RECLAMATION
Managing Water in the West

Colorado River Basin Water Supply and Demand Study

Technical Report F – Development of Options and Strategies

U.S. Department of the Interior
Bureau of Reclamation

December 2012

Colorado River Basin Water Supply and Demand Study

Technical Report F – Development of Options and Strategies

U.S. Department of the Interior
Bureau of Reclamation

December 2012

Contents

Tables

Figures

Appendices

Acronyms and Abbreviations

2007 Interim Guidelines	*Record of Decision for Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead*
af	acre-feet
afy	acre-feet per year
Basin	Colorado River Basin
Basin States	Colorado River Basin States
BLM	Bureau of Land Management
BMP	best management practice
CALFED	California Water Policy Council and Federal Ecosystem Directorate
CAP	Central Arizona Project
CBM	coal bed methane
CCP	Central Colorado Project
CII	commercial, institutional, and industrial
Compact	Colorado River Compact of 1922
CRSS	Colorado River Simulation System
CUWCC	California Urban Water Conservation Council
desal	desalination
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
EIS	Environmental Impact Statement
gpcd	gallons per capita per day
ICS	Intentionally Created Surplus
IID	Imperial Irrigation District
ITCA	Inter Tribal Council of Arizona
kafy	thousand acre-feet per year
KBRT	Klamath Basin Rangeland Trust
kWh	kilowatt hours
mafy	million acre-feet per year
Mexico	United Mexican States
MW	megawatts
MWD	Metropolitan Water District of Southern California

M&I	municipal and industrial
O&M	operation and maintenance
OM&R	operation, maintenance, and replacement
QSA	Quantification Settlement Agreement
Reclamation	Bureau of Reclamation
ResOps	reservoir operations
SoCal	Southern California
Study	Colorado River Basin Water Supply and Demand Study
SysOps	system operations
TDS	total dissolved solids
tribes	federally recognized tribes
USGS	U.S. Geological Survey
WaterSMART	Sustain and Manage America's Resources for Tomorrow
weather mod	weather modification

Technical Report F — Development of Options and Strategies

1.0 Introduction

The Colorado River Basin Water Supply and Demand Study (Study), initiated in January 2010, was conducted by the Bureau of Reclamation's (Reclamation) Upper Colorado and Lower Colorado regions, and agencies representing the seven Colorado River Basin States (Basin States) in collaboration with stakeholders throughout the Colorado River Basin (Basin). The purpose of the Study is to define current and future imbalances in water supply and demand in the Basin and the adjacent areas of the Basin States that receive Colorado River water over the next 50 years (through 2060), and to develop and analyze adaptation and mitigation strategies to resolve those imbalances. The Study contains four major phases to accomplish this goal: Water Supply Assessment, Water Demand Assessment, System Reliability Analysis, and Development and Evaluation of Options and Strategies for Balancing Supply and Demand.

Spanning parts of the seven states of Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming, the Colorado River is one of the most critical sources of water in the western United States. The Colorado River is also a vital resource to the United Mexican States (Mexico). It is widely known that the Colorado River, based on the inflows observed over the last century, is over-allocated, and supply and demand imbalances are likely to occur in the future. Up to this point, this imbalance has been managed, and demands have largely been met as a result of the considerable amount of reservoir storage capacity in the system, the fact that the Upper Basin States are still developing into their apportionments, and efforts the Basin States have made to reduce their demand for Colorado River water.

Concerns regarding the reliability of the Colorado River system to meet future needs are even more apparent today. The Basin States include some of the fastest-growing urban and industrial areas in the United States. At the same time, the effects of climate change and variability on the Basin water supply has been the focus of many scientific studies that project a decline in the future yield of the Colorado River. Increasing demand, coupled with decreasing supplies, will certainly exacerbate imbalances throughout the Basin.

It is against this backdrop that the Study was conducted to establish a common technical foundation from which important discussions can begin regarding possible strategies to reduce future supply and demand imbalances. The content of this report is a key component of that technical foundation and describes the Study's development of options and strategies.

This development was initiated in November 2011 when project participants, stakeholders, and the public were encouraged to submit options and strategies to help resolve future supply and demand imbalances in the Study Area. Through February 2012, 160 ideas were submitted. The Study does not result in the selection or funding of a particular proposed option or set of options. Rather, the Study is intended to explore a broad range of options to help address future imbalances and the performance of those options across a range of future conditions. The Study also lays the foundation for future development and implementation of a number of options identified.

This report describes the submitted options, the process for characterization of these options, the results of characterization, and the development of exploratory portfolios from the characterization results to address future supply and demand imbalances.

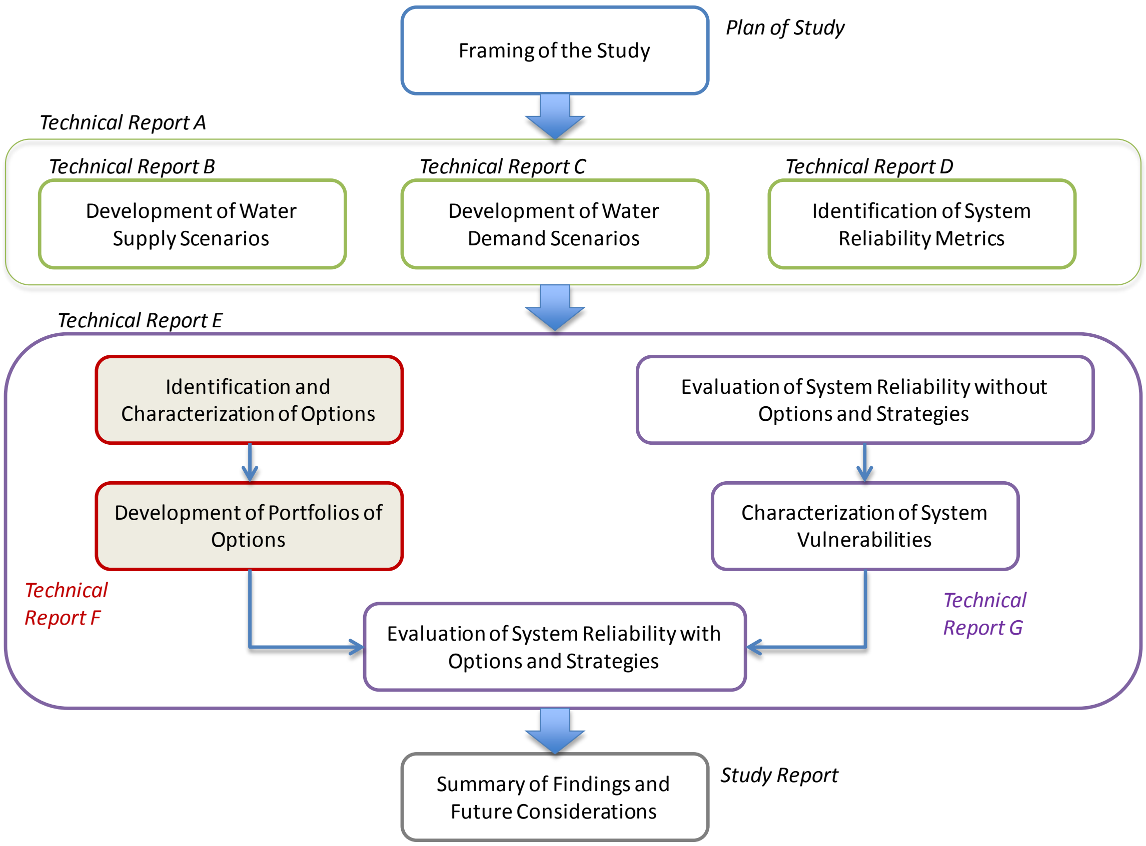
2.0 Approach for Options and Strategies Development

The overall Study approach and associated technical reports are shown in figure F-1. As outlined in *Technical Report E - Approach to Develop and Evaluate Options and Strategies*, the Study objectives center on addressing two primary questions:

1. What is the future reliability of the Colorado River system to meet the needs of Basin resources through 2060?
2. What are the options and strategies that can mitigate future risks to these resources?

The second question is the focus of this report. This question examines the potential water management response to future imbalances in supply and demand. The process to examine this response is shown in figure F-1 as the shaded boxes representing the identification and characterization of individual options and the subsequent development of portfolios of options. The effectiveness of the options and strategies at resolving imbalances and improving the reliability of the Colorado River system is described in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies.*

FIGURE F-1
Overall Study Approach



The following paragraphs provide a high-level summary of the development and characterization process as well as the development of portfolios. Additional detail is presented in the sections that follow.

An Options and Strategies Sub-Team, composed of representatives from Reclamation, the Basin States, federally recognized tribes (tribes) and communities, and conservation organizations, was established to develop options and strategies. Sub-Team members are listed in appendix F1 of this report.

The general approach for the development of options and strategies is summarized as follows:

- **Solicit input –** In order to examine a broad range of potential options, Study participants, interested stakeholders and the general public were asked to submit options.
- **Organize options –** The options were reviewed and organized into four broad types: (1) increase water supply, (2) reduce water demand, (3) modify operations, or (4) governance and/or implementation[1]. Options were further assigned individual categories based on their primary function such as importation, desalination, and municipal and industrial (M&I) conservation.

[1] Implementation refers to a mechanism that could be used to facilitate options rather than a specific option (for example, a tax used to raise funds for developing projects or monitoring).

- **Characterize options –** Each option was characterized using a set of 17 criteria, including both quantitative criteria such as timing of implementation, annualized cost per acre-foot (af), yield, and energy use, and qualitative criteria such as technical feasibility and implementation risk.
- **Develop representative options –** In order to avoid redundancy and simplify analysis, representative options were developed from the pool of submitted options.
- **Develop portfolios –** No single option, or type of project, will likely be adequate to meet all of the future demands of the Basin resources. Rather, a combination of options (portfolio) will be needed to address the imbalances between supply and demand. As such, portfolios representing potential strategies to address future supply and demand imbalances were developed from the representative options and option characterization results. Portfolios were developed by selecting certain option characteristics based on the particular strategy (e.g., remove options that rated low for implementation risk or technical feasibility.)

Each portfolio described in this report was then simulated across all water supply and demand scenarios to assess the ability of the strategy to address imbalances between supply and demand and resolve individual vulnerabilities. The results of these simulations are described in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies*.

3.0 Summary of Options Received

A report, *Phase 4: Development and Evaluation of Opportunities for Balancing Water Supply and Demand – Request for Ideas* (Reclamation, 2011), was published to provide relevant information to those interested in submitting options and strategies. The report provided preliminary projections of future supply and demand imbalances, a summary of previous studies that assessed future imbalances and explored options and strategies, a description of ongoing efforts for balancing supply and demand, and presented a summary of the Study work in progress.

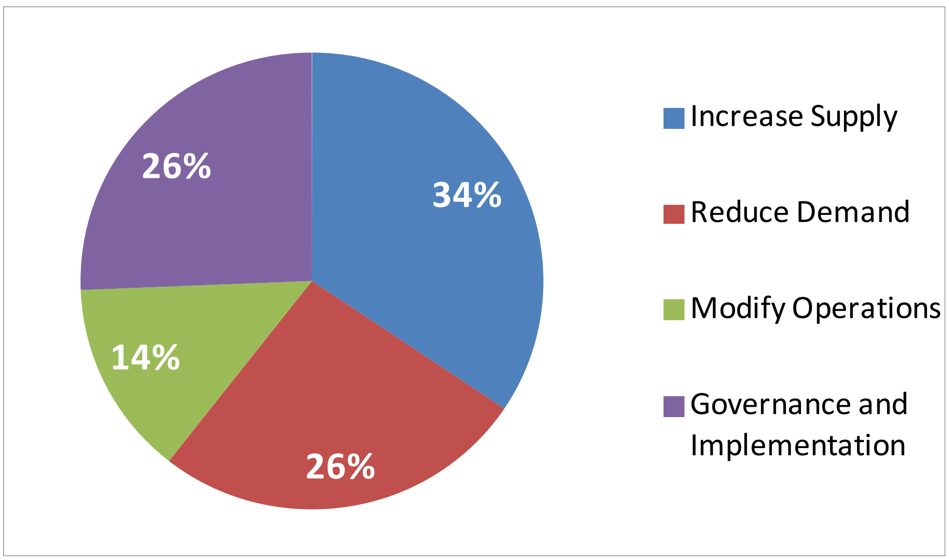
A total of 160 options were received. The submittals are summarized in appendix F2 and the original submittals are available via links from the electronic version of appendix F2 available on the compact disc that accompanies this report and the version of appendix F2 on the Study website at http://www.usbr.gov/lc/region/programs/crbstudy.html. The options were separated into four types based on their approach for resolving the imbalance:

- Increase Supply: These options include suggestions for importing water into the Basin from the Green River, Snake River, from Alaska or the Columbia River via ocean routes, or exchanges with Missouri and Mississippi river supplies; desalination projects along the Pacific Ocean, along the Gulf of California (Gulf), or brackish water desalting projects in California and Arizona; wastewater reuse; greater use of local supplies; and application of watershed management techniques such as weather modification or vegetation management to increase supply.
- Reduce Demand: These options include suggestions for M&I water conservation, agricultural water conservation, and energy water use efficiency.

- Modify Operations: This type includes suggestions for methods for reducing evaporation from lakes and canals, changing system operations, augmenting storage, and inclusion of water banking and transfer programs.
- Governance and Implementation: These suggestions are related to changes in policy, management, legal structure, or future implementation and governance of the Colorado River system.

A total of 55 options were submitted related to increasing supply, 42 options related to reducing demand, 22 options related to modifying operations, and 41 options related to governance and implementation. The percentage of options represented by each category is shown on figure F-2. The options were further organized into categories and groups, from which representative options were selected or developed for consideration in the analysis.

FIGURE F-2
Distribution of Options Received



4.0 Characterization of Options

The *Plan of Study* (see *Study Report, Appendix 1 – Plan of Study*) identified specific objectives related to the development and evaluation of options. As the Study progressed, a definitive process for the characterization of options was developed. This process included the quantitative characterization of options through the assignment of ratings to a number of evaluation criteria. Additionally, this process included the qualitative characterization of options that do not directly increase supply or reduce demand. The qualitative characterization consisted of identification of opportunities and constraints, including potential legal and regulatory issues.

4.1 Approach for Characterization

Option characterization was performed in order to describe each of the submitted options, provide a relative comparison of the option attributes, and support the eventual development of option and portfolio evaluations. Characterization of proposed options was primarily based on information provided by the option submitter; however, available literature and/or relevant studies were reviewed to support the characterization process.

Characterization of the options was based on 17 evaluation criteria that are consistent with the criteria outlined in the *Plan of Study*. The approach to characterization included the following steps to each of the 17 criteria for each of the proposed options:

1. ***Review the submission of the option for relevance and completeness of data***. In some cases, clarification or additional information was requested from the submitter as appropriate and if needed for appropriate characterization of the option. Options that have limited definition or are not directly amenable to characterization through the 17 evaluation criteria were identified and cataloged for future consideration but are not characterized here.
2. ***Validate and refine information submitted with the option.*** Criteria information submitted with the option was compared with similar information in relevant case studies or readily available databases to confirm accuracy. If quantitative information was not readily available for a criterion, the Options and Strategies Sub-Team used its collective expertise and experience to qualitatively evaluate information submitted.
3. ***Characterize each option using a classification system.*** For the appropriate options, ratings were generated for each criterion using the submitted or refined information. Ratings were reviewed by the Options and Strategies Sub-Team. A characterization summary table was developed by listing each rating for an option. Where possible quantitative information was developed (e.g., cost, yield, and timing). In addition, for each option a rating of A, B, C, D, or E was also assigned for each criterion. In general, the “A” rating is most favorable and the “E” rating is least favorable. If insufficient information was available to assign a rating, the associated entry in the option characterization summary table was left blank.

4.2 Characterization Criteria and Assumptions

Option characterization was based on the 17 criteria shown in table F-1. A summary description of the criteria is provided in the table. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

TABLE F-1
Criteria Used to Characterize Representative Options

Criteria	Summary Description of Criteria
Quantity of Yield	The estimated long-term quantity of water generated by the option—either an increase in supply or a reduction in demand
Timing	Estimated first year that the option could begin operation
Technical Feasibility	Technical feasibility of the option based on the extent of the underlying technology or practices
Cost	The annualized capital, operating, and replacement cost per af of option yield
Permitting	Level of anticipated permitting requirements and precedent of success for similar projects
Legal	Consistency with current legal frameworks and laws, or precedent with success in legal challenges
Policy Considerations	Extent of potential changes to existing federal, state, or local policies that concern water, water use, or land management
Implementation Risk	Risk of achieving implementation and operation of option based on factors such as funding mechanisms, competing demands for critical resources, challenging operations, or challenging mitigation requirements
Long-term Viability	Anticipated reliability of the option to meet the proposed objectives over the long term
Operational Flexibility	Flexibility of option to be idled from year to year with limited financial or other impacts
Energy Needs	Energy required to permit full operation of the option, including treatment, conveyance, and distribution
Energy Source	Anticipated energy source to be used to allow option to be operational
Hydropower	Anticipated increases or decreases in hydroelectric energy generation associated with implementation of the option
Water Quality	Anticipated improvements or degradation in water quality associated with implementation of the option
Recreation	Potential impacts to recreational activities including in-river and shoreline activities
Other Environmental Factors	Other environmental considerations, such as impacts to air quality, or aquatic, wetland, riparian, or terrestrial habitats
Socioeconomics	Potential impacts to socioeconomic conditions in regions within or outside of the Basin as a result of implementing the option

When performing the characterization, the following overarching assumptions were made:

- ***Level of Evaluation*** **-** Consistent with the scope of the Study, the options were evaluated at a screening level of analysis only. In some cases, very detailed information on the options was provided, but in most cases the options were only conceptually described in the original submissions. Additional research was performed to validate and refine the submitted information, but this was of a limited nature and at an appraisal level.
- ***Basin-wide Approach*** **-** Where possible, options were conceptualized as distributed, Basin-wide options (e.g., conservation and reuse) as opposed to options implemented by specific entities in specific geographies. Several options, however, are geographically distinct (e.g., specific import options) and were retained in this form.
- ***Cost of Options*** **-** All costs presented were developed based on annualized capital costs added to annual operation and maintenance (O&M) costs (power, chemicals, etc.). Costs for infrastructure-related options were derived from industry-based parametric cost estimates that are commonly applied for water infrastructure projects. These costs include adjustments for proposed location and the scale of the project. Annualization of capital costs was performed using federal guidelines (see attachment B to appendix F3).
- ***Stepped Implementation of Large Options*** **-** Several options are sufficiently large that the potential exists to implement only a portion of the total option. In general, any option that may have more than 200 thousand acre-feet per year (kafy) of yield was separated into steps of up to 200 kafy. This scaling or phasing of large options allowed for characterization to reflect increasing complexity as project size increases.
- ***Independent Characterization of Options*** **-** Although it is likely that several options will be combined as part of eventual portfolios, the option characterization considered each option independently.
- ***Option "Fence Line"*** **-** The characterization of the options was limited to the direct effect of the action within the boundary, or fence line, of the option itself. For example, conversion of water-cooled power plants to air cooling results in a reduction in water demand. However, this conversion also results in a reduction of net power generation. Although this could be mitigated through energy conservation or energy development elsewhere, the option was evaluated independently of actions that may be taken outside of the "fence line."
- ***Sense of Urgency*** **-** The success rate and timeframe for which similar past projects have been implemented has varied widely. This variation is due to resistance from opponents, urgency from proponents, and political support or opposition. When evaluating permitting and potential timing of completion, it was assumed that there would be wide recognition of the associated issues, and therefore significant political alignment, sense of urgency, and consistent pursuit throughout the feasibility, environmental review, permitting, and implementation stages. The scope, scale, and timing of potential imbalances suggest the need for timely action coordinated among the stakeholders. This coordinated action is an important consideration in rating, in particular, the timing of option availability.

4.3 Limitations of Characterization Process

The process undertaken to characterize options strived to develop an objective and consistent evaluation of the options. Several iterations of the option characterization were performed in an attempt to normalize ratings wherever possible. However, several limitations are inherently associated with the characterization of such a broad range of options. The limitations of the characterization process are as follows:

- ***Limited Level of Analysis.*** The intent of the characterization was to perform a high-level analysis of a broad range of options potentially available to resolve Basin imbalances. Study resources limited performing highly detailed evaluations. Limiting the level of analysis helped ensure that all options were considered at a high level, but also added uncertainty to the characterization results because all of the potential challenges associated with option development and implementation may not have been considered. Further, the characterization did not specifically consider future financing and/or economic impacts.
- Some options considered have detailed information available from similar developed projects and other studies, whereas other options, specifically those associated with agricultural and M&I conservation and reuse, require an understanding of development policies, regulatory constraints, legal implications, and water planning criteria that vary significantly throughout the Study Area. A detailed assessment by individual location for those options was beyond the scope of the Study. Instead, the Study provides an appraisal-level approach to characterizing these options, and then applies these assumptions Basin-wide. The assumptions were adopted for purposes of the Study and do not necessarily reflect achievable, or even desirable, local conservation goals for individual municipalities or agricultural locations.
- ***Potential for Subjectivity.*** The classification system used in the characterization process was relatively prescriptive; however, there was still some room for subjectivity when selecting the appropriate ratings for each evaluated option. There was also some potential subjectivity related to defining the “fence line” of each option. However, the overall methodology applied for the option characterization underwent peer review as one means to validate its approach. The review was favorable toward the approach taken in the Study, but acknowledged the potential for differences in viewpoints for particular criteria Still, not all members of the Options and Strategies Sub-Team were in agreement with all ratings, but they recognize that future efforts will result in a more in-depth assessment of the criteria.
- ***Uncertainty.*** The characterization was performed based on limited and high-level analyses. Therefore, knowledge of items such as costs, permit requirements, and long-term feasibility are still highly uncertain. For example, cost estimates for infrastructure-type projects are based on similar past projects with adjustments for parameters such as scale and location. These adjustments are approximate, especially for projects where the scale of the project is larger than any previously completed similar project. Cost estimates for non-structural type projects are often even more uncertain because historical documentation of costs for similar past projects are often not fully applicable or fully documented, or such projects are based on changes in human behavior. In regards to infrastructure-type options, past studies by the Association for the Advancement of Cost

Engineering show that concept- level estimates can typically have an expected accuracy of between -30 to 50 percent. However, it is important to note that many of the infrastructure options and most non-infrastructure options have sufficient uncertainty in cost assumptions that an even wider range of cost variation is possible. Despite the uncertainties in estimating the magnitude of costs, a significant effort was made to provide cost estimates that are useful when considering relative costs. Similar statements can be made related to uncertainty when characterizing options against many other criteria. The characterization process for the non-cost items have some degree of uncertainty, but it is still useful for providing understanding of the potential advantages and disadvantages of the different options, considering a diverse set of criteria.

5.0 Option Characterization Results

The following sections present the characterization results for each of the representative options developed from the major option category. These option categories are: Importation, Desalination, Reuse, Local Supply, Watershed Management, M&I Conservation, Agricultural Water Conservation, Energy Water Use Efficiency, System Operations, and Water Transfers, Exchanges, and Banking. The presentation begins with a summary of the submitted options, followed by a description of each representative option in the category. These descriptions are followed by the characterization results, summarized by quantity of yield, timing, cost, and other key considerations.

5.1 Importation

River and other out-of-Basin freshwater imports have been proposed to increase the overall water supply of the Basin. Fourteen options related to river or other freshwater imports were received. The submitted options were reviewed and organized into three groups according to the location at which the imported water would provide water to the Colorado River or tributary or would provide exchange water for regions reliant upon Colorado River supplies. Representative options were developed for each option group to represent the distinct nature of the options within each group. 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” to represent likely project phasing. The option groups and representative options are described below.

Additional detail related to the representative options and specific characterization is included in appendix F4. 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.1.1 Imports to the Colorado Front Range

This group of options includes importing water from the Missouri River or Mississippi River to areas adjacent to the Basin that could use this water to meet projected shortfalls and/or reduce the amount of water these areas divert from the Basin. All of the Import to Front Range options involve large-scale diversion facilities (intake and diversion facilities of at least 800 cubic feet per second), more than 700 miles of conveyance infrastructure spanning at least two states, and more than 700 megawatts (MW) of power for pumping. Water would be conveyed to the Front Range of Colorado and specific areas of New Mexico and integrated into existing water supply systems. Although these options are termed "imports," water would not actually be imported into the Basin. Rather, water would be delivered to these adjacent areas to reduce the amount of water exported by transbasin diversion (or the amount that could be exported in the future) from the upper Colorado and San Juan rivers. In order for this option to become viable, support from the State of Colorado would be required.

Two representative options were developed from this group of options to reflect the differences in potential location of diversion, conveyance infrastructure needs, and associated impacts. The representative options consist of the following:

- Missouri River Imports
- Mississippi River Imports

5.1.2 Imports to the Green River Headwaters

This group of options includes diverting water from the upper headwaters of rivers adjacent to the Green River to the headwaters of the Green River. Potential sources of supply are diversions from the Bear River, upper Snake River[2], or Yellowstone River. These potential projects involve intake and diversion facilities, pumping plants and conveyance facilities, and delivery to the Green River. Because these options are focused on headwaters-to-headwaters transbasin diversions, the size of the projects (in terms of magnitude of water and facilities required) are smaller in scale than other importation options.

Three representative options were developed from this group of options to reflect the differences in potential location of diversion, conveyance infrastructure needs, and associated impacts. The representative options consist of the following:

- Bear River Imports
- Snake River Imports
- Yellowstone River Imports

5.1.3 Imports to Southern California

This group of options is focused on importing high-quality water from other regions using ocean routes to Southern California coastal areas. Potential sources of water include the Columbia River[2], rivers in Alaska, or icebergs. Delivery mechanisms include sub-ocean pipelines for Columbia River supplies, tanker ships for Alaskan river supplies, or tug boats for icebergs. All of the options in this group require extensive transport or conveyance of water from the source regions to Southern California and require relatively complex facilities and operations to integrate the supply within the current water supply system in Southern California.

[2] Among the more than 150 options submitted to Reclamation as responsive to the *Plan of Study*, additional importation of water supplies from various sources, including importation of water from the Snake and Columbia River systems, were submitted to the Study. Such options were appropriately reflected in the Study but did not undergo additional analysis as part of a regional or river basin plan or any plan for a specific Federal water resource project. This Study is not a regional or river basin plan or proposal or plan for any Federal water resource project.

Four representative options were developed from this group of options to reflect the differences in potential location of imported water, modes of transport and conveyance, and associated impacts. The representative options consist of the following:

- Columbia River Imports
- Icebergs
- Tankers
- Water Bags

The options related to Tankers and Water Bags were separated into sub-options of 200-kafy steps to allow for incremental characterization of these options.

5.1.4 Characterization of Options

Quantity of Yield

The total potential yield of all importation options considered in the Study is more than 3 million acre-feet per year (mafy). However, because the largest options are limited by the ability to convey, integrate, and exchange import water within existing water supply systems in Southern California, the Front Range of Colorado, and the Rio Grande in New Mexico, many of the options are mutually exclusive (e.g., either Mississippi River imports or Missouri River imports, not both). Considering these limitations, the potential yield of the options is more likely in the range of 1.2 to 1.3 mafy. The potential yield was assessed independently from technical feasibility, reliability, and other criteria. The characterization of these other criteria is summarized in subsequent sections.

The potential quantity of yield from Imports to the Front Range was limited by the realistic hydraulic capacity of a single large-diameter pipeline and integration potential within the existing Front Range water system. Specifically, limiting the pipe size to 144 inches and maintaining flow rates so that friction loss is less than 1 foot per 1,000 feet of pipe length results in a yield of about 600,000 acre-feet per year (afy). Similarly, the ability to exchange import water for reduced future diversions from the Colorado River to the Front Range limited consideration of larger quantities. Because the available diversion from the Missouri and Mississippi Rivers is not envisioned to be supply-limited to 600,000 afy, multiple parallel pipes could increase the quantity of yield of this option, but it is likely that service areas would need to be expanded beyond the Front Range and the Rio Grande to exchange for significantly reduced Colorado River diversions.

Conversely, the potential yield from the Import to Green River Headwaters options were limited by estimates of the potentially available supply. Previous analyses prepared as part of the 2008 Colorado River Augmentation Study (Colorado River Water Consultants, 2008) estimated maximum limits to the diversion potential from the Snake, Bear, and Yellowstone Rivers and were used in this assessment. The previous study included evaluation of both water rights and hydraulic assessments to estimate potential diversion from the adjacent headwaters. The projected yield for these import options ranges from 33,000 afy to 75,000 afy.

The estimates of potential yield from Imports to Southern California were limited by the ability to integrate the import supply into the existing water supply system within Southern California. The availability of supply for locations in Alaska or the Columbia River was not assumed to be the limiting factor. Integrating large quantities of new supply to offset

Colorado River diversions would be difficult due to infrastructure constraints. Although the exact integration limit is difficult to quantify, 600,000 afy was selected based on rough estimates of integration capability. This volume is coincidentally consistent with other large-scale import options and therefore provides some degree of comparability.

Timing

The Import to Front Range group of options consists of large-scale infrastructure projects with at least 700 miles of conveyance infrastructure crossing at least two states and requiring at least 700 MW of power for pumping. Conveyance projects of this scale are rare and would require extensive feasibility studies, permitting, and design. Although the scale adds complexity, the type of infrastructure required has been implemented in many historical projects and has proven to be highly reliable. Confirming technical feasibility is anticipated to take approximately 5 years. The permitting phase will require multi-state negotiations, possible permits for new power plants, National Environmental Policy Act compliance, and evaluation of Endangered Species Act impacts. Even if the permit process were pursued with urgency and with political support, the process is expected to take up to 15 years. Once permitted, numerous design and construction crews could be mobilized to simultaneously construct several segments of the project. It is therefore possible to construct large-scale water transmission projects of this size in approximately 10 years. The total estimated time before the option could become operational is 30 years.

The group of options related to Imports to the Green River Headwaters is anticipated to divert quantities of less than 75,000 afy. The conveyance facilities vary in length between 15 miles and 140 miles and the infrastructure used to convey the water has been proven reliable. Therefore, project feasibility could potentially be evaluated within 3 years. Although these projects are not major infrastructure projects, the concepts include transbasin diversions from areas designated as state or national forests; therefore, special use permits for construction in the public lands will be required. Also, transbasin water projects have become increasingly challenging to permit due to both political and environmental concerns. Due to these concerns, at least 7 years of permitting is anticipated. Once permitted, numerous design and construction crews could implement these types of projects in up to 5 years. The total estimated time before options within this group could become operational is 15 years.

All options within the Imports to Southern California group of options could take at least 10 years to evaluate feasibility. Interstate negotiations would be required, as well as permitting at both the source water location and receiving water locations. It is estimated that this permitting process could take between 5 and 10 years and could take longer for the sub-ocean pipeline due to potential additional marine-related permitting. Once permitted, it would likely take 5 years to design and construct the ports and procure the required ships for transfer by tankers, water bags, or icebergs. It would take longer to construct more than 1,000 miles of sub-ocean pipeline. In summary, the feasibility phase would require at least 10 years; permitting would require at least 5 years; and implementation would require at least 5 years, totaling at least 15 years. The sub-ocean pipeline is anticipated to require up to 40 years due to the uncertainty related to the feasibility of this option and longer time required for construction.

Cost

To estimate costs for the Import to Front Range option group, topographic and aerial mapping were used to select a rough alignment for the proposed conveyance corridor. The pumping needs were estimated based on evaluating topographic relief and maintaining industry standard pressures. Once the size of the pipeline and number and size of the pumping stations were determined, recent historical parametric costs were used to estimate the total capital costs, which ranged from less than $9 billion to more than $14 billion for the different options. Annual costs include electricity costs, maintenance, repair, and replacement costs. The unit costs were developed by annualizing capital costs and adding in the associated annual O&M cost. The unit annual costs for the Import to Front Range options considered in the Study vary between $1,700 per af and $2,300 per af.

The group of options that import water to the Green River was analyzed by assuming configurations that utilized existing reservoirs, minimized pipeline lengths and utilized tunnels to reduce energy costs where feasible. Once the size and length of the facilities were determined, cost database information was used to estimate the total capital costs. Annual costs include electricity costs, maintenance, repair, and replacement costs. The unit annual costs for the options considered in the Study vary between $700 per af and $1,900 per af.

Costs for the Import to Southern California option group were based on literature research. Specifically, the cost per day to lease a Class VLCC (Very Large Crude Carrier) tanker ship (which includes the cost of the ship, crew, and fuel) was researched. The cost to construct a new terminal at an existing port near Los Angeles and in Alaska was estimated based on recent studies to build a new oil terminal in Los Angeles. The cost to build pipelines and pump stations from the port to Diamond Valley Lake was based on the cost of previously completed pipelines and pumping stations in this region. Total capital costs were estimated to be approximately $3.5 billion. The costs for sub-ocean pipeline concepts were based on previous Reclamation studies and were adjusted for inflation. The unit annual costs for the options considered in the Study vary between $2,700 per af and $3,400 per af

Other Key Considerations

In addition to yield, timing, and cost, the Front Range importations group of options were characterized against several other criteria. All of the Import to Front Range options were estimated to have very high energy needs and the potential for significant permitting, legal, and policy challenges due to project size, geographic extent, and concern related to potential impacts in the source watersheds. The resulting ratings for these criteria are low (“D” or “E”). The Front Range projects have high debt service costs because they are capital-intensive projects. Therefore, the Front Range options did not score well against operational flexibility criteria because the high cost of debt would still be incurred if the project is put into an idle mode. Although significant challenges would need to be overcome in order to implement such a project, once in operation the long-term viability (reliability of producing the expected yield) is expected to be relatively high. Imports to the Front Range would result in less water diverted than the State of Colorado is legally entitled to divert from the Colorado River headwaters, which would improve Basin hydropower, water quality, and recreation, and may improve some environmental conditions in the Basin; however, it is possible that the options would have some adverse impacts on the same criteria in the basin of origin due to reduced flows in those rivers. Imports to the Front Range would result in water quality that would meet all drinking water standards with conventional water treatment, but the source water quality would be poorer than the current supply used by many Front Range urban purveyors. Agreement from the State of Colorado, and the many water providers within Colorado, would have to occur in order for this option to be implemented.

Moreover, to the extent that it would require reducing the amount of water that the State of Colorado is legally entitled to take from the Basin, this option could require an amendment to the Colorado River Compact of 1922 (Compact) and Upper Colorado River Basin Compact of 1948.

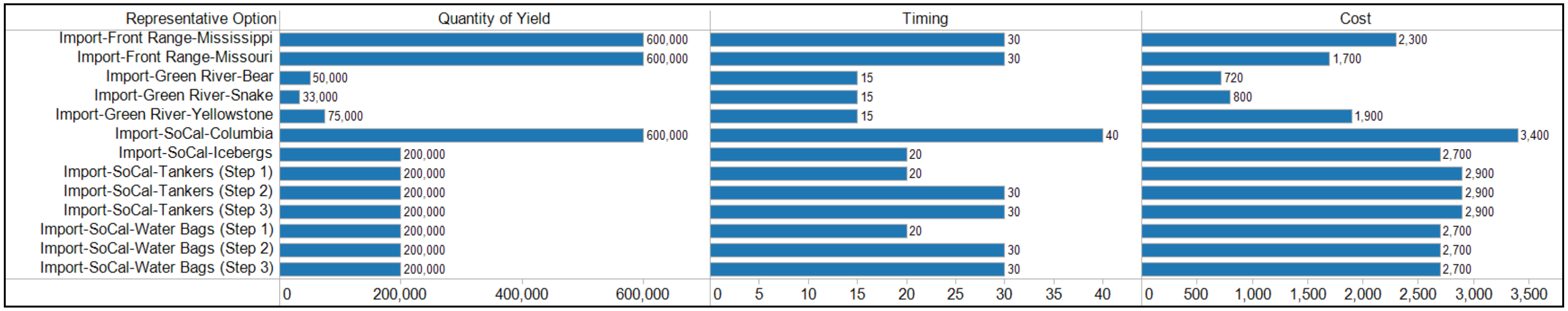
In general, imports to the headwaters of the Green River are similar to those described for the Imports to the Front Range group of options, with the following exceptions. Implementation risk is assumed to be lower because the challenges associated with raising capital are assumed to be lower for these smaller projects. Long-term viability is assumed to be more uncertain because the diversions are greater in relative percentage to the natural flow than other options and could face more long-term environmental challenges than diverting water from the Missouri or Mississippi rivers. The energy needs are much lower due to starting at higher elevations and the use of tunnels. Hydropower and recreation benefits are assumed to be fewer than the Front Range imports, due to the significantly lower flow volumes. Water quality impacts are assumed to be more positive because the water delivered to the Basin is essentially of the same quality as native Basin headwaters; however, water quality impacts in the basin of origin would also need to be considered.

The Import to Southern California group of options rated relatively low for technical feasibility. This is because sub-ocean pipelines, iceberg towing at large scale, or tanker operation at this scale is largely unprecedented. Permitting, legal, and policy issues will have all of the same issues as the other imports and will also have issues related to California Coastal Commission permits and marine permits. As with Imports to the Front Range, implementation challenges for these options include raising significant capital. In addition, these options are more challenging to integrate into existing systems than the other importation options. All of the imports via ocean routes required extensive energy or fuel and therefore have long-term viability challenges. Impacts to hydropower, recreation, and the environment would depend on the resulting change in operations of the Colorado River and potentially could have negative impacts if the Import to Southern California water option is exchanged for Colorado River water for diversion by others. Bringing this high-quality water to the region is expected to have a positive impact to salinity levels in the receiving region.

5.1.5 Characterization Summary

A summary of the characterization findings are shown in figure F-3. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy step, followed by subsequent steps In general, a “C” rating 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.

FIGURE F-3
Summary Characterization for Importation 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
Import-Front Range-Mississippi	A	D	D	B	C	C	D	D	E	C	C	A	C	D	D	A	C
Import-Front Range-Missouri	A	D	C	B	C	C	D	D	E	C	C	A	C	D	D	A	C
Import-Green River-Bear	E	C	B	A	A	D	D	D	C	C	D	C	C	C	D	C	C
Import-Green River-Snake	E	C	B	A	A	D	D	B	D	C	C	C	C	C	E	C	C
Import-Green River-Yellowstone	E	C	C	A	A	D	D	B	E	C	C	C	C	C	D	C	C
Import-SoCal-Columbia	A	E	E	E	D	E	D	E	E	C	D	C	C	E	E	D	B
Import-SoCal-Icebergs	D	C	D	D	D	D	D	C	E	D	C	C	C	D	C	C	A
Import-SoCal-Tankers (Step 1)	D	C	D	D	D	D	D	C	E	D	C	C	C	D	C	C	A
Import-SoCal-Tankers (Step 2)	D	D	D	D	D	D	D	C	E	D	D	C	C	D	C	D	A
Import-SoCal-Tankers (Step 3)	D	D	D	D	D	D	D	C	E	D	D	D	C	D	C	D	A
Import-SoCal-Water Bags (Step 1)	D	C	D	D	D	D	D	C	E	D	C	C	C	D	C	C	A
Import-SoCal-Water Bags (Step 2)	D	D	D	D	D	D	D	C	E	D	D	C	C	D	C	D	A
Import-SoCal-Water Bags (Step 3)	D	D	D	D	D	D	D	C	E	D	D	D	C	D	C	D	A

Southern California (SoCal)

5.2 Desalination

Ocean and brackish water desalination has been proposed to increase the overall water supply of the Basin. Fourteen options related to desalination were received. The submitted options were reviewed and organized into three groups according to the source of water to be desalinated. Representative options were developed for each option group to represent the distinct nature of the options within each group. 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" to represent likely project phasing. The option groups and representative options are described below.

Additional detail related to the representative options and specific characterization is included in appendix F5. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.2.1 Ocean Desalination

This group of options includes constructing new or expanding existing (or currently proposed) ocean desalination plants in strategic locations along the Southern California coast or near the international boundary in Mexico. The desalinated water would be delivered to some of the larger existing operational reservoirs in the Metropolitan Water District of Southern California (MWD) system or similar reservoirs in MWD member agencies' systems. This concept also includes constructing new ocean desalination plants along the Gulf of California in Mexico. This desalinated water would be delivered to Imperial Dam just north of the international boundary, where it could be left in the river to meet water commitments to Mexico or diverted by the All American Canal. For both the Pacific Ocean and Gulf of California desalination plants, the water could be exchanged to Lake Havasu or higher up the river to Lake Mead or Lake Powell, allowing the new supply to benefit water users up and down the river.

Three representative options were developed from this group of options to reflect the different potential desalination plant locations. The representative options consist of the following:

- Pacific Ocean Desalination in California
- Pacific Ocean Desalination in Mexico
- Gulf of California Desalination

The options related to Pacific Ocean desalination in California and Gulf of California desalination were separated into sub-options of 200-kafy steps to allow for incremental characterization of these large-scale options.

5.2.2 Desalination of Agricultural Drainwater

This group of options includes constructing new diversions upstream of the Salton Sea on the New River and Alamo River that would capture agricultural drainage water and deliver it to a regional brackish water desalination facility. The desalinated water would be delivered back to the All American Canal upstream of the East Highline Canal, allowing the water to be delivered to Imperial Irrigation District (IID) by exchange to the and Coachella Valley Water District, which rely on the All American Canal system. Simultaneously, an in-kind amount of reduction in diversions is possible from the Colorado River at Imperial Dam by exchange.

In this case, only one representative option was developed:

- Salton Sea Drainwater Reuse

The Salton Sea Drainwater Reuse representative option was separated into sub-options of 200-kafy steps to allow for incremental characterization of this large-scale options.

5.2.3 Desalination of Brackish Groundwater

This group of options is made up of relatively small local projects by municipal water providers in Southern California and Arizona consistent with past similar projects. This concept also includes refurbishing the Yuma Desalting Plant back to full-scale production.

Two representative options were developed from this group of options to reflect the differences in potential source water location, conveyance infrastructure needs, and associated impacts. The representative options consist of the following:

- Southern California Groundwater Desalination
- Brackish Water Desalting in the Yuma Area

5.2.4 Characterization of Options

Quantity of Yield

Based on discussions with MWD, yield from the options related to Pacific Ocean desalination in California are estimated to be limited to 600,000 afy. Yield from the options related to Pacific Ocean desalination near the border in Mexico is estimated to be limited to 75,000 afy. In the case of either Pacific Ocean representative option, integration considerations with existing infrastructure are the limiting factor. For the Gulf of California, additional yield is assumed to be limited to 1.2 mafy. However, for both Pacific Ocean and Gulf of California desalination options, sub-options of 200 kafy each were considered to allow for incremental characterization of these large-scale projects.

Agricultural drainwater desalination is limited to the amount of agricultural drainage water entering the Salton Sea and limitations of maintaining sufficient supply to mitigate for environmental impacts (e.g., air quality of increased exposed playa) at the Salton Sea. Between 300,000 afy and 500,000 afy of sustainable yield was assumed. Sub-options of up to 200 kafy each were considered to allow for incremental characterization of this large-scale option.

Yield from brackish groundwater desalination is limited by sustainable groundwater extraction rates, sustainable brine disposal capabilities, or the capacity of existing facilities. Without updating past studies, it is difficult to calculate the amount of remaining sustainable brackish groundwater yield in Southern California. A rough estimate based on those studies and previously identified projects is about 20,000 afy of additional sustainable yield remaining. The yield of brackish groundwater in the vicinity of Yuma, Arizona, is assumed to be limited to 100,000 afy by the available capacity of the Yuma Desalting Plant.

Timing

Each of the representative options for the ocean desalination group has unique permitting and legal challenges. The Pacific Ocean projects would require California Coastal Commission permits that can be challenging to obtain and would significantly impact the timing of the project. Similarly the Gulf of California ocean desalination option would require international negotiations and also environmental mitigation that could take an unknown amount of time. These challenges and uncertainties make it difficult to estimate the timing for both types of projects. It is roughly estimated that a 200-million-gallons-per-day (approximately 200,000-afy) project could require 5 years of feasibility, 10 years of permitting, and 5 years of implementation, totaling 20 years. For the Pacific Ocean desalination near the border in Mexico option, feasibility studies have been completed and additional studies are underway. It is roughly estimated that a 56,000-afy plant at this location could require 10 years of permitting and 5 years of implementation, totaling 15 years.

Desalinating agricultural drainwater in the vicinity of the Salton Sea changes the existing flow balance, and therefore compliance with the California Environmental Quality Act and National Environmental Policy Act would be required, as well as the acquisition of permits from entities in California. Mitigation of some of the impacts of reduced Salton Sea inflows is part of the Quantification Settlement Agreement (QSA). Consistency with the QSA would need to be evaluated. Although these would all take time, it is assumed that the option could be accomplished with 5 years of feasibility, 5 years of permitting, and 5 years of implementation, totaling 15 years. Each larger increment of this option was assumed to require an additional 5 years to implement due to greater potential impacts and permitting review.

For the brackish groundwater desalination group, both the concept related to municipal utilities developing relatively small-scale brackish groundwater desalting plants and the concept of refurbishing the Yuma Desalting Plant are proven technologies. Therefore, the timing for these projects is limited to 5 years of permitting and 5 years of implementation, totaling 10 years.

Cost

Several recent studies have included cost estimates for ocean desalination facilities. In addition to the information available from these studies, water treatment plant conceptual design and cost estimating tools were used to estimate treatment costs. The ultimate dollar-per-af cost for these options can vary significantly, based on scale and conveyance facility requirements. The larger the scale and the closer the delivery location, the lower the unit cost. Capital cost estimates ranged from approximately $2.8 to $4.2 billion. The unit annual costs for the representative options considered in the Study vary between $1,900 per af and $2,100 per af.

The same cost tools used to estimate the ocean desalination option group were used to estimate the desalination of Salton Sea agricultural drainwater option. Unit capital costs as well as electricity, chemicals, maintenance, repair, and replacement costs were assumed consistent with the ocean desalination option group. Assuming the drain water total dissolved solids (TDS) is approximately 2,500 milligrams per liter and the product water is 700 milligrams per liter, a unit annual cost of about $1,000 per af was estimated (capital costs were estimated at $2.1 billion).

The cost of the brackish groundwater group of options is highly dependent on the assumed salinity concentration of the groundwater and the method of disposing the brine stream from the reverse osmosis units. Capital costs were estimated at approximately $80 million. The unit annual costs for the representative options considered in the Study vary between $600 per af and $750 per af.

Other Key Considerations

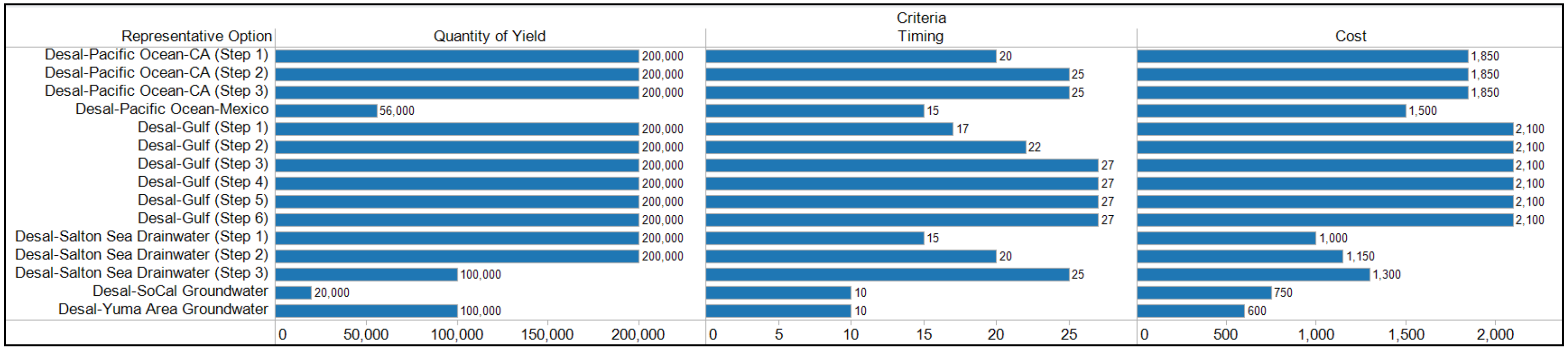
In regard to technical feasibility, ocean desalination facilities have been completed in numerous locations around the world, but none at the scale described for the larger concepts. Therefore, technical feasibility characterization varies based on scale and precedence for similar options. When considering long-term viability, there is some concern about the potential for increased electricity costs to impact viability. None of the desalination options rate high for operational flexibility criteria because these options would have high debt service costs that exist even when the option is put into an idle mode. These options rely on exchanges along the river to varying degrees, and these exchanges allow the yield to be distributed across numerous locations and could result in a change in how the river reaches are operated. These options could potentially have adverse impacts when considering hydropower, recreation, and other environmental flow-dependent resources. In regard to water quality, these options have the potential to have a significant positive impact in reducing salinity levels in locations where lower salinity water is delivered. Without more-detailed assessments, neutral conditions were assumed for socioeconomics.

The other key considerations for the agricultural drainwater and brackish groundwater desalination groups are similar to those described for the ocean desalination options, with a few exceptions. These options are rated higher for technical feasibility because they are on a scale more similar to existing desalination operations. Implementation risk and long-term viability are also rated higher due to the existing precedent for these types of operations and the reliable water source. Agricultural drainwater desalination at the Salton Sea is rated high for energy source because of the availability of geothermal energy in this region.

5.2.5 Characterization Summary

A summary of the characterization findings are shown in figure F-4. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps. In general, a “C” rating 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.

FIGURE F-4
Summary of Characterization Ratings for Desalination 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
Desal-Pacific Ocean-CA (Step 1)	D	C	C	B	B	C	D	D	D	C	C	C	C	C	D	C	B
Desal-Pacific Ocean-CA (Step 2)	D	D	C	C	B	C	D	D	D	C	D	C	C	C	D	D	B
Desal-Pacific Ocean-CA (Step 3)	D	D	C	C	C	D	D	E	D	C	D	D	C	C	D	D	B
Desal-Pacific Ocean-Mexico	E	C	C	A	B	C	D	D	D	C	C	C	C	C	D	C	C
Desal-Gulf (Step 1)	D	C	D	B	B	C	D	D	D	C	C	C	C	C	D	C	C
Desal-Gulf (Step 2)	D	D	D	C	B	C	D	D	D	C	D	C	C	C	D	C	C
Desal-Gulf (Step 3)	D	D	D	C	C	D	D	E	D	C	D	D	C	C	D	D	C
Desal-Gulf (Step 4)	D	D	D	D	C	D	D	E	D	C	D	D	C	C	D	D	C
Desal-Gulf (Step 5)	D	D	D	D	D	D	D	E	D	C	D	D	C	C	D	D	C
Desal-Gulf (Step 6)	D	D	D	D	D	D	D	E	D	C	D	D	C	C	D	D	C
Desal-Salton Sea Drainwater (Step 1)	D	C	B	B	C	A	D	C	C	A	C	C	C	D	D	C	C
Desal-Salton Sea Drainwater (Step 2)	D	C	B	C	D	B	D	D	C	A	D	C	C	D	D	C	C
Desal-Salton Sea Drainwater (Step 3)	D	D	B	C	D	B	D	D	C	A	D	C	C	D	D	D	C
Desal-SoCal Groundwater	E	B	B	A	A	B	C	B	C	C	C	C	C	A	B	C	B
Desal-Yuma Area Groundwater	D	B	B	A	B	A	C	C	C	C	D	C	C	A	C	C	C

Desalination (Desal); Gulf of California (Gulf)

5.3 Reuse

Reuse of existing water supplies was proposed as a method of increasing overall water supply in the Basin. Ten options were submitted related to wastewater reuse. The submitted options were reviewed and organized into three groups. Representative options were developed for each option group to represent the distinct nature of the options within each group. 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" to represent likely project phasing. The option groups and representative options are described below.

Additional detail related to the representative options and specific characterization is included in appendix F6. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.3.1 Municipal Wastewater Reuse

This group of options includes concepts related to reuse of municipal wastewater in major urban areas beyond projects currently planned. The group considers reuse options utilized for non-potable purpose such as irrigation or for potable purposes through indirect or direct methods.

One representative Basin-wide option was developed for this group, but includes regional differentiations related to types of reuse. For example, non-potable reuse was considered in all major municipal areas receiving Colorado River water. However, indirect potable reuse was considered for areas in Southern California and Arizona due to the current and already planned high levels of non-potable reuse programs. The municipal reuse representative option considers reuse for municipal uses including parks.

Current levels of municipal reuse vary throughout the Study Area. In adjacent areas where Colorado River water is essentially used to extinction, such as the Front Range of Colorado, increases in supply due to reuse are minimal. In addition, the future demand scenarios for these areas assume 100 percent reuse of additional Colorado River supplies.

Municipal Wastewater Reuse was separated into sub-options of 200-kafy steps to allow for incremental characterization of this large-scale options. Nonpotable reuse was assumed to occur initially such that the first step is entirely nonpotable reuse.

5.3.2 Industrial Wastewater Reuse

This group of options considers wastewater flows generated from a variety of industries that are not discharged through municipal wastewater systems. These are typically industries that have their own water supply and are often outside of municipal limits. The reuse of wastewater from various industries was considered. In this case, the only representative option is general industrial wastewater reuse.

5.3.3 Grey Water Reuse

Grey water is generally defined as untreated wastewater that has not been contaminated by any toilet discharge, has not been affected by unhealthy bodily wastes, and does not present a threat from contamination by unhealthful processing, manufacturing, or operating wastes (California Water Code, 2010). The reuse or recycling of this water at individual homes or communities can be used for non-potable purposes. This group of options assumes reuse of water for non-potable purposes at individual homes and is limited by the amount of residential wastewater generated as well as the seasonal nature of the associated non-potable demand. The representative option is described as grey water reuse in adjacent urban areas.

5.3.4 Characterization of Options

Quantity of Yield

For the municipal wastewater reuse group of options, potential demand was estimated based on their potential for non-potable reuse. This potential was only examined where wastewater return flows do not return to the Colorado River. The potential was reduced by currently planned reuse programs and generally by limitations on reuse due to water rights obligations. This method resulted in a non-potable reuse potential of about 360,000 afy in the Study Area. For California and Arizona, indirect potable reuse was assumed to be the most likely reuse method. Between the two states, yield estimates are approximately 570,000 afy based on integration limitations and preference for non-potable reuse where available. The total estimated reuse potential is approximately 930,000 afy.

Industrial reuse targeted specific industries and byproducts. The target industries largely lie within the self-supplied or “self-served industrial” category. Targeting 10 percent of the self-served industrial demand results in about 40,000 afy of reuse water.

Grey water reuse at individual homes for non-potable purposes could potentially supply about 178,000 afy by 2060. This rate is based on the assumption that 50 percent of residential indoor water use could be considered grey water (washing machines, showers, and sinks) and that grey water derived from this use could only be utilized to supply residential non-potable demands. These demands are on average approximately 60 percent of total household demand. An adoption rate of 50 percent was further assumed.

It is important to note that in many adjacent urban areas, such as the Front Range in Colorado, Colorado River grey water is treated and re-diverted for reuse by municipalities or for use by other downstream diverters entitled to the return flows under Colorado Water Law. Use of grey water for irrigation may reduce treatment costs; however, unless the actual outdoor irrigation consumptive use is decreased, there will be no net supply increase to the system.

Timing

Because traditional municipal wastewater non-potable reuse is commonly practiced in the Southwest, these options were assumed to require about 3 years for feasibility, 2 years for permitting, and 5 years for implementation for a total of 10 years. Indirect potable reuse options included an additional 10 years to reflect both their scale as well as associated permitting and implementation challenges due to integration with municipal treated water supplies. Each subsequent 200-kafy increment of municipal reuse was assumed to require an additional 5 years to implement.

Industrial reuse was assumed to be implemented in a similar timeframe to traditional non-potable reuse.

Grey water reuse options were also assumed to be implementable within a 10-year timeframe. The primary constraint is largely related to legal issues associated with plumbing code consistencies and health and safety concerns (individual systems).

Cost

Costs for municipal wastewater reuse were estimated for each type of reuse (e.g., non-potable and indirect potable). Traditional non-potable uses were derived from the augmentation study (Colorado River Water Consultants, 2008) with unit annual costs of about $1,500 per af. A parametric cost estimating tool was used to directly estimate the indirect potable reuse options, resulting in unit annual costs of about $1,800 per af due to additional treatment and distribution system costs. Capital costs to treat and convey the indirect potable reuse water were estimated to be approximately $4.8 billion. Based on the costs for each increment of municipal reuse, it was assumed that non-potable programs would be implemented first, followed by indirect potable reuse programs.

The industrial reuse group included treatment of produced water with TDS concentrations on the order of 15,000 milligrams per liter. Additional costs for collection and distribution of this water resulted in a unit annual cost of at least $2,000 per af.

Grey water recycling costs were derived from information available at www.greywateraction.org and had the highest cost of the reuse options due to the distributed nature of the systems. Water produced through this option is estimated to cost $4,200 per af.

Other Key Considerations

In addition to yield, timing, and cost, the municipal wastewater reuse group of options was characterized against several other criteria. In general, reuse is highly feasible and has been implemented on similar scales in other places in the region, nation, and the world. Reuse scores poorly under operational flexibility due to the likely associated debt service for a stranded asset. Energy needs range from 500 kilowatt hours (kWh) per af to 4,300 kWh per af for these options, with the indirect potable options having the greatest energy use. All options would have power from the grid, resulting in a mix of fuel sources. These projects are generally neutral with respect to hydropower production due to the distributed nature of Basin-wide reuse, but at larger scales the reuse is concentrated in Southern California and may have impacts due to potential for reduced releases from Hoover Dam for exchanges. Reuse options in the Upper Basin could result in increases in salinity as experienced in areas where reuse is heavily practiced. The indirect potable options would likely improve overall water quality given the removal of salt load through desalination for these options, but will require effluent disposal of concentrated brines, which could be challenging. Recreation impacts are assumed to be largely neutral, and no appreciable positive or negative impacts to socioeconomics are noted.

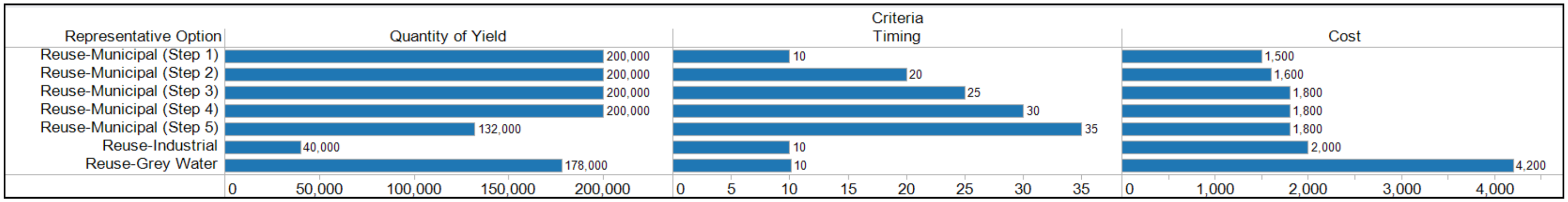
Industrial wastewater reuse characterizes similarly to municipal wastewater reuse. Energy needs would be on the order of 1,600 kWh per af with more treatment required than traditional non-potable reuse but less than for indirect or direct reuse. Industrial wastewater reuse may also require diesel fuel as the significant energy source due to hauling from the distributed locations.

Grey water reuse also characterizes similarly to municipal wastewater reuse. Grey water reuse would score well on operational flexibility in that it would likely be implemented on a case–by-case basis, resulting in little debt service and therefore no associated stranded asset. In addition, grey water reuse rated high for permitting and other environmental factors in that it would result in reduced wastewater discharge to sewer systems.

5.3.5 Characterization Summary

A summary of the characterization findings are shown in figure F-5. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy yield steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps (e.g., Municipal1, Municipal2, Municipal3.) In general, a “C” rating 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.

FIGURE F-5
Summary of Characterization Ratings for Reuse Options



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
Reuse-Municipal (Step 1)	D	B	C	A	B	B	D	A	B	C	B	C	C	A	A	C	D
Reuse-Municipal (Step 2)	D	C	C	A	B	B	D	A	C	C	B	C	C	A	A	C	D
Reuse-Municipal (Step 3)	D	D	C	B	B	C	D	B	D	C	C	C	C	B	B	C	B
Reuse-Municipal (Step 4)	D	D	C	B	B	C	D	B	D	C	D	C	C	B	B	D	B
Reuse-Municipal (Step 5)	D	E	C	B	C	C	D	C	D	C	D	C	C	B	B	D	B
Reuse-Industrial	E	B	C	B	B	B	C	B	C	D	C	C	C	D	B	C	C
Reuse-Grey Water	D	B	E	B	B	B	A	A	B	C	A	C	C	B	B	C	C

5.4 Local Supply

Developing new local supply was proposed to increase the overall water supply of the Basin. Four options related to local supply were received. The submitted options were reviewed and organized into two groups according to the source of local supply. Each group is described below. Because of the scope and level of detail provided in the proposed options, the option groups are also used as representative options for the characterization process.

Additional detail related to the representative options and specific characterization is included in appendix F7. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.4.1 Coal Bed Methane-produced Water

In the process of developing natural gas resources, poor quality groundwater is typically "produced" from natural gas wells. The coal bed methane (CBM) industry has generally disposed of produced water at the least possible cost rather than treat and use this potential resource. In most cases, CBM-produced waters are disposed by injection into Class II underground injection wells. This group of options considers treating the relatively high salinity water and using it to augment supply in the Basin.

5.4.2 Rainwater Harvesting

Rainwater harvesting is the capture, diversion, and storage of rainwater for landscape irrigation and other uses. This option group considers how individual household rainwater harvesting can increase local supply in some areas of the Basin, with particular emphasis on those areas that do not provide return flows to other users downstream.

5.4.3 Characterization of Options

Quantity of Yield

Field estimates for CBM-produced water are based on recent CBM development data and production estimates combined with unit water production data specific to the Rocky Mountain region coal basins. Using the CBM reserves data and a conservative unit water production of 5 to 10 gallons per million cubic feet of CBM gas, total potential produced water volumes for the four major coal basins located within the Basin are projected to be between 161,000 to 322,000 afy, based on proved reserves, and between 279,000 to 558,000 afy, based on total estimated reserves. For the purpose of the Study, it was assumed that CBM wells are installed to extract all the reserves over the next 40 years, resulting in between 4,000 afy and 14,000 afy.

Yield estimates for individual rainwater harvesting are based on normal precipitation in specific regions combined with average roof size, landscaped area, and number of households. Using this information, a simple rainwater harvesting tool was developed to estimate the potential yield from implementation of distributed rainwater harvesting systems. The resulting Basin-wide yield estimate is approximately 75,000 afy.

Timing

A number of CBM wells are currently producing water; however, the infrastructure needed to treat and convey the water would first require policy incentives and then construction. Additionally, to realize full-scale benefits, more CBM wells need to be developed. For the Study, the time required to affect policy incentives was assumed to be 5 years. The needed infrastructure to treat and convey the water was assumed to need another 5 years for construction, and the development of additional wells could take up to 20 years. Therefore, it would take 5 to 10 years to produce some volumes of new water, and up to 20 years for large-scale benefits to be realized. Availability of this source will be dependent on continued CBM production and therefore it will be subject to market volatility and long-term viability issues, increasing supply uncertainty. For the purposes of the Study, it was assumed that CBM production would occur over the next 40 years until proven reserves are exhausted.

Rainwater harvesting is already being used in some areas of the Basin. The concept is currently feasible, in many cases does not require permitting, and is simple to implement with very little infrastructure. Therefore, in locations where there is not a water rights issue, the 50-percent adoption rate used to estimate yield could be achieved within 5 years.

Cost

Because of typically poor water quality, required treatment facilities are the principal factor in capital costs. To treat 500 gallons per minute of CBM-produced water with TDS concentration of 15,000 milligrams per liter, approximately $4 million in treatment facilities are required. Intensive pre-treatment and reverse osmosis result in estimated operating costs of $600 to $635 per afy of produced water. When conveyance is considered, an average cost of $2,000 per afy was assumed.

The cost for purchase and installation of a 500-gallon storage tank and irrigation modifications was assumed to be $1,000 per household. Because of the limited storage capacity and the mismatch in timing of rain events and water demand, harvested rainwater only delivers approximately 10 percent of outdoor demand, or approximately 0.02 af per household. As a result, the calculated unit cost of water is estimated at $3,150 per afy.

Other Key Considerations

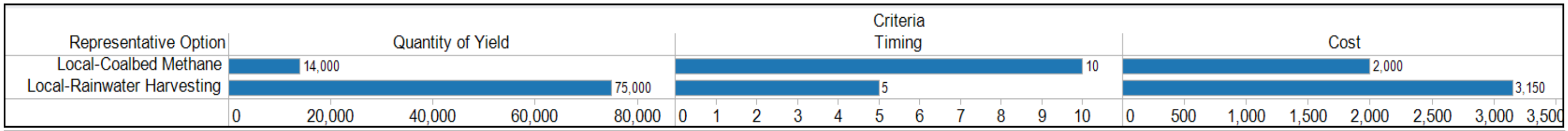
In addition to yield, timing, and cost, the CBM-produced water option group was characterized against several other criteria. National Pollution Discharge Elimination System permits would be required to discharge the treated water into the watershed, and modifications to existing permits would be needed for brine disposal. Challenges associated with implementation include the water source’s dependence on the highly volatile energy sector and the large spacing between wells, which increases operating costs and reduces flexibility. Finally, the process is energy-intensive. Desalting the water would require approximately 4,700 kWh per af, and transporting the water from individual wells to collection sites would most likely be done using trucks. In addition, there are legal issues that would have to be addressed in order to implement the use of CBM-produced water.

Aside from the high capital cost for individual households, the rainwater harvesting option group is easy to implement, is already practiced in many states, has no energy needs, and, depending on state and local laws, does not require any permitting. Nonetheless, in some states this option is not currently permissible under state laws. Due to water rights concerns to downstream users and state law, rainwater harvesting was not considered for Colorado or Utah.

5.4.4 Characterization Summary

A summary of the characterization findings are shown in figure F-6. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. 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.

FIGURE F-6
Summary of Characterization Ratings for Local Supply Options



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
Local-Coalbed Methane	D	B	C	B	B	C	C	B	D	D	C	C	C	B	B	C	C
Local-Rainwater Harvesting	E	A	E	A	A	B	A	A	A	A	B	C	C	B	B	C	C

5.5 Watershed Management

Changes to watershed management have been proposed to increase the overall water supply of the Basin. Ten options related to watershed management were received. The submitted options were reviewed and organized into five groups according to the specific type of watershed management recommendations. Each group is described below. 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".

Additional detail related to the representative options and specific characterization is included in appendix F8. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.5.1 Tamarisk Control

Control of invasive tamarisks has been proposed for riparian areas to reduce their overall consumptive use and increase streamflow in the Colorado River. Removal of tamarisk is proposed in riparian benches where water that would have otherwise contributed to streamflow is being consumptively used by tamarisk. A comprehensive report on the state-of-the-science of tamarisk management in the Basin is the *Colorado River Basin Tamarisk and Russian Olive Assessment* prepared for the Basin States by the Tamarisk Coalition (2009). It is the primary basis of the yield estimates.

5.5.2 Forest Management

A large percentage of the runoff from the Basin is derived from forests, particularly in Colorado. Previous studies and information have demonstrated that areas in which forest cover is reduced by clear-cutting or fires have shown dramatically increased amounts of runoff. This is the result of reduced interception, decreased evapotranspiration, and sometimes reduced permeability of the soil surface. The magnitude of increased runoff over affected areas may be as much as 100 millimeters, or 4 inches, per year. The forest management group of options would entail 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. The demonstration of the viability of this option starts in Colorado because the majority of flow of the Colorado River system results from runoff generated in that state. Even though Arizona, New Mexico, Utah, and Wyoming have significant forested areas, the annual amounts of runoff from the forested areas in these states is much lower than in Colorado. The forested area in Colorado covers more than 21,000,000 acres, most of which is in the Basin and generates an average annual runoff of approximately 11 mafy.

The Forest Management representative option was separated into sub-options of 200-kafy steps to allow for incremental characterization of this large-scale option.

5.5.3 Brush Control

Brush control involves reducing brush and therefore reducing consumptive use by vegetation communities. There is some evidence that removal of brush and replacement with native grasses improves runoff conditions, particularly in areas receiving more than 18 inches of rainfall annually. The Basin includes as many as 100,000 square miles of land under the control of the Bureau of Land Management (BLM) that is vegetated to varying degrees by brush. The brush control group of options recommends various techniques available for brush removal including chemical spraying, chaining, roller chopping, root plowing, grubbing, and controlled fires. For all types of removal, reseeding with native grasses is required. Most removal methods must be repeated at approximately 8- to 10-year intervals to prevent new growths of brush from emerging and dominating.

5.5.4 Dust Control

These options propose to control land-based dust sources that contribute to dust accumulation on snow, which changes the albedo of the snow resulting in earlier snowmelt (Painter et al., 2007 and 2010; 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.

The Dust Control representative option was separated into sub-options of 200-kafy steps to allow for incremental characterization of this large-scale option.

5.5.5 Weather Modification

The weather modification group of options was based on two practices. The first is by cloud seeding, particularly by introduction of atmospheric silver iodide to serve as condensation nuclei that would increase snowfall over mountain regions. The second is to create more inland seas, thereby increasing the amount of atmospheric moisture due to increased evaporation. Because neither data nor investigations were submitted to support the viability of the second option, the primary focus was on evaluating the feasibility of weather modification through cloud seeding. Winter cloud-seeding operations have been practiced throughout the West since the late 1940s. In recent years, ongoing cloud-seeding operations have been documented in at least five of the seven states within the Basin.

The Weather Modification representative option was separated into sub-options of 200-kafy steps to allow for incremental characterization of this large-scale option.

5.5.6 Characterization of Options

Quantity of Yield

The total tamarisk acreage in the Basin has been mapped at 250,000 acres. This value is considered low because a significant amount of the data are point data with no actual acreage assigned to this information. If one-fourth of the total tamarisk acreage can be managed by a tamarisk removal program, the total program acreage is about 60,000 acres. As a Basin-wide average, normalized for climate, elevation and latitude estimates of water savings due to reduced evapotranspiration by removal of tamarisk and replacement by other species are roughly 0.54 af per acre per year. At this rate of water savings, conversion of 60,000 acres from tamarisk to other species would save approximately 30,000 afy of consumptive water use.

As a simplifying assumption for the forest management group of options, it was estimated that if 5 percent of the forested area in Colorado were managed to increase runoff and the magnitude of the increased runoff was 4 inches, more than 300,000 afy of increased flow would be generated. However, the increased yield is expected to rapidly decline as new growth begins to replace harvested areas.

Average runoff in the areas of BLM land considered for the brush control group of options is minimal, typically in the range of 0.05 to 0.1 inch annually. Therefore, total runoff from this area is approximately 250,000 to 500,000 afy. For evaluation purposes, it was assumed that brush control could potentially increase runoff by 10 percent. The resultant maximum benefit that could be expected if brush control were implemented on all BLM land in the Basin would be 25,000 to 50,000 afy.

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. 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 evaluated to be no more that 50 percent of the total potential amount, or 400,000 afy. Two steps of this representative option were derived based on targeting key areas of emissive lands versus more-distributed dust control.

For the weather modification group of options, it is estimated that cloud seeding six major runoff-producing areas could produce between 1.1 and 1.8 mafy in the Upper Basin and an additional 830,000 kafy in the Lower and adjacent basins. Of the total, it has been estimated that approximately 1.7 mafy would be available to reduce deficits or meet new demands. Due to the large potential of this option, sub-options of 200,000 afy each were characterized to reflect potential issues associated with the scale of the option.

Timing

Several ongoing studies and programs have focused on tamarisk control. It is assumed that implementing this option group would involve a new program that would build upon earlier efforts. A programmatic approach to permitting is assumed that would result in evaluation of feasibility within 2 years, obtaining required permits within 5 years, and then implementation over a 5-year time frame. Therefore, it is possible to see full-scale benefits from the tamarisk control group of options within 12 years.

The forest management group of options is feasible only if the approach is to perform selective harvesting of mature trees in areas where the density is too high, combined with understory clearance to minimize forest fires. Other areas of focus would be revegetation of lands that have been deforested by forest fires or insect infestations. The time to evaluate the feasibility of forest management activities was estimated to be 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, although not for purposes of increasing runoff. The timing for implementation of forest management practices was estimated at 10 years to conform to time frames experienced with other forest management measures. Therefore, the total time for development of the forest management group of options is estimated to be 20 years. An additional 10 years is assumed to implement the program at a full scale.

Brush control on BLM land involves 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. The time requirements for evaluation of feasibility were estimated to be 5 years, 5 years for permitting, and 5 years for phased implementation. Therefore, the total time required for availability of increased runoff from brush control on BLM land would be at least 15 years.

The essential consideration in determination of timing for developing increased runoff through dust control is that dust management practices would have to be implemented over a relatively large portion of the Colorado Plateau and the Great Basin. The large areal extent led to an estimate of the timeframe to evaluate effectiveness as 5 years, followed by 5 years for permitting, and 5 years for the first phase of implementation, for a total of 15 years. An additional 10 years is assumed for the next increment of implementation due to the more distributed nature of management. 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.

Weather modification programs have been in effect for many years throughout the West, including in the Basin. Based on these existing practices, no additional time would be required for feasibility or permitting of smaller-scale projects. Implementation of smaller-scale projects could be completed in 5 years, with each larger increment assumed to require an additional 5 years for implementation.

Cost

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

For the forest management group of options, the extent to which existing forest roads are available (to provide better access for vegetation harvesting and replacement) will have a significant impact on cost. One study indicated that the cost could be around $500 per acre after considering potential revenue benefits by selling harvested products to processing mills. Additional estimates of costs experienced by the U.S. Forest Service for similar management activities ranged from $114 to $786 per acre, with estimates for individual forest areas from $215 to $1500 per acre on a 20-year rotation. The median cost value was $875 per acre. Assuming a cost of $1,000 per acre on a 20-year rotation, with annual maintenance costs of about 10 percent of that amount, the unit annual cost of additional runoff generated is approximately $500 per af.

For brush control on BLM land, the preferred method of control would be spraying of 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, annual cost would be approximately $7,500 per af.

For the dust control option, it was assumed that conversion of the land to native grasses would require practices similar to enrollment in the U.S. Department of Agriculture Conservation Reserve Program. 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 average cost of $15 per acre per year was derived. Implemented over an area of 10,000 square miles, the cost per af of increased yield is $500. The first phase of a dust control program is assumed to target those areas of the Colorado Plateau that are the most prolific in generating dust emissions and would produce greater yield per acre of management than the second phase, so cost per afy is estimated at $220.

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 reference 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 annual cost estimate of $20 to $30 per af. Higher costs were estimated for larger-scale programs due to reduction in yield enhancement for less productive regions or storms for similar levels of investment.

Other Key Considerations

For the tamarisk control option group, some studies have indicated that the species replacing tamarisk may have consumptive water use levels as great as the tamarisk unless the revegetation process is actively managed, resulting in a low rating for long-term viability. However, one would not consider managing tamarisk to increase water supply unless the replacement vegetation was native and used less water. Active management is also required to ensure that tamarisk do not reinvade the replacement species in the riparian zone. Reinvasion is reduced along regulated rivers because the ability of seed to be dispersed by flood in river valley bottoms (and germinated in the wet zone) is minimized. Studies have also shown that tamarisk stands along alluvial channels are effective in anchoring stream banks and preventing stream erosion. One unintended consequence of tamarisk control may be an increase in stream erosion in affected reaches, resulting in a low rating for water quality until replacement vegetation is established. If the option is practiced only on the upland terraces, this adverse impact would be minimized. Also, tamarisk control was rated poorly for energy source because the equipment used for implementation would likely rely on diesel and gasoline fuel. A potential benefit of tamarisk control is improved access to the areas of control for recreational purposes because replacement species are more amenable to recreational activities, but removal of tamarisk currently being used by endangered and protected species may be an important consideration. There are other benefits in terms of riparian habitat improvements associated with this option.

Forest management is a mature science. Objectives have generally been to increase lumber production, maintain habitat and ecosystems, or limit erosion. The primary objective of forest management has rarely been to improve runoff conditions. As a result, the overall technical feasibility, implementation risk, long-term viability, and operational flexibility are uncertain. Forest management would require overcoming substantial implementation and permitting hurdles. Although energy needs would be relatively low, the source of energy would likely be diesel and gasoline fuel.

Although the brush control group of options is considered in terms of potential benefit through implementation of brush control over a large area, the specific process used for brush control to best optimize resultant impacts on hydrology, vegetation, and habitat is very site-specific. Brush management over a large scale is expensive and requires ongoing maintenance to ensure that the benefits of brush removal are being realized. For example, when brush is removed and replaced with native grasses, proper grazing management is required for several years to make sure that the grasses are well-established. When not done properly, brush control can adversely affect hydrology and grazing and habitat values. For these reasons, technical feasibility, implementation risk, long-term viability, and operational flexibility were all given low ratings.

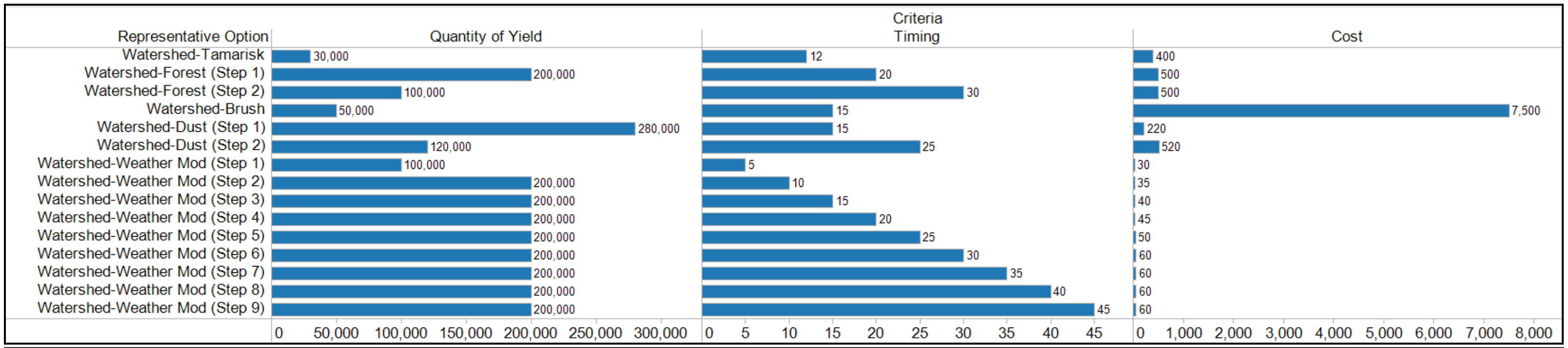
Other key criteria for the dust control option were also ranked similarly to the other watershed management options.

Weather modification ranked high for operational flexibility 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.

5.5.7 Characterization Summary

A summary of the characterization findings are shown in figure F-7. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy yield steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps (e.g., Dust1, Dust2, Dust3.) In general, a “C” rating 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.

FIGURE F-7
Summary of Characterization Ratings for Watershed Management Options



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

Weather modification (Weather mod)

5.6 Municipal and Industrial Water Conservation

Development of additional M&I water conservation was proposed to further reduce the overall M&I water demand in areas currently relying upon water supply from the Colorado River. A number of M&I conservation options were submitted for consideration in the Study, with several of the submitted options suggesting specific conservation measures. Many of these measures have been implemented at a number of locations in the Study Area.

Because levels of current and future conservation vary throughout the Study Area, different levels of potential savings are possible for a given conservation measure. These savings range from essentially no savings where measures have been fully implemented to significant savings where measures have not been implemented or where adoption rates are relatively low. Disaggregating the savings potential by conservation measure and individual location was beyond the scope of the Study. Instead, M&I conservation measures were considered for the entire Study Area with the acknowledgement that, despite state and regional differences in current levels of conservation and potential for future conservation, additional conservation is achievable on a Study Area-wide basis. Likewise, it is assumed that additional conservation is due to an "active" incentive-based program, such as paying for conversion of turf to xeriscape, toilet replacement, etc. The total potential yield of M&I conservation exceeds 200 kafy, therefore the representative option was characterized in progressive 200 kafy "steps".

Additional detail related to the representative options and specific characterization is included in appendix F9. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.6.1 Overall Approach

These levels of additional M&I demand reduction could be implemented through use of progressively ambitious water conservation best management practices (BMPs) and adoption rates targeting residential indoor; commercial, institutional, and industrial (CII); outdoor landscaping; and water loss demand. Example BMPs and a more-complete discussion of the approach to characterizing the additional M&I conservation option can be found in appendix F9. Not included in this approach are water use restrictions that may be used as a local response to short-term drought. These practices are commonly included in municipal drought management plans and may include activities such as enhanced public education and outreach, tiered levels of voluntary and mandatory restrictions, short-term rationing, and short-term water rate increases. These drought response measures have not been included because they vary significantly by geographic location and reflect a short-term agency-specific response to supply challenges rather than a long-term measure for balancing supply and demand.

Many of these BMPs have already been enacted throughout the Study Area, resulting in significant conservation savings. For example, a recent study of municipal deliveries of Colorado River water (Pacific Institute, 2011) found that most of the municipalities receiving

Colorado River had experienced significant reductions in per capita water deliveries for the period 1990 through 2008. A number of States such as California and Utah have programs in place that target a certain amount of reduction over time (e.g. California's 20x2020 program). Likewise, a number of individual communities, such as Phoenix, Albuquerque, Denver, and Las Vegas, have specific M&I conservation goals. As such, representative BMPs are available to varying degrees throughout the Basin.

In order to examine the potential for additional M&I conservation and to explore the range of costs and other factors, three levels of conservation were considered based on assumed levels of reductions and adoption rates for residential indoor, CII, landscape, and water loss. Table F-2 presents the assumptions for Level 1, Level 2, and Level 3 conservation. The assumptions in table F-1 were derived from state of Colorado (Colorado Water Conservation Board, 2011) and California (CALFED, 2006) approaches and applied to Study Area projected demand to result in a Basin-wide estimate of potential water savings. The assumptions were derived for purposes of the Study and do not necessarily reflect realistic or achievable local conservation goals.

Although performing a municipality or regional level analysis of the M&I conservation is beyond the scope of the Study, the assumptions are generally consistent with regional approaches considered in Colorado (Colorado Water Conservation Board, 2011) and California (CALFED, 2006).

TABLE F-2
Study Area M&I Conservation Assumptions

	Level 1	Level 2	Level 3
Residential Indoor			
Indoor gallons per capita per day (gpcd)	60	50	40
Adoption rates	50%	60%	70%
Example types of BMPs: Public education programs, conservation-oriented plumbing and building codes, residential water surveys, high efficiency showerheads and faucets, ultra low-flow toilets, efficient clothes washers, meter retrofits, etc.			
CII			
Target reduction in demand	15%	25%	30%
Adoption rates	50%	60%	70%
Example types of BMPs: Public education programs, conservation-oriented plumbing and building codes, green building codes, CII surveys and audits, high efficiency faucets and fixtures, ultra low-flow toilets, high-efficiency clothes washers, dishwasher high-efficiency pre-rinse spray valves, meter retrofits, efficiency in industrial processes and cooling, etc.			
Outdoor Landscaping			
Target reduction in demand	15%	25%	35%
Adoption rates	50%	60%	70%
Example types of BMPs: Public education programs, conservation-oriented pricing, large landscape water surveys and audits, evapotranspiration-based irrigation controllers, large landscape separate metering, irrigation efficiency improvements, conversion of turf to lower water use landscaping, etc.			
Water Loss			
Target water loss	7%	7%	7%
Adoption rates	50%	60%	70%
Example types of BMPs: Utility water loss control, supply system audits and leak detection programs, etc.			

5.6.2 Characterization of Options

Regional Considerations

The potential M&I water conservation measures are assumed to apply to the Study Area, but significant differences in potential water savings exist between geographies due to the current level of conservation adoption, commercial and industrial base, and climate. In addition, because return flows may provide flow for indirect recycling for some in-Basin locations, indoor conservation has little to no net effect on water resources to meet M&I water demand in these locations. For in-Basin locations, only reductions in consumptive use will reduce overall Colorado River system demand as the return flows from the urban areas is returned to the Colorado River or a tributary.

In many of the major urban areas receiving Colorado River or tributary water, the overall water supply served to communities consists of a significant portion of other supplies (other surface supplies, groundwater supplies, reuse, etc.) in addition to Colorado River or tributary water. In most of these out-of-Basin areas, the supplies are commingled in the water supply and distribution systems before delivery to the consumer. Due to the distributed nature of water conservation, water conservation will reduce the overall demand on these supplies, but is not likely to result in a one-for-one reduction in Colorado River demand. Likewise, in many adjacent areas, water exported from the Basin is reused essentially to extinction. Municipal conservation in these areas reduces the amount of water available for reuse, and does not result in a one-for-one reduction in Colorado River demand.

Implementation Approaches

The primary implementation approach under consideration for M&I water conservation is an incentive-based program. Public education programs, regulations dictating standard practices for new development, and incentive-based programs encouraging more efficient water use are typically implemented. These programs provide the necessary incentives (financial or otherwise) to achieve the levels of conservation. Financial incentives provide a cost share for implementation of BMPs and have been widely used to facilitate conversion to higher-efficiency fixtures and toilets. These types of mechanisms are anticipated to continue to be widely used to achieve higher levels of conservation in areas served by Colorado River water. Non-incentive based approaches such as plumbing code changes and public education programs are considered as well.

Quantity of Yield

As described in *Technical Report C – Water Demand Assessment,* M&I water conservation measures have been implemented at many locations throughout the Basin, resulting in significant reductions from historical per capita use. The future demand scenarios include, to varying degrees, by both scenario and location, some portion of passive conservation (resulting from outside entities/programs, such as federal standards) and active conservation (resulting from active state and local programs). Conservation considered in the demand scenarios ranges from about 300 kafy to more than 1.1 mafy, depending on the assumptions within each scenario regarding degree of per capita water demand reductions[3]. Additional conservation beyond that included in the demand scenarios was considered in the three additional conservation levels (Levels 1, 2, and 3). The demand reduction from each of these levels was computed by applying the assumptions in table F-1 to the M&I demand over the entire Study Area. Table F-3 presents the potential additional savings of Colorado River water under these assumptions. For all scenarios, these values represent the additional demand reduction by 2060.

[3] The level of M&I conservation included in the water demand scenarios is estimated by first re-computing the M&I demands under each scenario, assuming the 2015 gpcd value from that scenario. The difference in the M&I demand in 2060 with gpcd held at 2015 levels from the M&I demand in 2060 under the actual demand scenario is the amount of M&I conservation achieved under that demand scenario.

TABLE F-3
Reductions in Colorado River Basin Demand (afy) for Each Demand Scenario and Conservation Level at 2060

Conservation Level	Current Projected (A)	Slow Growth (B)	Rapid Growth (C1)	Rapid Growth (C2)	Enhanced Environment (D1)	Enhanced Environment (D2)
Savings Assumed in Demand Scenarios	478,000	296,000	621,000	1,048,000	1,052,000	1,114,000
Additional Savings from M&I Conservation						
Level 1	185,000	187,000	207,000	56,000	44,000	55,000
Level 2	576,000	504,000	681,000	427,000	238,000	383,000
Level 3	1,051,000	888,000	1,258,000	960,000	654,000	908,000

Significant water conservation has occurred in the recent decades through most urban centers in the Study Area. The M&I water conservation savings realized in the demand scenarios and potential additional measures will likely occur at a lower annual rate than what has been observed in recent historical periods due to differing types of conservation measures and greater adoption rates that will need to be included. In addition, as water use efficiency increases, the ability to further reduce use diminishes and the uncertainty with respect to future yield increases.

As noted for other options, in order to represent the challenges associated with increasing scale, when options exceed 200-kafy yield or demand reduction, they were generally assumed to be implemented in 200-kafy steps. For example, for the Current Projected (A) scenario, M&I conservation options would be available in five steps of 200 kafy each and a final sixth step of at 51 kafy. These steps are assumed to proportionally implement progressive amounts of the individual levels noted in the table. For example, for the Current Projected (A) scenario, the first increment of conservation will implement 185 kafy of “Level 1” practices and 15 kafy of “Level 2” practices.

Timing of Option Availability

Because the M&I water conservation options would be ramped over time, each of the options could begin implementation with benefits starting to accrue within 5 years. The potential savings of the options would be small in the early years of implementation and grow over time. Ultimate savings for each level are assumed to occur in 2060, with the savings progressively ramping upward from 2015 through 2060. However, it is possible that adoption rates could be slower or faster than those included in the conservation-level assumptions. In addition, conservation Level 2 would in all likelihood need to have adopted all conservation Level 1 measures, and conservation Level 3 would need to have adopted the majority of the measures and adoption rates from Level 2.

Costs

Table F-4 presents the estimated costs per af of water conservation savings to implement the suite of BMPs for each conservation level. The costs range from roughly $350 to $1,400 per afy reduction in demand. These costs do not reflect any associated reduction in revenue due to reduced water sales. CII and outdoor landscaping water conservation measures represent the most cost-intensive measures. Based on the assumption that the water conservation savings result in proportional savings to all supplies contributing to Study Area delivery, the demands for Colorado River water may only be reduced by about 40 percent of the total Study Area demand reduction. However, it is assumed that the cost to Colorado River water users is solely for the reduction (benefit) that they achieved and that "other" beneficiaries would pay for their portion of the overall benefit. It is quite possible that M&I water conservation in some regions outside of the hydrologic basin may result in little to no reduction in Colorado River demand due to cost considerations within the region's water supply portfolio.

TABLE F-4
Estimated Costs per af Demand Reduction for Each Conservation Level at 2060

Costs (afy) for Demand Reduction by Category			
	Level 1	**Level 2**	**Level 3**
Residential Indoor	$350	$450	$550
CII	$550	$900	$1,200
Outdoor Landscape	$700	$1,050	$1,400
Water Loss	$350	$350	$350
Weighted Average	$500	$750	$950

Other Key Criteria

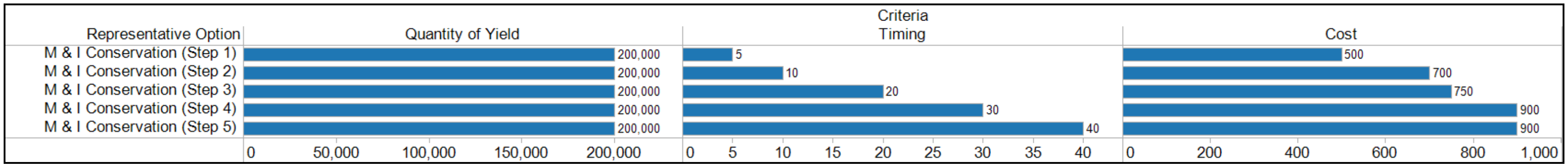
In addition to yield, timing, and cost, the M&I conservation options were characterized against several other criteria. In general, the initial reductions are feasible and comparable examples exist in areas of the Southwest and in other arid regions of the world. Subsequent reductions become progressively more difficult to achieve and maintain. Programs of this scale are underway at state levels, but have not been demonstrated on basins of the scale of the Colorado River in North America. It is not anticipated that permitting or legal changes will be required to implement these options, but agreements on the methodology and institutional structure will be required to implement these options in this multi-jurisdictional basin. Some policy changes may be required to fully implement the Level 3 assumptions, and implementation on such a large scale might require landscape conversion to xeriscape. There is some implementation risk in that yields will fluctuate over time and programs will require continuous funding to maintain overall results. Many conservation measures are based on achieving behavior changes in the way water is valued and used. The realized conservation savings associated with these measures may be dependent on future economic, social, and political conditions that maintain and strengthen these behavior changes. However, once savings are realized through most measures they generally can be maintained, resulting in long-term viability of the options. These options were rated high with respect to operational flexibility because the programs can be stopped at any time without incurring significant debt service or resulting in stranded assets. There are no inherent energy needs for the M&I conservation options in that they result in reduced demand and reduced need to treat and deliver water. For the highest levels of conservation, there could be some socioeconomic issues as turf is converted to xeriscaping.

5.6.3 Characterization Summary

A summary of the characterization findings are shown in figure F-8. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, for implementation purposes, some large options were broken into 200-kafy yield steps to reflect increasing complexity as project size increases. For conservation, the three conservation levels resulted in demand reduction (yield) from about 600,000 afy to 1.2 mafy. These resulting yields were implemented in 200-kafy steps. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps.

In general, a “C” rating 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.

FIGURE F-8
Summary of Characterization Ratings for M&I Conservation 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
M & I Conservation (Step 1)	D	A	A	A	A	B	A	A	A	A	A	A	B	A	A	B	B
M & I Conservation (Step 2)	D	B	A	A	B	B	A	A	A	A	A	A	B	B	A	B	B
M & I Conservation (Step 3)	D	C	A	A	B	B	A	A	A	A	A	A	B	B	A	B	B
M & I Conservation (Step 4)	D	D	A	B	C	C	A	A	A	A	A	A	C	B	A	B	B
M & I Conservation (Step 5)	D	E	A	B	C	C	A	A	A	A	A	A	C	B	A	B	B

5.7 Agricultural Water Conservation

Options were submitted proposing agricultural water conservation to reduce the overall water demand in areas currently relying upon water supply from the Colorado River. These options ranged in type from specific conservation mechanisms or BMPs (e.g., improved irrigation efficiencies, modernization, conveyance system efficiencies, changes in types of crops under irrigation, etc.) to general implementation approaches to achieve further water conservation (e.g., water pricing or water transfers). These options were used to develop agricultural water conservation representative options. The representative options were parsed into 200 kafy "steps" to represent likely project phasing.

Additional detail related to the representative options and specific characterization is included in appendix F10. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.7.1 Overall Approach

The concepts received were first organized into six Basin-wide agricultural water conservation mechanisms that reflect different types of activities that could generate water savings in the agricultural sector. These agricultural water conservation measures consist of advanced irrigation scheduling, deficit irrigation, on-farm irrigation system improvements, controlled environment agriculture, conveyance system efficiency improvements, and fallowing of irrigated lands. However, because the method of implementation is important for realization of warter savings, two implementation approaches that could be used to encourage or incentivize adoption of these water conservation mechanisms were used to develop representative options— (1) *Basin-wide agricultural conservation* through a federal or state incentivized program to encourage agricultural water use efficiency, and (2) *Basin-wide agricultural conservation with water transfers* on a willing transferor-willing transferee basis that promotes water conservation and/or short-term or permanent fallowing of irrigated lands to transfer conserved water to a transferee for a similar or different use.

For purposes of the Study, each of the various conservation measures were examined as a Basin-wide potential, but in reality the measures will have important regional limitations and in some cases may be mutually exclusive. The various measures should not be considered to be additive.

Because levels of current agricultural conservation measures vary throughout the Study Area, different levels of potential savings are possible for a given conservation measure. These savings range from essentially no savings, where measures have been fully adopted, to significant savings, where measures have not been adopted or where adoption rates are relatively low. Disaggregating the savings potential by conservation measure and individual location was beyond the scope of the Study.

In addition, the conservation measures could produce different amounts of savings depending on the location in the Basin, implementation approach, and combination of measures; the total quantities were estimated as an aggregate for each implementation approach. Up to 1 mafy of potential savings by 2060 was considered for each approach (conservation and conservation with transfers) although the approaches are not considered additive.

5.7.2 Characterization of Options

Regional Considerations

The potential agricultural water conservation measures are assumed to apply to the overall Study Area, but significant differences in potential water savings exist between in-Basin and adjacent irrigated areas due to water budget considerations, application efficiency and consumptive use considerations, and downstream uses dependent on return flows. In addition, applied water requirements and evapotranspiration vary across the Basin depending on elevation, climate, soils, irrigation methods, crop types, and other factors. Differences between in-Basin and adjacent area conservation potential and applied water requirements were considered, but the assessment of conservation was not planning area or state-specific.

Implementation Approaches. The two primary implementation approaches considered are conservation through incentive-based programs and conservation with water transfers. For either approach, program controls are necessary to ensure that water conservation investments provide measurable returns in verifiable water savings. Water conservation program controls should address the following issues:

- Conserved water needs to be measurable and easily observable and, where costs are not prohibitive, should be verified by volumetric water use measurement.
- Legal mechanisms must be in place to protect conserved water in-stream for intended uses, especially in areas where insufficient stream flow currently limits downstream water users from exercising their full diversion rights.
- Controls may be needed to prevent expansion of effectively irrigated areas associated with water conservation investments.
- A healthy agricultural economy must be maintained and associated policy implications considered.

A key distinction between incentive-based programs and water transfers as defined here is whether a legal transfer of water or water rights is involved. The incentive-based programs are assumed to be accomplished without legal transfer of water or water rights, whereas the water transfers specifically revolve around legal transfers of water or water rights.

Incentive-based Programs. Incentive-based programs can take different forms depending upon the type of water conservation option and the type of collaborator (e.g., water user versus water purveyor). Generally, this option involves providing financial incentives through:

- Grants or low-interest loans to construct infrastructure projects
- Cost-share payments to offset the costs of irrigation system conversion
- Incentive payments to growers that adopt water conservation practices and provide documentation of management practices (payments to implement specific observable practices)

- Incentive payments based on a reduction in volume of water diverted or consumptively used (no specific practice is required, but savings must be measured relative to a baseline)
- Water pricing changes

Several existing federal incentive programs could be applicable under this approach.

Water Transfers. Water transfers represent the legal transfer of water or water rights from one use to another. Within an agricultural water use framework, transfers can be implemented on a temporary basis (one growing season) from year to year through the acquisition or lease of water or a water right or on a permanent basis essentially through the acquisition or sale of water or a permanent water right. Typically, water transfers are negotiated on a willing-transferor, willing-transferee basis and can be implemented on a direct transferor-transferee arrangement or can be facilitated through a water bank.

Quantity of Yield

The methods used to quantify potential yield from agricultural conservation all distinguish between conserved water that would have been lost to the Basin versus conserved water that is simply re-routed within the Basin. Generally, any savings in water that would have been exported from the Basin is counted as reduced depletion and therefore potential yield; within the Basin, only reductions in consumptive uses are counted as potential yield.

Due to the "supply-limited" nature of irrigation water use in the Upper Basin and the high degree of sequential reuse of return flow, it is expected that agricultural water conservation savings in these areas will be limited due to downstream return-flow-dependent uses. For a given funded water conservation project, a portion of the field-scale water savings will likely be demanded by junior downstream users that have historically relied on these return flows. Exceptions to this condition will occur in the most downstream areas of irrigation projects where downstream ability to reuse return flows is limited. Additionally, there may be distinctions between surface and groundwater return flow impacts, with downstream users being more immediately and directly dependent upon surface return flows. The estimated quantities of yield and cost per afy of water conserved discussed below and presented in table F-5 are based on field-scale estimates and are not discounted for return-flow-dependent uses until they are shown in table F-5.

The estimated quantities of yield, before discounting for the effect of return-flow-dependent use, are discussed in this section for each of the agricultural water conservation measures. Table F-5 summarizes the percent reduction in consumptive use or total diversion associated with implementing a unit amount of each measure. These estimates are explained in the following sections.

TABLE F5
Estimated Potential Water Savings Percentages at the Farm Scale for Each Agricultural Water Conservation Measure

Water Conservation Measure	Reduction in Consumptive Use (In-Basin)	Reduction in Total Diversion (Outside Basin)
Advanced Irrigation Scheduling	0%	13%
Deficit Irrigation	13%	20%
On-Farm Irrigation System Improvements	0%	20%
Conveyance System Efficiency Improvements	1%	20%
Controlled Environment Agriculture	50%	50%
Irrigated Lands Fallowing	40 to 100%	Up to 100%

Water savings for reductions in total diversion have not been discounted for effects of return-flow-dependent use.

Because the conservation measures could produce different amounts of savings depending on the location in the Basin, implementation approach, and combination of conservation measures, the total quantities were estimated as an aggregate for each implementation approach rather than a summation of individual conservation measures. Up to 1 mafy of potential savings by 2060 was considered for either Basin-wide conservation with or without transfers but is not considered additive. By comparison, the summation of potential water savings from each conservation measure totals 2.44 mafy when accounting for non-consumptive use savings outside the Basin and ignoring return flow impacts. This amount is reduced to 833,000 afy when only consumptive use savings are considered under each approach category. Table F-6 summarizes the potential agricultural water conservation savings by measure and implementation method.

TABLE F-6
Estimated Potential Water Savings at the Farm Scale for Each Agricultural Water Conservation Measure

Water Conservation Measure	Reduction in Consumptive Use (af)	Reduction in Total Diversion (af)
Advanced Irrigation Scheduling	0	270,000
Deficit Irrigation	100,000	130,000
On-Farm Irrigation System Improvements	0	490,000
Conveyance System Efficiency Improvements	0	820,000
Controlled Environment Agriculture	13,000	13,000
Irrigated Lands Fallowing	720,000	720,000
TOTAL	**833,000**	**2,443,000**

Timing of Option Availability

Because the agricultural water conservation options would be ramped over time, it was considered that the improvements to irrigation management, on-farm irrigation improvements, and changes in crop consumptive use could occur in as early as 10 years. Large infrastructure projects, including conveyance system efficiency improvements and controlled environment agriculture, were estimated to require at least 15 years before full implementation due to the planning, permitting, design, and construction needs.

Costs

Costs for implementing agricultural water conservation measures will vary regionally and with different levels of conservation programs. Costs were estimated based on review of existing programs implementing such measures.

Based on the estimates reported by Cooley et al. (2010), the costs for improved irrigation scheduling and deficit irrigation were approximately $100 per afy and $43 per afy and the cost of on-farm irrigation efficiency improvements was $390 per afy. These estimates were based on total water savings, not reduction in consumptive use.

Achievements of reduced consumptive use through rotational or permanent fallowing were estimated based on existing fallowing programs and administration costs. The IID has recently offered $125 per af to growers for fallowing fields to provide conserved water for transfer and for mitigation purposes (IID, 2012). This price applies to the full reduction in applied water.

Costs for conveyance system efficiency improvements vary substantially depending on the characteristics of the existing delivery system. System improvement options developed for the IID Efficiency Conservation Plan (2007) ranged from $140 to $800 per af of reduced diversion.

Controlled environment agriculture costs vary by crop type, hydroponic or aquaponic system, and installation technique. Initial capital costs are more than 10 times higher than traditional agricultural operations, with construction costs of $3 to $7 per square foot reported for relatively large-scale greenhouses (U.S. Department of Agriculture, 2003; Mississippi State University Extension Service, 2009). Based on an assumed 1.5 af per acre per year savings, unit costs are likely approaching $6,000 per af. This cost would be offset to some extent by improved crop yield, quality, and price, but these benefits are highly dependent on market conditions.

In general, it is anticipated that agricultural conservation programs would be implemented from least costly to more costly and that these costs will vary somewhat by the implementation program and specific BMPs considered. It is assumed that “Conservation” is more focused on on-farm and delivery system improvements, whereas “Conservation with Transfer” is more focused on fallowing. These assumptions are based on current implementation programs and legal structures that favor specific practices depending on whether the conserved water is transferrable. Table F-7 presents the estimated costs for about 1 mafy of savings when 200,000-afy steps are considered. Note that the initial step of “Conservation” is dominated by On-Farm conservation with other measures such as System conservation and Fallowing being implemented in greater proportions in subsequent levels. When transfers are considered, however, fallowing is the dominant measure. In both cases, costs increase with increasing yield requirements.

TABLE F-7
Agricultural Conservation Annual Costs per af of Savings by Implementation Type

	Savings (mafy)	Conservation[1]		Conservation with Transfer[2]	
Step 1	0.2	On-Farm	$150	Fallowing	$250
Step 2	0.4		$300		$400
Step 3	0.6	System	$500	System	$500
Step 4	0.8		$600		$600
Step 5	1.0	Fallowing	$750	On-Farm	$750

[1] Begins with programs more heavily weighted toward On-Farm Measures (Deficit Irrigation, Advanced Irrigation Scheduling, On-Farm System Improvements) but includes some portions of System Improvements and Fallowing in subsequent steps.

[2] Begins with programs more heavily weighted toward Fallowing but includes some portions of System Improvements and On-Farm in subsequent steps.

Other Key Criteria

In addition to yield, timing, and cost, the agricultural water conservation options were characterized against several other criteria. A summary of the findings for all criteria is shown in figure F-9. In general, these options are technically feasible and examples exist in areas of the Southwest and in other arid regions of the world. Controlled environment agriculture is unlikely to be economically feasible on a large scale under foreseeable circumstances. Irrigation management and efficiency improvement programs have been undertaken at district and state levels, but have not been demonstrated in basins on the scale of the Colorado River in North America. It is not anticipated that significant permitting will be required to implement these options. However, these options will affect diversion patterns, return flow quantities and locations, and groundwater recharge. These changes could generate legal challenges.

Coupling agricultural conservation with a transfer mechanism can have varying degrees of political and legal complexities depending on the nature of the transfer. For example, an Upper Basin banking concept was explored in the Study that assumes water generated through agricultural conservation is transferred to a downstream conceptual water bank near Lake Powell. Transfers of this nature would have significant policy and legal challenges. The characterization ratings shown in figure F-9 do not reflect transfers associated with banking arrangements and assume all saved water in the Upper Basin States is made available to local water users within the priority system.

All options have some implementation risk in that yields will fluctuate over time and programs will require continuous funding to maintain overall results. Controlled environment agriculture has additional challenges due to the very large capital requirements: at an average $5.43 per square foot (Mississippi State University Extension Service, 2009), more than $2.6 billion would be required to construct the facilities for 11,000 net acres of production. Additional long-term challenges would include maintaining sufficient revenue to pay the debt service and operations. For the other options, once savings are realized they can be maintained, resulting in long-term viability.

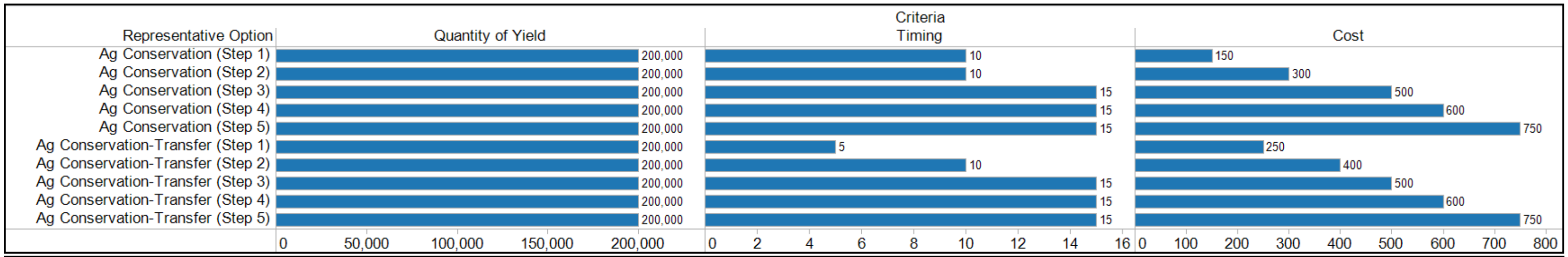
The non-structural options were rated high with respect to operational flexibility, because the programs can be stopped at any time without incurring significant debt service or resulting in stranded assets. However, structural (including irrigation infrastructure) options do not have high operational flexibility. Non-structural agricultural water conservation options do not require energy, but on-farm irrigation improvements generally will require energy for pressurizing sprinkler and drip systems or for pumping recycled tailwater. Greenhouses require pressurized irrigation and may require heating and cooling systems, depending on location and season of operation. Agricultural water quality issues primarily relate to fertilizers and pesticides in return flows to surface or groundwater. All of the options reduce return flows, so they could have positive effects on water quality. All options would likely have generally positive or neutral impacts on hydropower and recreation. Impacts on other environmental factors are uncertain. In some cases, the lower diversions could be positive by leaving additional flow in streams; in other cases, reduced return flows could affect environmental resources such as riparian vegetation along canals and drains that have come to rely on the return flow. Structural options such as system conveyance improvements and controlled environment agriculture would have construction-related impacts.

All of the options would require some additional spending in local communities to implement, and would therefore support local economic activity. Only the reduced consumptive use option was rated low on socioeconomics due to the potential effect on agricultural communities under long-term fallowing and reduced crop production. It is possible that these effects can be mitigated by taking a Basin-wide rotational approach to this option such that individual communities do not experience the impacts in a sustained manner.

5.7.3 Characterization Summary

A summary of the characterization findings are shown in figure F-9. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy yield steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps. In general, a “C” rating 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. For purposes of consistency with the other options that were separated into sub-options of 200-kafy steps, both agricultural conservation with and without transfers were assumed to be implemented through steps of 200 kafy.

FIGURE F-9
Summary of Characterization Ratings for Agricultural Water Conservation Options



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
Ag Conservation (Step 1)	D	B	A	B	B	D	E	B	A	A	B	A	B	A	B	B	A
Ag Conservation (Step 2)	D	B	A	B	B	D	E	B	A	A	B	A	B	A	B	B	A
Ag Conservation (Step 3)	D	C	A	B	B	D	E	B	A	A	B	A	B	A	B	B	A
Ag Conservation (Step 4)	D	C	A	B	B	D	E	B	A	A	B	A	B	A	B	B	A
Ag Conservation (Step 5)	D	C	A	B	B	D	E	B	A	A	B	A	B	A	B	B	A
Ag Conservation-Transfer (Step 1)	D	A	A	B	C	C	A	B	A	A	B	A	D	C	B	C	A
Ag Conservation-Transfer (Step 2)	D	B	A	B	C	C	A	B	A	A	B	A	D	C	B	C	A
Ag Conservation-Transfer (Step 3)	D	C	A	B	C	C	A	B	A	A	B	A	D	C	B	C	A
Ag Conservation-Transfer (Step 4)	D	C	A	B	C	C	A	C	A	A	B	A	D	C	C	C	A
Ag Conservation-Transfer (Step 5)	D	C	A	B	C	C	A	C	A	A	B	A	D	C	C	C	A

Agricultural (Ag)

5.8 Energy Sector Water Use Efficiency

Options to improve the water use efficiency of the energy sector have been proposed to reduce the water demand in the Basin. Four options related to energy water use efficiency were received. The submitted options were reviewed and organized into two groups according to the different concepts proposed for reducing water demand. The option groups are described below.

Additional detail related to the representative options and specific characterization is included in appendix F11. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.8.1 Conversion of Power Plants to Air Cooling

This option group includes removing the evaporative cooling systems at the 15 largest power plants in the Basin and installing air-cooling systems. When evaluating this option, the following obstacles to retrofitting existing water-cooled power plants with air-cooling systems were considered:

- High cost of installing air-cooling systems
- Effect of air cooling on plant power output during hot weather
- Effect of air cooling on plant efficiency
- Applicability of air-cooling technology to the plant systems designed for water- cooled service
- Larger site footprint required for air-cooled system
- In general, air cooling reduces the overall capacity to produce power by about 10 to 15 percent, with disproportionate reductions during the warmer months when peak load often occurs.

5.8.2 Water Use Efficiencies in the Oil and Gas Industry

This concept addresses the need for a reliable water source for oil and gas development, and suggests options for ensuring sufficient supplies through a number of improved efficiency measures. Options suggested increased regulation on oil and gas exploration to protect water resources from contamination, and use of treatment processes to make the byproduct water available as a new supply instead of disposing the water to evaporation lagoons or deep wells. Another option involves maximizing efficiency of water use at oil and gas refineries. Although described here for completeness, the treatment and use of the natural gas byproduct water is included in the local supply category and is not characterized here. Also, increased reuse of industrial type waters is covered in the industrial reuse category and not characterized here.

5.8.3 Characterization of Options

Quantity of Yield

Developing yield estimates for these options includes researching historical and estimated future use of water by power plants. The 15 largest power plants in the Basin consume approximately

167,000 afy of water. Assuming 95 percent of that amount could be saved by converting to air cooling, about 160,000 afy of yield is potentially available with this concept.

Timing

Feasibility studies to identify the estimated amount of power generation loss due to reductions in efficiency and plans for making up those losses are assumed to take up to 3 years. Revised air quality and noise permits are required for the alternate equipment, and it could take 2 or more years to acquire those permits. Detailed design and construction could take another 5 years, with a total timeframe of at least 10 years.

Cost

The cost for the decommissioning of wet cooling systems and construction of air-cooling systems, plus the increased cost of operation of the power plants, were estimated in the *Study of Long-Term Augmentation Options for the Water Supply of the Colorado River System* (Colorado River Water Consultants, 2008). The study estimated the costs at approximately $1,300 per af for plants of 2,000 MW and greater capacity and as much as $4,000 per af for plants smaller than 1,000 MW capacity. The costs will vary at each facility, but the estimated weighted average annual cost is about $2,000 per af of water saved.

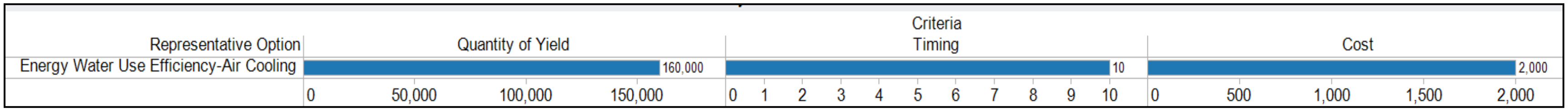
Other Key Considerations

The technology behind improving energy water use efficiency is proven and reliable, resulting in a high feasibility rating. In regard to implementation, there is likely to be opposition from the power industry due to increased costs and reductions in efficiency, and possible opposition from the public due to potential increases in costs of energy to the greater community. Long-term viability is believed to be high because once the technology is installed and paid for, water demand is permanently reduced. Due to the investment and infrastructure required, operational flexibility is limited because the criterion penalizes options with high debt service costs that exist even when the option is put into an idle mode. Although the option conserves water use in the energy generation process, it is projected to reduce energy generation by 10 to 15 percent. Applying the “fence line” concept described earlier to the option characterization implies that the reduced generation is outside of the “fence line,” resulting in a neutral score. When considering hydropower, water quality, recreation, and other environmental impacts, this concept could result in reduced diversion for these Upper Basin power plants, and increased water in the river. It is also unknown how this water would be used by others, which could result in a change in how the downstream river reaches are operated. Due to these unknowns, neutral conditions were assumed for these criteria. Socioeconomic impacts are difficult to fully assess because jobs will be created with all of these options. There is also likely to be a combination of positive and adverse impacts in the exporting regions. Without more-detailed assessments, neutral conditions were assumed for socioeconomics.

5.8.4 Characterization Summary

A summary of the characterization findings are shown in figure F-10. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. 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.

FIGURE F-10
Summary of Characterization Ratings for Energy Water Use Efficiency Options



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
Energy Water Use Efficiency-Air Cooling	D	B	C	A	B	A	E	B	C	C	C	B	C	C	A	B	C

5.9 System Operations

Options dealing with modified system operations have been proposed to increase the overall water supply, decrease demand, reduce evaporation losses, and improve efficiency within the Basin. The submitted options were reviewed and organized into three option groups according to the overarching concept driving the new or modified operation. Representative options were developed for each option group to represent the distinct nature of the options within each group. 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 option groups and representative options are described below.

Additional detail related to the representative options and specific characterization is included in appendix F12. A more complete discussion of the criteria and ratings descriptions is provided 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 at http://www.usbr.gov/lc/region/programs/crbstudy.html.

5.9.1 Evaporation Control Covers

This group of options includes physical and chemical methods to reduce evaporation from the major canals and reservoirs. Physical covers would incorporate solar photovoltaic panels to simultaneously reduce evaporation and generate electricity. Concepts involving chemical covers include the introduction of a chemical to the water surface of large reservoirs to reduce the evaporation rates of the reservoirs.

Based on these distinct concepts, three representative options were developed:

- Solar Panel Canal Covers
- Solar Panel Reservoir Covers
- Chemical Type Covers

5.9.2 New Water Storage

These options involve the construction or expansion of reservoir projects in order to increase the amount of system storage available. There are two representative options in this group:

- New Water Storage
- Improved Groundwater Management

5.9.3 Modified Reservoir Operations

Recommendations for changing current operations were proposed to improve water management in the Basin. While many of the characterization criteria apply to these options, the options' complexity limits the ability to select ratings for each criterion. The application criteria are discussed qualitatively in the following section.

The submitted options were reviewed and organized into five representative options according to the specifics of the recommendation:

- Reduce Reservoir Evaporation
- Prioritize Lake Mead Storage

- Maximize Hydropower Generation
- Operating for Environmental Purposes

5.9.4 Characterization of Options

For the system operations category of options, only the options in the Evaporation Control Covers and New Water Storage underwent a characterization with ratings assigned to each criterion. Due to their technical and legal complexity, the options that comprise the Modify Operations group were not assigned ratings. However, available information on relevant criteria are discussed below.

Quantity of Yield

For the evaporation control covers options, estimated yields varied based on the scope of application. Expected savings due to reduced evaporation are 18,000 afy for canal covers, 200,000 afy for reservoir covers, and 850,000 afy for chemical type covers.

Adding additional reservoirs or other storage could result in additional yield. Storing 1.2 million af in the proposed high-altitude Union Park Reservoir instead of in Lake Powell would result in some additional yield due to reduced losses from evaporation. Based on existing evaporation rates at each location, approximately 20,000 afy could be saved under ideal conditions. Because specific locations have not been identified for additional storage reservoirs to capture unused water already released from Lower Basin reservoirs, the additional volume of water made available cannot be accurately estimated.

The improving groundwater management option is related to recovering groundwater in areas where long-term sustainable groundwater pumping is not being practiced. This option does not produce “new” yield for the system.

Typical evaporation at Lake Powell is around 50 inches per year. Similarly, evaporation at Lake Mead is estimated to average approximately 80 inches per year (USGS, 2006). The reservoirs have differing surface area to storage characteristics, and there are numerous other operational objectives that must be met; therefore, it is not possible to perform simple calculations to estimate potential benefits of evaporation savings associated with revised operations. A detailed modeling assessment was not performed for the Study. However, historical studies (Colorado River Consultants, 2008) and analysis conducted for this Study suggest that between 0 and 300,000 afy could be saved through reoperation. For the remaining representative options in the modified reservoir operations group, no new yield is expected. Prioritizing Lake Mead storage would result in higher evaporation losses and negative yield to the system.

Timing

To better understand the potential of the physical cover options, a 2-year feasibility study should be considered. If deemed feasible and the concept was aggressively pursued, 2 years of permitting followed by 5 years of construction is plausible, totaling about 10 years. An additional 5 years is anticipated to be required for the floatovoltaic concepts to address potential issues with covering the lakes. Because use of chemical covers to reduce evaporation is not common practice, feasibility studies followed by pilot programs on smaller water bodies would be expected before being attempted on a large scale. Also, extensive permitting would likely be required to show (with confidence) that adding the chemical to the water does not have negative impacts on water quality, public health, or the ecosystem. It is assumed that the studies and small pilot-scale test could take place within 5 years. Next, a larger-scale pilot of an additional 5 years may be required. Next, permitting and additional testing would likely take 3 years, and application could take another 2 years. Therefore, 15 years could be required for full- scale implementation.

All aspects of the proposed CCP (Central Colorado Project) (New Water Storage) are currently feasible from a technical standpoint. Feasibility analysis of the concept has already begun and could be completed within 3 years; however, construction of a new dam and modified flows in the upper reaches of the basin would require significant permitting and most likely an environmental impact statement. Allowing for 15 years to complete the permitting process and 5 years to construct the facilities, the CCP would take approximately 20 years to implement.

Because other specific projects have not been identified for additional storage to capture unused released water, the time required to implement the project cannot be estimated.

The modification of Lakes Powell and Mead operations to reduce evaporation losses has significant legal and political implications. Any operational modifications could not occur until after 2026, when the 2007 Interim Guidelines (*Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead* (U.S. Department of the Interior [DOI], 2007) expire. Furthermore, re-operating either reservoir solely to reduce evaporative losses is not consistent with either facility's authorized purposes. The other representative options in this group are all technically feasible but require changes to existing operating agreements, permitting, and must be within existing authorizations.

Cost

SPG Solar performed a pilot study and published the results showing that 3 acres of floatovoltaic coverage has an estimated capital cost of $5 million and generates about 1 MW of power (SPG Solar, 2007). Assuming the photovoltaic panels have a 15-year life and are amortized at 4.125 percent, the annual cost of the $5 million installation is about $450,000 per year. Assuming the power generated can be sold at $0.05 per kWh, the power generation is worth $135,000 per year. Assuming 5 feet per year evaporation reduction, a very rough estimate of costs is $20,000 per af.

In the case of chemical covers, the costs include airplanes, fuel, pilots, aircraft maintenance, and the chemical product. Assuming chemical application every 10 days and two planes for chemical application, annual O&M is on the order of $38 million. Amortizing the cost of purchasing or leasing the airplanes ($3.8 million) and estimating the annual costs of the other cost items results in a rough estimated unit cost of about $100 per af.

According to the information provided in the option submittal, construction of the Union Park Reservoir would cost approximately $400 million. For the purposes of the Study, it has been assumed that other facilities considered in the plan, including pipelines and pump stations between the new and existing reservoirs, would cost an additional $200 million to construct. It is also assumed that the cost of operations would be significantly reduced by the revenue generated from energy production. Based on these assumptions and considering a yield of 20,000 afy, the unit cost of saved water is approximately $2,250 per af of conserved water.

Assuming the cost per unit of water conserved would be half as efficient as the recently completed Warren H. Brock Reservoir System, the option to create a reservoir to capture unused releases is estimated to cost about $500 per af.

The annualized unit cost of improved groundwater management is not applicable because no additional yield is realized.

The concept requiring reoperation of the river system between Lake Powell and Lake Mead to reduce evaporation requires no new facilities. However, there would likely be significant costs associated with the changes in timing of water deliveries, hydropower generation, and ecological and recreational impacts. Due to their complexity, these costs were not estimated for purposes of the Study. The remaining option groups relating to modifying operations of existing reservoirs were estimated to generate no additional yield. Therefore, cost estimates are not applicable for these option groups.

Other Key Considerations

In addition to yield, timing, and cost, solar panel cover type options were characterized against several other criteria. In regards to technical feasibility, a neutral rating was given because floating solar panels have been implemented previously, but not at the proposed scale. Permitting, legal, and policy considerations are expected to be positive or neutral for options related to covering the canals, but more challenging for options that physically cover the lakes. In regards to long-term viability, covering canals is viewed to have few challenges, but physically covering the lakes is viewed to be more challenging related to potential loss of permits even after initial implementation. Operational flexibility is related to the ability to put the concept in idle in wet years without negative consequences, and installing physical covers does not have that degree of flexibility. In regards to energy needs, the solar panel covers actually generate energy. In regards to hydropower, concepts that reduce evaporation in reservoirs can later increase hydropower production. Moderate improvements to water quality are anticipated for all evaporation reduction options due to higher river flows that reduce salinity concentrations. Recreation is likely to be impacted due to the physical covers limiting access to part of the lakes. Conversely, reducing evaporation will likely increase lake levels and may positively influence shoreline recreational access. Environmental impacts for the concepts related to physically covering the lakes are unknown, but impacts related to changing sun exposure might be possible. Socioeconomic impacts are difficult to fully assess because jobs will be created with these options, but there is also likely to be a combination of positive and negative impacts when considering more than just job creation. Without more-detailed assessments, neutral conditions were assumed for socioeconomics.

In regards to technical feasibility, chemical covers do not characterize as well as physical covers due to the limited amount of published literature studying whether the concept would work on large reservoirs the size of Lake Mead or Lake Powell that are located in hot, dry and windy climates. The option scores poorly on permitting due to potential pilot testing that may be required to confirm that adding the chemicals will not have a negative impact on the ecosystem. The chemical cover option did score better than the physical covers option for operational flexibility because in wet years it is possible to halt operations and stop the practice of adding the chemicals to the water. Implementing the chemical cover concept requires regular introduction of the chemical to the lake via airplanes and therefore requires energy in the way of airplane fuel. Adverse impacts to recreation are expected because of reduced access to the reservoirs. Socioeconomic impacts are difficult to fully assess because jobs will be created with these options, but there is also likely to be a combination of positive and negative impacts when considering more than just job creation. Without more detailed assessments, neutral conditions were assumed for socioeconomics.

Additional key criteria for the pumped storage CCP option include permitting, operational flexibility, and energy needs. No recent precedent exists for successfully permitting such a facility in the proposed region in the recent past, and the project has had significant organized opposition for the past 30 years. Although there are no technical feasibility issues with operational flexibility, the debt service for the capital costs would still be required in years when less revenue could be generated. This is problematic because the debt is proposed to be serviced by power-generating revenues dependent on the normal reservoir operations. Last, the unused releases water reservoir concept is difficult to characterize without a more-detailed plan. The concept is dependent on very specific conditions that may not exist elsewhere in the Basin.

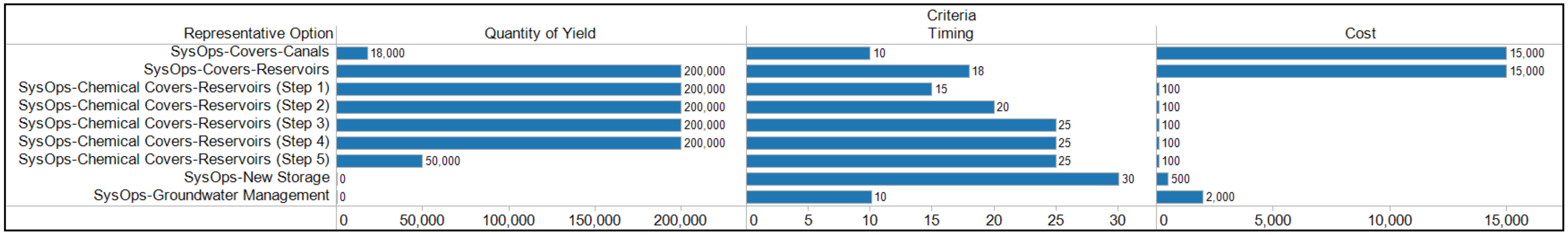
The option to modify reservoir operations to reduce evaporation would require distinctly different operations than are currently in place. Therefore, long-standing policies that would have wide impacts to Basin stakeholders would need to be reconsidered. This option would also reduce or at least change the flows through the Grand Canyon, which could have environmental impacts.

Options to prioritize Lake Mead storage would have significant environmental, recreational, and policy issues. There would likely be significant public opposition to lowering Lake Powell resulting from impacts on legal obligations and policy objectives, because Lake Powell provides the mechanism for the Upper Basin to satisfy its compact obligations.

5.9.5 Characterization Summary

A summary of the characterization findings are shown in figure F-11. The top portion of the figure shows the estimated quantity of yield, earliest timing of implementation, and estimated cost. The bottom portion of the figure shows the 17 criteria and associated ratings (“A” through “E”) for each option. As noted previously, some large options were broken into 200-kafy yield steps to reflect increasing complexity as project size increases. These steps are denoted numerically, with “step 1” being the first 200-kafy increment, followed by subsequent steps. In general, a “C” rating 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.

FIGURE F-11
Summary of Characterization Ratings for System Operations Options



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
SysOps-Covers-Canals	E	B	E	C	C	B	D	C	A	A	A	C	C	A	A	C	B
SysOps-Covers-Reservoirs	D	C	E	C	D	D	E	D	A	A	C	D	C	D	D	A	B
SysOps-Chemical Covers-Reservoirs (Step 1)	D	C	A	E	D	D	A	E	B	D	D	D	C	D	C	A	C
SysOps-Chemical Covers-Reservoirs (Step 2)	D	C	A	E	D	D	A	E	B	D	D	D	C	D	C	A	C
SysOps-Chemical Covers-Reservoirs (Step 3)	D	D	A	E	D	E	A	E	B	D	D	E	C	D	C	A	C
SysOps-Chemical Covers-Reservoirs (Step 4)	D	D	A	E	D	E	A	E	B	D	D	E	C	D	C	A	C
SysOps-Chemical Covers-Reservoirs (Step 5)	E	D	A	E	D	E	A	E	B	D	D	E	C	D	C	A	C
SysOps-New Storage	E	D	A	A	B	E	D	D	B	C	D	C	C	A	B	C	C
SysOps-Groundwater Management	E	B	C	B	B	A	C	C	B	C	C	C	C	D	B	C	C

5.10 Water Transfers, Exchanges, and Banking

Water transfers, exchanges, and banking have been proposed to increase the efficient use of existing supplies in the Basin. This group consists of options that are reflected in the following representative options:

- Water Transfers and Exchanges
- Guided Water Markets
- Upper Basin Water Banking
- Lower Basin Water Banking
- Groundwater Banking

Due to their complexity and the inability to develop representative options indicative of all water banking or transfer-type options, these options have not been assigned ratings for the 17 criteria. Water transfers and banking options generally require working in conjunction with conservation options (agricultural or M&I) in order to generate the water to be transferred or banked. The characterization of the options to conserve water is described in the respective conservation sections of this report, M&I Water Conservation, and Agricultural Water Conservation.

5.10.1 Water Transfers and Exchanges

Water transfers are a voluntary change in the way water is distributed among water users. Intrastate transfers can be temporary or long-term changes in points of diversion, place of use, or purpose of use due to a transfer or exchange of water or water rights (California Water Code, 2010). Water rights in the Basin are governed by a complex structure of federal laws and agreements that collectively form the Law of the River, which governs the allocation of water to and among states and in certain cases among water users, and state water rights structures, which allocate water to individual water right holders within states.

Water transfers can consist of a temporary lease or permanent sale of water or a water right by the water right holder, a lease of the right to use water from the water right holder, or a sale or lease of a contractual right to water supply. Water transfers can also take the form of long-term contracts for the purpose of improving long-term supply reliability. Typically, temporary water transfers have durations of 1 year or less, whereas long-term water transfers have durations of more than 1 year. It should be noted that the nature of these transfers reflects certain legal and policy changes that are more challenging than would be expected solely with implementation of conservation measures.

There are several methods used to make water available for transfer. Some of these methods include the following:

- Reducing the existing consumptive uses of water through crop idling, crop shifting, or water use efficiency measures to make water available.
- Reducing return flows or seepage from conveyance systems that would otherwise be irrecoverable for downstream beneficial uses.
- Pumping groundwater (groundwater substitution) instead of using surface water delivery and transferring the surface water rights.

- Transferring water from storage that would otherwise have been carried over to the following year. The expectation is that the reservoir will refill during subsequent wet seasons.
- Banking available water and transferring previously banked groundwater either by directly pumping and transferring the banked groundwater or by pumping the banked groundwater for local use and transferring surface water that would have been used locally to another user.

Various legal constraints must be adhered to, depending on existing federal and state regulations and laws, to permit the transfer of water from one location to another. The physical infrastructure needed to convey or exchange the water from the existing user to the new user must be in place, and all infrastructure owners must be included in transfer negotiations. Depending on the nature of the transfer, more-significant political and legal challenges may exist.

Historically, water transfers in the Basin have taken the form of either permanent agricultural land fallowing ("buy and dry") to transfer water to a different purpose of use, temporary agricultural land fallowing agreements to meet M&I uses during drought or multiple-year periods, or transfers through conveyance system and on-farm efficiency measures. Flows used by downstream water users or riparian environmental purposes may be maintained in both timing and magnitude.

Some of the largest recent examples include the Colorado Big Thompson Project, San Diego County Water Authority–IID Water Transfer Agreement, and the MWD/Palo Verde Water District Forbearance and Fallowing Program. All three of these examples transferred water used from agricultural purposes to urban use. The Colorado Big Thompson Project included a large number of small quantity transfers from individual users along Colorado's Front Range (Colorado Water Institute, 2011). The San Diego County Water Authority–IID Water Transfer Agreement transferred up to 200,000 afy from Imperial Valley agricultural use to San Diego County urban use through a combination of land fallowing and efficiency-based water conservation measures. Similarly, the MWD/ Palo Verde Water District program transferred up to 110,000 afy from use in the Palo Verde Valley to Southern California urban use through crop rotation and land fallowing.

Although the vast majority of water transfers have occurred between agricultural users or between agricultural and urban users, some transfers have occurred to transfer water from agricultural uses to environmental purposes. The water transfer options propose to seek new transfer agreements to optimize transactions for water supply reliability and environmental purposes.

5.10.2 Guided Water Markets

During prolonged and severe droughts, some water users in the Upper Basin may be curtailed in order to meet the obligations under Article III(d) of the Compact. Instead of relying only on seniority of rights to manage shortages, this option would seek to maximize opportunities for using economically beneficial transactions to secure necessary reductions of consumptive water uses. The proposed program would work with related federal programs to maximize environmental and agricultural benefits throughout the Upper Basin. With a strategic, guided approach, water market transactions could be proactively used to meet demand reduction goals. Basically, such guided markets would seek to give irrigators who have low profit margins or who have less-productive lands within their operation early opportunities to participate in the market, reducing pressure on more-profitable irrigation operations that might otherwise be subject to cutbacks due to junior water rights. As an example of how this concept could work with existing programs, the Salinity Control Program could be used in combination with market-based, compensated transactions with willing sellers to prioritize reductions in irrigation on lands that contribute high levels of salinity to further reduce salinity loading in the Basin. Other variations of this concept include creating individual state banks and exchanges and allowing temporary exchange from irrigation to municipal uses during extreme drought conditions.

The most likely source of newly available water would come from large irrigators with low profit margins or less-productive lands. Assuming 3 feet of consumptive water use per acre, fallowing 33,000 acres of alfalfa or similar crops in the Upper Basin may yield as much as 100,000 afy. However, studies of consumptive water use for alfalfa in the Upper Basin vary, with some showing lower consumptive use. Additional fallowed acreage may be required to meet the assumed 100,000 afy yield.

Because the need for this approach could involve changes to existing laws, and possibly to interstate agreements as well, about 10 years of feasibility and permitting work would be required for implementation of the proposed program. Additionally, implementation would likely require several years due to the unprecedented nature of the program. For the purposes of the Study, it was assumed the program could be operating in as few as 15 years.

The costs associated with this option include the purchase or lease of water or water rights, and the lease of local reservoir storage space. Based on existing sources, the cost of water rights is highly variable depending on the region. In 2001, the estimated value of a permanent water right in the San Juan Basin was $3,000 per af, and Colorado-Big Thompson water rights were valued at $10,000 per af in 2010. The cities of Aurora and Colorado Springs have lease storage space in Pueblo Reservoir at values between $20 and $60 per afy. For the Study, it was assumed water rights could be purchased for a one-time cost of $4,000 to $8,000 per af and storage for 5 years would cost $50 per af per year. Amortized over 50 years, the resulting cost is approximately $600 per af.

5.10.3 Upper Basin Water Banking

This option proposes that a similar concept to the Intentionally Created Surplus (ICS) program in the Lower Basin be applied in the Upper Basin. This option creates an Upper Basin water bank in either Lake Powell or in an off-stream groundwater bank to increase protection against curtailment in the Upper Basin. In conjunction with the water bank, various conservation (M&I, agricultural, and energy) efforts across the Upper Basin would be coordinated for the purpose of yielding water to store in the bank. In order to ensure the conserved water is credited to the bank entirely, agreements amongst and within those Upper Basin States would be required to “shepherd” that water to Lake Powell or other storage facilities in the Upper Basin. In doing so, there are likely to be benefits for various ecological and recreational resources that depend upon in-stream flows. Significant legal and policy issues would need to be overcome in order to successfully implement and operate such a program. These challenges would be in addition to those of conservation measures chosen to generate water for the bank. As such, implementing this option would be more challenging than implementing a number of its individual components. However, for the Study analysis it was assumed that such a program could be in place near 2020, which is likely well before there is significant risk of Upper Basin curtailment as estimated in the system reliability analysis (*Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies*).

A representative option that adds more specificity to the concepts described above was developed in order to include this option in the portfolio modeling of the system reliability analysis. The modeling assumptions associated with this representative option are provided in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies, Appendix G-2, Colorado River Simulation System Modeling Assumptions.* In summary, the representative option consists of two tiers comprising M&I conservation and energy water use efficiency (tier 1) and short-tem rotational fallowing (tier 2) in which the water saved is shepherded to Lake Powell or other storage facilities in the Upper Basin. This banked water is then used to protect against curtailment in the Upper Basin. The process of shepherding the water results in increased reliability for ecological and recreational resources while the banked water provides curtailment protection.

From the quantification of conservation options independent of this specific option, there was assumed to be Basin-wide potential for approximately 1 mafy of conservation in each the agricultural and M&I sectors by 2060. Considering the geographical distribution of demand, there is an assumed potential for approximately 250 kafy of M&I conservation and 400 kafy of agricultural conservation by 2060 in the Upper Basin. Additionally, there is assumed to be up to 160 kafy of water conservation potential in the energy sector by 2060 within the Upper Basin.

5.10.4 Lower Basin Water Banking

The 2007 Interim Guidelines (implemented an ICS mechanism to provide for the creation, accounting, and delivery of conserved system and non-system water, thereby promoting water conservation in the Lower Basin (DOI, 2007). The ICS mechanism allows for conserved water in the Lower Basin to be stored in Lake Mead for subsequent delivery in future years.

Several options suggested continuation of this program beyond the expiration of the 2007 Interim Guidelines in 2026 and the expansion or modification to include participants beyond entitlement holders to Colorado River mainstem water in the Lower Basin, including Mexico[4]. These options also suggested adjustments to the rules guiding the creation and delivery of ICS such that certain participants may utilize the program to provide beneficial flow past Morelos Dam to the limitrophe reach as well as to provide other benefits within Mexico. Expansion of the ICS program for these purposes would require consultation with Mexico and is outside the scope of the Study.

5.10.5 Groundwater Banking

This concept utilizes groundwater recharge and recovery as an underground water bank. An entity could divert water to groundwater storage when there is a surplus or reduced need for

[4]Minute 319 was adopted by the United States and Mexico on November 20, 2012. There was not sufficient time to incorporate operational changes associated with Minute 319 prior to publication of this report. . A copy of the Minute may be found at http://www.ibwc.state.gov/Files/Minutes/Minute_319.pdf.

surface supplies. When there is a critical or increased need for additional supply, the entity could then withdraw an amount of water equivalent to that it previously banked subject to withdrawal limits. This concept is already used in several areas of the Lower Basin and is done so on an interstate basis in accordance with Title 43, Code of Federal Regulations, Part 414, Off-Stream Storage of Colorado River Water and Development and Release of Intentionally Created Unused Apportionment in the Lower Division States.

Groundwater banking offers two primary benefits over existing surface storage: (1) storage in groundwater aquifers will reduce evaporation compared to surface water storage, and (2) to provide additional storage capacity when surface storage facilities are full. Without further study of specific aquifer locations available, it is difficult to quantify the potential yield. The option is conceptually similar to either of the Upper Basin or Lower Basin banks and will have many of the same implementation challenges. Also, even though groundwater storage eliminates evaporation losses, other possible losses come into play, such as stranded water in the vadose zone, reduced water quality, and/or migration away from wells that can recapture the water. Additionally, availability of surplus water is based on uncertain, multi-annual, wet Colorado River conditions. In spite of these uncertainties, groundwater banking does have the potential to increase yield, but was not quantified directly in the Study.

Groundwater banking projects using infiltration basins would require extensive acquisition of lands if injection wells are not utilized. They also require construction of well fields to extract groundwater, pipelines, and power supplies. Due to the large investment and significant amount of impacted lands, extensive feasibility studies, permitting, and environmental assessments would be required. The cost for infiltration basins, wells, pipelines, pump stations, power lines, land acquisition, and mitigation must be balanced against increased yield, which could be highly variable from year to year based on the amount and frequency of recharge. It is also worth noting that groundwater storage has minimal evaporation losses compared to reservoir storage, but can have losses due to groundwater movement and groundwater stranded in the vadose zone. Both of these losses are difficult to quantify, but are important in selecting preferences of groundwater storage over surface water storage. Rough estimates considering evaporation benefits in addition to potential increased yield due to underground storage range from approximately $1,500 to $2,500 per af.

5.11 Water Management and Allocation

Options were submitted that suggested modifications to Basin water management processes and changes in the distribution of water supply available in the Basin under the Law of the River. The four representative options in this group are: changes to apportionment of water supply, processes for expanded stakeholder involvement, population control, and conservation and trust funds.

5.11.1 Changes to Apportionment of Water Supply

Options were received that suggested changes in the distribution of the Basin water supply under the Law of the River. These submissions acknowledged that the Colorado River was apportioned during a particularly wet period and utilized a short period of record for recorded streamflows. Given that there is now a longer period of record, which indicates the average natural streamflow is less than records available at the time of the Compact, the submissions suggested that water be reallocated based on updated assumptions on the amount of water supply available on average, and that more water be allocated to protect critical habitat.

Several options proposed a voluntary demand cap on the Upper Basin. These options proposed a negotiated agreement between the Upper and Lower Basin, in which the Upper Basin would agree to forebear annual consumption of Colorado River water above some specified amount and the Lower Basin would agree to relax the stipulation in Article III(d) of the Compact that the Upper Division States will not cause the flow of the river at the Lee Ferry Compact Point to be depleted below an aggregate of 75 maf for any period of 10 consecutive years. As described in the options submitted, the primary purpose of the mutual forbearance arrangement would be to provide additional water supply reliability to users in both the Upper and Lower Basin. The Lower Basin would obtain additional security in the Upper Basin's ability to not cause the flow at Lee Ferry to be depleted as specified in Article III(d), and the Upper Basin would obtain additional insurance against those provisions.

Another submission suggested creating a Colorado River Authority that uses eminent domain to reallocate water from farmers and others for urban purposes.

Due to the political and legal complexity of these options, they were not considered further. Appendix F2 contains the options as they were submitted, and, in some cases, provide additional information.

5.11.2 Process for Expanded Stakeholder Involvement

Options were submitted that suggested the establishment of a forum to allow tribes and stakeholders the opportunity to formally provide input into the Colorado River decision-making process and to discuss long-term, Basin-scale solutions to water supply and management challenges.

One option suggested that a wide range of stakeholders, including environmental groups, tribes, rural farm communities and others, meet regularly to discuss ongoing issues and proposals, to develop proposals related to water management, and to provide input to the Basin States and Reclamation, as appropriate. This group's recommendations would be advisory in nature. Another option recommended the creation of a Blue Ribbon Committee composed of independent scientists, non-governmental organizations, tribal representatives, businesses, and other interests to recommend a vision for future water use in the Basin. The committee would develop a plan that helps to meet future water needs and restores a healthy Colorado River system.

Reclamation and the Basin States acknowledge that the future of the Colorado River system is critical to the livelihood of the millions of people who reside in the Basin and the multiple uses that are dependent on the water. Interest in the Study has been broad and has included active participation from tribes with rights or claims to Colorado River or tributary water, agricultural users, purveyors of M&I water, power users and providers, recreational groups, and conservation organizations. It is important that input and participation by this broad range of stakeholders continue in order to successfully manage the Basin and confront the challenges that lie ahead if projected future supply and demand imbalances are realized.

5.11.3 Population Control

This group of options suggested that measures be taken to slow, or even halt, economic and population growth in the Basin. Some options in this group suggest that the Southwest will naturally become a less desirable place to live in the next 20 to 30 years due to high temperatures, high energy costs, insecure water supply, and stagnant job growth. Others suggest the federal government should create incentives for business and industry to locate outside the Southwest to regions where water and energy supplies are less strained.

Developing strategies for constraining population growth has significant political and legal challenges, is beyond the objectives of the Study, and was therefore not considered further.

5.11.4 Conservation and Trust Funds

This group of options suggested the establishment of conservation funds, trusts, and other funding mechanisms for local and Basin-wide environmental enhancement and water improvement projects. Some suggestions were more local in scope, including using conservation on a utility-scale level to support local and regional environmental enhancement, or suggesting that water agencies draft resolutions calling for a fiscal requirement on new growth to fund local water improvement projects. One option suggested a Basin-wide trust fund, in which funds raised from municipal water users, recreationists, and hydropower could be used for climate change adaptation, environmental enhancement, and a variety of water efficiency programs. These options represent mechanisms that could be used to implement other options noted above, such as water transfers or M&I or agricultural water conservation.

Finding ways to fund desired improvements is a critical component that can make the difference between a theoretical idea and an implementable solution. Reclamation offers opportunities to partner with private and public partners to leverage resources for ecosystem and economic benefits.

Examples of such partnerships include grants provided through Reclamation's WaterSMART (Sustain and Manage America's Resources for Tomorrow) program. WaterSMART works with states, tribes, local governments, and non-governmental organizations to secure and stretch water supplies for use by existing and future generations to benefit people, the economy, and the environment, and to identify adaptive measures needed to address climate change and future demands[5]. Grants through the WaterSMART program provide 50-50 percent cost-shared funding for a variety of projects, including water efficiency, conservation, and Public Law 102-575, Title XVI water reclamation and reuse projects[6].

Because it lacks the authority to establish a Basin-wide fund in which additional fees are levied on water use, Reclamation encourages local water agencies to develop innovative ways of funding conservation and local water improvement projects. The WaterSMART program is an example of a Reclamation program that could be used as a model for collaborative cost share funding to assist financially with water supply and ecosystem improvements

[5] From: DOI WaterSMART Strategic Implementation Plan March 22, 2011 http://www.usbr.gov/WaterSMART/docs/FedRegister_WaterSMART_Implementation_plan_FINAL.PDF

[6] Information on projects funded through the WaterSMART program as well as the current status on WaterSMART funding can be found on the following website: http://www.usbr.gov/WaterSMART/grants.html

5.12 Tribal Water

Tribes hold quantified rights to a significant amount of water from the Colorado River and its tributaries (approximately 2.9 maf of annual diversion rights). The term "quantified rights", as used in the context of the Study, is defined as the quantity of water rights reserved by or granted to tribes by federal court decrees, state court decrees, treaties, agreements, and Executive Orders. In many cases, these rights are senior to other users. Reclamation and the Basin States acknowledge that tribes are critical partners in current and future efforts to resolve water supply and demand imbalances.

Options pertaining to water development and use were submitted by tribes for consideration in the Study. The submitted concepts do not lend themselves to characterization criteria ratings and modeling through CRSS; however, they raise important issues that deserve and will receive future discussion and further study, where appropriate (see *Study Report – Future Considerations and Next Steps*). The options submitted by tribes are summarized in the sections below and every effort was made to retain the original intent. Appendix F13 contains the submittals of the Ten Tribes Partnership and Inter Tribal Council of Arizona (ITCA) in their entirety. Options submitted by individual tribes can be found in appendix F2.

5.12.1 Voluntary Tribal Water Transfers

Options were submitted by the tribes, recognizing the role of tribal water rights and in particular, the possibility of voluntary transfer of that water, in helping to resolve future supply and demand imbalances. The suggested water transfer mechanisms included, among other suggestions, water banks, water marketing, forbearance, and intra- and interstate/Basin leases. The basic concept is that undeveloped portions of tribal water entitlements could be voluntarily made available to other users in (or in some cases beyond) the hydrologic boundaries of the Basin for an agreed-upon level of compensation. These voluntary transfers could be renewed or revisited annually or could be in place for a longer specified amount of time depending on the agreed-upon terms of the transfer.

5.12.2 Tribal Water Storage and Intentionally Created Surplus

The Ute Indian Tribe of the Uintah and Ouray Reservation and the ITCA requested that consideration be given to storing tribal water in new or existing reservoirs for improved irrigation, community and economic development, or conversion to year-round use. These options were designed to help enable tribes with rights to water to beneficially use all of the water to which they have rights. Tribes in the Lower Basin suggested an incentive program be developed to encourage conservation of tribal waters. Specifically, a demonstration program titled Tribal Conservation Reserve was suggested, in which tribes are eligible to store a specified amount of water in Lake Mead in the form of a reserve and then divert that water in a future year by calling on its credits. This option also suggested that agricultural drainage water be stored and put to beneficial reuse use on tribal lands.

5.12.3 Inter-governmental Forum

The Ten Tribes Partnership and the ITCA suggested that additional study, led by tribes and the federal government, be conducted to better understand the role of tribal water in the Basin. It is anticipated that the additional study would require involvement of the states and could support an inter-governmental forum to discuss and resolve current and future issues affecting the management of the Colorado River.

5.12.4 Resolution of Tribal Claims

The ITCA believes that resolution of tribal water claims must be a major priority and it requested that DOI take all necessary steps to facilitate the settlement of claims that have yet to be quantified. It was suggested that Reclamation and the affected tribes work together to develop a water acquisition strategy and implementation plan to provide water to satisfy currently unquantified tribal rights.

5.12.5 Affordability of Tribal Waters via Central Arizona Project Canal

Tribes have expressed concern regarding increased costs of Central Arizona Project (CAP) water to which tribes located in central Arizona have rights. Additionally, these concerns state that federal policy on Colorado River water must ensure that CAP water in all tribal settlements is affordable.

5.12.6 Barriers to Tribal Participation in Federal Programs

The ITCA noted that water conservation and increases in the efficiency of agricultural, municipal, and other water use in reservation areas are high priority issues for all tribes. With a limited tax base, lack of funding is a serious obstacle for tribes. Tribal governments need to draw on a variety of federal programs to provide that funding. Barriers to tribal participation include: requirements for explicit waivers of sovereign immunity, cost-sharing requirements with limited or no possibility of exceptions for communities with the most severe need and least ability to pay.

5.12.7 Recognition of Limits

The ITCA believes that all communities must respect limits to the quantity of water in the system, not just tribal communities. Future population growth and economic development in the non-Indian communities of the Basin must be conditioned by the federal, state, and local governments on the availability and sustainability of the water resources necessary to support such growth and development.

5.12.8 Stabilization of Soil

The ITCA suggested that streamflow in the Colorado River may be augmented through a soil stabilization program on the Navajo reservation and nearby lands at Hopi.

5.12.9 Non-Tributary Groundwater Use

The Ute Indian Tribe of the Uintah and Ouray Reservation requested that it be allowed to engage in new tribal development of groundwater that is not hydrologically connected to surface waters in the Basin and that groundwater that is not hydrologically connected should not be deducted from Utah’s Colorado River allocation. Development of such sources may augment supplies and alter demands in the Upper Colorado River Basin.

5.12.10 Protection Against Overallocation

The Ute Indian Tribe of the Uintah and Ouray Reservation suggested that the State of Utah and the tribe should protect against overallocation by entering into agreements for any non-tribal water use allocated from the tribe’s reserved quantity.

5.13 Data and Information

Options were submitted that suggested improvements to data and information used by Reclamation for analysis and modeling. There are two representative options in this group, summarized below.

5.13.1 Colorado River Simulation System Modeling Improvements

One option suggested the incorporation of additional "nodes" in CRSS that correspond to U.S. Geological Survey (USGS) streamflow gaging stations. The primary goal of this suggestion was to allow Reclamation to better model impacts to recreational and ecological resources at a finer spatial scale.

Currently, there are 29 USGS streamflow gaging stations (20 in the Upper Basin upstream of and including the Lees Ferry gaging station in Arizona, and 9 below Lees Ferry including the Paria River and inflow points in the Lower Basin) represented in CRSS as nodes at which natural flow is input. Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location.

The addition of "nodes" that correspond to USGS streamflow gaging stations would first require the computation of natural flow at that location. The computation of natural flow, performed in Reclamation's Natural Flow model, requires fine resolution data for gaged flows, reach gains and losses, diversions, depletions, and return flows. There are inherent challenges to adding flow nodes to the model because much of the fine resolution data required are not available. For example, USGS gages have varying record lengths at various locations. In addition, water use information may not presently be available at the required resolution, or it may be determined through differing methodologies across different geographic areas. These inconsistencies and unavailability of data, combined with record length, pose significant challenges to the development of a Basin-wide higher resolution natural flow model to provide the data needed to run CRSS.

Although there are limitations in spatial and temporal (CRSS is at a monthly time step) resolution in CRSS, the Study has utilized alternative methods of evaluating impacts to recreation. There are many different recreational activities that are supported by rivers and streams throughout the Basin. River and whitewater boating were considered an attribute of interest in the Study. River and whitewater boating experiences vary with flow conditions, as well as other non-flow-related factors. For the Study, American Whitewater developed relationships between flow conditions and the quality of the boating experience by applying methodology developed by Whittaker et al., 2005. The method takes monthly values from CRSS and, based on historical data, estimates daily flows. These values are then compared against survey data to determine how many days in that month would have provided optimal, acceptable, or unacceptable whitewater and boating recreation. This methodology is described in detail in *Technical Report D – System Reliability Metrics*, appendix D2.

Reclamation is committed to working with partners and stakeholders to refine CRSS and other supporting models where it is feasible and useful to provide the most realistic representation of how the system is currently operated and how it will likely be operated in the future.

5.13.2 Improved Water Use Accounting in the Upper Basin

Improvements to Upper Basin water use accounting methods were suggested. Specifically, the suggestions advocated for the Upper Basin to agree to common standards for water use accounting, which in turn would be implemented via programs of each state. These standards may result in timely annual reporting of consumptive use and losses, and would encourage adoption of appropriate technologies (for example, metering or remote sensing).

In 1968, the Colorado River Basin Project Act directed the Secretary of the Interior to

> make reports as to the annual consumptive uses and losses of water from the Colorado River system after each successive five-year period starting on October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a State-by-State basis. Specific figures on quantities consumptively used from the major tributary streams flowing into the Colorado River shall also be included on a State-by-State basis. Such reports shall be prepared in consultation with the States of the lower basin individually and with the Upper Colorado River Commission, and shall be transmitted to the President, the Congress, and to the Governors of each State signatory to the Colorado River Compact…

These reports (the Colorado River System Consumptive Uses and Losses Reports[7]), have been prepared by Reclamation, in collaboration with the Basin States, for every 5-year period from 1971 through 2005. To date, the report covering 2001 through 2005 is in final review and a provisional report covering the period 2006 through 2008 has been prepared.

Reclamation, independent of the Study, is collaborating with the Upper Colorado River Commission and the Upper Basin to develop more-timely and standardized methods of reporting for Upper Basin consumptive uses and losses. This effort entails exploring the numerous methodologies that are currently available for computing consumptive uses and losses, and evaluating the strengths and weaknesses of these methodologies. The evaluation will include both technical considerations and constraints that contribute to the method's potential utility on an operational basis. Once the catalog of methodologies is complete, the appropriateness of the use of a single methodology or a set of methodologies for the computation of consumptive uses and losses will be discussed.

5.14 Characterization Summary

Table F-8 summarizes the potential yield for each of the main option groups in 2035 and 2060. A total of 7.6 mafy of potential yield was identified for options that increase supply. The options with greatest yield of this type are related to watershed management methods, desalination of ocean and brackish water, importation, and reuse. A total of 2.2 mafy of potential savings was identified through options that reduce demand. The principal options that comprise this type are agricultural water conservation, M&I water conservation, and energy water use efficiency. Potential savings totaling 1.2 mafy were identified under the options that modify system operations and primarily reflect reducing reservoir or canal evaporation through physical or chemical covers, or through preferential reservoir storage. When considering all options and all categories by 2060, a total of more than 11 mafy in

[7] Available at: http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html

potential yield was identified. The potential yield is approximately 5.7 mafy by 2035. However, not all options are equally feasible or reliable in the long term. Likewise, some of these options are mutually exclusive. Many options, such as imports to Southern California or watershed management, are uncertain from both a technical feasibility and reliability standpoint. By excluding options that were rated low for these factors ("D" and "E"), the total potential yield is reduced to approximately 3.7 mafy by 2035 and to approximately 7 mafy by 2060.

The cost, yield, and timing of the representative options are shown in figure F-12 (sorted based on cost). Some of the least-cost options are related to weather modification and chemical covers, but these have considerable uncertainty related to their long-term viability and implementation risk. Agricultural water conservation, M&I water conservation, watershed management methods, smaller import options, and brackish water desalination projects represent the next-least-expensive set of options. Seawater desalination, reuse, and importation projects are estimated to have higher costs, but still can have substantially lower costs than distributed rainwater harvesting and grey water reuse options, and canal and reservoir covers.

TABLE F-8
Summary of Option Cost and Potential Yields by 2035 and 2060

Option Category	Option Group	Estimated Cost ($/afy)	Years before Available	Potential Yield by 2035 (afy)	Potential Yield by 2060 (afy)
Importation	Imports to the Colorado Front Range from the Missouri or Mississippi Rivers	1,700–2,300	30	0	600,000
	Imports to the Green River from the Bear, Snake, or Yellowstone Rivers	700–1900	15	158,000	158,000
	Imports to Southern California via Icebergs, Water Bags, Tankers, or the Columbia River	2,700–3,400	15	600,000	600,000
	Subtotal			**758,000**	**1,358,000**
Desalination	Gulf of California	2,100	20–30	200,000	1,200,000
	Pacific Ocean in California	1,850–2,100	20–25	200,000	600,000
	Pacific Ocean in Mexico	1,500	15	56,000	56,000
	Salton Sea Drainwater	1,000	15–25	200,000	500,000
	Groundwater in Southern California	750	10	20,000	20,000
	Groundwater in the Area near Yuma, Arizona	600	10	100,000	100,000
	Subtotal			**776,000**	**2,476,000**
Reuse	Municipal Wastewater	1,500–1,800	10–35	200,000	932,000
	Grey Water	4,200	10	178,000	178,000
	Industrial Wastewater	2,000	10	40,000	40,000
	Subtotal			**418,000**	**1,150,000**

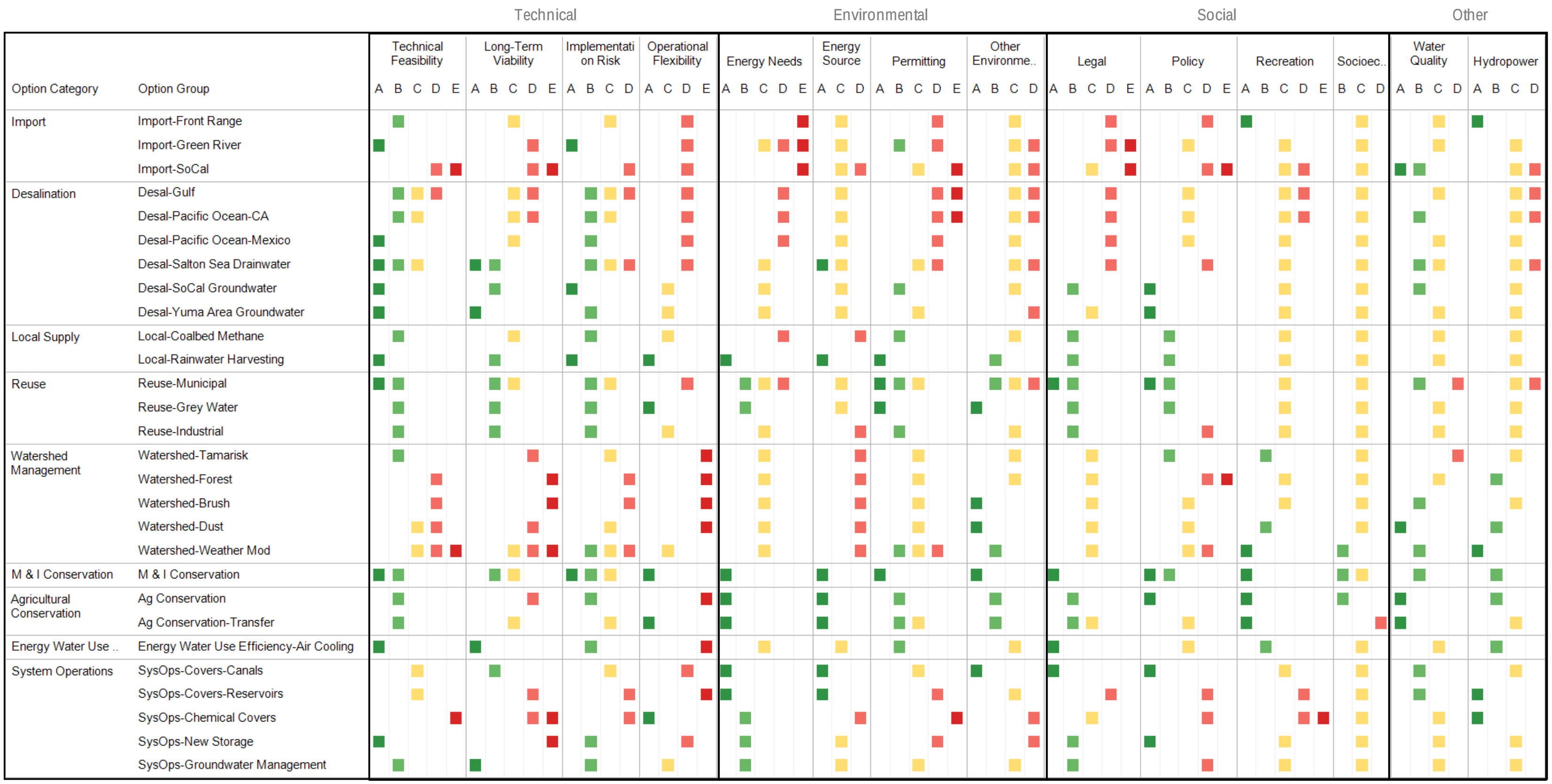
TABLE F-8
Summary of Option Cost and Potential Yields by 2035 and 2060

Option Category	Option Group	Estimated Cost ($/afy)	Years before Available	Potential Yield by 2035 (afy)	Potential Yield by 2060 (afy)
Local Supply	Treatment of CBM -Produced Water	2,000	10	100,000	100,000
	Rainwater Harvesting	3,150	5	75,000	75,000
	Subtotal			**175,000**	**175,000**
Watershed Management	Brush Control	7,500	15	50,000	50,000
	Dust Control	220–520	15–25	280,000	400,000
	Forest Management	500	20–30	200,000	300,000
	Tamarisk Control	400	15	30,000	30,000
	Weather Modification	30–60	5–45	700,000	1,700,000
	Subtotal			**1,260,000**	**2,480,000**
M&I Water Conservation	M&I Water Conservation	500–900	5–40	600,000	1,000,000
	Subtotal			**600,000**	**1,000,000**
Agricultural Water Conservation	Agricultural Water Conservation	150–750	10–15	1,000,000	1,000,000
	Agricultural Water Conservation with Transfers	250–750	5–15	1,000,000	1,000,000
	Subtotal			**1,000,000**[1]	**1,000,000**[1]
Energy Water Use Efficiency	Power Plant Conversion to Air Cooling	2,000	10	160,000	160,000
	Subtotal			**160,000**	**160,000**
System Operations	Evaporation Control via Canal Covers	15,000	10	18,000	18,000
	Evaporation Control via Reservoir Covers	15,000	18	200,000	200,000
	Evaporation Control via Chemical Covers on Canals and Reservoirs	100	15–25	200,000	850,000
	Construction of New Storage	2,250	15	20,000	20,000
	Improved Groundwater Management	N/A	N/A	N/A	N/A
	Modified Reservoir Operations	unknown	15	0-300,000	0-300,000
	Subtotal			**588,000**	**1,238,000**
	Total of All Options			**5,735,000**[2]	**11,037,000**[2]

[1] The two agricultural water conservation representative options derive potential yield from similar measures and are thus not additive

[2] Total does not account for several options that may be mutually exclusive due to regional integration limitations or are dependent on the same supply

FIGURE F-12
Summary of Options Characterization Ratings (aggregated by option groups)



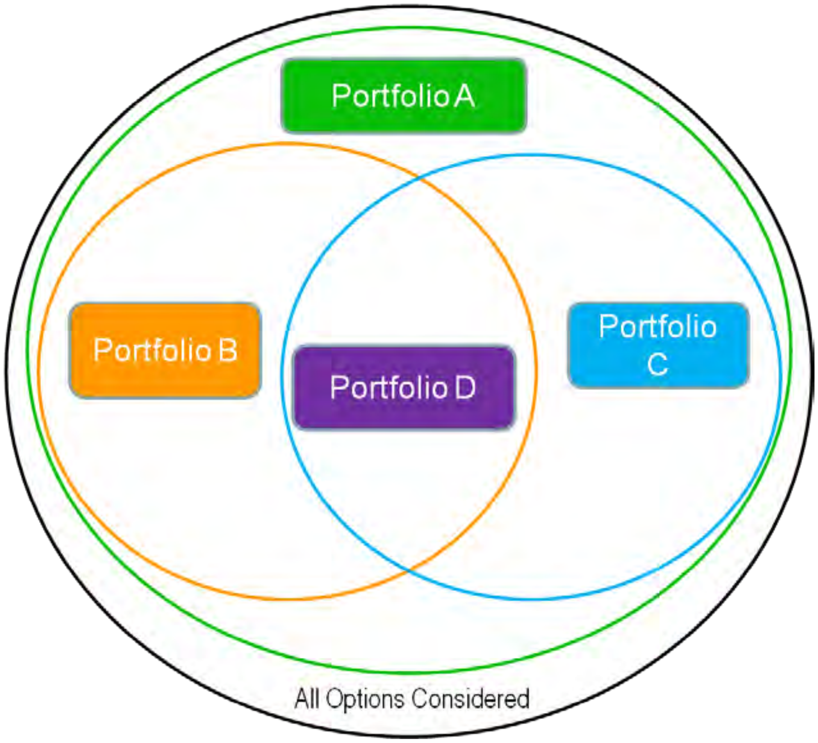
6.0 Development of Portfolios

Based on the results of the characterization and development of representative options, various options have been combined into portfolios representing different potential adaptation strategies. The Study developed four exploratory portfolios to reflect different strategies for selecting and combining options to address Colorado River imbalances between water supply and water demand. Each portfolio consists of a unique selection of options that were considered to address vulnerabilities (e.g., declining Lake Mead pool elevation) that may exist under future combinations of supply and demand. The portfolios were implemented dynamically in CRSS, meaning options were implemented based on the portfolio strategy depending on the timing and nature of the vulnerabilities. Portfolios were then analyzed to assess the effects of the strategy on resolving vulnerabilities to Basin resources.

The four distinct strategies and dynamic portfolios represent a range of reasonable but different approaches for resolving future supply and demand imbalances (figure F-13). The portfolios were developed by the Options and Strategies Sub-Team and are meant to be exploratory in nature. The portfolios are not intended to represent all possible strategies for grouping options. Further, the Study did not intend to result in the selection of a particular portfolio or any one option from any portfolio. Rather, the objective of the portfolio analysis was to demonstrate the effectiveness of different strategies at resolving future supply and demand imbalances.

Using the ratings associated with the criteria, preferences were expressed that resulted in two portfolios, *Portfolio B* and *Portfolio C*. Two other portfolios were then added, *Portfolio A* which represents a highly inclusive strategy (includes all options in either *Portfolio B* or *Portfolio C*) and *Portfolio D*, which represents a highly selective strategy (includes only options in both *Portfolio B* and *Portfolio C*). *Portfolio B* includes options with high technical feasibility and long-term reliability, but excludes options with the highest permitting, legal, policy, or long-term viability risks. *Portfolio B* also excludes any options that cost more than $2,500 per af. *Portfolio C* focuses on options that are also highly feasible, but excludes options that could have greater environmental impacts. This portfolio excludes options that cost more than $4,200 per af. The schematic in figure 13 shows the relationships of the options included in the Study portfolios.

FIGURE F-13
Relationships between Options in the Four Study Portfolios



6.1 Defining Portfolios and Option Preferences

Information about the options characteristics, including expected yield, cost, available timing, and 14 other attributes, such as technical feasibility, operational flexibility, and energy needs (table F-9) was used to help define portfolios. These portfolios reflect an initial look at option performance based on different strategies for resolving imbalances. Additional analysis to fully define appropriate options will be required as future conditions evolve.

TABLE F-9
Option Criteria and Categories Utilized in the Development of Portfolios

Technical	Environmental	
Technical Feasibility Implementation Risks Long-Term Viability Operational Flexibility	Permitting Energy Needs Energy Source Other Environmental Factors	
Social	**Other**	
Recreation Policy Legal Socioeconomics	Quantity of Yield Cost Timing	Hydropower Water Quality

In developing each unique portfolio, a set of preferences regarding the characteristics of options, as defined by the criteria ratings, was defined. These preferences reflect the particular strategy of the portfolio. The options were then arranged with the desired criteria ratings by cost effectiveness – a measure of the cost per unit yield. The availability of each option is restricted to be no earlier than the first year identified under the “timing” criterion. As more restrictions are placed on the range of option characteristics, the number of options and potential yield included in the portfolio are reduced.

The Options and Strategies Sub-Team assisted in the development of the four portfolios by suggesting general strategies, option criteria preference sets, and reviewing draft portfolios. The option criteria preferences included in each portfolio are listed in table F-10. In general, *Portfolio A* contains the fewest restrictions on option preferences and therefore includes the largest number and broadest set of options. Conversely, *Portfolio D* contains the most restrictions on option preferences and therefore includes the fewest options. *Portfolio B* and *Portfolio C* reflect different strategies for addressing the long-term projected imbalances and include a modest range of options. Adjustments to portfolios were made to either include or exclude specific options or to specify that an option is to be implemented as soon as it is available based on input from the Options and Strategies Sub-Team members.

The following sections describe each exploratory portfolio in greater detail.

TABLE F-10
Option Criteria Preferences for the Four Portfolios

Criteria Category	Option Criteria	Portfolio			
		Portfolio A	**Portfolio B**	**Portfolio C**	**Portfolio D**
Technical	Technical Feasibility	excludes options rated D & E	excludes options rated D & E	excludes options rated D & E	excludes options rated D & E
	Implementation Risk	all	all	all	all
	Long-term Viability	excludes options rated E	excludes options rated D & E	excludes options rated E	excludes options rated D & E
	Operational Flexibility	all	all	all	all
Environmental	Permitting	excludes options rated E	excludes options rated E	excludes options rated D & E	excludes options rated D & E
	Energy Needs	all	all	excludes options rated D & E	excludes options rated D & E
	Energy Source	all	all	excludes options rated E	excludes options rated E
	Other Environmental Impacts	all	all	excludes options rated D & E	excludes options rated D & E
Social	Recreation	all	all	excludes options rated D & E	excludes options rated D & E

TABLE F-10
Option Criteria Preferences for the Four Portfolios

Criteria Category	Option Criteria	Portfolio			
		Portfolio A	Portfolio B	Portfolio C	Portfolio D
	Legal	excludes options rated E	excludes options rated E	excludes options rated E	excludes options rated E
	Policy	excludes options rated E	excludes options rated E	excludes options rated E	excludes options rated E
	Socioeconomics	all	all	all	all
Other	Hydropower	all	all	all	all
	Water Quality	all	all	all	all
	Cost	< $4,200 per af	< $2,500 per af	< $4,200 per af	< $2,500 per af

Portfolio A and Portfolio C also include the following options: Upper Basin Water Bank, Watershed-Dust (Step 2), Desal-Salton Sea (Steps 2 and 3), Reuse-Municipal (steps 3-5), and Desal-Yuma. Portfolio D also includes the following options: Desal-Salton Sea (Steps 2 and 3), Reuse-Municipal (Steps 3-5), and Desal-Yuma. Portfolio C and Portfolio D exclude the following option: Local-CBM.

6.2 Portfolio A

Portfolio A features options that are included in both *Portfolio B* and *Portfolio B.* Implementing all options in this portfolio when available would yield on average about 6.3 maf of new supply or reduced demand. In the full implementation of this portfolio, about 4.1 mafy of options that increase supply are included, and about 2.2 mafy of options that reduce demand are included. This portfolio also includes the Upper Basin water bank concept described in *Portfolio C*.

Figure F-14 indicates the options included in the portfolio and their relative cost, yield, and timing availability. Table F-11 summarizes the portfolio of options by option category and yield in the near term and long term as well as whether the option is always on or is triggered by system conditions (responds to signposts).

FIGURE F-14
Ordered Options, Yield, Cost, and Timing Availability for *Portfolio A*

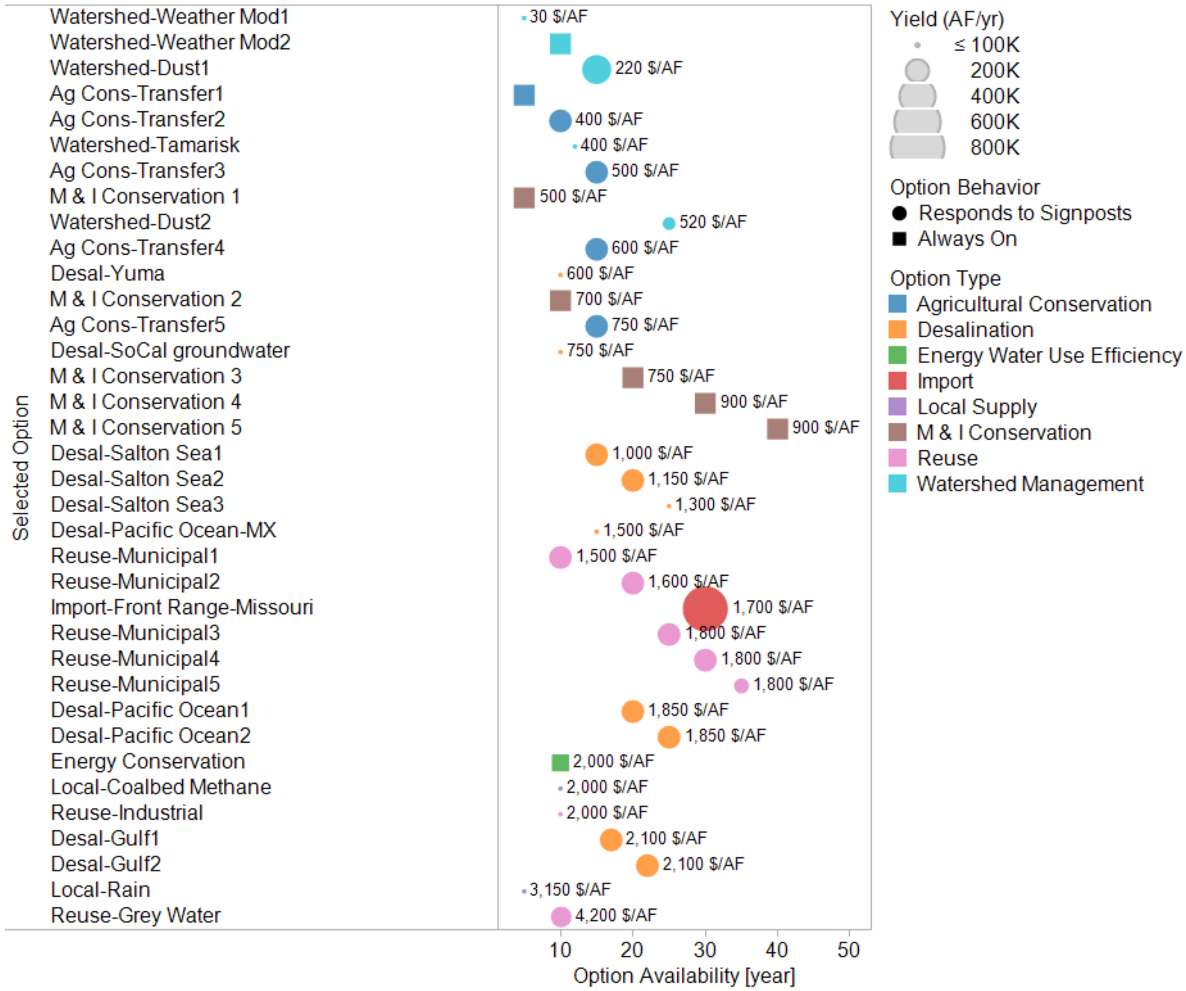


TABLE F-11
Summary of Included Options for *Portfolio A*

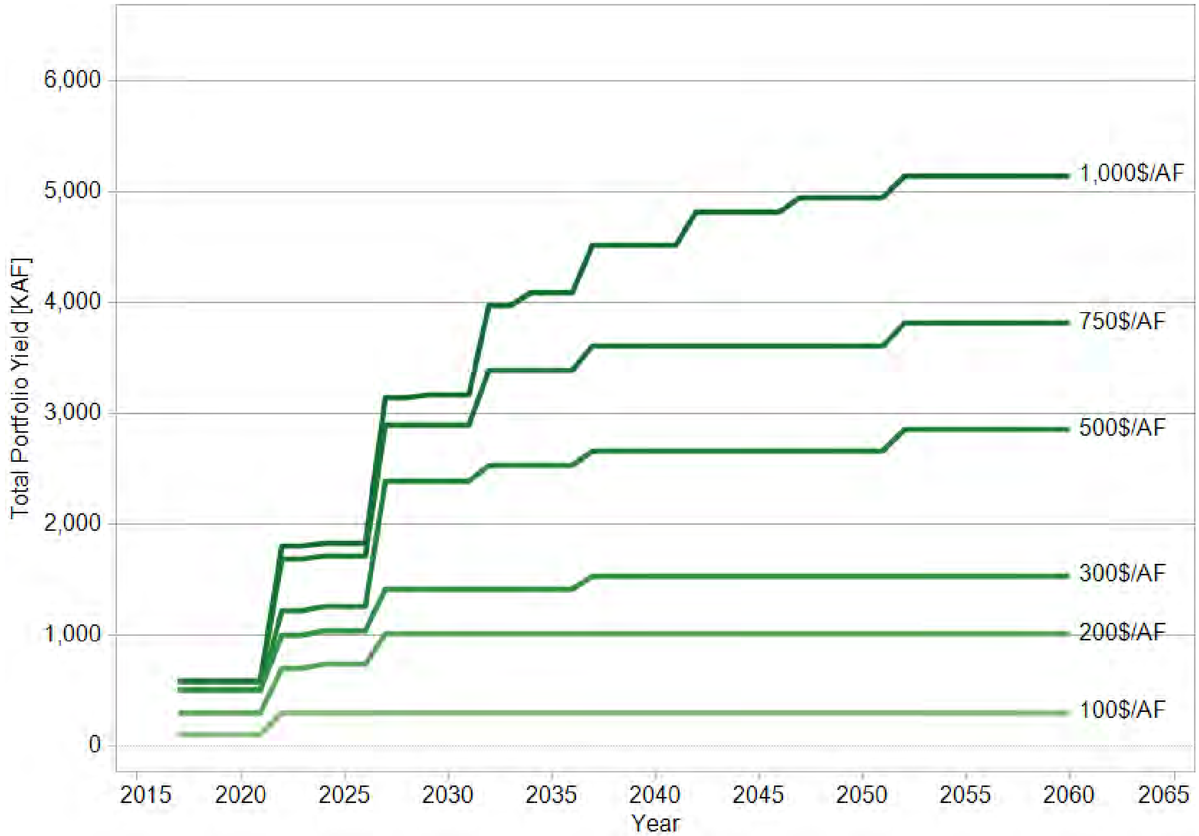
		Near-Term[1]		Long-Term[2]		Total	
Option Category	**Option Type**	**Number of Options**	**Sum of Yield (afy)**	**Number of Options**	**Sum of Yield (afy)**	**Number of Options**	**Sum of Yield (afy)**
Augment Supply	Desal	8	1,176	2	300	10	1,476
	Import	0	0	1	600	1	600
	Local Supply	2	175	0		2	175
	Reuse	4	618	3	532	7	1,150
	Watershed Management	4	610	1	120	5	730
	Total	18	2,579	7	1,552	25	4,131
Reduce Demand	Agricultural Conservation	5	1,000	0	0	5	1,000
	Energy Water Use Efficiency	1	160	0	0	1	160
	M & I Conservation	3	600	2	400	5	1,000
	Total	9	1,760	2	400	11	2,160
	Grand Total	27	4,339	9	1,952	36	6,291

[1] Near-Term refers to options that can be implemented before 2035.

[2] Long-Term refers to options that are implemented after 2035.

To demonstrate the yield and cost of options over time included in *Portfolio A*, figure F-15 shows the total portfolio yield over time for several different portfolio average costs. The top line shows the yield reaching the maximum amount of 5.1 mafy in 2052 with an average portfolio cost of around $1,000 per af. If the implementation of this portfolio only required roughly 3.0 mafy by 2050, then the average cost of the portfolio would be closer to $500 per af. Because the portfolio is described as a preference of options that are then ordered by cost effectiveness, each subsequent option that is called for in a portfolio reflects an increasing cost.

FIGURE F-15
Total Portfolio Yield over Time by Average Cost for *Portfolio A*



6.3 Portfolio B

Portfolio B is based on a strategy that seeks long-term water supply reliability through implementation of options with high technical feasibility and long-term reliability. The strategy can be defined as one that seeks options with proven technology and that, once in place, will produce reliable long-term yield. The strategy represents a low-risk strategy in the long term, but may consider greater risk with respect to permitting and implementation. However, this portfolio excludes options with the highest permitting, legal, and policy risks, or ones that are estimated to cost more than $2,500 per af (table F-10). The portfolio includes a blend of options that increase supply and those that decrease demand. Water conservation and a variety of desalination options are included in the near-term (first 25 years), and imports and expansion of reuse programs dominate the longer-term options. If all 31 options in this portfolio were implemented when available, the total system yield in the near term would increase by about 3.8 maf and by the end of the Study period (2060) would increase by about 5.6 maf. Figure F-16 indicates the options included in the portfolio and their relative cost, yield, and timing availability. Table F-12 summarizes the portfolio of options by option category and yield in the near term and long term.

FIGURE F-16
Ordered Options, Yield, Cost, and Time Availability for *Portfolio B*

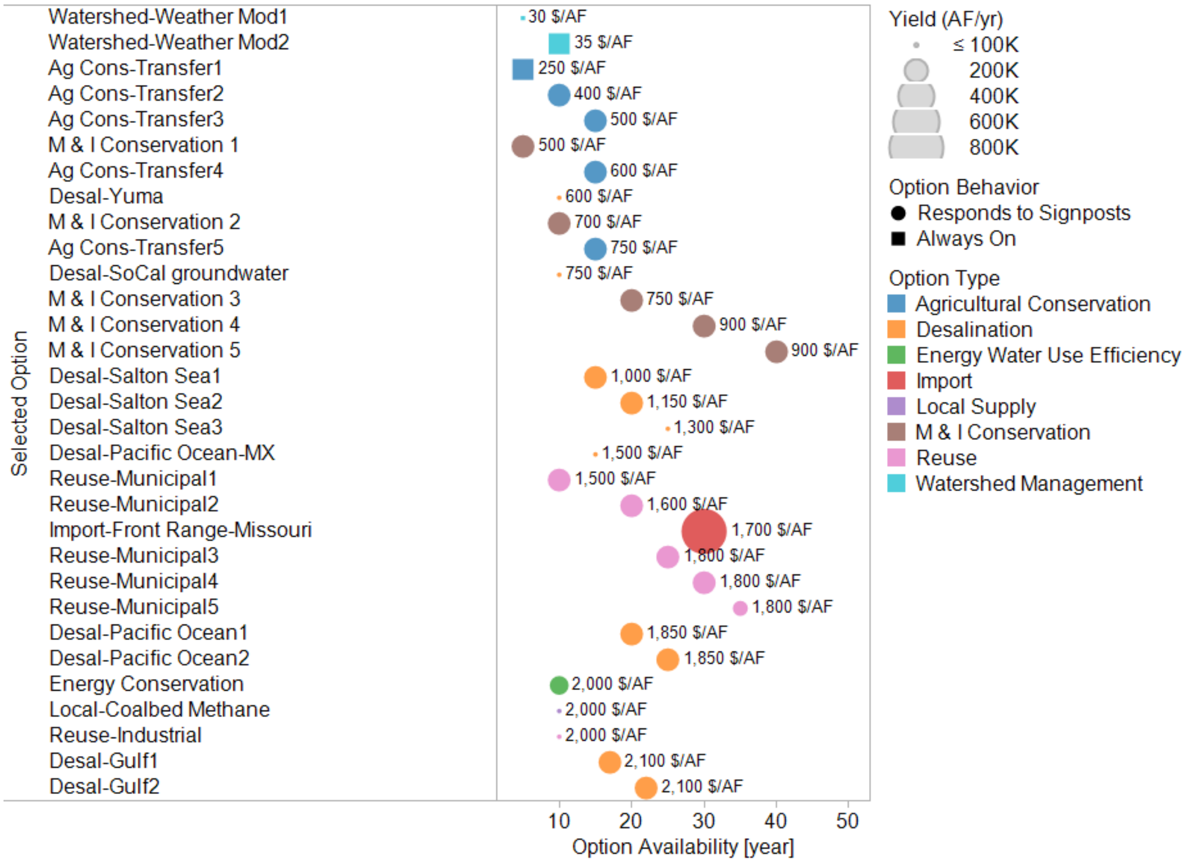


TABLE F-12
Summary of Included Options for *Portfolio B*

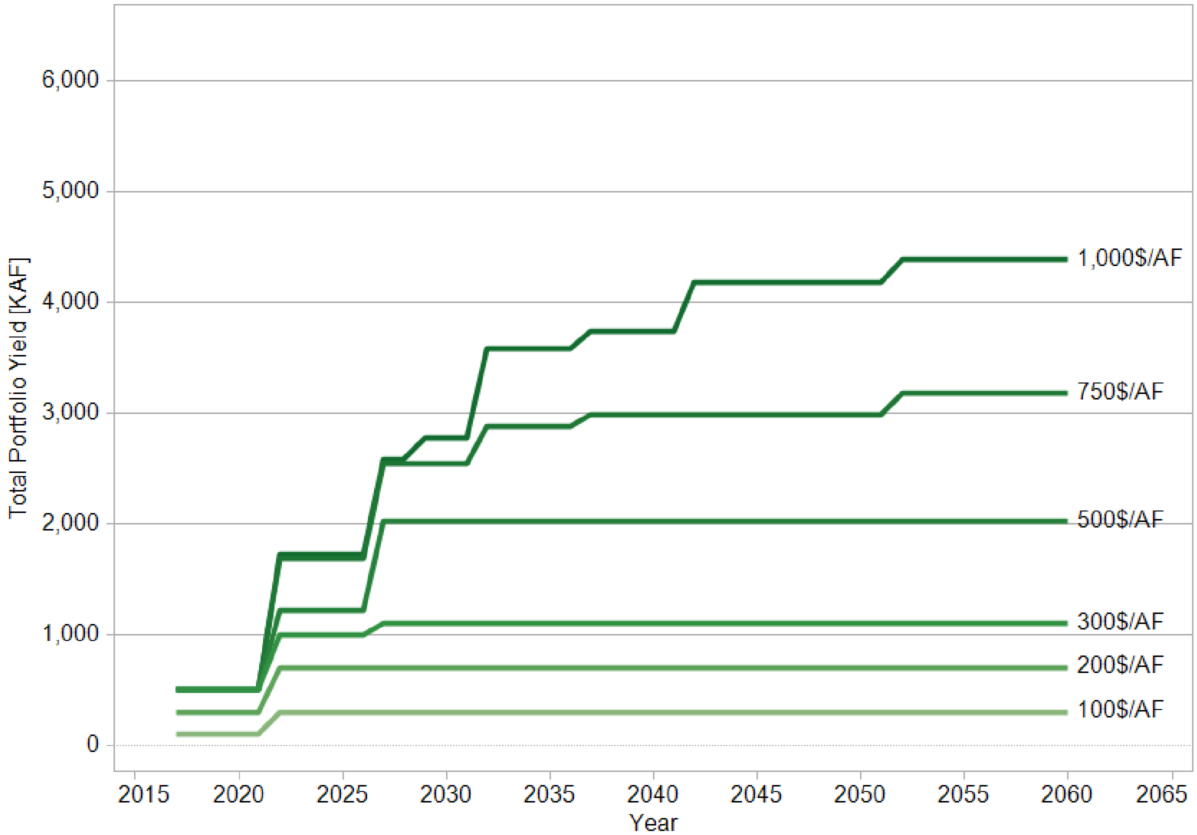
		Near-Term[1]		Long-Term[2]		Total	
Option Category	**Option Type**	**Number of Options**	**Sum of Yield (kafy)**	**Number of Options**	**Sum of Yield (kafy)**	**Number of Options**	**Sum of Yield (kafy)**
Increase Supply	Desal	8	1,176	2	300	**10**	**1,476**
	Import	0	0	1	600	**1**	**600**
	Local Supply	1	100	0	0	**1**	**100**
	Reuse	3	440	3	532	**6**	**972**
	Watershed Management	2	300	0	0	**2**	**300**
	Total	**14**	**2,016**	**6**	**1,432**	**20**	**3,448**
Reduce Demand	Agricultural Conservation	5	1,000	0	0	**5**	**1,000**
	Energy Water Use Efficiency	1	160	0	0	**1**	**160**
	M & I Conservation	3	600	2	400	**5**	**1,000**
	Total	**9**	**1,760**	**2**	**400**	**11**	**2,160**
	Grand Total	**23**	**3,776**	**8**	**1,832**	**31**	**5,608**

[1] Near-Term refers to options that can be implemented before 2035.

[2] Long-Term refers to options that are implemented after 2035.

To demonstrate the yield and cost of options over time included in *Portfolio B*, figure F-17 shows the total portfolio yield over time for several different portfolio average costs. The top line shows the yield reaching the maximum amount of 4.4 mafy in 2052 with an average portfolio cost of around $1,000 per af (annualized). If the implementation of this portfolio only required roughly 3.0 mafy by 2050, then the average cost of the portfolio would be closer to $750 per af. Because the portfolio is described as a preference of options that are then ordered by cost effectiveness, each subsequent option that is called for in a portfolio reflects an increasing cost.

FIGURE F-17
Total Portfolio/ Yield over Time by Average Cost for *Portfolio B*



6.4 Portfolio C

Portfolio C focuses on options that are technically feasible but also have low environmental impacts—low energy needs, lower carbon energy sources, easier permitting, and low impacts to other environmental resources. This portfolio also avoids options that are potentially unfavorable to recreational interests. In addition, this portfolio excludes options with the highest permitting, legal, and policy risks, or ones that have an annualized cost of more than $4,200 per af. If all 29 options in this portfolio were implemented when available, total system yield in the near term (year 25) would increase by about 3.6 maf and by 2060 would increase by about 4.7 maf. The portfolio includes significant conservation in the near term and relies on reuse and watershed management rather than desalination and imports to augment supplies in the longer term. In addition to options that either reduce demand or increase supply, the portfolio also includes a mechanism to transfer water conserved in the Upper Basin through M&I and agricultural water conservation, and energy water use efficiency, to a conceptual Upper Basin water bank. Water is stored in the water bank until needed to be released in order to avoid Upper Basin curtailment due to Compact obligations.

Figure F-18 indicates the options included in the portfolio and their relative cost, yield, and timing availability. Table F-13 summarizes the portfolio of options by option category and yield in the near term and long term.

FIGURE F-18
Ordered Options, Yield, Cost, and Time Availability for *Portfolio C*

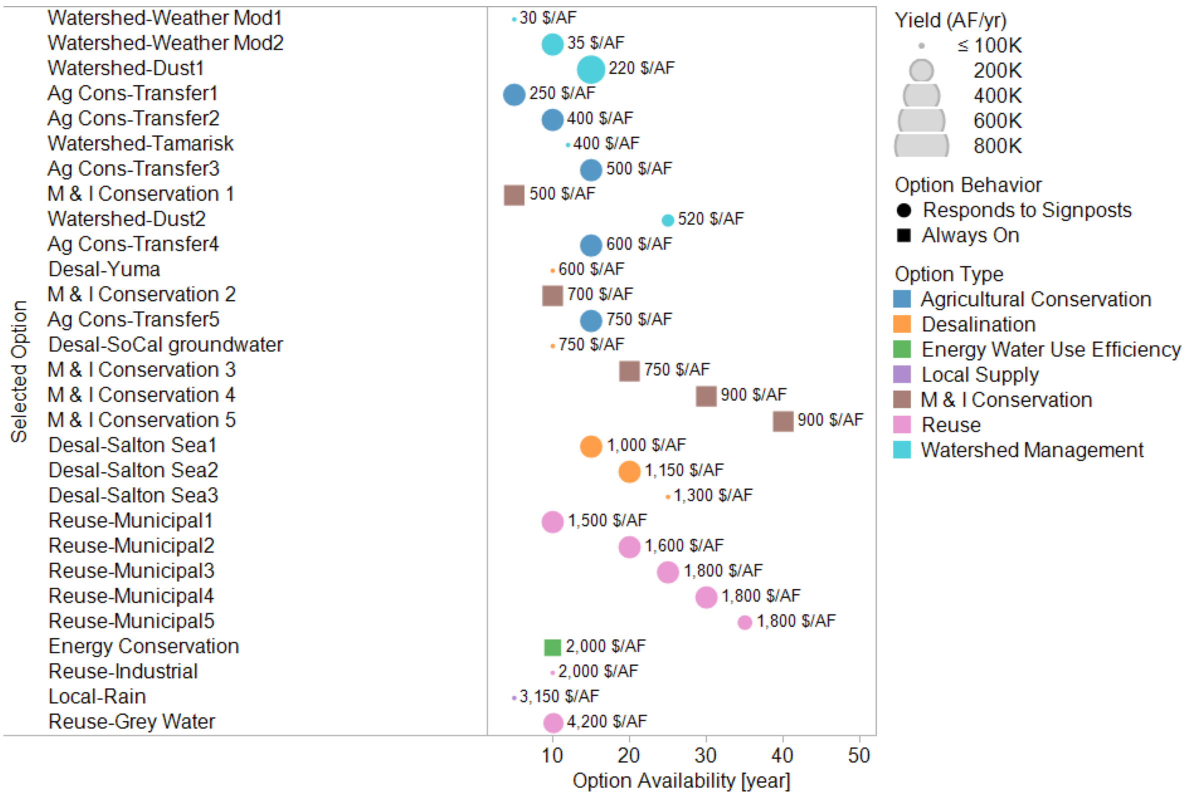


TABLE F-13
Summary of Included Options for *Portfolio C*

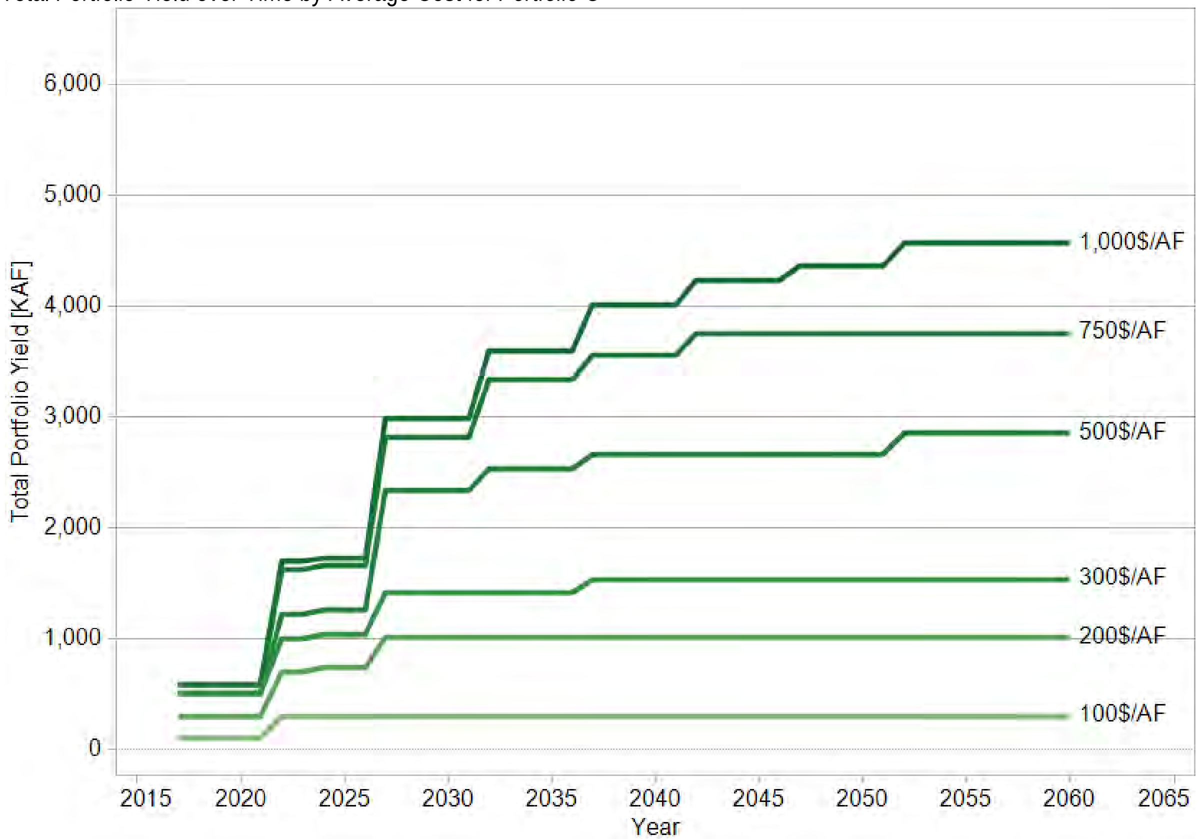
Option Category	Option Type	Near-Term		Long-Term		Total	
		Number of Options	Sum of Yield (afy)	Number of Options	Sum of Yield (afy)	Number of Options	Sum of Yield (afy)
Augment Supply	Desal	4	520	1	100	**5**	**620**
	Import	0	0	0	0	**0**	**0**
	Local Supply	1	75	0	0	**1**	**75**
	Reuse	4	618	3	532	**7**	**1,150**
	Watershed Management	4	610	1	120	**5**	**730**
	Total	**13**	**1,823**	**5**	**752**	**18**	**2,575**
Reduce Demand	Agricultural Conservation	5	1,000	0	0	**5**	**1,000**
	Energy Water Use Efficiency	1	160	0	0	**1**	**160**
	M & I Conservation	3	600	2	400	**5**	**1,000**
	Total	**9**	**1,760**	**2**	**400**	**11**	**2,160**
	Grand Total	**22**	**3,583**	**7**	**1,152**	**29**	**4,735**

[1]Near-Term refers to options that can be implemented before 2035.

[2]Long-Term refers to options that are implemented after 2035.

To demonstrate the yield and cost of options over time included in *Portfolio C*, figure F-19 shows the total portfolio yield over time for several different portfolio average costs. The top line shows the yield reaching the maximum amount of 4.7 mafy in 2052 with an average portfolio cost of around $1,000 per af. If the implementation of this portfolio only required roughly 3.0 mafy by 2050, then the average cost of the portfolio would be closer to $500 per af. Because the portfolio is described as a preference of options that are then ordered by cost effectiveness, each subsequent option that is called for in a portfolio reflects an increasing cost.

FIGURE F-19
Total Portfolio Yield over Time by Average Cost for *Portfolio C*



6.5 Portfolio D

Portfolio D includes only those options included in both *Portfolio B* and *Portfolio C*. Implementing all options in this portfolio when available would yield on average about 4.0 maf of new supply or reduced demand. Significant options not included in this portfolio are several desalination options and imports from the Missouri River. In addition to containing less potential yield than other portfolios, *Portfolio D* includes the fewest number of options.

Figure F-20 indicates the options included in the portfolio and their relative cost, yield, and timing availability. Table F-14 summarizes the portfolio of options by option category and yield in the near term and long term.

FIGURE F-20
Ordered Options, Yield, Cost, and Timing Availability for *Portfolio D*

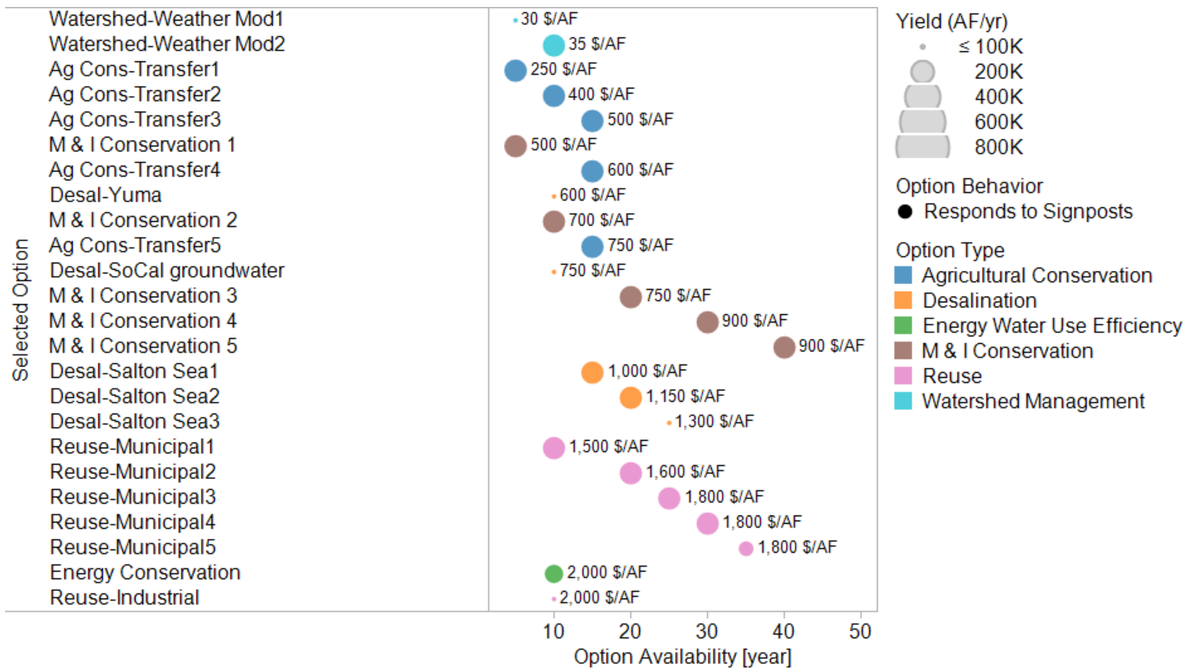


TABLE F-14
Summary of Included Options for *Portfolio D*

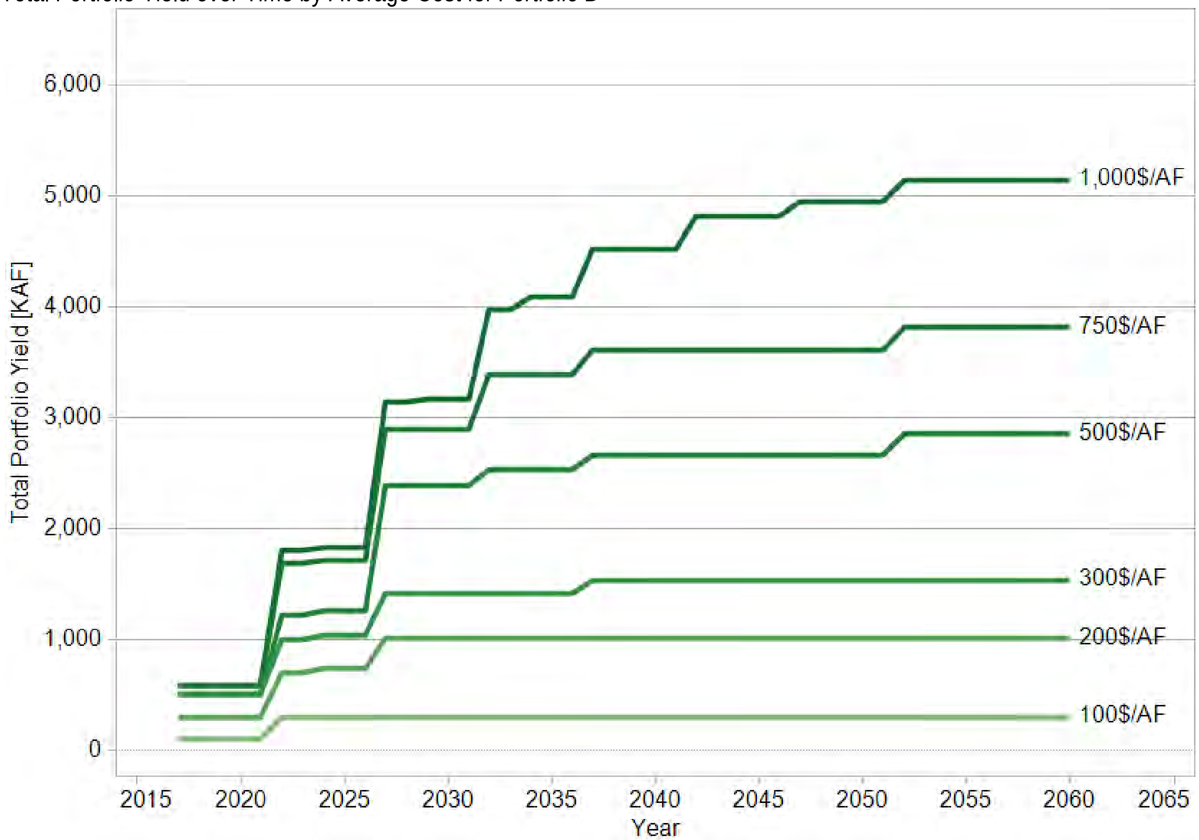
Option Category	Option Type	Near-Term		Long-Term		Total	
		Number of Options	Sum of Yield (afy)	Number of Options	Sum of Yield (afy)	Number of Options	Sum of Yield (afy)
Augment Supply	Desal	4	520	1	100	**5**	**620**
	Import	0	0	0	0	**0**	**0**
	Local Supply	0	0	0	0	**0**	**0**
	Reuse	3	440	3	532	**6**	**972**
	Watershed Management	2	300	0	0	**2**	**300**
	Total	**9**	**1,260**	**4**	**632**	**13**	**1,892**
Reduce Demand	Agricultural Conservation	5	1,000	0	0	**5**	**1,000**
	Energy Water Use Efficiency	1	160	0	0	**1**	**160**
	M & I Conservation	3	600	2	400	**5**	**1,000**
	Total	**9**	**1,760**	**2**	**400**	**11**	**2,160**
	Grand Total	**18**	**3,020**	**6**	**1,032**	**24**	**4,052**

[1]Near-Term refers to options that can be implemented before 2035.

[2]Long-Term refers to options that are implemented after 2035.

To demonstrate the yield and cost of options over time included in *Portfolio D*, figure F-21 shows the total portfolio yield over time for several different portfolio average costs. The top line shows the yield reaching the maximum amount of 5.1 mafy in 2052 with an average portfolio cost of around $1,000 per af. If the implementation of this portfolio only required roughly 3.0 mafy by 2050, then the average cost of the portfolio would be closer to $500 per af. Because the portfolio is described as a preference of options that are then ordered by cost effectiveness, each subsequent option that is called for in a portfolio reflects an increasing cost.

FIGURE F-21
Total Portfolio Yield over Time by Average Cost for *Portfolio D*



6.6 Portfolio Comparison

The four portfolios described above represent different exploratory approaches for addressing the projected imbalances between water supply and demand. These portfolios were developed in conjunction with the Options and Strategies Sub-Team, but should not be considered as individual suggestive pathways. Rather, they were developed to explore the range of options, different preferences for option characteristics, and different levels of option inclusion. Table F-15 provides a high-level comparison of the options that were either included in all portfolios, included in some but not all portfolios, or were not included in any portfolio. As can be seen in the table, the highest steps of Gulf of California and Pacific Ocean desalination options, the most complex import options, reservoir and canal covers, and many of the watershed management options were not selected for inclusion in any of the portfolios. However, only 12 options are included in some but not all portfolios. These included ocean desalination options, imports from the Missouri River, expensive options related to local distributed supply or reuse development such as rainwater harvesting and grey water reuse, and watershed management options such as tamarisk control and dust management.

TABLE F-15
Frequency of Option Inclusion Across the Four Study Portfolios

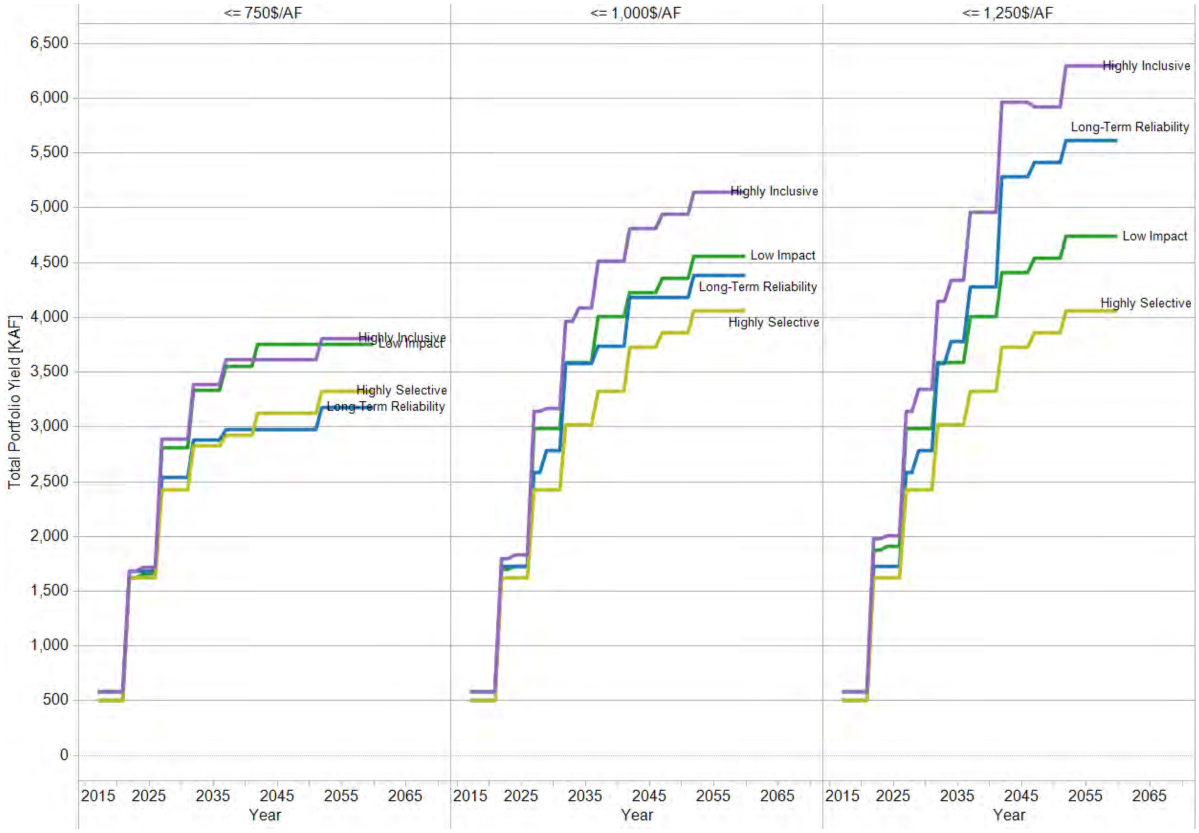
Option Type	Included in All Portfolios	Included in Some Portfolios	Not Included in Any Portfolio
Conservation	Ag Cons-Transfer (Step 1) Ag Cons-Transfer (Step 2) Ag Cons-Transfer (Step 3) Ag Cons-Transfer (Step 4) Ag Cons-Transfer (Step 5) M&I Conservation (Step 1) M&I Conservation (Step 2) M&I Conservation (Step 3) M&I Conservation (Step 4) M&I Conservation (Step 5)		Ag Conservation (Step 1) Ag Conservation (Step 2) Ag Conservation (Step 3) Ag Conservation (Step 4) Ag Conservation (Step 5)
Desal	Desal-SoCal groundwater Desal-Yuma Desal-Salton Sea (Step 1) Desal-Salton Sea (Step 2) Desal-Salton Sea (Step 3)	Desal-Pacific Ocean-Mexico Desal-Gulf (Step 1 Desal-Pacific Ocean-CA (Step 1) Desal-Gulf (Step 2) Desal-Pacific Ocean-CA (Step 2)	Desal-Gulf (Step 3) Desal-Gulf (Step 4) Desal-Gulf (Step 5) Desal-Gulf (Step 6) Desal-Pacific Ocean (Step 3)
Energy Water Use Efficiency	Power Plan Conversion to Air Cooling		
Import		Import-Front Range-Missouri	Import-Front Range-Mississippi Import-SoCal-Columbia Import-SoCal-Icebergs Import-SoCal-Tankers (Step 1) Import-SoCal-Tankers (Step 2) Import-SoCal-Tankers (Step 3) Import-SoCal-Water Bags (Step 1) Import-SoCal-Water Bags (Step 2) Import-SoCal-Water Bags (Step 3)
Local Supply		Local-Rain Local-CBM	
Reuse	Reuse-Industrial Reuse-Municipal (Step 1) Reuse-Municipal (Step 2) Reuse-Municipal (Step 3) Reuse-Municipal (Step 4) Reuse-Municipal (Step 5)	Reuse-Grey Water	

TABLE F-15
Frequency of Option Inclusion Across the Four Study Portfolios

Option Type	Included in All Portfolios	Included in Some Portfolios	Not Included in Any Portfolio
System Reoperations			SysOps-Covers-Canals SysOps-Covers (Step 1) SysOps-Covers (Step 2) SysOps-Covers (Step 3) SysOps-Covers (Step 4) SysOps-Covers (Step 5)
Watershed Management	Watershed-Weather Mod (Step 1) Watershed-Weather Mod (Step 2)	Watershed-Tamarisk Watershed-Dust (Step 1) Watershed-Dust (Step 2)	Watershed-Brush Watershed-Forest (Step 1) Watershed-Forest (Step 2) Watershed-Weather Mod (Step 3) Watershed-Weather Mod (Step 4) Watershed-Weather Mod (Step 5) Watershed-Weather Mod (Step 6) Watershed-Weather Mod (Step 7) Watershed-Weather Mod (Step 8) Watershed-Weather Mod (Step 9)
Water Banking		Upper Basin Water Bank	

The differences in the selection or inclusion of options in the portfolios also influences the total potential yield and implementation cost. Figure F-22 shows the potential yield of the four portfolios over time for three different limits on the portfolio average cost. On the right, the portfolios are essentially unconstrained by cost (average costs are less than $1,250 per af). Not surprisingly, *Portfolio A* has the highest potential yield (~6.3 maf) and *Portfolio D* has the lowest potential yield (~4.0 maf). *Portfolio B* and *Portfolio C* yields are similar through 2042. At that point, *Portfolio B* yield increases significantly more than *Portfolio C*. For lower average costs, the differences between the four portfolios are less significant (figure F-22, left), particularly between *Portfolio B* and *Portfolio C*.

FIGURE F-22
Total Yields over Time for Average Costs less than or equal to $750 per af (left), $1,000 per af (center) and $1,250 per af (right) for Portfolios



6.7 Implementing Dynamic Portfolios in CRSS

The Study developed these four portfolios as exploratory approaches for addressing future supply and demand imbalances. The portfolios represent a preference set for options that may be implemented in the future to address imbalances. However, the portfolios are implemented dynamically in CRSS modeling such that options are only brought on line as needed to address a particular vulnerability. For example, if a particular future only requires 2 mafy of additional options to address the vulnerabilities, then only a portion of the portfolio list of options would be implemented. Similarly, if the vulnerability that arises in the scenario of the future is regionally specific, then only those options that can address the regional vulnerability would be implemented. As a result, the outcome of the modeling analysis of each portfolio under future plausible combinations of supply and demand will be a range of option implementation, portfolio yields, and portfolio costs. Additional detail on the implementation and results of the portfolio analysis is described in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies*.

7.0 Summary and Limitations

In response to projections of increasing imbalance between Colorado River water supply and water demand, a process was developed to identify and develop options and strategies to mitigate and adapt to the potential impacts to Basin resources. The process involved identification and characterization of options that may be used to address imbalances, and development of portfolios of options that explore a range of strategies to adapt to evolving imbalances over time. The activities that comprise the options and strategies process were carried out through a collaborative process involving representatives of numerous organizations, including Reclamation, the Basin States, tribes and communities, and conservation organizations.

Approximately 160 options were received as part of the solicitation for ideas to resolve imbalances. The options were reviewed and organized into option types and categories for further analysis. Each submitted option was assigned to one category based on its primary function, and from these categories, about 40 unique representative options were described to capture the range of options submitted to and considered in the Study. A set of 17 characterization criteria were identified and described reflecting the option attributes of interest in the Study. For each of the options, a qualitative letter score from A through E was assigned for each criterion. However, some options, such as many in the System Operations category, all in the Governance and Implementation category, and those related to tribal water use were considered in a qualitative manner not directly associated with the criteria.

Because it is recognized that no single option is likely to address the all of the projected imbalances between supply and demand, four exploratory portfolios consisting of combinations of options were developed. Options were selected for inclusion in the portfolios based on the option characteristics and the overall strategy chose for a given portfolio. The portfolios contain unique sets of options, potential yield, cost, other attributes, and operational measures that represent a broad range of future adaptation possibilities. The effect of portfolio implementation at addressing vulnerable system conditions that may be present under future water supply and demand scenarios is described in *Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies*.

The process undertaken in identifying and developing the options and strategies aimed at establishing an objective, and consistent process for evaluation. However, the evaluation of options was performed at a limited and high level, consistent with the broad range of options submitted. Limiting the level of analysis helped ensure that all options were considered at a consistent, high level, but limited the characterization of options in further detail. Although all attempts were made to make the evaluation of options as objective as possible, the evaluation of a broad range of options for such a wide array of criteria cannot fully remove all subjectivity. The assumptions have been documented, and the Options and Strategies Sub-Team was encouraged to challenge assumptions in the initial ratings. Not all members of the Sub-Team were in agreement with all ratings but recognized that future efforts may result in a more in-depth assessment of the selected criteria.

Finally, the four portfolios considered in the Study represent different potential strategies for dynamically addressing system vulnerabilities that may develop in the future. Because there are many more strategies than could have been evaluated in the Study, the portfolios should be considered as exploratory. The primary focus of portfolio development and subsequent evaluation in the Study is to determine the range of responses, types of options implemented, the effectiveness at addressing vulnerabilities, and the range of cost and other attributes that result from different portfolio implementations.

8.0 References

CALFED. 2006. *Water Use Efficiency Comprehensive Evaluation.*

California Water Code. 2010. Retrieved from http://www.leginfo.ca.gov/cgi-bin/calawquery?codesection=wat.

Colorado River Water Consultants. 2008. *Study of Long-Term Augmentation Options for Water Supply of the Colorado River System*.

Colorado Water Conservation Board. 2011. *SWSI 2010 Municipal and Industrial Water Conservation Strategies*.

Colorado Water Institute. 2011. *Relative Costs of New Water Supply Opportunities for Front Range Cities.* June.

Cooley, H., J. Chrisian-Smith, P.H. Gleick, M.J. Cohen, and M. Heberger. 2010. *California's Next Million Acre-Feet: Saving Water, Energy, and Money*.

Imperial Irrigation District (IID). 2012. 2012-2013 Land Fallowing Program. Retrieved July 2012, from http://www.iid.com/index.aspx?page=190.

Imperial Irrigation District (IID). 2007. *Imperial Irrigation District Efficiency Conservation Definite Plan*.

Mississippi State University Extension Service. 2009. *Starting a Greenhouse Business*. Publication 1957.

Pacific Institute. 2011. *Municipal Deliveries of Colorado River Basin Water*.

Painter, T. H., A. P. Barrett, C. C. Landry, J. C. Neff, M. P. Cassidy, C. R. Lawrence, K. E. McBride, and G. L. Farmer. 2007. "Impact of disturbed desert soils on duration of mountain snow cover." *Geophys. Res. Lett*., 34, L12502, doi:10.1029/2007GL030284.

Painter T, Deems J, Belnap J, Hamlet A, Landry C, and Udall B. 2010. "Response of Colorado River runoff to dust radiative forcing in snow." Proceedings of the National Academy of Sciences.

Reclamation. 2011. *Phase 4: Development and Evaluation of Opportunities for Balancing Water Supply and Demand - Request for Ideas.*

Research & Planning Consultants. 2000. *Assessment of Brush Control as a Water Management Strategy*.

Skiles, S. M., T. H. Painter, J. S. Deems, A. C. Bryant, and C. C. Landry. 2012. "Dust radiative forcing in snow of the Upper Colorado River Basin: 2. Interannual variability in radiative forcing and snowmelt rates" *Water Resour. Res*., 48, W07522, doi:10.1029/2012WR011986.

SPG Solar. 2007. *Far Niente Winery Case Study*.

Tamarisk Coalition. 2009. *Colorado River Basin Tamarisk and Russian Olive Assessment.*

Whittaker, Doug. 2005. *Flows and Recreation: A Guide to Studies for River Professionals.* Hydropower Reform Coalition and National Park Service – Hydropower Recreation Assistance.

U.S. Department of Agriculture. 2003. *Greenhouse Tomatoes Change the Dynamics of the North American Fresh Tomato Industry*. Economic Research Service. ERR-2.

U.S. Department of Interior (DOI). 2007. *Record of Decision for Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead*.

USGS. 2006. *Evaporation from Lake Mead, Arizona and Nevada, 1997-99*. U.S. Geological Survey, Scientific Investigations Report 2006-5252.

Disclaimer

The Colorado River Basin Water Supply and Demand Study (Study) is funded jointly by the Bureau of Reclamation (Reclamation) and the seven Colorado River Basin States (Basin States). The purpose of the Study is to analyze water supply and demand imbalances throughout the Colorado River Basin and those adjacent areas of the Basin States that receive Colorado River water through 2060; and develop, assess, and evaluate options and strategies to address the current and projected imbalances.

Reclamation and the Basin States intend that the Study will promote and facilitate cooperation and communication throughout the Basin regarding the reliability of the system to continue to meet Basin needs and the strategies that may be considered to ensure that reliability. Reclamation and the Basin States recognize the Study was constrained by funding, timing, and technological and other limitations, and in some cases presented specific policy questions and issues, particularly related to modeling and interpretation of the provisions of the Law of the River during the course of the Study. In such cases, Reclamation and the Basin States developed and incorporated assumptions to further complete the Study. Where possible, a range of assumptions was typically used to identify the sensitivity of the results to those assumptions.

Nothing in the Study, however, is intended for use against any Basin State, any federally recognized tribe, the federal government or the Upper Colorado River Commission in administrative, judicial or other proceedings to evidence legal interpretations of the Law of the River. As such, assumptions contained in the Study or any reports generated during the Study do not, and shall not, represent a legal position or interpretation by the Basin States, any federally recognized tribe, federal government or Upper Colorado River Commission as it relates to the Law of the River. Furthermore, nothing in the Study is intended to, nor shall the Study be construed so as to, interpret, diminish or modify the rights of any Basin State, any federally recognized tribe, the federal government, or the Upper Colorado River Commission under federal or state law or administrative rule, regulation or guideline, including without limitation the Colorado River Compact (45 Stat. 1057), the Upper Colorado River Basin Compact (63 Stat. 31), the Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico (Treaty Series 994, 59 Stat. 1219), the United States/Mexico agreement in Minute No. 242 of August 30, 1973 (Treaty Series 7708; 24 UST 1968), or Minute No. 314 of November 26, 2008, or Minute No. 318 of December 17, 2010, or Minute No. 319 of November 20, 2012, the Consolidated Decree entered by the Supreme Court of the United States in Arizona v. California (547 U.S 150 (2006)), the Boulder Canyon Project Act (45 Stat. 1057), the Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), the Colorado River Storage Project Act of 1956 (70 Stat. 105; 43 U.S.C. 620), the Colorado River Basin Project Act of 1968 (82 Stat. 885; 43 U.S.C. 1501), the Colorado River Basin Salinity Control Act (88 Stat. 266; 43 U.S.C. 1951) as amended, the Hoover Power Plant Act of 1984 (98 Stat. 1333), the Colorado River Floodway Protection Act (100 Stat. 1129; 43 U.S.C. 1600), the Grand Canyon Protection Act of 1992 (Title XVIII of Public Law 102-575, 106 Stat. 4669), or the Hoover Power Allocation Act of 2011 (Public Law 112-72). In addition, nothing in the Study is intended to, nor shall the Study be construed so as to, interpret, diminish or modify the rights of any federally recognized tribe, pursuant to federal court decrees, state court decrees, treaties, agreements, executive orders and federal trust responsibility. Reclamation and the Basin States continue to recognize the entitlement and right of each State and any federally recognized tribe under existing law, to use and develop the water of the Colorado River system.