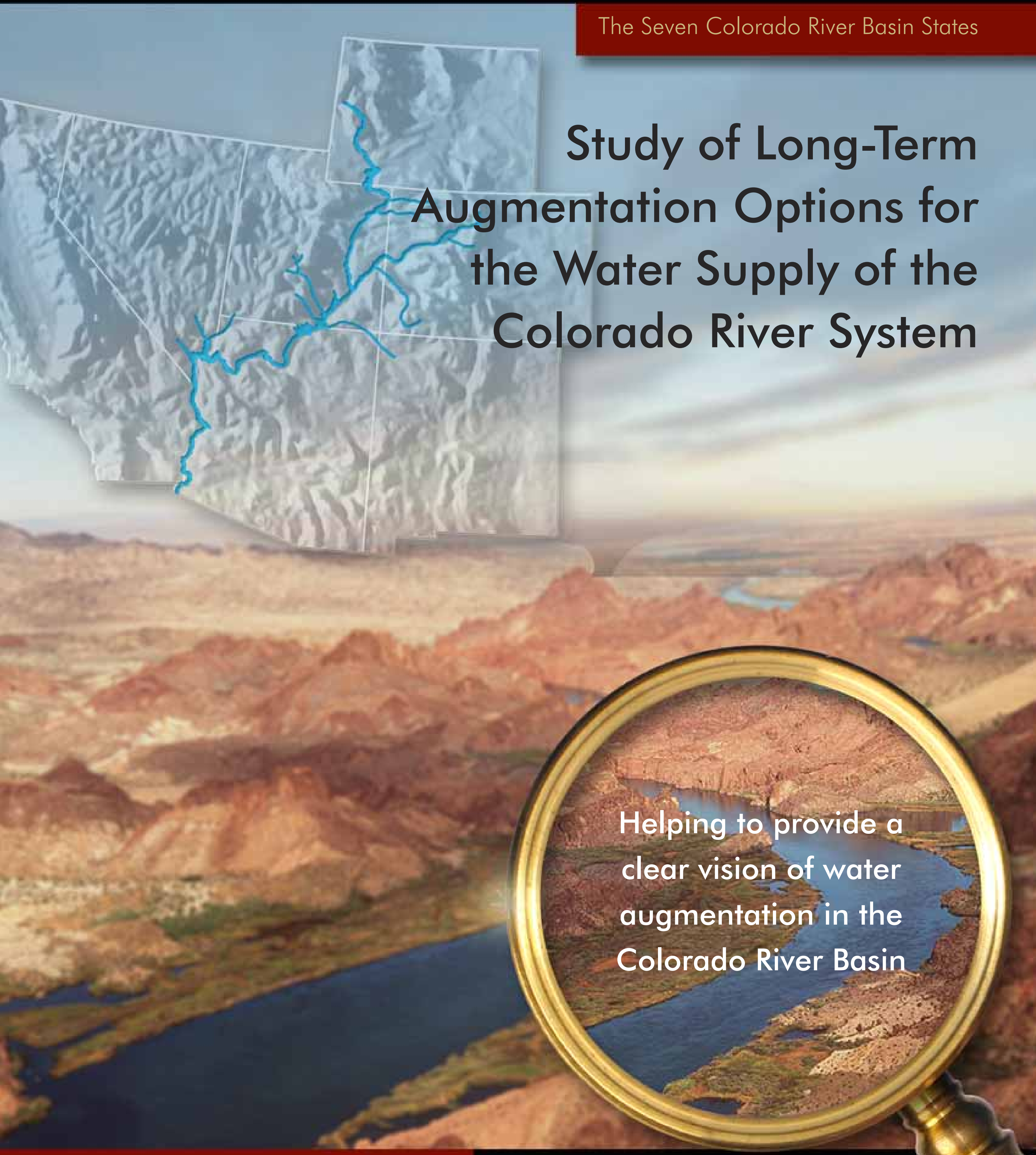
The Seven Colorado River Basin States

Study of Long-Term Augmentation Options for the Water Supply of the Colorado River System



Helping to provide a clear vision of water augmentation in the Colorado River Basin

March 2008

Colorado River Water Consultants

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Seven Colorado River Basin States

Purpose of Study

The Seven Colorado River Basin States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming (Seven States) are implementing a proactive program to meet the needs of water users within the Colorado River Basin (Basin) and to provide continued stewardship of the Colorado River. As part of this program, the Seven States authorized the Colorado River Water Consultants (CRWC) to provide a Technical Evaluation of Options for Long-Term Augmentation of the Colorado River System (Study). Twelve potential options were evaluated in terms of water quality, technical feasibility, reliability, environmental factors, and permitting considerations.

The Seven States will use the information from this study in evaluating long-term strategies for augmentation of the Colorado River. Augmentation strategies selected will be carried forward in coordination with the U.S. Bureau of Reclamation (Bureau) and others as appropriate. The Seven Colorado River Basin States recognize that there will be many challenges involved with advancing alternatives and are willing to consider partnerships beneficial to all.

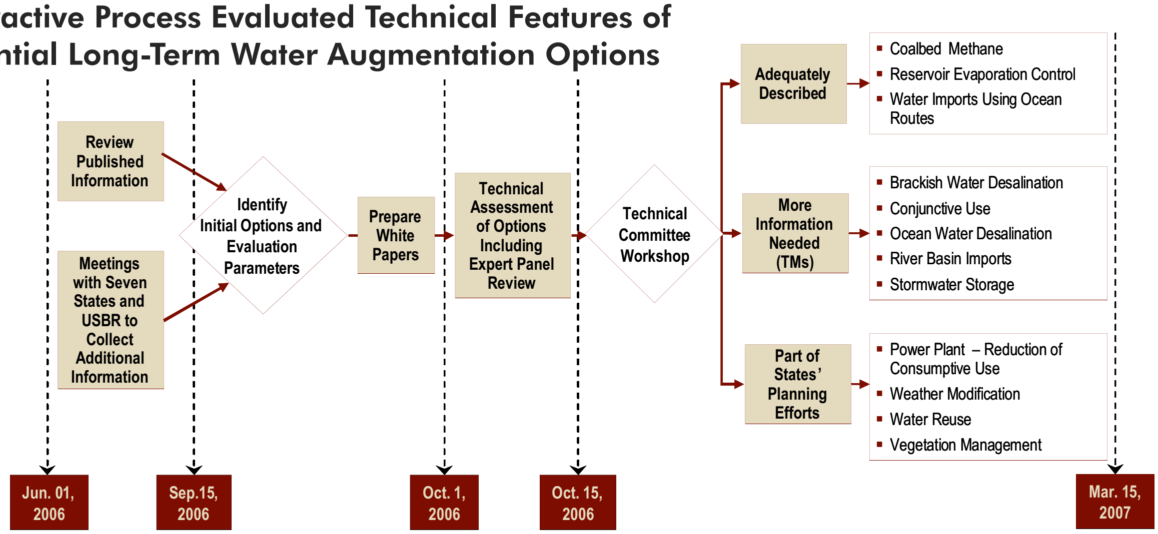
Introduction

Drought conditions in the Colorado River watershed have demonstrated the need for development of long-range measures to manage the system as well as implement options to augment the flow of the River. This is further supported by data from reconstructed streamflow of the Colorado River and the potential impacts to water supplies in the Basin that may happen if climate change and global warming occur as presently predicted. The Study is part of multi-faceted proactive efforts being implemented by the Seven States and others to meet the needs of water users within the Basin and to provide continued stewardship of the Colorado River.

This report briefly traces the history of the River and discusses the legal framework which provides protections for the Seven States, Indian Tribes within the Basin, and Mexico. Ongoing programs are also described, including activities of the U.S. Bureau of Reclamation and cooperative programs within and among the Seven States.

The major portion of this report describes the Study methodology and findings. Supporting documents in the form of White Papers were prepared for 12 potential long-term options. Options were evaluated against parameters related to water quality, technical implementation, environmental considerations, permitting, relative costs and projected water yield. Through a review process it was determined that six of the options should be evaluated in more detail at the Technical Memorandum (TM) level.

Interactive Process Evaluated Technical Features of Potential Long-Term Water Augmentation Options



A Shared Resource

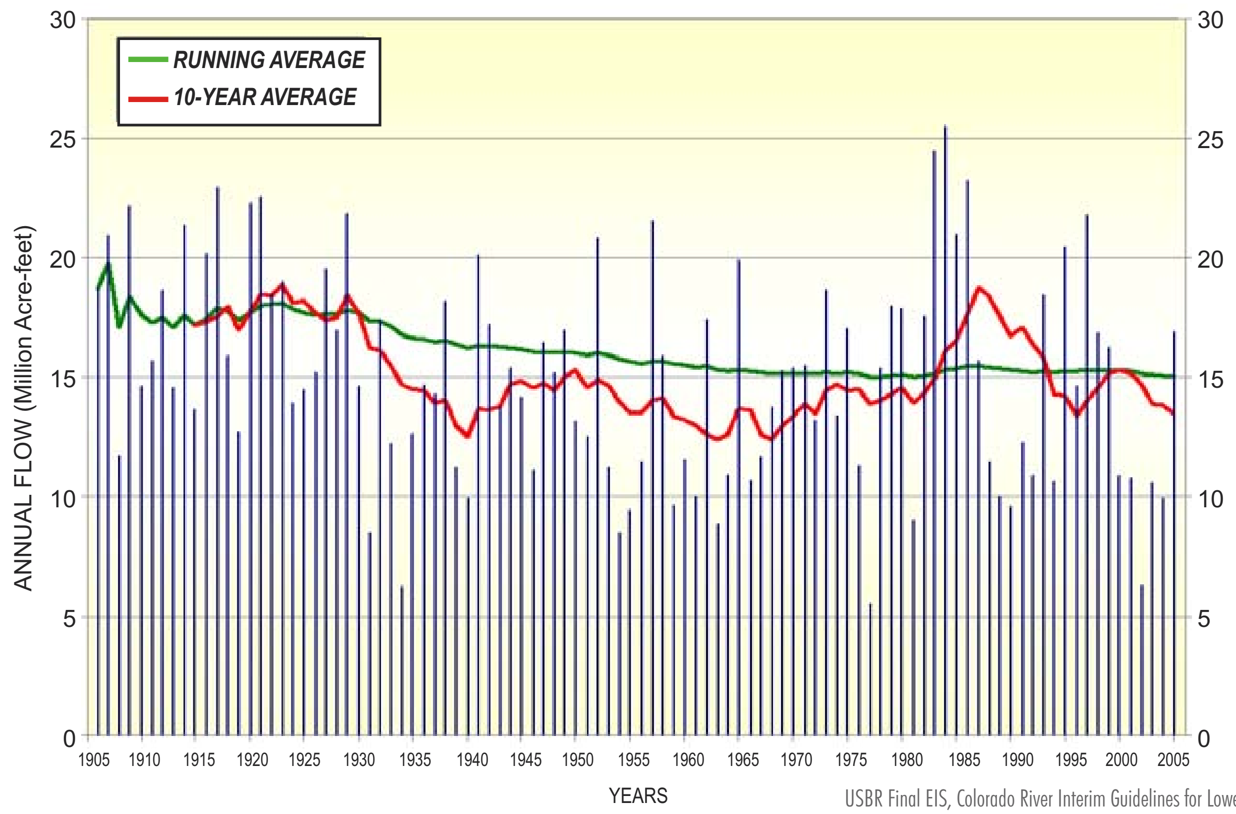
For millions of years, the Colorado River has flowed from the Rocky Mountains into the Gulf of California. Over eons, the River cut a channel which became the Grand Canyon, considered one of the Seven Natural Wonders of the World.

The River begins as snowmelt in the Rocky Mountains. The snowmelt travels through a series of tributaries into the River, which winds its way south for 1,400 miles. The River drains 241,900 square miles, with total annual natural flows at Lees Ferry historically ranging from 5.5 million acre-feet (MAF) to over 25 million acre-feet from 1906 through 2006.

The first development of the River has been traced to 600 AD, when the Anasazi Indians developed a distribution system in Chaco Canyon in northwestern New Mexico. Spanish explorers arrived in the mid-16th century, followed by religious settlers in the mid-1800s. In 1867, Congress authorized $50,000 for construction of an irrigation canal on the Colorado River Indian Reservation, the first federally-funded irrigation project in the U.S. Two years later, John Wesley Powell led a three-boat expedition that explored the River through the Grand Canyon.

Colorado River Consumptive Use Allocations	Million Acre-Feet/Year (MAFY)
California	4.4
Colorado	3.9
Arizona	2.85
Utah	1.7
Wyoming	1.0
New Mexico	0.85
Nevada	0.3
Mexico	1.5
Total	**16.5 MAFY**

Long-Term Natural Flow of the Colorado River at Lees Ferry, Arizona Is Lower than Runoff Assumed for Compact



1996 through 2005: Provisional data, subject to change.

USBR Final EIS, Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead

Large-scale diversions from the River began at the outset of the 20th century. Because of the competing demands on the River, it has the most complete allocation of its water resources of any river in the world and is also one of the most heavily regulated.

A key component of the "Law of the River" is the Colorado River Compact, approved in 1922. The agreement apportioned consumptive use of water between the Upper and Lower Basin States. The Upper and Lower Basins were each apportioned 7.5 MAF for annual consumptive use. A 1944 treaty with Mexico guarantees an annual flow of not less than 1.5 MAF, except in times of extraordinary drought or serious accident to the irrigation systems in the United States. Rarely since the signing of the Compact has the River had a 10-year average natural flow equal to these allocations, which indicates the importance of reservoir storage and the need for augmentation of the basin water supplies.

In the past decade, it has been determined that the base flow used to establish Colorado River allocations was abnormally high. Recent studies of tree rings and hydrologic data have shown that the River has been drier and more prone to severe drought than was the case in the early 20th century. The year 2000 ushered in a major drought that has exacerbated pressures created by the needs of a rapidly-expanding population. The River now supplies water to over 35 million people and over two million acres of irrigated land.

Another complicating factor is climate change. Temperature-related effects on stream flows could include increased rain to snow ratios, increased winter runoff/decreased summer runoff, and earlier and faster snowmelt. A recent University of Washington report found that the Basin may be "especially susceptible to reduced stream flow volumes" due to the almost complete allocation of consumptive uses.

Predictions of precipitation change, especially over the interior of the continent (e.g. Colorado River Basin) span the entire range from substantial (greater than 20 percent on annual average) decreases to substantial increases.

The ever-evolving **Law of the River** is a combination of interstate compacts, U.S. Supreme Court decrees, a treaty between the United States and Mexico, federal and state legislation, and associated contracts and agreements. Key components include:

- **Colorado River Compact** (1922). Divided the River into the Upper and Lower Basin at Lees Ferry, Arizona. Allocated use of 7.5 MAFY to both the Upper and Lower Basins to apportion among themselves.
- **Boulder Canyon Project Act** (Introduced 1922, enacted in 1928). Authorized the construction of Hoover Dam and Lake Mead, the largest reservoir on the River system. Authorized Arizona, California, and Nevada to enter into an agreement apportioning, respectively, 2.8 MAF, 4.4 MAF, and 0.3 MAF annually to these states.
- **U.S. Treaty with Mexico** (1944). Allotted 1.5 MAFY to Mexico.
- **Colorado River Storage Act** (1956). Paved the way for construction of Glen Canyon Dam forming Lake Powell, the second major reservoir on the mainstem of the Colorado River and for other reservoirs in the Upper Basin.

Colorado River and the Grand Canyon

Cooperative Solutions

Today, the Basin is suffering from the worst drought in a century and one of the most severe in 500 years. In recognition of the serious drought conditions and the growing demand for water, the Seven States, other public agencies, and a variety of stakeholders are moving forward on several fronts to ensure the protection of the River and all of its beneficial uses. A key player in this effort is the U.S. Department of the Interior, which oversees the management of the river system's major reservoirs. Programs and policies are administered through the U.S. Bureau of Reclamation, which resides within the Department.

Bureau of Reclamation

The Bureau's Upper Colorado Region and Lower Colorado Region have issued a final Environmental Impact Statement (EIS) on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

In December 2007, the Secretary of the Interior signed a Record of Decision implementing new, interim operational guidelines to meet the challenges of the current eight-year drought in the Basin and, potentially, low-water conditions caused by continued drought or other causes in the future. The Record of Decision adopts four key elements of river management.

Lake Powell above Glen Canyon Dam,
photo credit: Bureau of Reclamation

The States of Arizona, California, Colorado, Nevada,
New Mexico, Utah and Wyoming
Governor's Representatives on Colorado River Operations

February 3, 2006

Honorable Gale A. Norton, Secretary
Department of the Interior
1849 C. Street, NW
Washington, D.C. 20240

Re: Development of Lower Basin Shortage Guidelines and Coordinated Management Strategies for the Operation of Lake Mead and Lake Powell Under Low Reservoir Conditions

Dear Secretary Norton:

The materials attached to this letter contain descriptions of the programs that the seven Colorado River Basin States suggest be included within the scope of the environmental impact statement (EIS) for the proposed *Colorado River Reservoir Operations: Development of Lower Basin Shortage Guidelines and Coordinated Management Strategies for Lake Powell and Lake Mead Under Low Reservoir Conditions* (70 Fed. Reg. 57322) (Sept. 30, 2005).

The Basin States, Bureau of Reclamation and others have consulted regularly since our previous correspondence on August 25, 2005 to further discuss and refine recommended management strategies for the Colorado River system. Subsequently, individual entities within the seven Basin States submitted oral and written comments to the Bureau of Reclamation on the above-referenced EIS process. Attachment A, "Seven Basin States' Preliminary Proposal Regarding Colorado River Interim Operations," is submitted as a consensus document on behalf of the seven Basin States. Please recognize that the States are still actively working on the matters addressed in this submission and anticipate further refinement.

"…The States will move forward with a package of other actions that include… a demonstration program for extraordinary conservation… system efficiency project…[an action plan for] weather modification [and] **initiation of a study for long-term augmentation of Colorado River System water supplies."**

Seven States Proposal

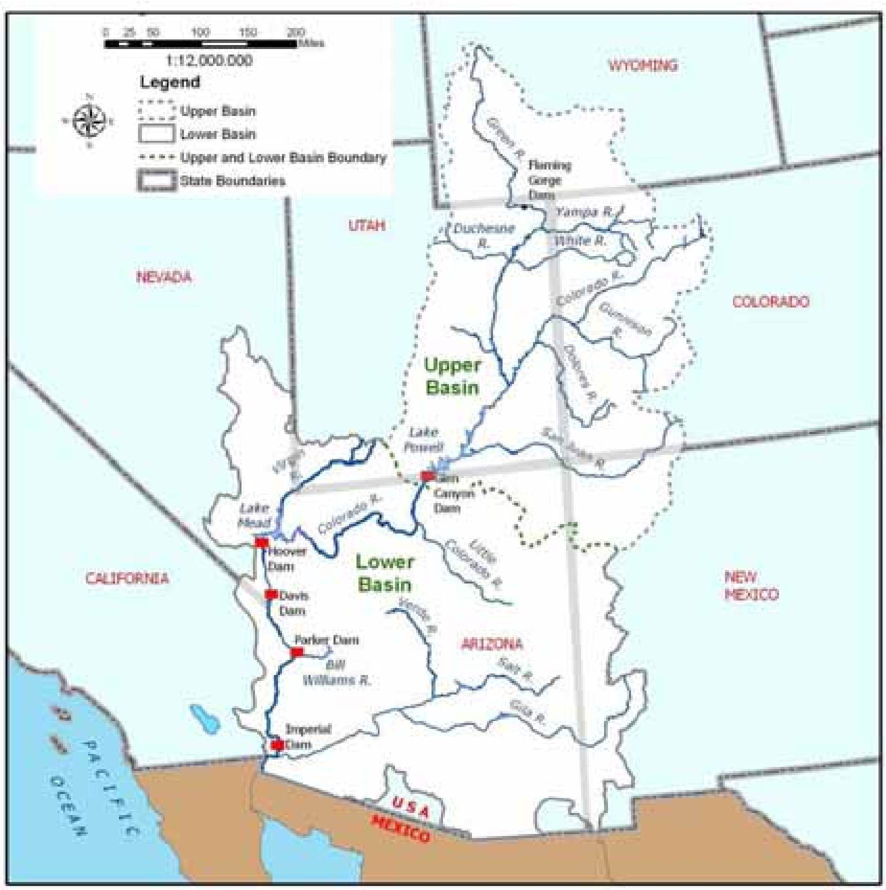
On February 3, 2006, the Seven States sent a proposal to the Secretary of the Interior in response to the Bureau's initiation of the shortage guidelines EIS. The letter was signed by the States' Governors' Representatives on Colorado River Operations. The States' consensus proposal outlined several operational and water accounting procedures for consideration by the Bureau and other actions the States will undertake during and following the EIS process.

Evaluation of Long-Term Augmentation Options for the Colorado River System

One key activity identified in the Seven Basin States February 3, 2006, letter was a Technical Evaluation of Long-Term Augmentation Options. The results of that evaluation are presented in this report.

The States selected CRWC to perform technical analyses. The States will consider the technical evaluations in conjunction with legal, environmental, and/or institutional matters. CRWC has conducted the technical evaluations in close coordination with the States and with the two regional offices of the Bureau.

Colorado River Basin Map



Stakeholder Meetings with Representatives of the Seven States and the Bureau Provided Information on Options

- Colorado, July 25, 2006
- New Mexico, August 18, 2006
- Utah, September 7, 2006
- Wyoming, July 19, 2006

- Arizona, August 23, 2006
- California, August 11, 2006
- Nevada, August 15, 2006

- Bureau of Reclamation Upper Colorado Region, September 8, 2006
- Bureau of Reclamation Lower Colorado Region, August 17, 2006

Long-Term Options

Identification of Options

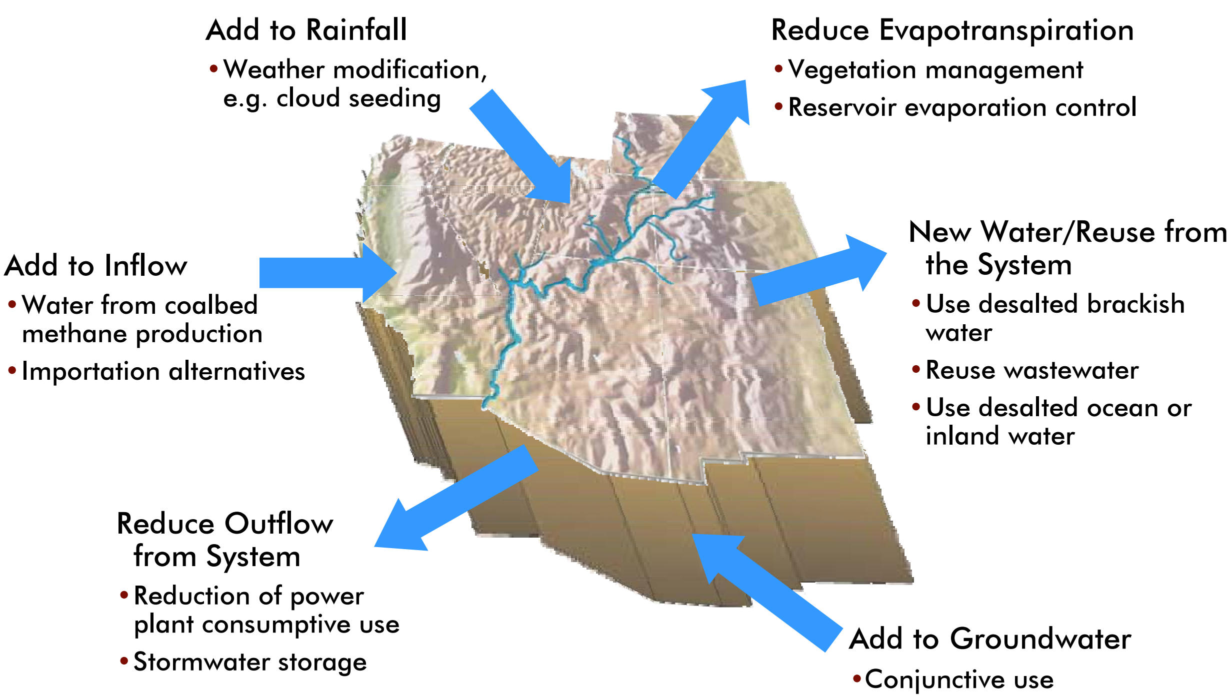
Twelve potential long-term options were identified and were evaluated against eight parameters (as shown on page 7) agreed upon by representatives of the Seven States. An Expert Panel also was convened to test the completeness of the options. Finally, the Technical Committee evaluated and reviewed the options, some of which were examined in greater detail.

Outreach Effort

An outreach effort was conducted to obtain input on potential augmentation options. The objectives of this outreach effort were to identify all viable options and to obtain pertinent previous studies and reports about these options. The CRWC attended meetings in each of the Seven States and in the offices of both the Lower Colorado and Upper Colorado Regions of the Bureau of Reclamation. Minutes of these meetings were prepared and reviewed to document these outreach efforts. As a result of this process, the following 12 long-term augmentation options were identified:

- Brackish Water Desalination
- Coalbed Methane Produced Water
- Conjunctive Use of Surface and Groundwater
- Ocean Water Desalination
- Power Plants – Reduction of Consumptive Use
- Reservoir Evaporation Control
- River Basin Imports/Exports (Exchanges Resulting in Export Reductions)
- Stormwater Storage
- Vegetation Management
- Water Imports Using Ocean Routes
- Water Reuse
- Weather Modification

Examples of Major Augmentation Options



Expert Panel Review

As part of the process to identify and evaluate augmentation options, an Expert Panel was convened to review the White Papers prepared on the 12 options and to comment on potential additional options.

The Panel agreed that the 12 options were viable and that some combination of options would probably comprise a beneficial long-term strategy. The Panel also suggested three additional options: structured agricultural/urban transfers, accelerated urban water conservation, and additional storage in the Upper Basin.

In the subsequent discussions with the Seven States Technical Committee, it was determined that agricultural/urban transfer programs are currently part of the water management planning programs of the individual States and are not a feasible regional option at this time. It was also the consensus of the Technical Committee that water conservation is already a part of the States' planning and implementation efforts. Additional storage in the Upper Basin is part of ongoing planning efforts of the Upper Basin States and does not need to be evaluated through the Seven States Process.

Evaluation Results

At an evaluation workshop with the Technical Committee, the 12 options were grouped by the purpose they achieve and the benefit provided: (1) firm up supply/reduce shortages, (2) provide new supplies, and (3) increase water use efficiency. The Technical Committee directed that six options be evaluated in more detail (TM level). For the remaining options, it was determined that sufficient information had been developed or that the options were already being addressed by the States' water planning efforts.

- **Part of States' Planning Efforts:** Power Plant Conservation, Water Reuse, and Weather Modification.
- **Sufficient Information Developed:** Coalbed Methane Produced Water, Reservoir Evaporation Control, and Water Imports Using Ocean Routes.
- **TMs Commissioned:** Brackish Water Desalination, Conjunctive Use, Ocean Water Desalination, River Basin Imports/Exports, Stormwater Storage, and Vegetation Management.

Parameters Used to Evaluate Options

Location of Supply: General geographic location of supply options.

Quantity of Water Potentially Available: Amount of water expected to be produced, measured in acre-feet per year (AFY).
- Quantifiable new water created that adds to Colorado River supply.
- Improvement in supply that reduces deficiencies or improves efficiencies.
- Localized, site-specific improvements that may improve overall Basin supply.

Water Quality: Anticipated quality of water to be developed and potential concerns associated with its use as a water supply.

Technical Issues: Availability of water at the source and the means of collecting it to a centralized location, treatment requirements (if any), and requirements for delivery to ultimate place of use.

General Reliability of Supply: "Track record" of performance and ability to provide sufficient water during a dry year or drought.

Environmental Issues: Short-term (construction) and long-term impacts on fish and wildlife, recreation, aesthetics, etc.

Permitting: Degree of federal, state, and local approvals required. Need for new or amended compacts or treaties.

Costs per Acre-Foot: Cost of infrastructure (new or modified) and O&M required to implement the option.

Coalbed Methane Produced Water

Coalbed methane (CBM) is a natural gas associated with coal deposits. To produce gas from CBM wells, water is pumped out of the formation.

The primary areas of CBM production in the Colorado River Basin are the San Juan Basin in New Mexico and Colorado, the Uinta Basin in Utah, the Piceance Basin in Colorado, and the Powder River Basin in Wyoming. An individual CBM well typically produces 2.5 to 4 gallons per minute of high TDS water (2,000 to 15,000 mg/L) over a production life of about 10 years. The amount of water recoverable for water supply ranges from 3,000 to 20,000 AFY, but individual wells are widely dispersed.

The CBM industry generally has viewed and treated the water produced as part of gas recovery as a waste product; therefore, experience with the beneficial use of this water, particularly for stream flow augmentation, is currently very limited. The White Paper assessed potential CBM produced water sources within the Basin. The Technical Committee determined that adequate information about this alternative had been developed in the White Paper.

Wells extract water as well as coalbed methane
Photo credit: Wyoming Oil and Gas Conservation Commission

Coalbed Methane Produced Water Summary:

Location of Supply: San Juan Basin (CO, NM), Piceance Basin (CO), Uinta Basin (UT), Greater Green River Basin (WY, CO).

Quantity of Water Potentially Available: Potentially 3,000 to 20,000 AFY. Production wells are dispersed, making collection of water difficult.

Water Quality: High TDS concentrations (typically 2,000 to 15,000 mg/L) will necessitate treatment.

Technical Issues: Additional collection, treatment, and delivery systems will be required to implement this option. Wide spacing of wells and distance from major Colorado River tributaries are factors to consider.

General Reliability of Supply: Supply is reliable only if development of new coalbed methane wells continues. Individual wells have limited life (~10 years) and low water production (2–4 gpm per well) after first 1–2 years of operation.

Environmental Issues: Typical issues related to construction and operation of water conveyance and treatment facilities. Disposal of high TDS treatment residuals is required.

Permitting: Ability to readily obtain NPDES permits for direct discharge to Colorado River and/or major tributaries is unknown.

Costs per Acre-Foot: Range from $900 to $4,600.

Conjunctive Use

Conjunctive Use Option Summary:

Location of Supply: Sources within the Lower Basin States to be stored in Arizona and California groundwater basins.

Quantity of Water Potentially Available: For TM projects, 2.8 MAF of water could be stored and recovered over the next 20 to 30 years (annual quantity of 8,000 to 40,000 AFY). Expansion potential.

Water Quality: Expected to meet requirements of end users.

Technical Issues: No major technical issues.

General Reliability of Supply: Dependent on the availability of surface water and ability to convey water to the banking location. However, not a perpetual water supply and the States are currently operating projects to benefit local supply and demands.

Environmental Issues: Not expected to be significant.

Permitting: Interstate banking projects in other states will require agreements. Environmental concerns are generally not present.

Costs per Acre-Foot: Range from $400 to $700.

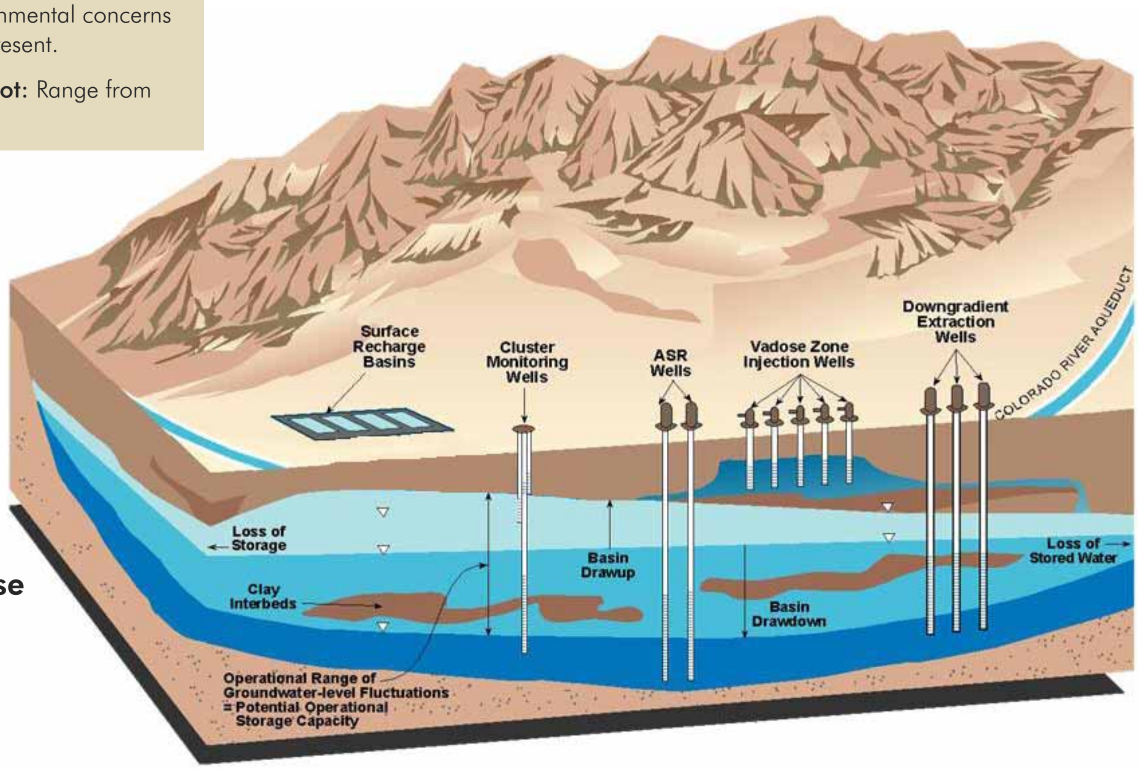
Conjunctive use, also referred to as "water banking," is the coordinated management of surface water and groundwater in a way that their combined yield and reliability are greater than when they are managed independently. Most commonly, surface water is used during wet periods and groundwater during dry periods. Surplus flows of surface water not otherwise used to meet water supply or ecosystem needs are diverted and used to recharge local groundwater basins. The water is then available for later withdrawal to meet peak, emergency or drought conditions.

It was determined that the conjunctive use option defined in the White Paper should be expanded to focus on interstate options within the Lower Basin. (Current law potentially prohibits the transfer of water from the Upper Basin to the Lower Basin without Congressional approval.)

The TM explored three alternatives for developing additional interstate water banking projects: (1) expansion of the Arizona Interstate Water Bank, (2) use of established water banking programs in California, and (3) a major groundwater storage project in Southern California.

Conjunctive use in the Lower Basin States, particularly interstate water banking, can be implemented in a relatively short period of time through expansion of Arizona Water Bank agreements or acquisition of capacity in existing programs.

As an example, the Southern Nevada Water Authority has participated in interstate banking in Arizona and California. Other opportunities within California and other basin states should be explored.



Conjunctive Use Concept

Ocean Water Desalination

Ocean water desalination is similar to brackish water desalination, except that the water is much saltier, ranging from 28,000 to 37,000 mg/L in the Pacific Ocean. The ocean is an extremely reliable source of new water. The White Paper reported that cost is currently high, but that unit costs are expected to decrease.

During the evaluation process, it was determined that the ocean water desalination option should be expanded to focus on opportunities along the Pacific Ocean coast of California and Baja California. Later discussions among the states identified the coast in the Gulf of California as well.

The TM developed a methodology to define a common cost approach for desalination facilities. Several studies were reviewed, and cost comparisons were developed. Reverse osmosis membrane technology was assumed, and a robust pre-treatment process was selected to handle water quality, environmental, and permitting issues.

Option-specific evaluations included co-location with an existing power plant and energy use (amount of energy used, ways to address the greenhouse gas effect).

A cost sensitivity analysis was performed, which showed that energy rates substantially affect unit water costs. For example, a one-cent increase in the energy rate results in an increase of about $50 per AF in treated water cost. A five-cent increase in the energy rate results in about a $250/AF increase in treated water cost.

Opportunities in Baja California are similar to those in California except that permitting requirements would be more complex if a new or amended bi-national treaty were required.

To date, only a few ocean desalting plants of relatively small capacity have been built along the California coast. These currently augment supplies for water agencies in the state. The treated water from ocean desalination facilities constructed to improve Colorado River water supplies would be used in California or Mexico in place of water otherwise diverted from the Colorado River, thereby adding to the available supply in the Colorado River and avoiding the costs of long-distance diversion.

Ocean Water Desalination Option Summary:

Location of Supply: Sites on the Pacific Ocean coast of California and Baja California.

Quantity of Water Potentially Available: Ocean water is essentially unlimited. Capacities evaluated range from 20 to 100 million gallons per day (20,000 to 100,000 AFY).

Water Quality: Source water highly saline, but can be treated to meet all regulatory requirements.

Technical Issues: Brine disposal and effect of intake structure on marine life.

General Reliability of Supply: Highly reliable. Feasibility of specific projects dependent on availability of electricity and delivery infrastructure.

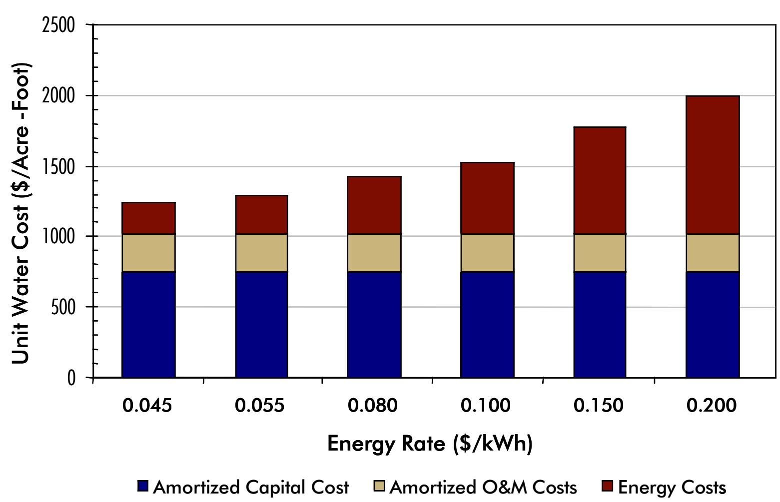
Environmental Issues: Raw water intake, brine disposal, significant energy requirements. Construction impacts.

Permitting: Raw water intake and brine disposal. Need for new or amended treaty for bi-national projects. Agreements required for interstate projects

Costs per Acre-Foot: Range from $1,100 to $1,800.

Ocean Water Desalination Energy Rate Sensitivity

(Based on 40 mgd Desalination Facility and Alamitos Conveyance Facilities in the City of Long Beach, California)



A Wide Range of Opportunities

	ALTERNATIVE	Quantity Evaluated (AFY)	Cost $ / AF
	Brackish Water Desalination	4,000 – 50,000	$700 – $2,000
	Coalbed Methane Produced Water	3,000 – 20,000	$900 – $4,600
	Conjunctive Use	8,000 – 40,000	$400 – $700
	Ocean Water Desalination	20,000 – 100,000	$1,100 – $1,800
	Power Plants - Reduce Consumptive Use	1,500 – 160,000	$1,000 – $4,000
	Reservoir Evaporation Control	0 – 270,000	$500 – $2,000
	River Basin Imports	30,000 – 700,000	Needs more refinement
	Stormwater Storage	0 –100,000	$600 +
	Vegetation Management	20,000 – 150,000 *	$30 – $100
	Water Imports Using Ocean Routes	10,000 – 300,000	$1,400 – $4,000
	Water Reuse	20,000 – 800,000	$900 – $1,700
	Weather Modification	150,000 – 1,400,000	$20 – $30

* Lower Basin Only

Power Plant - Reduction of Consumptive Use

Power Plant - Reduction of Consumptive Use Summary:

Location of Supply: Power plants are located throughout the Colorado River basin.

Quantity of Water Potentially Available: The quantity of water is dependent upon the size of the power plant and the existing cooling technology. Up to 160,000 AFY is potentially available.

Water Quality: The water quality of augmented water would be expected to be equivalent to existing water quality.

Technical Issues: Air-cooled power plants are not as efficient as wet-cooled power plants. In addition, an existing power plant cannot easily be retrofitted with air-cooled technology.

General Reliability of Supply: The reliability of the augmented water would be expected to follow the same trends as the Colorado River.

Environmental Issues: There are few if any environmental issues with converting existing power plants from water-based cooling to air-based cooling.

Permitting: There are few if any permitting issues with converting existing power plants from water-based cooling to air-based cooling.

Costs per Acre-Foot: Range from $1,000 to $4,000.

Thermoelectric power generation requires a significant amount of water within the Basin to provide cooling to power plants and remove waste heat from the power generation cycle. Evaporative cooling is the most common cooling method used within the Basin.

The White Paper compared "wet cooled" systems, such as once-through cooling systems and recirculated cooling water systems, to air-cooled systems, which use an air-cooled condenser instead of the typical water-cooled condenser. It was found that air-cooled systems eliminate the consumptive use of water for plant cooling, but at the cost of lower plant efficiencies and increased plant capital costs. The Technical Committee determined that this option should be addressed by individual States.

Navajo Power Plant

Plant Name	Plant Capacity (MW)	Consumptive Use (AFY)	Water Source
Navajo	2,409	27,366	Lake Powell
Jim Bridger	2,312	25,266	Green River
Four Corners	2,270	22,515	San Juan River
San Juan	1,848	19,981	San Juan River
Hunter	1,441	18,968	Cottonwood Creek
Huntington	996	12,307	Huntington Creek
Bonanza	500	7,964	Green River
Reid Gardner	612	7,500	Muddy River
Naughton	707	6,081	Hams Fork River
Hayden	465	2,896	Yampa River
Carbon	189	2,679	Price River
Craig	1,339	2,534	Yampa River
South Point Energy Center	708	1,955	Colorado River
Desert Basin Power	646	1,810	Central Arizona Project Canal Water
Nucla	114	1,520	San Miguel River

Reservoir Evaporation Control

This White Paper addressed methods for evaporation control at the two largest reservoirs on the Colorado River: Lake Mead, located in southern Nevada, and Lake Powell, located in southern Utah and northern Arizona. Two sub-options were assessed: the use of chemical covers and consideration of reservoir management alternatives. Chemical covers have been used in pools and golf course reservoirs to reduce evaporative water loss. However, attempting to use chemical covers on water bodies as large as Lake Mead and Lake Powell would be impractical and would raise extensive environmental, recreational, and permitting issues. The Technical Committee determined that no further consideration should be given to this sub-option.

Optimized operation of Lake Mead and Lake Powell and other reservoirs in the system is a prudent strategy and is currently ongoing. The States will continue operational studies for these reservoirs. In addition, the Record of Decision adopted specific operational guidelines for Lakes Powell and Mead through 2026.

Reservoir Evaporation Control Summary:

Location of Supply: Lake Mead and Lake Powell.

Quantity of Water Potentially Available: Chemical covers not practical. Extreme modifications to reservoir operations could yield up to 270,000 AF based on preferential storage at Lake Powell and minimum elevation of 1,000 feet at Lake Mead.

Water Quality: Reduced TDS due to reduction in evaporation loss.

Technical Issues: Low levels in Lake Mead impact water intakes, wastewater discharges, and recreation. Chemical covers are impractical on large reservoirs.

General Reliability of Supply: Overall reliability of supply enhanced by reduced evaporation loss.

Environmental Issues: Habitat in Lake Mead would be adversely impacted. Reduced dilution of wastewater discharges to Lake Mead.

Permitting: Significant NEPA review would be required.

Costs per Acre-Foot: Range from $500 to $2,000.

Lake Mead, photo credit: Bureau of Reclamation

River Basin Imports

River Basin Imports Option Summary:

Location of Supply: River basins with large volumes of water discharging into the ocean or with large quantities of unappropriated water.

Quantity of Water Potentially Available: Preliminary estimates of water potentially available varied significantly from tens to hundreds of thousands of acre feet annually

Water Quality: Variable by source, generally good to excellent.

Technical Issues: Alternatives will require some storage, diversion and conveyance facilities, discharge infrastructure, and high voltage power supplies in relatively remote locations.

General Reliability of Supply: Reliability depends primarily on water rights, interstate compacts, and surplus volumes available.

Environmental Issues: Effects of reduced river flows at the source, construction impacts, potential environmental and biological impacts, and water quality impacts at points of discharge into receiving river basins.

Permitting: Extensive permitting likely required especially when crossing multiple states. Potential issues of construction on state and federal lands.

Costs per Acre-Foot: Needs more refinement.

There are many possible river basin import options. However, all come with numerous technical, environmental, legal and political obstacles. River Basin Imports were considered in this review, however, the level of effort needed to determine the viability of any river basin import alternative was beyond the scope of this report. More detailed analysis of political, legal, socioeconomic, technical, environmental and other factors will be required in multiple basins to fully understand the challenges, potential impacts and benefits associated with a particular river basin import alternative.

In general, it appears that river basin import alternatives may offer potential to bring a significant quantity of water to the Basin States or the Colorado River System. The preliminary findings in the White Paper and TM also suggest that there are several key issues that need further study before any alternative is defined. Issues include but are not limited to the environmental effects of reduced discharge from the exporting basin, potential effects on biological communities in both export and import basins, infrastructure requirements and conveyance facility alignment between export and import points, potential footprint impacts related to facilities' construction, and the need for high voltage power facilities in remote locations. Findings also indicate a high likelihood for extensive permitting requirements, and the potential that the reliability of imports could be affected by instream flow requirements and intergovernmental agreements. The technical committee is generally of the opinion that if any import project is to proceed with any chance for success it must be done in partnership with all the governmental agencies affected and in a manner that will provide some benefit to all.

Stormwater Storage

Stormwater has been captured for flood control purposes for many years. The concept of using stormwater to augment water supplies is more recent, but practiced extensively in Australia, Singapore, and some parts of the United States. Stormwater storage within the Basin does not provide much benefit because Upper Basin and Lower Basin water is already captured in Lake Powell, Lake Mead, and lower mainstem reservoirs. An exception is the Gila River, which conveys stormwater runoff to the Colorado River. At the direction of the Technical Committee, a TM was proposed to focus on the feasibility of storing stormwater at Painted Rock Dam and Reservoir with a diversion canal to above Imperial Dam.

Painted Rock Dam has a drainage area of 50,800 square miles, and more than half of the storm runoff entering the reservoir is unregulated inflow. The dam provides temporary storage space for runoff and is designed to release flood flows at a rate no greater than the downstream channel capacity.

In 1978, the Bureau of Reclamation studied a proposal for Gila River flood flows to be conveyed to the Colorado River upstream of Imperial Dam. The study noted that the infrequency of floods and the high evaporation loss rate for Painted Rock Reservoir would require flows to be released soon after their storage. The recommendation was to develop a canal alternative to transport the water from Painted Rock Dam to Imperial Dam. Cost information in the 1978 report was indexed to December 2006 to determine the cost of building a 110-mile canal today.

A review of 46 years of flow data from the gauge below the dam indicated that water available from the Gila River exceeded 10,000 AF only 20 years of the 46-year period of record, or about 43.5 percent of the time. The evaluation of inflows from 1960 to 2005 indicated that many years have significant inflows to the reservoir. However, many other periods — such as the nine years from 1996 through 2004 — have inflows insufficient to allow any significant releases. This means that use of the reservoir for water supply would be for skimming flows during years when runoff is sufficient.

Several water quality issues are associated with this option. Pesticide contamination in the Gila River is significant, and Painted Rock Reservoir acts as a "contaminant sink." In addition, high nutrient inflows and abundant sunlight cause algal growths, which have depleted oxygen levels at the reservoir, frequently creating anaerobic conditions. The subsequent release of hydrogen sulfide gases causes objectionable odors as well as corrosive conditions impacting the reservoir control features.

Stormwater Storage Option Summary:

Location of Supply: Southwest Arizona from Painted Rock Dam on the Gila River to Imperial Dam on the Colorado River.

Quantity of Water Potentially Available: Painted Rock inflows greater than 100,000 AFY in one-third of years and greater than 10,000 AFY in 43 percent of years. Inflow for 1996 through 2004 essentially zero.

Water Quality: Issues with sediments, pesticides, metals, inorganics, and nutrients.

Technical Issues: Construction of major infrastructure to convey water from Painted Rock Dam to Colorado River. Potential retrofit of Dam to be operated as a storage facility as well as a flood control facility

General Reliability of Supply: Variable supply availability, but no dependable annual yield.

Environmental Issues: Effect of reduced river discharge on Gila River ecology. Construction impacts.

Permitting: Several permits required. Significant issues.

Costs per Acre-Foot: From $600 and up.

Painted Rock Control Tower, photo credit: USACE

Brackish Water Desalination

Brackish Water Desalination Option Summary:

Location of Supply: Groundwater sources in Yuma, Arizona, and Riverside County, California.

Quantity of Water Potentially Available: Amounts ranging from 4,000 to 50,000 AFY. (Groundwater storage for the Yuma supply is in the range of 600,000 to 800,000 AF, but regional demand is approximately 27,000 AFY).

Water Quality: Source water highly saline, but can be treated to meet all regulatory requirements.

Technical Issues: Brine disposal is a significant issue, especially for inland sites.

General Reliability of Supply: Highly reliable for Yuma site. Limited to eight months per year at Riverside site. Yuma groundwater may be a fixed volume.

Environmental Issues: Brine disposal. Construction impacts (except at Yuma location).

Permitting: Brine disposal permitting issues could be significant.

Costs per Acre-Foot: Range from $700 to $2,000.

Brackish water has a mineral content between fresh water and ocean water. Total dissolved solids (TDS) concentrations typically range from 1,000 to 10,000 milligrams per liter (mg/L). The White Paper reviewed technologies for desalting groundwater, surface water, agricultural return flows, and drainage water.

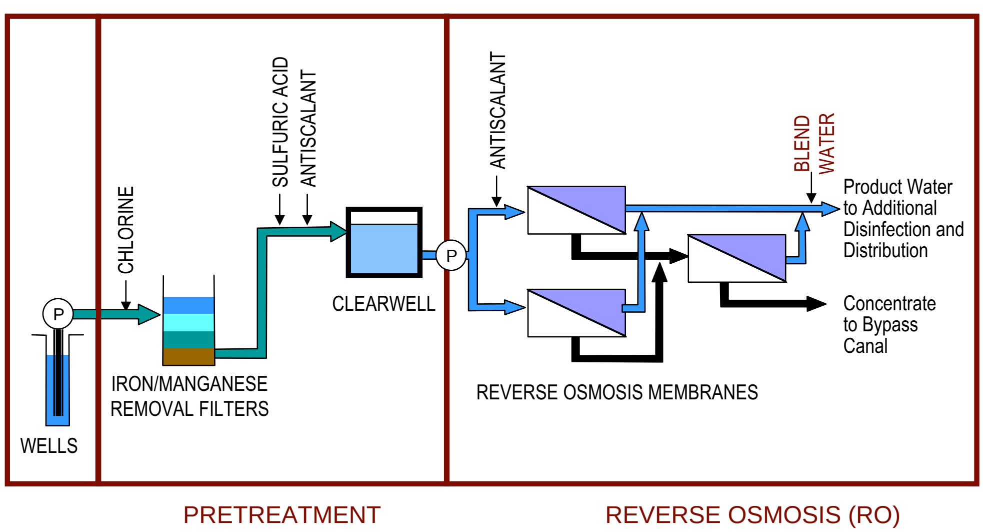
The Yuma, Arizona, area is a promising source because of the existence of the Yuma Desalting Plant (YDP) and the large volume of brackish groundwater in the area. Testing of the plant at ten percent of capacity occurred from March through May 2007. Use of the YDP is now under consideration, based on the testing results. Brackish water desalination was therefore evaluated in a TM, which developed two potential resources: (1) available water stored in a groundwater mound near Yuma, Arizona, and associated retrofit of the YDP to treat the water and (2) an unused groundwater source in Riverside County, California.

The Bureau's Yuma Area Office has been actively conducting a research project to understand the implications of processing groundwater through the YDP instead of processing drainage return flows from the Wellton-Mohawk Irrigation and Drainage District Main Outlet Drain Extension (MODE), the intended feed water to the YDP.

The Bureau is also conducting the YDP Potable Water Study to determine what changes would be necessary to allow the YDP to produce potable quality water for use by local water districts.

Yuma Desalting Plant, photo credit: Bureau of Reclamation

Brackish Water Desalination YDP Process Schematic



Vegetation Management

Vegetation Management Option Summary:

Location of Supply: Saltcedar control scenarios are described for the Virgin and Lower Colorado Rivers.

Quantity of Water Potentially Available: Gains from saltcedar control are estimated to be 20,000 AFY on the Virgin and 150,000 AFY on the Lower Colorado.

Water Quality: Variable. Dependent on saltcedar control method. Similar to shallow groundwater quality.

Technical Issues: Selection of removal method; accessibility of thickets; maintenance requirements of long-term control.

General Reliability of Supply: Reliability dependent upon depth to shallow groundwater and degree to which saltcedar roots effectively explore available soil water.

Environmental Issues: Substantial long-term biological, recreation, and fire management benefits. Short-term concerns are water quality, special status species, and cultural resources.

Permitting: Potential changes in habitat would require regulatory compliance.

Costs per Acre-Foot: Range from $30 to $100 for saltcedar management.

This option considered two sub-options: saltcedar (tamarisk) removal and forest management. Saltcedar is an aggressive non-native species that by some estimates could account for up to one million AF of water consumption in the Basin. This consumptive use is expected to increase dramatically if saltcedar growth continues unchecked. Opportunities exist for water savings wherever saltcedar is removed in the Colorado River Basin. Through the evaluation process, it was determined that the relationship of non-native species to the declining flows on the River should be further explored.

Information on forest management practices (such as tree harvesting and prescribed burning) was considered sufficient in the White Paper; the concept did not need to be developed further.

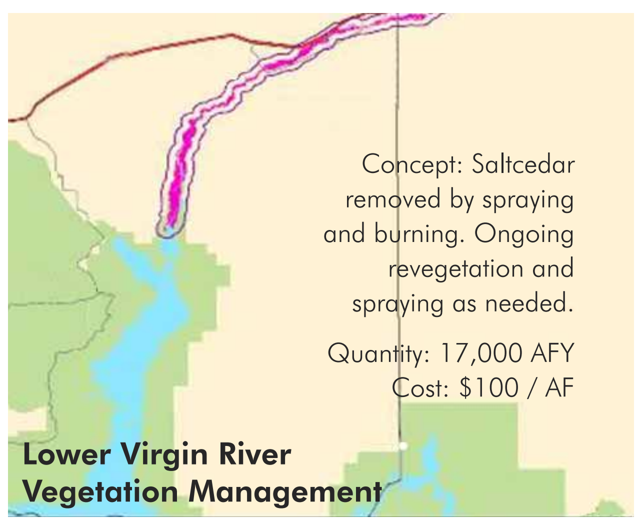
The TM evaluated the relationship of non-native species to the declining flows on the River; saltcedar occurrence, spread, and control; and the sustainability of controls.

Recent studies show that, in the last 20 years, saltcedar has spread at a rate of about 3 – 4 percent per year and nearly doubled in acreage.

To determine how vegetation management will produce (conserve) water that is usable, the TM team developed three conceptual vegetation management scenarios for increased water yield: (1) saltcedar control on the lower Virgin River, which represents a single, smaller watercourse where the location and yield primarily would be in Nevada, (2) saltcedar control on the Lower Colorado River, a large regional project with substantial implications for multiple states, and (3) a no-action scenario evaluating potential increased spread of saltcedar and the implications on Basin water yield.

If no major efforts to control the spread of saltcedar are implemented, the species could spread from about 300,000 acres at present in the Colorado River Basin to about 600,000 acres in the year 2020. This would result in the loss of as much as an additional one million AF of water each year.

Saltcedar along the Colorado River



Water Imports Using Ocean Routes

Some of the options available for providing long-term augmentation of the water supply within the Basin include importing water from other sources. In addition to the TM on River Basin Imports described on page 16, a White Paper was prepared on Water Imports Using Ocean Routes. Four methods were evaluated: (1) undersea pipeline from the Columbia River or northern California rivers, (2) water tankers bringing supplies from Alaska, (3) transporting water bags, and (4) towing icebergs.

System features for the undersea aqueduct would include transition conduits, undersea pipelines, a terminal storage reservoir, and land-based pumping facilities. Transport by tankers or water bags would require land-based or offshore loading and unloading facilities, a terminal storage reservoir, and pipelines to bring water to and from these facilities. Iceberg transport would require some type of plastic to cover the iceberg and land-based or offshore facilities to dock the iceberg and capture the meltwater. Technical issues range from fuel consumption (all options) to undersea construction methods (pipeline), materials integrity (water bags), and water loss (icebergs).

The consensus of the Technical Committee was that the White Paper presented useful information and that additional evaluation was not required at this time.

Towing an iceberg

Water Imports Using Ocean Routes Summary:

Location of Supply:

- The undersea aqueduct would draw water from the Columbia River or northern California
- The tanker and water bag options would draw water from rivers in Alaska.
- Icebergs would likely be from the Arctic.

Quantity of Water Potentially Available:

- Quantity of water available from the Columbia river is not well defined; more water would be available in the winter.
- Up to 1 million AF of water may be available from Alaska.
- Each small iceberg could produce 250 to 850 AF of water. Total annual quantity from 10,000 to 300,000 AFY.

Water Quality: Water quality from all sources considered is generally good and in some cases excellent.

Technical Issues:

- Transporting water by tankers and water bags occurs in limited areas now. The primary technical issues are fuel consumption and integrity of the water bags.
- The undersea aqueduct has major technical issues including crossing submarine canyons and fault zones, selection of pipe materials, and underwater construction in depths of 250 – 300 feet.

General Reliability of Supply: Reliability of the supply depends primarily on the water rights agreements made.

Environmental Issues: Include the effect of reduced river discharge on biological communities especially on anadromous fish species and impacts due to construction of facilities.

Permitting: Most complex for the undersea aqueduct. Water transport from northern California rivers would require approval from the State Water Resources Control Board and other agencies.

Costs per Acre-Foot: Range from $1,400 to $4,000.

Water Reuse

Water Reuse Summary:

Location of Supply: Large urban areas or any locality where wastewater is available, particularly southern California.

Quantity of Water Potentially Available: Ranges from 20,000 AFY to 760,000 AFY.

Water Quality: Generally good. Reuse from Colorado River-derived wastewater somewhat higher in TDS than Colorado River water.

Technical Issues: Treatment requirements may be extensive. Seasonal storage may be required. Location of reuse water available may be distant from area of need.

General Reliability of Supply: Extremely reliable and constant supply.

Environmental Issues: Site specific, primarily related to construction activities.

Permitting: Site specific for urban, however, mostly driven by the Regional Water Quality Control Board in southern California.

Costs per Acre-Foot: Range from $900 to $1,700.

Water recycling and reuse is one of many effective ways to conserve water. Through recycling, water that normally would be discharged as treated wastewater to inland or coastal bodies of water is treated and reused. Development of urban and agricultural reuse projects assists in augmenting water supplies by replacing the need for potable (drinkable) water for non-potable uses as well as surface or groundwater for agricultural use.

The White Paper described how urban and agricultural reuse could be used as options to extend water resources in the Seven States. The focus was on reuse in large urban areas. Urban reuse in the Seven States has been practiced for decades. However, the Basin's several large urban areas have additional recycling opportunities. Agricultural reuse also has potential for selected applications. A major advantage to agricultural reuse is the potential to recycle large quantities of water in controlled environments with limited public access. Water reuse technologies have a long track record in the Seven States, which are implementing their own programs. Through the evaluation process, it was determined that reuse contributes to water efficiency, and this option will continue to be addressed by individual States as part of their water management efforts.

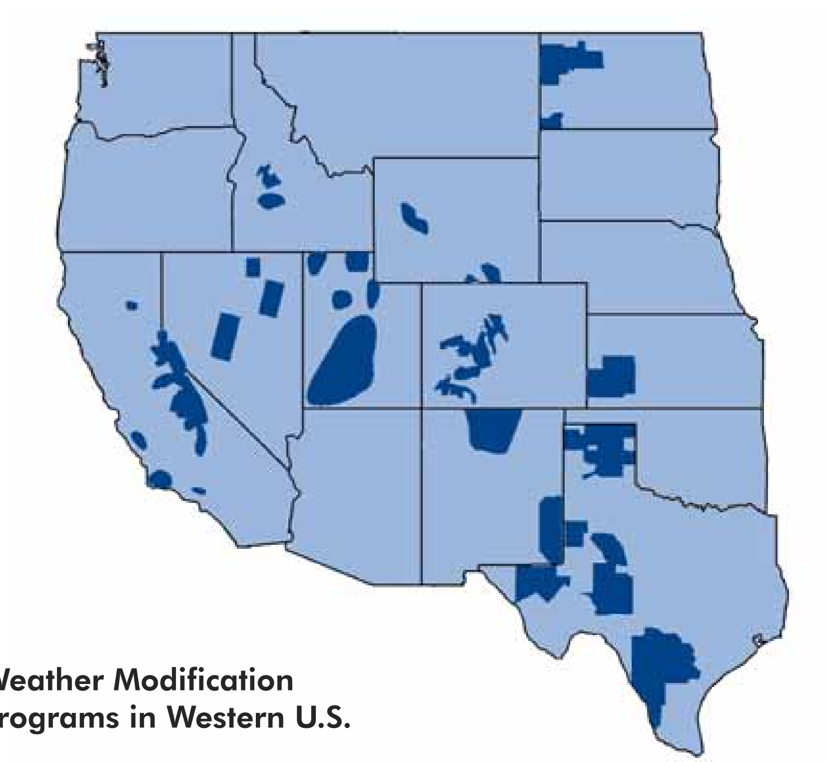
Irrigation using reclaimed water

Weather Modification

The majority of runoff produced in the Basin comes from melting snow within the Upper Basin watersheds. Much of this snow accumulates at elevations above 8,000 feet, remains throughout the winter season, and becomes runoff between mid-May and mid-July. Additional precipitation in the form of snow produced from operation of winter cloud seeding programs would increase the total runoff within the Basin.

The process of wintertime cloud seeding is simple in theory. The seeding operation releases multitudes of embryonic ice nuclei that can convert supercooled cloud droplets to ice crystals, which, upon reaching an adequate size, fall to the ground as snow flakes. Under the right conditions, these snow flakes will fall in an intended target area. It is commonly believed that snow flakes produced by seeding are formed from water droplets which otherwise would be lost to evaporation.

The White Paper focused on the use of winter cloud seeding programs to increase water precipitation within the Basin and augment the system. The majority of additional runoff would flow into Lake Powell, and a smaller amount would be available in Arizona and California. It would be difficult to quantify the additional water obtained and determine the location of additional supply. However, cloud seeding has promise, and several of the Basin States are currently sponsoring weather modification programs.



Weather Modification Programs in Western U.S.

Weather Modification Summary:

Location of Supply: The majority of additional runoff would flow into Lake Powell and a smaller amount of additional runoff can be obtained in Lower Basin states of Arizona and California.

Quantity of Water Potentially Available: As much as 1,200,000 AF in Upper Basin, and 150,000 AF in Lower Basin.

Water Quality: Quality assumed equal to existing water within Colorado River basin. Some unquantifiable improvement in quality may occur.

Technical Issues: Additional collection, treatment, and delivery systems will not be required for utilization of additional water supply. Difficulty in quantifying additional water obtained and determination of location of additional supply.

General Reliability of Supply: Weather modification activities most advantageous to increase winter snowpack in mountains. Significant anecdotal evidence that operating programs create a 10 percent increase in precipitation and snow melt runoff. Proof of additional supply is difficult.

Environmental Issues: Some concerns over spread and disposition of silver iodide used for cloud seeding.

Permitting: Some concern related to disposition of silver iodide.

Costs per Acre-Foot: Range from $20 to $30.

Summary

The Seven States are implementing proactive programs to meet the needs of water users within the Basin and to provide continued stewardship of the Colorado River. As part of this program, the Seven States authorized CRWC to provide a technical evaluation of options for long-term augmentation of the River system. Twelve potential options were evaluated in terms of water quality, technical feasibility, reliability, environmental factors, and permitting considerations.

The Seven States will use the information from this study in evaluating long-term strategies for augmentation of the Colorado River. The augmentation strategies carried forward will be coordinated among the Basin States and with the appropriate Federal agencies, including the Bureau of Reclamation.

SUMMARY OF AUGMENTATION OPTIONS

Option	Water Supply Benefit	Water Quality	Technical Issues	Reliability	Environmental	Permitting
Brackish Water Desalination	New water, opportunity to use existing facilities	Highly saline, but treatable	Brine disposal	High	Brine disposal	Extensive
Coalbed Methane Produced Water	New water	Highly saline, but treatable	Extensive collection, treatment and delivery systems required	Low	Brine disposal	Significant permitting issues
Conjunctive Use	Site-specific options improve local supply, Interstate water bank would improve systemwide supplies	Various constituents, but all treatable	No major technical issues	High	Not expected to be significant	Moderate, except for interstate banking projects in California
Ocean Water Desalination	New water, highly reliable, created near user	Highly saline, but treatable	Brine disposal	Excellent	Brine disposal, energy requirements	Extensive
Power Plant Reduction of Consumptive Use	Increase water use efficiency	Equivalent to present Colorado River quality	Reduced plant efficiency, air-cooled retrofit difficult	High	No significant impacts	Few permitting issues
Reservoir Evaporation Control [1] Chemical covers [2] Operations at Lake Mead and Lake Powell	Firm up supply, reduce shortages	Equivalent to present Colorado River quality	[1] Unproven at scale required [2] Potential impacts on water intakes and wastewater discharges	[1] Negligible [2] Undetermined	Further analysis of impacts on habitat and recreation required	Extensive NEPA review required
River Basin Imports	New water	Ranges from good to excellent	Infrastructure requirements. High voltage power lines in remote areas	Dependent on water rights and compacts	Effects of reduced river discharge, construction within National Forests	Extensive
Stormwater Storage (Painted Rock Reservoir)	New water in years when high flows on Gila River	Wide range of water quality issues	Infrastructure requirements for canal	Low	Effects of reduced river discharge in Gila River	Significant
Vegetation Management • Saltcedar control • Forest management	Systemwide benefit	Equivalent to present Colorado River quality	Follow-up maintenance	Dependent upon depth to shallow groundwater	Substantial long-term benefits, minor short-term concerns	Related to environmental issues
Water Imports Using Ocean Routes • Undersea aqueduct • Tanker transport • Water bags • Towing icebergs	Potential new water, but of variable reliability	Generally good to excellent	Major technical issues with undersea aqueduct, moderate technical issues with other options	Moderate	Potential flow impacts in source rivers	Extensive for aqueduct, moderate for other options
Water Reuse (Reuse of municipal and agricultural wastewater not returning to the Colorado River)	Increase water use efficiency	Various constituents, but treatable	Extensive treatment requirements, may require long-distance transmission	High	Site specific, primarily related to construction	Site specific due to urban environment
Weather Modification	Firm up supply, reduce shortages	Equivalent to present Colorado River quality	Difficult to quantify increase in supply	Moderate	Spread and disposition of silver iodide	Moderate requirements

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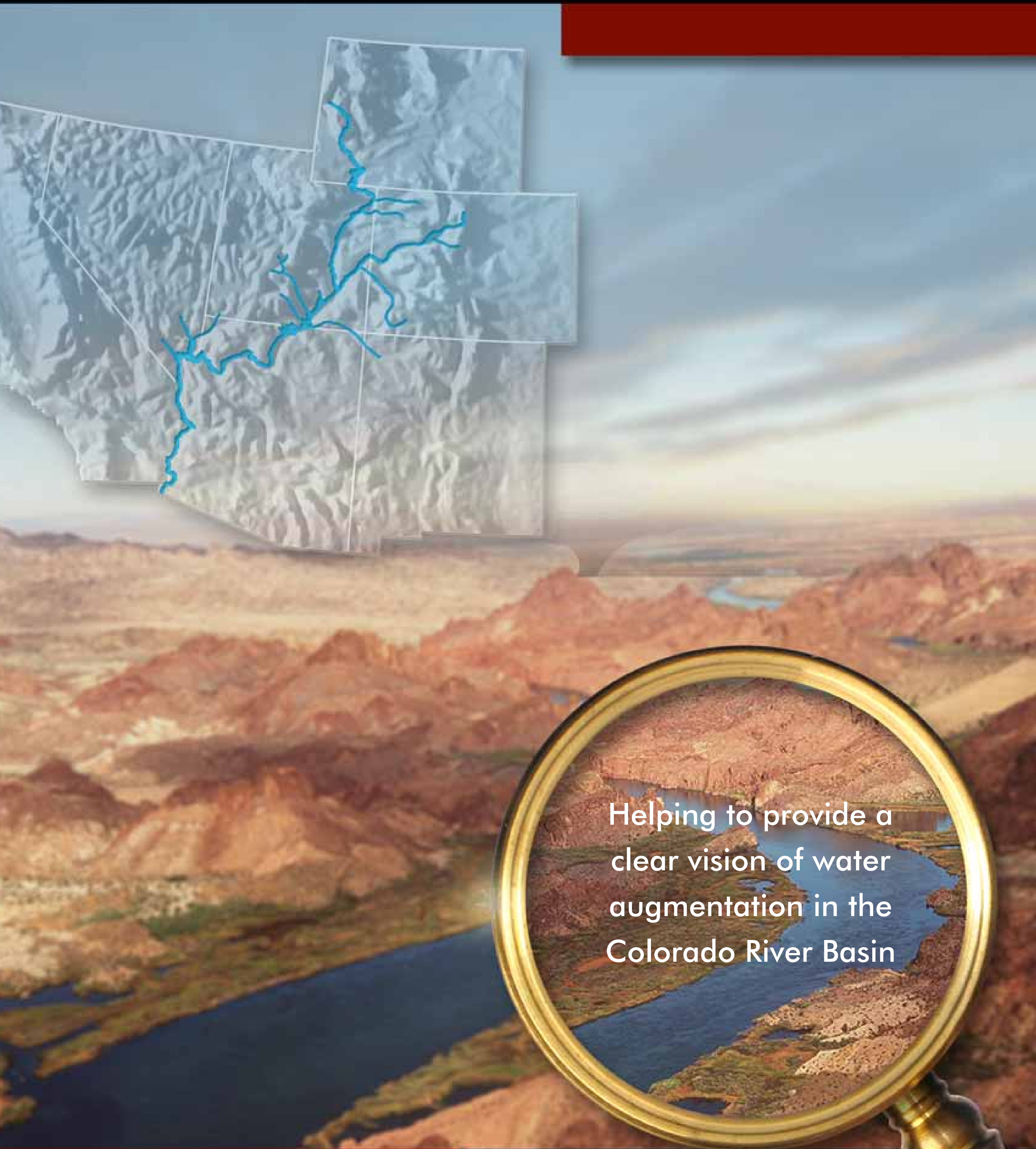

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