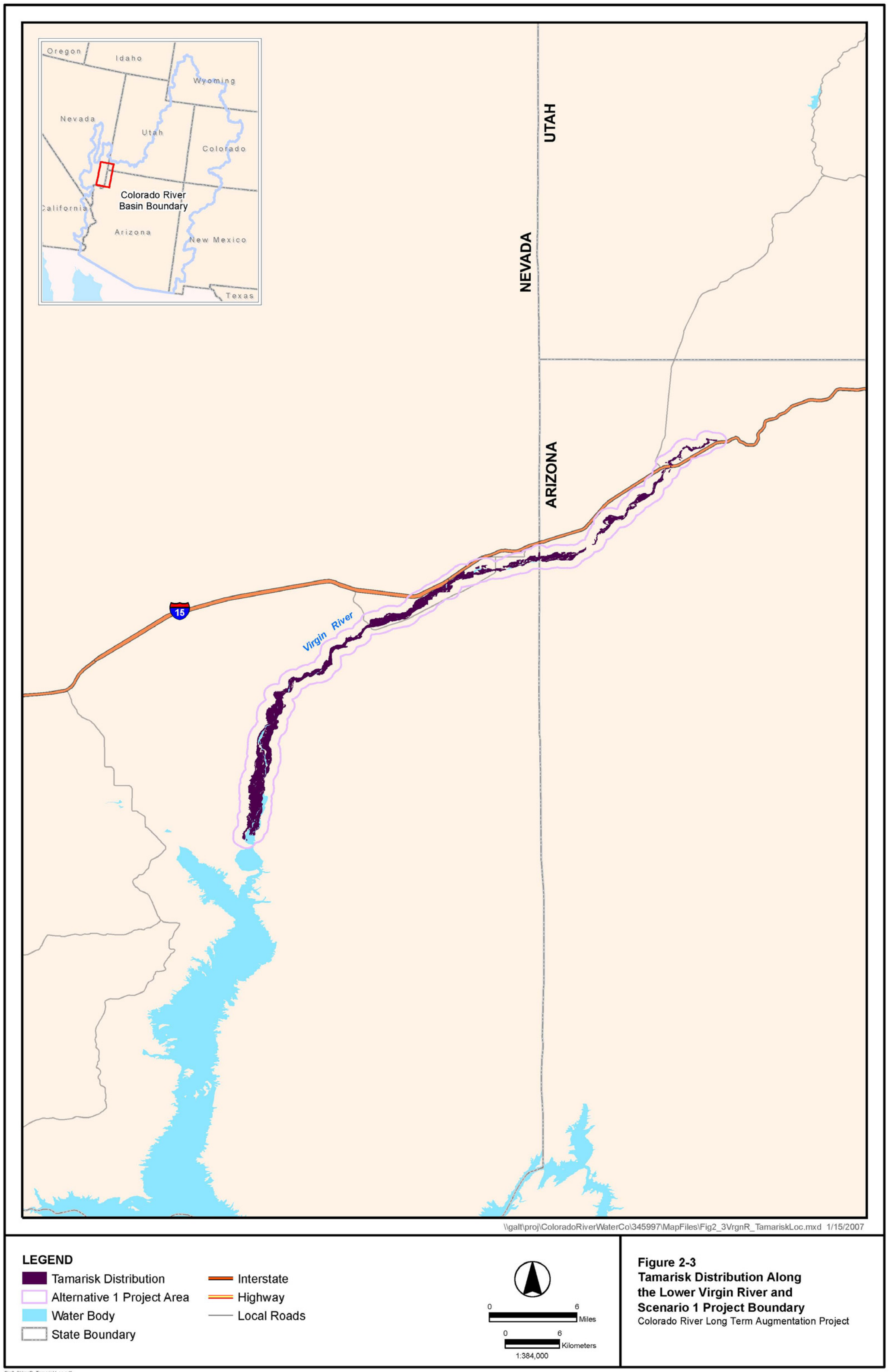

Figure 2-3
Tamarisk Distribution Along the Lower Virgin River and Scenario 1 Project Boundary
Colorado River Long Term Augmentation Project

Technical Issues: Realizing Water Yield. Groundwater development has occurred in the Virgin River Valley in the alluvial basin-fill deposits along the river. Most of the wells in the alluvium are 200 ft deep or less, and water levels range from 10 to 300 ft below land surface. Well yields vary from 5 gallons per minute (gpm) in small domestic and stock wells to 2,000 gpm in larger irrigation wells. An estimated 6,000 AF of water was pumped from the Arizona portion of the basin in 1990. Most of the water is used for irrigating crops grown in the Virgin River floodplain and is used to supplement surface water diverted from the Virgin River. Direct recharge from precipitation is small, and for the Arizona portion, estimated at not more than 5,900 AFY (ADWR 2006). Data are not available for the Nevada portion of the groundwater basin.

Downriver from Arizona, the Southern Nevada Water Authority (SNWA) holds surface water rights for 113,000 AF on the Virgin River, an amount granted by state permit based on studies of the river's capacity (ADWR 2004). However, the primary need for this water is in Las Vegas, and no facilities are currently available to transport the water. The SNWA is considering "wheeling" the water through Lake Mead to Las Vegas; however, this approach has complex legal issues. Alternatively, SNWA is considering developing infrastructure to transport water directly from the Virgin River area to Las Vegas (ADWR 2004).

Whatever the outcome, it is clear that increased yield from this watershed would be important as SNWA appropriates its water rights on surface flows. Water salvaged from saltcedar removal may be captured by shallow to deep groundwater wells or from surface flows. Designing and installing a comprehensive monitoring system that includes climate data, groundwater wells, surface flow measurements, monitoring irrigation diversions, and monitoring of municipal and agricultural well pumping may be necessary to accurately identify true water yield. The potential for this type of monitoring should be evaluated. Apart from this type of system monitoring, increased water yield is expected, but the fate of that water may be unknown, and may not be realized in measurable surface flow.

Costs. Estimated costs for implementation of Scenario 1 (saltcedar control at the Lower Virgin River) are provided in Table 2-2.

Preliminary Conclusions. With a total projected yield of 17,222 AFY, and costs indicated in Table 2-2, the cost of the water is estimated at $100/AF yielded over a 20-year period. Assuming ongoing maintenance will be implemented to ensure saltcedar will not reinvade, these costs could be amortized over a much longer time period, significantly decreasing the cost per AF. By far, the highest costs are associated with revegetation; however, if revegetation were not implemented, annual costs to maintain would be reduced considerably given the large area proposed for restoration (i.e., economy of scale).

Table 2-2. Scenario 1 Cost Estimate: Lower Virgin River				
Item	**Quantity (ac)**	**Unit Cost ($/ac)**	**Initial Cost**	**20-year Annualized O&M Cost**
Saltcedar Removal				
Aerial Spraying	8,611	$200	$1,722,200	
Stem Removal (controlled burn)[1]	8,611	$100	$861,100	
Ongoing Maintenance	8,611	$30		$301,000
Revegetation				
Hydroseed Upland Scrub[2]	5,741	$2,500	$14,351,523	
Riparian Woodland Cuttings[3]	2,870	$2,500	$7,175,977	
Water Yield Monitoring				
Groundwater Wells	10	$1,800	$18,000	
Surface Flow Measures	3	$1,500	$4,500	
Acquire and Manage Monitoring Records	1	$30,000		$30,000
Environmental Documentation and Permitting				
National Environmental Policy Act Document	1	$85,000	$85,000	
Special Permits	3	$15,000	$45,000	
Water Diversion and Delivery	**NOT INCLUDED**			
TOTAL			**$24,263,300**	**$331,000**

Notes:
1- Assumes stem removal would occur on all areas treated.
2- Assumes 2/3 of area would be suitable for revegetation by upland scrub and would be hydroseeded.
3- Assumes 1/3 of area would be suitable for revegetation with riparian woodland and would receive cuttings.

2.8.2 Scenario 2 – Lower Colorado River

Scenario 2 would involve widespread saltcedar removal along the LCR from Hoover Dam at Lake Mead to the international boundary with Mexico, a distance of about 400 river mi and encompassing three states. Figure 2-2 shows the Alternative 2 project area, along with the distribution of saltcedar along the LCR. Comprehensive saltcedar removal was proposed by the Bureau for portions of this area, as previously described, but this proposal was never implemented (Bureau 1995). Some limited saltcedar removal has been implemented at the LCR by various groups (CRCF 2005, for example). In addition, the LCR Multi-Species Conservation Program (MSCP) is a long-term multi-agency effort to conserve and work towards the recovery of endangered species, and protect and maintain wildlife habitat on the LCR. Part of the MSCP proposal is to restore 8,100 ac of riparian, marsh and backwater habitat at various locations along the LCR over the 50-year life of the program. This effort will include some saltcedar removal and

revegetation with native species, along with restoration of wetland and aquatic habitat

(Bureau 2006).

Potential Water Yield. Based on available Bureau mapping data, a total of 57,167 ac of saltcedar are present in the Scenario 2 area. This scencario proposes complete eradication of the saltcedar, and replacement of 10 percent of the floodplain area with native riparian woodland (cottonwood-willow), and replacement of the remaining 90 percent of the removal area with native upland scrub, such as saltbush, greasewood, and arrowweed. Based on the previous assumptions, the riparian woodland replacement would not yield significant water; however, the upland native scrub would yield 3.0 AFY per acre treated. Using these parameters, a total of 154,000 AFY of water is expected for the entire Scenario 2 area.

Technical Issues: Removal, Revegetation, and Maintenance. Because of the large size and potential high cost of saltcedar removal and revegetation under this scenario, an alternative approach at the LCR was proposed: saltcedar removal implemented with leaf beetles. Given the high level of success in field trials, this would provide effective control over a large area. In addition, the slow process of defoliation and die-back would reduce potential effects to southwestern willow flycatcher. Standing dead vegetation would be left intact where fire hazard is minimal, or otherwise eliminated with controlled burns. The riparian woodland zone (expected to be 10 percent of the floodplain) would be planted with dense cuttings of willow and cottonwood to provide alternative nesting habitat for the willow flycatcher. The remaining upland portion of the floodplain would not be planted. No irrigation would be installed. Ongoing saltcedar spraying to limit reinvasion would be implemented until native vegetation was well established.

This approach would be tailored to specific land jurisdictions along the LCR. For example on Havasu National Wildlife Refuge, upland planting may be required throughout the floodplain. In addition, the specific timing of vegetation removal and riparian planting would be coordinated to minimize effects on the willow flycatcher. Also, revegetation and restoration could be coordinated with the MSCP or other restoration efforts at the LCR.

Technical Issues: Realizing Water Yield. The Bureau keeps detailed records of LCR water use and will continue to document delivery and use of water in this three-state area. A restoration effort of this magnitude would involve multiple partners, including the Bureau, USDI Bureau of Land Management, USDI Fish and Wildlife Service, States of California, Nevada, and Arizona, Imperial Irrigation District, Metropolitan Water District of Southern California, other water users along the river, and many others. The specific partners, funding sources, and water yield accounting from this effort would have to be resolved through an extensive stakeholder process. Additional monitoring may be required to more precisely determine water yield, especially yield in shallow or deep groundwater.

Costs. Costs for implementation of Scenario 2 (saltcedar control at the Lower Colorado River) are provided in Table 2-3. Costs assume that 25 percent of the treated area would receive stem removal treatment, 10 percent of the treated area would be suitable for and revegetated with riparian woodland, and only 10 percent of the remaining treated area (90 percent) would require hydroseeding for upland scrub.

Preliminary Conclusions. With a total projected yield of 154,000 AFY and costs as indicated in Table 2-3, the cost of the yielded water is estimated to be $29/AF over a 20-year period. Assuming ongoing maintenance will be implemented to ensure saltcedar will not reinvade, these costs could be amortized over a much longer time period, significantly decreasing the cost per AF. The highest costs are associated with revegetation; revegetation would be required to mitigate for loss of willow flycatcher habitat or to provide native habitat establishment on upland areas.

Table 2-3.
Scenario 2 Cost Estimate: Lower Colorado River

Item	Quantity (acres)	Unit Cost	Initial Cost	20-year Annualized O&M Cost
Saltcedar Removal				
Biological Control	57,167	$25	$1,429,175	
Stem Removal (controlled burn)[1]	14,292	$100	$1,429,175	
On-going Maintenance	57,167	$50		$2,985,000
Revegetation				
Hydroseed Upland Scrub[2]	5,145	$2,500	$12,862,575	
Riparian Woodland Cuttings[3]	5,717	$2,500	$14,291,750	
Additional Salvaged Water Monitoring	Not Included			
Water Diversion and Delivery	Not Included			
Environmental Documentation and Permitting				
Estimated as 5% of total project cost	1	$1,500,634	$1,500,634	
TOTAL			**$31,513,309**	**$2,985,000**

Notes:
1- Assume stems are removed on 25% of total saltcedar removal area.
2- Assumes 90% of saltcedar removal area is upland scrub suitable, and hydroseed occurs on 10% of this area.
3- Assumes 10% of saltcedar removal area is riparian suitable, and all receives planting.

2.8.3 No Action Scenario

Saltcedar currently occupies at least 288,000 ac (2001 data) throughout the Basin, displacing native vegetation that uses less water. As such, there are current and ongoing water losses from saltcedar in the Basin. In addition, saltcedar spread is about 3-4 percent per year. If no major efforts to control the spread of saltcedar are implemented, the species could spread to as much as 3 million ac throughout the west. Just as saltcedar removal could save water, invasion of saltcedar into previously native habitats may reduce available ground and surface water throughout the Basin. This scenario evaluates potential impacts to current water yield and risk to future water yield within the Basin by not implementing measures to control or limit the spread of saltcedar.

Potential Water Loss. Based on a spread rate of 3.5 percent per year, saltcedar cover within the Basin is expected to nearly double to 593,000 ac by the year 2022. Assuming two-thirds of the currently occupied area represents upland areas with potential low ET use by native vegetation, and one-third represents riparian areas with potential native vegetation ET rates comparable to saltcedar, the estimate of current water lost (based on 2001 data) is 576,000 AFY. In 2022, with an approximate doubling of the saltcedar acreage (and assuming two-thirds of invasion would be into native habitats with current vegetation having low ET rates, and one-third into riparian areas with ET comparable to saltcedar), the water potentially lost from saltcedar spread would be 1,186,000 AFY.

Future Costs. Cost of water alone (using an average cost of $15/AF (CDWR 2005) for lost water between 2001 and 2022 is estimated at $279 million. Amortized over this period, the cost of lost water would be about $12 million/year. Additional unquantified costs may be associated with increased flooding, increased fire hazard, loss of recreation potential, and loss of wildlife habitat.

Preliminary Conclusions. With current saltcedar distribution, and continued saltcedar spread resulting in decreased ground and surface water throughout the Basin, as much as 576,000 AFY of water would be lost, potentially doubling to 1,186,000 AFY by the year 2022.

3.0 COST OPINION AND COST-YIELD ANALYSIS

3.1 Overview

To assist in developing a unit-cost comparison, estimated costs for saltcedar removal and revegetation are provided in Table 3-1. Based on Scenarios presented in Subsection 2.8, the potential costs of water yield for two project scenarios are provided in Table 3-2. Scenario 1 (Virgin River) shows the cost could be $100/AF of salvaged water. Scenario 2, which investigated efficiencies of scale over the larger LCR, shows the cost could be reduced to $30/AF of salvaged water.

Table 3-1.
Saltcedar Removal and Revegetation Methods and Costs

Saltcedar Removal		
Removal Method	**Cost per Acre (Heavy Infestation)**	**Cost per Acre (Light Infestation)**
Hand Cutting/ Herbicide Application	$5,000	$1,500
Mech. Removal – Root plow and rakes	$800	---
Mech. Removal – Mulching and herbicide	$500 – 1600	$220 – 700
Hand Herbicide Application	$5 per plant; up to $2,500	$5 per plant; may reach $250
Aerial Herbicide Application	$200 – 250; minimum 1,000 ac	---
Biological Control – *Diorhabda elongata*	$10 (preliminary estimate)	---
Dead Tree Removal – Burn or mulch	$50 – 400	$200
Revegetation		
Landscaping Component	**Cost per Acre**	
Cottonwood – Willow Cuttings	$500 - $5,000	
Container Stock Planting	$12,000 - $25,000	
Temporary Irrigation	$5,000 - $20,000	
Hydroseed	$2,500 - 4,000	
Ongoing Maintenance	10% of installation costs per annum	
Sources: Tamarisk Coalition (2005); CH2M HILL (unpubl. data); Shafroth, et al. (2005).		

Table 3-2 Cost-Yield Analysis of Proposed Scenarios			
Scenario	**30-year Annualized Cost**	**Yield per Annum (AF)**	**Cost per AF of Yield**
Scenario 1—Virgin River	$1,800,000	17,200	$100
Scenario 2—Lower Colorado River	$3,900,000	154,000	$30