Appendix F8
Option Characterization – Watershed Management

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1.0 Introduction

Watershed management options have been proposed to increase the overall water supply of the Colorado River Basin (Basin). A number of watershed management options were submitted for consideration in the Colorado River Basin Water Supply and Demand Study (Study). Because of the scope and level of detail provided in the proposed options, the option groups are also used as representative options. When potential yield of a representative option exceeds 200 kafy and the option is scalable, the representative option was characterized in progressive 200 kafy "steps". The submittals are summarized in appendix F2 and the original submittals are available via links from the electronic version of appendix F2 on the compact disc that accompanies this report and the version of appendix F2 on the Study website at http://www.usbr.gov/lc/region/programs/crbstudy.html.

Ten options related to watershed management were received. The following submitted options were reviewed and organized into five groups according to the specific type of watershed management approach:

- Tamarisk Control
- Forest Management
- Brush Control
- Dust Control
- Weather Modification

Figure F8-1 shows the general locations of the watershed management options and their approximate extent.

This appendix summarizes the types of options received, the assumptions made and methods used to characterize the options, and the characterization results. Additional detail related to the options characterization is included in appendix F3. Attachment A of appendix F3 contains more detailed descriptions of the ratings. Attachment B provides the methods used for completing the unit cost calculations. Attachment C presents the detailed characterization information and is available on the compact disc that accompanies this report and on the Study website.

2.0 Tamarisk Control

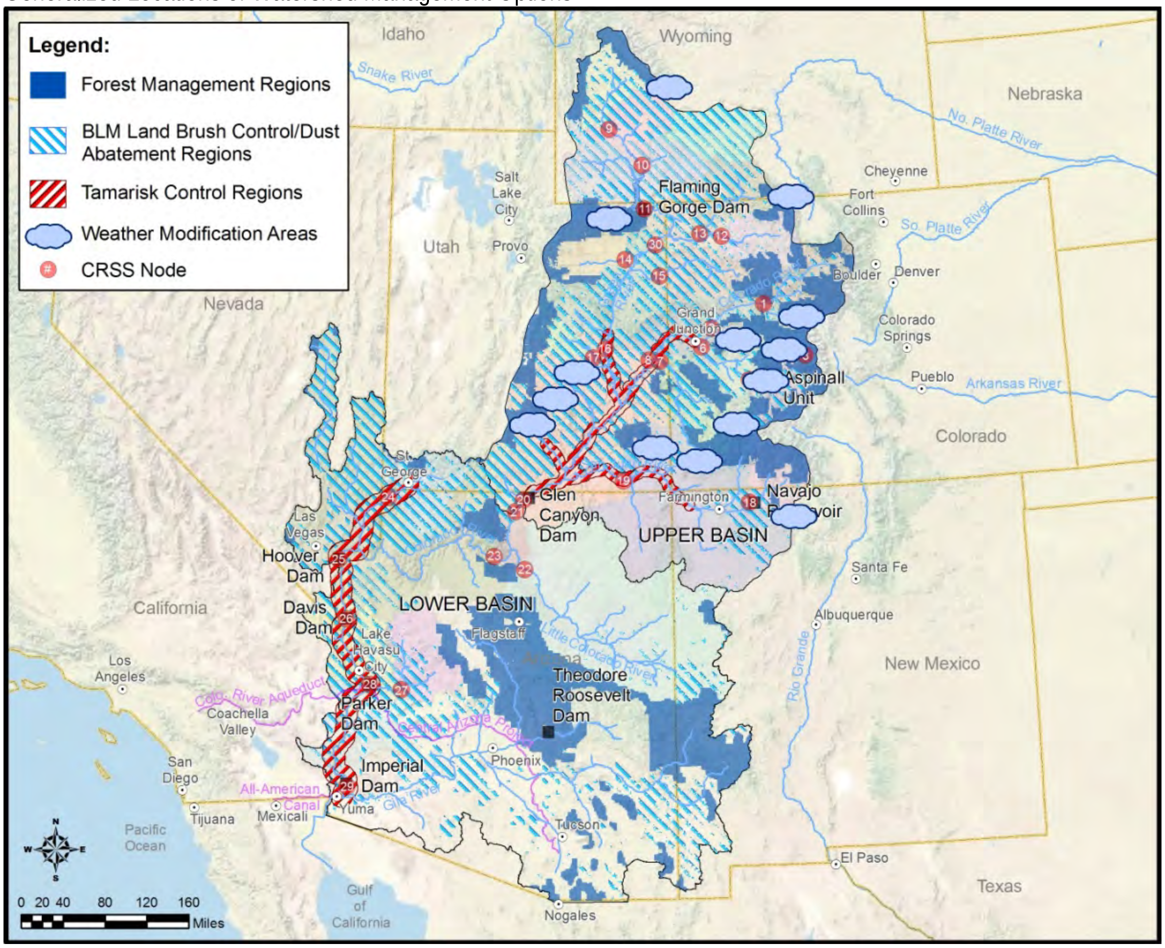
Control of invasive tamarisk trees has been proposed for riparian areas to reduce their overall consumptive use and increase streamflow. The estimates for tamarisk control were based primarily on the *Colorado River Basin Tamarisk and Russian Olive Assessment* prepared for the Basin States[1] by the Tamarisk Coalition in 2009.

Yield estimates for all watershed management concepts were developed by evaluating the fundamental aspects of watershed hydrology related to the amount of runoff that is generated and

[1] Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming.

then assessing the impacts of changes to basic runoff parameters. In this case, the parameter proposed to be modified to increase runoff is reduction in evapotranspiration from tamarisk trees or a forest.

FIGURE F8-1
Generalized Locations of Watershed Management Options



Yield for tamarisk control was based on the area over which the measure was implemented and the change in evapotranspiration resulting from the vegetation management measure. The estimated change in evapotranspiration was then related to the overall water balance to estimate the change in runoff associated with the measure.

The total tamarisk acreage in the Basin has been mapped as 250,000 acres (Tamarisk Coalition, 2009). This value must be considered low because a significant amount of the data is point data with no actual acreage assigned to this information. If one-fourth of the total tamarisk acreage can be removed by a tamarisk management program, the total acres for the program are 60,000. Estimates of water savings by removal of tamarisk and replacement by other species range from zero and up to 1.5 acre-feet (af) per acre (Nagler et al., 2009). A reasonable estimate for planning purposes is 0.54 af per acre (Tamarisk Coalition, 2009). At that rate of water savings, conversion of 60,000 acres from tamarisk to other species would save 30,000 acre-feet per year (afy) of consumptive water use.

Although all of the vegetation management options are based on control of vegetative conditions to improve watershed runoff capabilities, there are significant differences in terms of areal extent and degree of current adoption that affect the evaluation of timing for implementation. Tamarisk control is focused on removal of tamarisk in riparian areas and their replacement with species that do not consume as much water. It was estimated that 2 years would be required to evaluate the feasibility of this practice. This short duration reflects the widespread current adoption of these practices across the Basin, although at a much smaller scale than envisioned by this option. Permitting at the scale considered here would require approximately 5 years. Implementation time is estimated to be 5 years based on the large area proposed for tamarisk control. Therefore, the total time estimated for reduction in consumptive use through control of tamarisk is estimated to be 12 years.

Cost estimates for tamarisk management options were derived primarily through literature research and actual project implementation experiences (Barz et al., 2009; Tamarisk Coalition, 2009) and applying the costs to these concepts. Cost estimates for tamarisk management measures are highly variable, due primarily to the variability in site conditions such as tamarisk density, which control the method to use, site access, etc. The uncertainty relates not only to the costs of the practices used to accomplish tamarisk management but also to the effectiveness of these measures and the frequency with which the measures might have to be repeated. For example, some sites are better managed by more–frequent, smaller-scale removal than by less-frequent, large-scale mobilization and activity.

The Tamarisk Coalition has estimated that the unit annual costs of water saved by tamarisk management range from $260 to $1,050 per af (Tamarisk Coalition, 2009), with a Basin-wide average unit annual cost of less than $400 per af. For the purposes of the Study, a unit annual cost of $400 per af was assumed.

In addition to yield, timing, and cost, the tamarisk management options were characterized against several other criteria. A summary of the findings for all criteria is shown in table F8-1. Key considerations related to technical feasibility, permitting, legal, and policy were largely covered in the descriptions related to option timing. Tamarisk management ranked low on long-term viability due to the uncertainty as to whether the quantity of yield could be achieved or maintained over time. For operational flexibility, tamarisk management ranked low because the option cannot be idled from year to year without substantial loss of subsequent yield. When considering hydropower, water quality, recreation, and other environmental criteria, options that resulted in more water in headwaters locations were rated high. Socioeconomic impacts were generally judged to be neutral because all options created some jobs, although the number of jobs might vary from year to year.

3.0 Forest Management

Forest management entails the replacement of mature forests that have been cleared by harvesting, fires, or insect infestations with stands of replacement growth more likely to be favorable for generating runoff. This option suggests that initial yield realization may be 300,000 afy in forested areas of Colorado based on active management of 5 percent of Colorado's forests and assuming 4 inches of increased yield (National Research Council, 2008). However, the increased yield is expected to rapidly decline as new growth begins to replace harvested areas. The increased yield is anticipated to only last about 3 to 4 years and provide no benefit thereafter. The concept may only be feasible if the approach is via selective harvest of mature trees in areas where density is too high, combined with understory clearance. Characterization of this option was performed as increments of 200 thousand acre-feet per year (kafy) in order to capture issues of scale and other complexities of large-scale programs.

Forest management of areas over which selective harvesting is practiced or over which extensive forest fires have occurred provide the opportunity for programmed revegetation. The time to evaluate the feasibility of these activities was estimated as 7 years. The timeframe for permitting was estimated to be 3 years, largely due to the consideration that these forest management activities are currently being practiced (MacDonald and Stednick, 2003), although not for purposes of increasing runoff. The timing for implementation of forest management practices was estimated at 10 years to conform to timeframes of other forest management measures. Therefore, the total time for development of forest management options is estimated to be 20 years.

Cost estimates for forest management options were derived primarily through literature research and applying the costs presented in the literature to these concepts. Cost estimates for forest management measures are generally highly uncertain. The uncertainty relates not only to the costs of the practices used to accomplish forest management but also to the effectiveness of these measures and the frequency with which the measures might have to be repeated.

The extent to which existing forest roads are available will have a significant impact on cost. Estimates of unit annual costs experienced by the US Forest Service for similar management activities ranged from $114 to $786 per acre, with estimates for individual forest areas between $215 to $1,500 per acre on a 20-year rotation (National Research Council, 2008, and Evans, 2008). The median unit annual cost value was $875 per acre. Assuming a unit annual cost of $1,000 per acre on a 20-year rotation and annual maintenance costs of about 10 percent of that amount, the unit annual cost of additional runoff generated is approximately $500 per af. This estimate is based on annualized costs of $160 per acre treated with each acre treated generating one-third of an af of additional runoff. The resulting characterizations of other key criteria for this option were very similar to the tamarisk control option.

4.0 Brush Control

Brush control involves reducing brush and therefore reducing consumptive use by brush vegetation.

Brush control may have limited benefit in arid regions. It has been demonstrated that improved runoff conditions are unlikely for regions receiving less than 18 inches of rainfall annually (Ball and Taylor, 2008). Most of the areas where brush control has been considered within the Basin are in the regions with less than 18 inches of annual precipitation. For evaluation purposes, it was roughly assumed that in these arid areas average runoff is between 0.05 and 0.1 inch per year (Linsley et al., 1982). The area covered by U.S. Bureau of Land Management (BLM) land in the Basin is approximately 100,000 square miles, resulting in a range of 250,000 to 500,000 afy in total runoff. Assuming brush control resulted in a 10 percent increase in runoff, between 25,000 and 50,000 afy of net benefit would realized.

Brush control on BLM land involves the conversion of vegetative cover from trees such as mesquite and juniper to native grasses. This has been implemented over small areas, but not over the large area envisioned by this option. The implementation would also require programmatic and financial support from federal and state agencies as well as coordination with private contractors who are using the BLM land for grazing. It was estimated that the time requirements for evaluation of feasibility would be 5 years, for permitting would be 5 years, and for phased implementation would be 5 years, for a total of at least 15 years for availability of increased runoff from brush control on BLM land.

The preferred method of control would be spraying the brush with herbicides formulated for control of the selected variety of brush, followed by mechanical removal of the brush, and then seeding with native grasses to revegetate the affected areas. Chemical spraying costs about $30 per acre and has to be repeated at about 10-year intervals (Research & Planning Consultants, 2000). If yields could be achieved and maintained, the unit annual cost would approximately be $7,500 afy per year.

Other key criteria were characterized similarly to the other two vegetation management options.

5.0 Dust Control

These options propose to control land-based dust sources that contribute to dust accumulation on snow, which changes the albedo, or reflective power, of the snow and results in earlier snowmelt (Painter et al., 2007, 2010 and 2012; Skiles et al., 2012) and more evaporative moisture losses. By implementing measures to reduce the accumulation of dust on snow, lower evaporative losses are anticipated. This is a relatively new concept supported by recent literature (Painter et al., 2007).

Referenced modeling studies by the National Oceanic and Atmospheric Administration (Painter et al., 2010) and others indicate that as much as 800,000 afy might be recovered by controlling the amount of dust accumulating on snow. However, these studies do not address the practicality of implementing measures to control dust generation in the large area of the Colorado Plateau. Management practices to reduce dust emissions may include soil fences, straw grids, and/or revegetation. Another promising although largely untested technique involves the spray application of cyanobacteria to promote the formation of biological soil crusts that reduce erosion.

Due to the uncertainty about the effectiveness of measures to control the generation of dust and prevent its deposition on snow, the amount of additional runoff that could be obtained was estimated to be no more that 50 percent of the total potential amount, or 400,000 afy. Characterization of this option was performed as two increments reflecting a more focused program of “hot spot” regions for the first 280 kafy, and a more distributed program for the remaining 120 kafy. Characterization of this option was performed as increments of 200 thousand acre-feet per year (kafy) in order to capture issues of scale and other complexities of large-scale programs.

The primary factor in determining the timing of increased runoff through dust control measures is the relatively large portion of the Colorado Plateau and the Great Basin over which dust control practices would need to be implemented. The large areal extent led to estimates of 5 years to evaluate effectiveness, followed by 5 years for permitting, and 5 years for the first phase of implementation, for a total of 15 years. The essential element of implementation is the widespread adoption of practices to minimize wind erosion over large areas. This is most likely to be accomplished through financial, regulatory, and educational measures promoted at both federal and state levels.

To approximate the cost of programs for dust management, it was assumed that conversion of the erodible lands to native grasses would require practices similar to enrollment in the U.S. Department of Agriculture's Conservation Reserve Program (2008). These costs were estimated for clearing the land by root plowing and then reseeding with native grass. It was also assumed that periodic maintenance by spraying would be required at approximately 10-year intervals. Based on the costs of these practices, an annual average cost of $15 per acre was derived. Implemented over an area of 10,000 square miles, the annualized cost per af of increased yield is $500. Although the eventual dust control program may implement a variety of control measures, these technologies are not yet established for the Basin.

Other key criteria were characterized similarly to other watershed management practices.

6.0 Weather Modification

This watershed management concept features two mechanisms that have been proposed for increasing precipitation over the Basin. The first is by cloud seeding, particularly to increase snowfall in mountain regions. The second is by creating more inland seas to increase the amount of atmospheric moisture due to increased evaporation.

Many earlier studies were summarized in a report prepared by the Metropolitan Water District of Southern California (Ryan, 2005). This report indicates that cloud seeding in runoff- producing areas could generate as much as 1.1 to 1.8 million additional afy in the Upper Basin and as much as 830,000 afy in the Lower Basin and adjacent basins. The report concluded that the potential maximum amount that could be generated from cloud seeding to provide additional runoff would be about 1,700,000 afy. Characterization of this option was performed as increments of 200 kafy in order to capture issues of scale and other complexities of large-scale programs.

There has been a long history of weather modification activities throughout the Basin. Based on these existing practices, no additional time would be required for feasibility or permitting. Implementation could be completed in 5-year phases.

For weather modification by cloud seeding, separate cost estimates were derived from the California Department of Water Resources and from the documentation provided in the *Study of Long-Term Augmentation Options for the Water Supply of the Colorado River System* (Colorado River Water Consultants, 2008). The California Department of Water Resources (2005) indicated that cloud seeding produced 300,000 to 400,000 af of additional runoff at a cost of around $7 million. The investigations associated with the augmentation study led to a unit annual cost estimate of $20 to $30 per af.

The other weather modification option proposed was to increase atmospheric moisture and thereby precipitation by creating more inland seas. Research (Trenberth, 1999) has indicated that less than 3 percent of precipitation is derived from local evaporation in the Southwest, though estimates based on moisture budget suggest higher precipitation-recycling ratio (Anderson, 2009). Not all local evaporation contributes to moisture that is recycled as precipitation in the hydrologic basin. Therefore, while increasing evaporation may marginally increase precipitation, it is likely that the water balance change is negative. A yield value of zero was assigned.

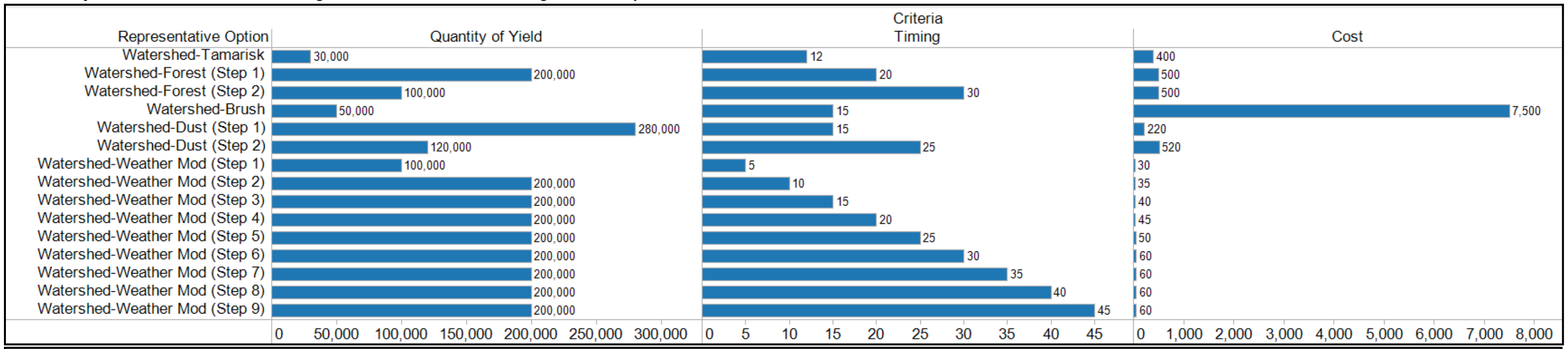
In addition to yield, timing, and cost, the watershed management options were characterized against several other criteria. Key considerations related to technical feasibility, permitting, legal, and policy were largely covered in the descriptions related to option timing. Many of the options ranked low on long-term viability due to the uncertainty related to whether the quantity of yield could be achieved or maintained over time. For operational flexibility, weather modification ranked high for this criterion because it can be easily implemented on various scales from year to year. When considering hydropower, water quality, recreation, and other environmental criteria, options that resulted in more water in headwaters locations were ranked positively. Socioeconomic impacts were generally judged to be neutral because all options created some jobs, although the number of jobs might vary from year to year.

7.0 Results

A summary of the characterization findings are shown in table F8-1. The top portion of the table shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the table shows the 17 criteria and associated ratings ("A" through "E") and is color-scaled. In general, "C" is typically designated as mostly neutral (yellow); "A" is largely positive (green); and "E" is largely negative (red).

Refer to appendix F3 for specific criteria descriptions and rating scales. Options that yield more than 200 kafy were broken into 200 kafy steps and numbered sequentially (e.g., Watershed-Forest Step 1, Watershed-Forest Step 2, etc.).

TABLE F8-1
Summary Characterization Ratings for Watershed Management Options



	Criteria																
Representative Option	Quantity of Yield	Timing	Cost	Technical Feasibility	Implementation Risk	Long-Term Viability	Operational Flexibility	Permitting	Energy Needs	Energy Source	Other Environmental	Recreation	Socioeconomics	Policy	Legal	Hydropower	Water Quality
Watershed-Tamarisk	E	C	A	B	C	D	E	C	C	D	C	B	C	B	C	C	D
Watershed-Forest (Step 1)	D	C	B	D	D	E	E	C	C	D	C	C	C	E	C	B	C
Watershed-Forest (Step 2)	D	D	B	D	D	E	E	C	C	D	C	C	C	D	C	B	C
Watershed-Brush	E	C	E	D	D	E	E	C	C	D	A	C	C	C	C	C	B
Watershed-Dust (Step 1)	C	C	A	C	C	D	E	C	C	D	A	B	C	C	C	B	A
Watershed-Dust (Step 2)	D	D	B	D	C	D	E	C	C	D	A	B	C	C	C	B	A
Watershed-Weather Mod (Step 1)	D	A	A	C	B	C	C	B	C	D	B	A	B	C	C	A	B
Watershed-Weather Mod (Step 2)	D	B	A	C	B	C	C	B	C	D	B	A	B	C	C	A	B
Watershed-Weather Mod (Step 3)	D	C	A	D	C	D	C	C	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 4)	D	C	A	D	C	D	C	C	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 5)	D	D	A	D	C	D	C	C	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 6)	D	D	A	D	D	D	C	C	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 7)	D	E	A	E	D	E	C	D	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 8)	D	E	A	E	D	E	C	D	C	D	B	A	B	D	C	A	B
Watershed-Weather Mod (Step 9)	D	E	A	E	D	E	C	D	C	D	B	A	B	D	C	A	B

8.0 References

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