TEN STRATEGIES FOR CLIMATE RESILIENCE IN THE COLORADO RIVER BASIN

TECHNICAL APPENDIX

TABLE OF CONTENTS

APPENDIX

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A.1 FOREST MANAGEMENT & RESTORATION

Description

Maintaining healthy forest landscapes is an important component of functioning watersheds. The devastating wildfires across the Western U.S. in 2020 have demonstrated how fast forest resources can be lost at vast scales and how quickly public awareness on the importance of maintaining our forests can grow. Overgrown and poorly managed forests can negatively impact water supply and wildlife habitat and fisheries, and ultimately result in more severe and widespread wildfires that further degrade forest conditions and compromise water availability.[1] When actively managed and maintained, forests provide numerous benefits, including preventing soil erosion; supporting water infiltration; regulating snow melt and water supply; improving water quality; lowering water treatment costs; capturing carbon; and benefiting wildlife habitat and fisheries. Implementing best practices in forest management and forest restoration can help maintain these benefits and potentially ***mitigate climate change impacts*** including watershed degradation and severe wildfire. Forest management and restoration can also help in ***adapting to climate shifts*** as conditions in the Basin change, such as regulating snow melt runoff and ***increasing economic resilience*** through job creation and reduced emergency costs, among other benefits.

Forest management, as defined by the IPCC's Climate Change and Land Report, means "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and their potential to fulfill now and in the future, relevant ecological, economic and social functions at local, national and global levels and that does not cause damage to other ecosystems."[2] Forest restoration, on the other hand, means engaging in practices that regain ecological integrity from degraded systems.[3] Forest management and restoration are both essential practices to maintain system functionality and biodiversity in places where landscape degradation is historic, current, or predicted based on climate warming scenarios projected to transform ecological systems. In addition to the ecosystem benefits, such activities can also create jobs and provide public funding savings because of the reduced expenses on emergency wildfire response.

Prioritizing investments in forest management and restoration promotes watershed management and resilience in the Basin. As Harris Sherman, the former Undersecretary for Natural Resources and the Environment for the USDA stated, "Ultimately, the condition of our forests, and the ability of these forests to respond to climate change, disease, development, and wildfires will help to shape the future of the Colorado River."[4]

Current State of Knowledge

There are several reasons why the forests are deteriorating in health. The U.S. has maintained a culture and history of fire suppression for the past hundred years. From its beginning, the U.S. Forest Service (USFS) was committed to minimizing the size and number of fires, and after a series of uncontrollable fires in 1910 that led to more than 3 million acres being burned and at least 85 deaths, the USFS doubled down on fire suppression.[5] This history of fire control has contributed to the condition of the West's forests. Without fire to clear small trees and brush, the forests become overrun with trees which negatively affects the ecosystem and leaves the forest vulnerable to severe wildfires. In contrast to management practices that suppress fires, several North American Tribes have carefully used fire as a land management tool in forests for thousands of years.[6] There is extensive knowledge and practice in Indigenous communities, and partnerships with the communities are key to advancing forest resilience and fuel reduction efforts.[7]

A.1

Several other management challenges impact forest health. Logging that removes mainly large, older trees, and leaves surface fuel increases fire hazard and severity.[8] Insects, disease, and recreational activities have also significantly affected the state of the forest. Moreover, a lack of funding has hindered the U.S. Forest Service from implementing planned forest management projects. For example, in Arizona, around 800,000 acres in northern Arizona – a region that encompasses six national parks – are waiting to be treated.[9] In California, there are around 225,000 acres of prescribed fire projects that the agency has yet to complete.[10]

Improperly maintained forests can also affect snow accumulation, duration of snow melt, aquifer recharge, and spring runoff to tributaries. Burned forests accumulate snow unimpeded, but snow melt and ground-level sublimation (direct loss to the atmosphere) occur early and fast in the late winter resulting in reduced recharge or flows that precede the ecological and human temporal demands for water[11] (i.e., not enough water from June to October). On the other end of the management spectrum, dense forest canopies can also impact watersheds. "Overstocked"[12] coniferous forests have interlocking branches or touching canopies that both prevent snow from reaching the cold forest floor and exacerbate sublimation of snow deposited on foliage exposed to sunlight.[13] Strategic thinning of canopies can reach a trade-off favoring inter-tree and narrow-gap snow accumulation on forest floors that will slowly melt due to sufficient shading from the remaining canopy.

Prescribed burning and forest thinning, along with forest restoration, are necessary to maintain and improve the forests.[14] Collective action mixed with sustained financial investment are central to implementing management and restoration techniques and to creating the scale that is necessary to build forest resilience. The Rio Grande Water Fund by the Nature Conservancy is one example of a large-scale initiative for forest restoration.[15] The Fund is a public-private partnership project to restore 600,000 acres of forest north of Albuquerque funded by private investments from individuals, businesses, corporations and foundations.

Applicability in the Colorado River Basin

A significant portion of the land in the Basin is owned and managed by the Bureau of Land Management, Bureau of Reclamation, and Forest Service.[16] The Department of Defense, Fish & Wildlife Service, and National Park Service also own a large portion of land. In the Upper Basin, over 50% of the land is scrub and shrub land, 20% is evergreen forest, and 10% is grassland. In the Lower Basin, a majority of the land is shrub, with some large portions of evergreen forest.[17] The figures below from Earth Economics' Nature's Value in the Colorado River Basin report provide an in-depth look at the land cover in the Basin (Figures A.1. and A.2.).[18]

A.1

Figure A.1. Sub-Basin Forest Sub-Types[19]

Lower Basin				
	Gila River Basin	*Lake Mead Basin*	*Lower Colorado River Basin*	*Middle Colorado River Basin*
Dominant Coniferous Forest Types	Piñon-Juniper, Juniper, Ponderosa Pine	Piñon-Juniper, Juniper, Ponderosa Pine, Singleleaf Piñon	Piñon-Juniper, Juniper, Ponderosa Pine	Piñon-Juniper, Juniper, Ponderosa Pine
Dominant Deciduous Forest Types	Mesquite, Evergreen and other Oaks	Evergreen Oak, Mesquite, Mountain Mahogany	Mesquite, Evergreen Oak	Mesquite, Evergreen Oak
Upper Basin				
	San Juan River Basin	*Upper Colorado River Basin*	*Green River Basin*	*Lake Powell Basin*
Dominant Coniferous Forest Types	Ponderosa Pine, Douglas Fir, Piñon-Juniper, Spruce, Other Pines	Ponderosa Pine, Piñon-Juniper, Spruce, Lodgepole Pine, Other Firs	Piñon-Juniper, Spruce/Fir, Lodgepole Pine, Ponderosa Pine, Other Pine and Firs	Piñon-Juniper, Spruce/Fir, Other Pines
Dominant Deciduous Forest Types	Evergreen Oak, Aspen, Woodland Oaks	Aspen, Cottonwood	Aspen, Other Woodlands	Aspen, Mountain Mahogany, Gambel Oak

Figure A.2. Acreage by Land Cover Inside or Outside 200-Foot River or Lake Buffer[20]

Land Cover	*Total Acres*	*Within Buffer*	*Outside Buffer*
Barren/Desert	5,341,391	237,663	5,103,727
Lakes and Reservoirs	496,251	496,251	0
River and Streams	142,242	142,242	0
Riparian	1,399,331	1,399,331	0
Deciduous Forest	5,408,448	442,612	4,965,836
Evergreen Forest	30,825,660	2,490,565	28,335,094
Mixed Forest	404,289	21,104	383,184
Shrub/Scrub	100,151,833	9,454,555	90,697,278
Grassland	9,756,256	682,033	9,074,223
Pasture/Hay	1,817,690	303,815	1,513,875
Cultivated Crops	1,674,351	96,166	1,578,185
Woody Wetlands	352,790	156,423	196,368
Emergent Herbaceous Wetlands	172,711	43,466	129,246
Urban Green Space	32,701	32,701	0
Total	*157,975,942*	*15,998,926*	*141,977,016*

A.1

The condition of the forests in the Basin are an essential component to the health of the watershed, and the health of the Colorado River. The severity of wildfires that occurred in Colorado, California, Wyoming, and Arizona in 2020 demonstrate the need for supporting healthy forest landscapes. The forested land across the Basin states is at risk of more frequent and severe wildfires as drought and climate change continues to impact the landscape. A number of organizations are working on forest restoration projects in the Basin, as shown in Figure A.3. below. Moreover, the U.S. Department of Agriculture, Forest Service has a Shared Stewardship Investment Strategy that is focused on collaborating with states, tribes, and other partners to collaboratively improve forest conditions.[21] All of the Western states have signed shared stewardship agreements with the Forest Service, and progress is underway; this past January, California released a Wildfire and Forest Resilience Action Plan which builds on the state's shared stewardship agreement.[22]

Figure A.3. Examples of Forest Restoration Projects & Funding Sources in the Basin States

Chaffee County, CO Measure 1A	Through Measure 1A, voters approved a 0.25% sales tax increase aims to generate about $1 million per year for forest health projects, working farms and ranch conservation, and recreation management.[23]
Blue Forest Conservation's Forest Resilience Bond	Blue Forest's bond is a public-private partnership that brings private capital to finance forest restoration across the western U.S.[24]
Denver Water	Denver Water and the Rocky Mountain Region of U.S. Forest Service started the From Forests to Faucets partnership as a response to the costs of a series of wildfires. Later, the partnership expanded to include the Colorado State Forest Service and the Natural Resources Conservation Service. The partners have committed to invest $33 million to restore more than 40,000 acres of forestland.[25]
Flagstaff Watershed Protection Project (FWPP)	FWPP is a project that was voted on by Flagstaff residents in 2012. Voters approved a $10 million bond for forest restoration work on certain watersheds on the Coconino National Forest and State of Arizona lands.[26] The project size is approximately 15,300 acres.
Four Forest Restoration Initiative (4FRI)	4FRI is a federally funded Collaborative Forest Landscape Restoration Project. The project aims to restore forest ecosystems on sections of four national forest in Arizona–the Coconino, Kaibab, Apache-Sitgreaves and Tonto forests. The project will implement restoration treatments across 2.4 million acres.[27]
Salt River Project	The Salt River Project's healthy forest initiative aims to support the thinning of 50,000 acres a year, for a total of 500,000 acres by 2035.[28]
Southwest Colorado Wildfire Environmental Impact Fund	The Mountain Studies Institute, Quantified Ventures, and Ellen Roberts plan to structure an Environmental Impact Fund to address wildfire risk to watersheds and communities in Southwest Colorado, mainly private lands near the San Juan National Forest, using an outcomes-based financing approach.[29]

Costs and Barriers to Implementation

There are several reasons why it has been difficult to implement forest management and restoration practices at scale. For example, prescribed burns run the risk of potentially expanding beyond the control of firefighters and causing devastating losses to communities (e.g. Los Alamos, New Mexico fire in 2000). Prescribed burns and thinning can have varying effects on wildlife and wildlife habitat, including mortality and habitat loss.[30] The cost for forest management varies from $1,000-4,000 an acre, with additional costs for difficult physiographic problems, helicopter logging, and maintenance.[31] There are jurisdictional challenges in implementing projects, as forest management efforts may need to be conducted by multiple agencies and cross state boundaries.[32] The culture of fire suppression also acts as barrier to encouraging parties to implement practices like prescribed burns.[33] Moreover, there is a challenge in undertaking certain practices like burns because homes have now been built in fire-prone areas.[34] The extent of the problem is vast, making the solution seem insurmountable, which can hinder funding and effective responses. The U.S. Forest Service also faces challenges with the potential for litigation to be brought over forest management, e.g. under the National Environmental Policy Act, such that any management action must be carefully planned.[35]

Opportunities: Research, Demonstration and Financing

To advance forest management and restoration efforts, it is necessary to support the advancement of science to improve understanding of where and how forest management activities can increase snowpack, snowmelt duration, water retention, and watershed resilience; improve flows/hydrographs; reduce the risk of high-severity wildfires; and provide net carbon storage.[36] It will also be necessary to develop financing and stakeholder support to implement projects and bring the actions to scale.

Creative funding sources have been used for forest health projects such as forest restoration bonds and other public-private partnerships. Even for these sources, federal, state, and local government funding remains a key component of overall project financing. For example, the Blue Forest bond is an innovative approach that allows for the upfront costs of forest health practices to be covered by private investors, who will then be reimbursed over time with a moderate rate of return by the entities who benefit from the treatments. The Rio Grande Water Fund[37] implemented a public-private partnership approach to forest restoration by convening watershed stakeholders and then together planning and fundraising. As the funding need is vast and the timeline is short to implement projects before the next wildfire, private financing is critical to implementing management and restoration projects because it can provide upfront funds and potentially be released more quickly than federal or state sources.

At the federal level, funding sources for restoration projects include grants under the U.S. Forest Services' Collaborative Forest Landscape Restoration Program.[38] Projects under this program have been selected in Arizona, Colorado, and New Mexico.[39] The 2018 Farm Bill reauthorized the program through 2023, with authorization for appropriation of $80 million.[40] The program is currently considering project proposals submitted in 2019. These are typically 10-year projects, so this program's funding may not be available again until the next Farm Bill renewal. Potential federal funding sources may also be found in Good Neighbor Authority projects. In the 2018 Farm Bill, Congress expanded the Good Neighbor Authority,[41] which provides opportunities for the Forest Service to work with states, counties, and tribes to complete forest restoration projects on federal lands managed by the Forest Service for services like reducing hazardous fuels.[42] There are no funds appropriated for implementing the Good Neighbor Authority, but the Forest Service may use available funds appropriated for the specified project purpose.[43]

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A.2

NATURAL DISTRIBUTED STORAGE

Description

Natural distributed storage refers to a project or a series of projects across a watershed that store water in shallow, unconfined floodplain aquifers that interact directly with streams, support native vegetation, and influence the timing and quality of streamflow. Natural distributed storage projects have the following characteristics:

- Use primarily natural materials appropriate to the specific site and landscape setting;
- Largely rely on natural riverine, wetland, hydrologic, or ecological processes;
- Result in aquifer recharge, transient floodplain water retention, or reconnection of historic floodplains to their stream channels with water retention benefits; and
- Are designed to produce two or more of the following environmental benefits—
  - stream flow changes beneficial to watershed health;
  - fish and wildlife habitat or migration corridor restoration;
  - floodplain reconnection and inundation; and/or
  - riparian or wetland restoration and improvement

Much of the naturally distributed storage historically present in Western watersheds was lost due to the ditching and draining of wetlands for agricultural conversion, intensive grazing of cattle and sheep, and the extirpation of beaver and the removal of their dams during the 19th and 20th centuries.[44] The net consequence of these combined forces was the widespread occurrence of channel incision and degradation, which both drained naturally distributed floodplain and meadow storage and continued to prevent its filling by typical annual flooding.[45]

The restoration of wet meadows and implementation of various analogs to beaver-related restoration tactics have shown promise as a means by which to re-establish naturally distributed storage at the watershed scale at which it was lost. Rather than necessarily being targeted for managing demand or increasing water supply (in fact, these restoration methods may temporarily decrease late season streamflow), investments in these activities are often aimed at improving watershed resilience through recharging groundwater reserves, supporting floodplain functions, regulating stream hydrographs, providing habitat, minimizing erosion, and resisting and supporting recovery from extreme events (i.e., droughts, floods, and fires).

These watershed resilience outcomes have the potential to ***build adaptive capacity*** in ecosystems and ranching operations to deal with ongoing climate shifts. Investments in natural distributed storage could also have important additional resilience benefits in ***mitigating climate change*** by reducing and sequestering greenhouse gas emissions and ***increasing economic resilience*** by providing cost-effective mechanisms to restore degraded working lands and potentially improve land value and profitability of operations.

Current State of Knowledge

Distributed natural storage serves as a key control on surface and groundwater flow regimes, and additionally influences water quality, biogeochemical processes and the drought resilience of native plant communities that support people and wildlife.[46] Two key categories are wet meadow restoration and beaver-related restoration, which have some overlap in geographic applicability and restoration techniques, and which are largely aimed at similar natural distributed storage goals.

Wet meadow restoration focuses on raising groundwater levels in historically mesic environments to re-establish native plant communities and increase groundwater storage.[47] Projects of this sort have become a restoration priority in high elevation, headwaters (low order) channels throughout the West.[48] In general terms, wet meadow restoration may involve a variety of techniques, many of which are commonly used in California's Sierra Nevada mountain range and other alpine environments.

Beaver-related restoration includes a range of tactics, all of which aim to re-introduce the process of beaver dam-building (by reintroducing beavers, reverse engineering environments to attract beavers, or building structures to mimic beaver dams) to streams, with one goal being to increase water stored in channels and groundwater.[49] In general terms, beaver-related restoration is more common to downstream, non-headwaters (higher order) degraded rangeland streams.

These type of restoration projects have been spreading rapidly throughout the Western states, largely due to their perception as a relatively low-cost, scalable tactic.[50] While the outcomes and resilience benefits of a given project are highly dependent on many factors and local conditions, there is considerable excitement and promise around the potential positive outcomes of these projects, namely, their potential to provide a variety of interconnected water, habitat, land management, and climate benefits including the following items.

- *Water Storage & Hydrologic Cycle*
  - raising water tables in floodplains and meadows adjacent to project sites[51]
  - increasing annual groundwater storage[52]
  - increasing the frequency and rate of surface and groundwater exchange[53]
  - altering hydrograph dynamics and moderating flood peaks on the order of 7-10 days, extending the receding limb of the hydrograph following a storm[54]
  - altering streamflow dynamics, particularly late season streamflow (although what the effect is on streamflow is under active scientific debate[55])
- *Habitat & Wildlife*
  - extending riparian habitat and facilitating transitions from xeric, upland species towards mesic and hydric species more commonly found in riparian areas and wetlands,[56] and creating/restoring aquatic and terrestrial habitat
  - supporting beaver reintroduction to previously occupied geographies[57]
  - supporting high-quality forage and habitat for resident, rare, and threatened avian, terrestrial, and aquatic species[58]
- *Sediment & Erosivity*
  - altering sediment dynamics[59]
  - capturing incoming sediment and redistributing it across floodplains[60]
  - reducing erosive potential by reducing stream velocity[61]
- *Climate*
  - increasing local carbon and nitrogen storage[62]
  - improving resilience to extreme events by increasing groundwater storage and moderating hydrograph dynamics, which:
    - improves drought resilience by increasing plant available water (amount and depth)[63] and managing surface and groundwater exchange
    - creates landscape-level firebreaks[64]
    - moderates flood events by lowering flood peaks and extending draw down by 7-10 days, effectively flattening the hydrograph's curve[65] and providing valuable response time for downstream reservoir operators to manage reservoir storage and releases

- *Social/Economic*
  - promoting ranching resilience to drought by increasing forage production in riparian pastures,[66]
  - promoting ranching economic resilience by improving livestock health and operational revenues by increasing yields and nutritional value of forage[67]
  - potential for greater involvement of landowners/ag community in restoration[68]
  - potential for job creation[69]

There is still a significant amount of information needed to understand the consequences of these projects, and ensure that they are sited, implemented, and monitored to achieve the desired watershed benefits. While NGO, practitioner, and academic natural storage projects and research have created a wealth of experience and knowledge from which to draw, too few projects have been implemented and monitored at a large enough scale to assess likely changes in streamflow, groundwater storage, and surface water storage. And as with many restoration projects, the scale and standards of monitoring are variable, which can make cross-project comparisons difficult.[70] It is hard to generalize from a single project site because it is rarely known how much site-specific factors are influencing the conditions.[71] Beaver-related restoration projects tend to be rarely monitored,[72] and many are often seen more as an experiment by which to relocate so-called "nuisance" beavers than an intentional means to tactically increase water storage.

Applicability in the Colorado River Basin

Natural distributed storage tactics have been deployed in a wide range of environments. As noted above, wet meadow restoration programs have typically focused on places where there once had been a broad, valley-spanning topographic or slope wetland that no longer exists due to downcutting. They target a very particular landform, commonly found on low-order, intermittent and ephemeral tributaries. Beaver-related restoration typically targets higher-order, degraded rangeland and streams. Beaver-related restoration programs are sometimes focused on places with evidence of historic beaver populations,[73] but might also be applicable in places without a historic beaver population. For example, many of the artificial structures used in beaver-related restoration are to structures used by Indigenous managers throughout the Colorado River Basin (e.g. Paiute wicker woven dams, Zuni brush dams), which were used absent a historic beaver population[74] for a variety of water management, erosion control, or other purposes, suggesting they may be effective for similar purposes even when deployed in locations absent historic evidence of beaver.

In the Colorado River Basin, wet meadow restoration is potentially most applicable in headwaters regions in the Upper Basin, particularly in high elevation, alpine environments. Beaver-related restoration could be applicable to degraded rangeland streams across the Basin. Where projects are focused on degraded rangelands, beaver-related restoration activities should be paired with grazing management in order for restoration to be effective.

One way to think about the applicability of these projects in the Basin is to consider potential projects at a variety of "scales" within the Basin – whether activities are implemented on a "Reach" scale (i.e., 6-15 structures on a single piece of private property, in an area with fragmented land ownership); "Catchment" (numerous reaches within the same catchment area); "Sub-basin" (continuous, linear, connected set of projects); "Regional" (similar to catchment, but potentially one or more catchments or connected sub-basins); and "Watershed/Basin" scale. These various scales provide different ways to prioritize actions, work with partners, and access different types of funding, as discussed more below.

Several relevant efforts already completed or underway in the Basin that illustrate the potential diverse applicability of these methods (however, as noted elsewhere, potential projects should be tailored to site-specific conditions and goals).

- In ***Wyoming***, low-tech restoration projects are being completed on streams in the Upper Green River Basin to reduce erosion, restore streams and meadows, and improve ecosystems essential to wildlife and livestock operations in a partnership between landowners, Sublette County Conservation District, federal and state agencies, and nonprofit organizations.[75]
- In ***Colorado***, projects in the Upper Gunnison Basin have been working to restore riparian area and wet meadows to increase hydrologic function, improve wildlife habitat, and build resilience at increasingly larger scales. A variety of restoration techniques have been implemented including one rock dams, low water crossing structures, filter dams, plug and spread structures, Zuni bowls, log and fabric structures, and drift fences. With over 1,500 structures along over 24 stream miles within eight watersheds, the effort has restored approximately 160 acres and has enhanced over 1,000 acres of habitat.[76]
- Also in ***Colorado***, ongoing mapping efforts by the Colorado Natural Heritage Program could help identify stream restoration and floodplain reconnection opportunities. The group is finalizing mapping of wetlands and waterbodies and water quality and quantity functions in the Roaring Fork watershed and it has plans to do similar mapping in the headwaters of the Colorado, Eagle, and Blue River watersheds.[77]
- In ***Utah***, beaver dam analog structures and beaver re-introduction, along with other management activities, are being implemented to improve the riparian and instream habitat on 6.2 river miles on BLM land of the lower Price River.[78]
- In ***New Mexico***, beaver restoration methods have been used on the Zuni reservation by the Tribe's Fish and Wildlife Department[79] and in the Jemez Mountains by the Pueblo of Santa Clara via a Forest Service grant (outside of the Colorado River basin but in an interconnected region).[80]
- In ***Arizona***, beaver restoration and reintroduction projects are ongoing, and mechanisms similar to BDAs such as Zuni bowls, media luna, and one rock dams have been used to slow runoff, reduce erosion, control headcuts, and infiltrate rainwater in gullied, intermittent wash landscapes.[81] Completed projects have largely been at the reach scale.

Costs and Barriers to Implementation

As noted above, natural distributed storage restoration methods are considered to be relatively low-cost. However, most of the available cost information relates to specific, reach-scale projects, which do not necessarily involve the level of permitting (and therefore costs) that would be involved for larger-scale projects. For individual, reach-scale projects, EQIP estimates the price per linear foot for beaver dam analogue projects[82] to be:

- Wyoming: $28.14
- Colorado: $28.74
- Utah: $23.22
- New Mexico: $26.57
- Nevada: $28.60
- Arizona: $27.43
- California: $30.95

Most project costs would be incurred in the early stages of the project during the design and engineering phases. However, it is anticipated that once the project reaches a certain size/scale, construction costs will outpace design costs. There are also costs associated with ongoing maintenance and monitoring, yet there is a dearth of data on those costs for natural storage projects.

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There are several important challenges, barriers, and uncertainties related to natural distributed storage projects that should be considered, particularly as they influence perception of these projects by potential partnering landowners and agencies. Three key general and interconnected categories are:

- ***Legal/Regulatory***. Overlapping jurisdiction, potential for liability, and the variety of regulatory requirements from different federal and state agencies for waterways, land management, and species habitat can be burdensome and intimidating.[83] A variety of local, state, and federal permits may be needed, and it can be difficult, time consuming, and costly to obtain all the necessary permits. In some places, regulatory agencies have processes for coordinating on these types of projects to enable flexibility for this restoration approach and streamline review and permitting.[84] For example, the Sierra Meadows Partnership, a collaborative meadow restoration effort between local, regional, state and federal agencies and nonprofit organizations, has a designated work group to help streamline permitting and environmental compliance for restoration projects and provide guidance for project implementation.[85] Even after obtaining necessary permits, there may remain potential liabilities (or perceived liabilities) associated with these projects. For example, what if structures wash out in a storm and damage downstream infrastructure or property? What if restoration activities change some character about the local habitat supporting endangered species?
- ***Hydrologic***. There are still unknowns related to how these projects affect the hydrologic cycle, particularly streamflow (see above), which might require adaptive management.[86] Uncertainties related to potential streamflow impacts may exacerbate legal/regulatory challenges, for example, avoiding/mitigating impacts to downstream water users and protected species/habitat and what types of water use or storage permits may be necessary (and for how long). There are also concerns about structures washing out in heavy precipitation years, threatening downstream infrastructure and property.[87] Additional monitoring, data and analysis is needed to understand the hydrologic benefits.
- ***Implementation & Maintenance***. Project planning and implementation requires significant coordination and education/outreach with landowner partners, expertise (engineering, planning, permitting, etc.), and an available workforce. Particularly at scale, finding and organizing the necessary team to do these projects may be challenging. Ongoing maintenance and adaptive management may be needed to ensure that the structures are performing as intended. To evaluate performance and inform adaptive management, ongoing monitoring, data collection, and research is needed. And, importantly, funding is needed for all aspects of this implementation, maintenance, and monitoring.[88] Additionally, there can sometimes be uncertainties about how implementation might change operations, yields, and revenues in the short and long term.

Timelines to implement vary by project scale. Reach-scale projects could be planned and implemented on relatively short timeframes (potentially 1 year), depending on producer interest and funding availability. Larger scale projects (Catchment, Sub-basin, Regional, and Watershed scales) require greater coordination and therefore generally have longer timeframes (3-5 years or more). Coordinating across a larger scale facilitates prioritizing of projects for greater impact, and it could link up with related projects to deal with “core” issues such as roads or grazing practices upstream that are causing sedimentation issues downstream, in addition to the stream restoration work. However, reach-scale projects (with their quicker timelines and available funding) would provide useful demonstration projects to inform larger-scale efforts as planning, coordination, and supportive policy work is ongoing.

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Opportunities: Research, Demonstration and Funding

Successful implementation of these restoration approaches will depend on careful site selection that considers existing flow regime, local lithology and sediment dynamics, known limiting factors for species of concern in the watershed, and social considerations.[89] Additional monitoring and study of projects on a larger scale is needed to better understand the potential water-related effects and potential co-benefits. As noted above, large-scale coordination could facilitate project prioritization and addressing core related issues; however, identifying and implementing reach-scale projects could be quicker and could provide meaningful information to inform larger-scale efforts.

Many of the current restoration tactics are close to exact versions of what some Indigenous communities have done and are continuing to do to manage and restore streams.[90] As such, there may be opportunities to partner with and support Colorado River Basin Tribes on natural distributed storage projects. Several Tribes manage important headwaters lands and stream, and/or areas with degraded intermittent/ephemeral channels within the Basin. The restoration methods described above could be well-suited to these areas and could generate important local and regional benefits. It will be important to engage with tribes to understand ongoing projects and future goals and understand what (if any) project support and expertise would be useful and desired.

A variety of funding sources and financing arrangements are potentially available for these types of projects, however there are still questions as to how they might match up with the various practices and potential scales for natural distributed storage projects in the Basin.

FEDERAL FUNDING

- Farm Bill / U.S. Department of Agriculture
  - Environmental Quality Incentives Program (EQIP) practice #643. Other EQIP practices might be available but are less tested (i.e., funding natural infrastructure storage).
  - Regional Conservation Partnership Program (RCPP), Watershed and Flood Prevention Operations Program (known as PL 566), and Conservation Innovation Grants might be available to fund natural infrastructure storage efforts at the Catchment, Sub-basin, and/or Regional scales.
  - Conservation Reserve Program and Conservation Reserve Enhancement Program to fund Regional-scale projects.
  - Conservation Stewardship Program, while not currently used much in the West, could potentially be used to monitor results or to maintain a project funded through another program.
- Bureau of Reclamation
  - Drought Recovery Program and Cooperative Watershed Management Act (CWMA) Phase II funding might be available to build natural infrastructure storage at the Catchment, Sub-basin, or Regional scales. While the CWMA is authorized for $20M/yr, it has never received even $5M/yr.
- U.S. Fish & Wildlife
  - Partners for Fish & Wildlife Program provides technical and financial assistance to landowners interested in improving habitat for migratory birds, endangered, threatened, and at-risk species, while maintaining their primary land management goals. This is a voluntary program in which landowners continue to manage their land for their objectives as well as for wildlife, which most of the time go hand-in-hand. In FY20, Congress appropriated $57M for this program.
- National Fish and Wildlife Foundation (NFWF)
  - RESTORE program in Colorado funds habitat restoration projects across priority landscapes (pooling funding from Colorado agencies and the Gates Family Foundation). Annual grants are available from the program in Colorado to fund "at-scale habitat restoration expansion

and improvement projects across priority landscapes including river corridors, riparian areas and wetlands" as well as forests to benefit wildlife and local communities. In 2021, the total amount available is $2.5M. One program priority is to "enhance and restore hydrology and connectivity for native species, including aquatic habitat restoration and fish barrier installation/removal." To the extent that a natural distributed storage project would benefit native species, it might be eligible for RESTORE funding.

- National Fish and Wildlife Foundation may have similar programs elsewhere in the Basin.
- Great American Outdoors Act
  - Could potentially fund activities on Bureau of Land Management /U.S. Forest Service land (could be match for NRCS funding).

STATE GRANT PROGRAMS

- Utah's Watershed Restoration Initiative
- Colorado Watershed Restoration Grants
- Colorado Parks & Wildlife Wetlands Project Funding
- Colorado Water Plan grants
- Arizona Watershed Protection Fund

PUBLIC-PRIVATE PARTNERSHIPS, INNOVATIVE FINANCING, ETC.

- Environmental impact / resilience bonds, etc. (i.e., Blue Forest Resilience Bond in CA)
- Wildfire Mitigation Environmental Impact Fund (CO)
- Land conservation easements, mitigation banking/credits

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A.3 REGENERATIVE AGRICULTURE

Description

Regenerative agriculture broadly encompasses systems of farming principles and practices that enrich soils, enhance biodiversity, restore watershed health, and improve overall ecosystem function and the health of communities connected to the land.[91] Regenerative agriculture systems draw from other fields like organic farming, agroforestry, intensive rotational grazing, and ecological restoration to design agricultural systems to fit specific landscape contexts.[92]

Practices such as no-till cultivation, use of cover crops, diverse crop rotations, rotating crops with livestock grazing, and intensive grazing rotation, among others, have become popular. Regenerative systems strive to follow general principles to encourage soil health, such as: keeping soil covered throughout the year; utilizing healthy disturbance; encouraging above- and below- ground diversity; incorporating livestock; minimizing irrigation; designing for water catchment; and layering cropping and animal systems temporally and spatially. Across the globe, soils are home to more than 25% of the earth's total biodiversity and are critical for nutrient cycling and retention, agriculture, and climate regulation.[93]

Regenerative agriculture offers an opportunity to enhance resilience in the Colorado River Basin. There is interest in exploring how regenerative agriculture principles and practices could help ***mitigate climate change*** by reducing greenhouse gas emissions and sequestering carbon,[94] ***adapt to climate change*** by expanding the capacity of soils to store water which helps keep local temperatures cooler and helps reduce dust and the impact of extreme flood and drought,[95] and ***reduce pressure on existing supplies*** by enhancing water-holding capacity in soils thereby reducing the need for irrigation. Regenerative agriculture can also help ***build economic resilience*** in communities by reducing downstream damages from acute weather events, assuring cleaner groundwater and groundwater recharge, and diversifying the forms of productive income available to agricultural communities.

Current State of Knowledge

Research into and application of regenerative agriculture techniques has expanded significantly in the last decade, driven by several factors including: the prospect of increased yields; the need to restore degraded soils; a desire to reduce fertilizer and pesticide inputs; water scarcity; and the potential for carbon markets to offer payments for increased storage of carbon in soils. Increasingly, the regenerative agriculture movement is shifting towards support and protection of Indigenous foodways.

Several studies project that widespread application of regenerative agriculture techniques could draw down enough carbon to significantly counter global warming,[96] in addition to the co-benefits of healthier soils, improved crop and rangeland yields, increased water retention,[97] and improved biodiversity.[98] Other research, however, clarifies that not all regenerative agricultural practices will sequester and permanently store carbon and questions whether the magnitude of regenerative agriculture's potential contribution to climate change mitigation is over-estimated.[99]

The U.S. Department of Agriculture, state agricultural agencies, universities, non-profit organizations, agricultural producers, corporate food companies and others are exploring, studying, reporting on and modifying regenerative agricultural practices.[100] As discussed below, there are several opportunities to further that exploration in the Colorado River Basin.

A.3

Applicability in the Colorado River Basin

Based on a significant literature review, as well as an assessment of on-going regenerative agriculture developments in various areas of the Colorado River Basin, there are multiple areas where regenerative agricultural practices could potentially provide hydrological resilience, economic resilience, and climate change mitigation benefits:

RANGELAND STEWARDSHIP AND RESTORATION

Regenerative rangeland restoration and stewardship practices focus on improved forage, use of native grasses, healthy soils, and overall land productivity. These practices can have water benefits by increasing groundwater recharge and storage, reducing hydrograph variability, and reconnecting streams to their historic flood plains. More information is needed to quantify carbon benefits from rangeland restoration and improved rangeland stewardship. Some studies conclude that additional carbon sequestration through rangeland management in arid regions is unlikely, but emphasize the other environmental benefits of such practices,[101] including watershed health, biodiversity, and reduction of the contribution of some of these lands to Colorado River salinity and dust on snow. One option would be to focus first on rangeland in federal, state or tribal ownership as together they hold a significant portion of land in the West, and as such, restoration work could be completed at large scales.[102]

IRRIGATED GRASS HAY AND PASTURE

Improving soil health in irrigated grass and hay pastures provides another opportunity for application of regenerative agricultural practices. Soils in the Colorado River Basin can have naturally high saline or clay levels that are low in nutrients and organic matter. Recovering soil health can start with techniques for feeding cattle that focus on placing bales of hay throughout the fields in a way that allows cattle to rotate around the field and spread manure and hay waste uniformly throughout. As the cattle move, they mix manure into the soil and create smaller pockets to retain moisture and seeds.[103] Shifting away from mostly alfalfa fields to a diverse mixture of forage and native grasses could help to build organic matter and nutrients in the soil.[104] While these techniques hold promise, considerably more research and pilot projects are needed to verify and quantify benefits in different regions of the Basin.

COVER CROPS

Despite the scientific uncertainties around the feasibility and durability of cover crops in arid regions,[105] there is still potential in pursuing this strategy to increase soil health. Research suggests that cover crops have significant potential for low-cost carbon mitigation.[106] The most significant benefit for carbon reduction would likely accrue from restoring degraded and marginal lands with permanent cover crops that could rebuild and retain soil. Options for cover crops would likely be native grasses that would require initial irrigation but could adapt to local precipitation regimes once established. More research is needed to analyze the extent to which cover crops could contribute to water savings in the Basin.

These regenerative practices are already being employed in some areas of the Basin.[107] For example, Colorado ranchers and farmers are experimenting with both regenerative farming and ranching techniques.[108] Some Native American tribes are also exploring how to expand traditional practices, which pre-date “regenerative agriculture” techniques.[109] State agricultural departments in Utah[110] and New Mexico[111] have established healthy soils outreach programs. Coalitions, like the Colorado Coalition to Enhance Working Lands (CO-CEWL) in Colorado are working to establish healthy soils partnerships, recognizing the potential to improve yields and profit margins, as well as create resilience to drought conditions.[112] Universities in the Basin states are partnering with producers, non-profits and others to explore and promote regenerative agriculture. For example, the new National Western Center at Colorado State University is prioritizing applied research into regenerative agriculture.[113] Arizona State University has supported a film project to communicate the benefits of sustainable and regenerative ranching.[114] UC Davis has worked on developing a robust reciprocal learning network between producers and land managers in California[115] and Chico State University established a Center for Regenerative Agriculture and Resilient Systems, which works to set up reciprocal learning systems with farmers and universities.[116]

ON-FARM WATER CATCHMENT

Stewarding hydrologic health—as much as soil health—is key to regenerating any agricultural system. The regenerative community is increasingly understanding the connection between water, soil cover, and erosion and how implementing water catchment and other water planning efforts on farms could help mitigate droughts and floods.

Sheet flow is not the only water phenomenon that erodes productive agricultural land. The size and speed of raindrops that hit the soil also impact agricultural land. If heavy rainfall hits the soil surface unencumbered, the heavy raindrops may dislodge particles that then either wash away with sheet-flow or pool on the surface, thus suspending particles in sitting water long enough to stratify light and heavy particles that then form hard caps on the soil surface.[117]

Regenerative design addresses both sheet flow and raindrop intensity, which in turn affects the quantity and quality of all the water that flows off a property. All the regenerative frameworks aim to maximize plant cover on soils. Plant cover provides a protective barrier to intercept heavier raindrops before their full mass and speed have a chance to erode the soil surface. Managing for plant density also helps create friction around stable root crowns to slow down the speed of flowing water, thus sinking more of it into the landscape.

Further, methodologies like those in Keyline design[118]—which uses strategically-placed storage ponds, water barriers, and precise plowing patterns to rip soils based on topographic contours—can also improve the landscape's ability to distribute, capture, and infiltrate water during flood events. Methods like these offer strategies for both flood- and drought-proofing landscapes.[119] Other methods, like planning roads and animal impacts slightly off contour lines, reconnecting floodplains, and stabilizing head-cuts on slopes can all affect agricultural productivity and overall hydrologic function.

Costs and Barriers to Implementation

It is challenging, if not impossible, to estimate the Basin-wide cost of implementing regenerative agricultural practices at scale, as site-specific factors such as farm size, range condition, existing soil parameters, climate, and current water availability will all play a role. Costs of implementing regenerative practices can include financial risk of adopting new practices, increased labor and equipment costs, fencing and other infrastructure, and training.

In their Catalytic Capital and Agriculture report, Climate Forest Capital and the Environmental Defense Fund summarized a variety of barriers to investment in sustainable agriculture including the multi-year gap between investments and financial benefits, the existing financing structure which favors conventional practices, the lack of market premiums for crops grown using soil health practices, and the unpriced externalities of environmental benefits.[120] Additional barriers include producers lacking ready access to information and training in regenerative practices; costs and technical challenges of measuring increased environmental and/or carbon sequestration benefits if conversion is dependent on ecosystem service payments; and short-term pressures on farm/ranch economics overriding a longer-term outlook, particularly for older producers.

A.3

Opportunities: Research, Demonstration and Financing

Given the growing interest in regenerative agriculture and the need for additional quantification of costs and benefits of particular approaches, (1) further research and analysis and (2) development of relationships with existing universities, organizations, and non-profits working on regenerative agriculture would help to aid the science and further explore the best approaches to the implementation of regenerative agriculture. Developing a Basin-wide network of such research could be valuable to eventual efforts to scale-up these practices in appropriate locations. Additional demonstrations of regenerative techniques in the Colorado River Basin on farms, irrigated hay and grass pastures, and public and private ranches would be helpful to better understand the benefits and costs of employing regenerative agriculture at larger scales. It may also be worth developing technical/legal assessments and mapping tools to identify priority opportunities for regenerative agriculture in the Basin.

While there may a desire for more environmentally sustainable and economically resilient agriculture, there is a lack of a financial bridge to make this transition achievable. Identifying financing sources will be critical. The report by Climate Forest Capital and the Environmental Defense Fund identified the benefits of "catalytic capital" (federal or state grants, philanthropic capital, or risk tolerant private capital) as a means to advance regenerative agriculture adoption, steward the development and validation of new investment models, attract market rate investors, measure and demonstrate key outcomes, and test financial solutions for use by mainstream financing institutions.[121]

At the federal level, there are a variety of potential funding sources for regenerative practices. Conservation program funding through the Natural Resource Conservation Service could support such projects. For example, the Conservation Reserve Program (CRP) & Grasslands Reserve Program[122] may be available if stewardship could include removing land from production. The Soil Health and Income Protection Program[123] (SHIPP) is authorized as part of the Conservation Reserve Program and administered by the Farm Service Agency (FSA). Through SHIPP, farmers may enter into short-term contracts of three to five years to place up to 15% of their total eligible land into a CRP contract. The land that is eligible must be the least productive land on the farm. Landowners may receive up to 50% of the normal CRP rate, but there is no financial assistance for seed. The goal of this program is for the most degraded soils on a farm to temporarily be taken out of production to conserve and regenerate the soil. There are also opportunities through stewardship contracts[124] for USFS and BLM range lands. USDA extension services highlight improving soil health[125] and a number of USDA programs, in the Farm Bill and other, are available for these practices. Conservation Innovation Grants[126] (CIG) are competitive grants that drive public and private sector innovation in resource conservation. CIG projects inspire creative problem solving that boosts production on farms, ranches, and private forests—ultimately, they improve water quality, soil health, and wildlife habitat. All non-Federal entities and individuals are eligible to apply. All CIG projects must involve EQIP-eligible producers.

A number of partnership opportunities may exist in the near term with private companies to bring private capital to bear for advancing regenerative agriculture and ultimately carbon resilience and sequestration projects. Carbon markets and funding generated through a comprehensive federal climate bill and potential individual state carbon markets should be added to this list as a significant future opportunity for bringing new resources to the agriculture sector and Colorado River Basin conservation. Companies such as Indigo, Dannon, Land O'Lakes, and Patagonia are currently spending a lot of time in the regenerative agriculture research and pilot phases. Other entities such as the Ecosystem Services Market Consortium are beginning to advance federal legislation to support private, voluntary agriculture-based carbon markets.

A.3

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A.4 UPGRADING AGRICULTURAL INFRASTRUCTURE & OPERATIONS

Description

Irrigated agriculture is the major water use in the Colorado River Basin, producing food and fiber for domestic and international consumption. About 90% of the harvested pastureland and cropland in the Basin is irrigated.[127] Figures A.4. and A.5. show irrigated acreage by U.S. state (including areas outside the Basin receiving Colorado River water). Colorado River water also irrigates almost 500,000 acres of farmland in the Colorado River Delta in Mexico.

Figure A.4. Agriculture in Areas Receiving Colorado River Water[128]

State	*Total Irrigated Acres Potentially Using Colorado River Water (2011)*[i]	*Colorado River Water Equivalent Irrigated Acres*[ii]
Arizona	614,950	298,087
California	723,037	640,357
Colorado	2,177,450	1,073,194
New Mexico	144,838	38,179
Utah	476,000	352,200
Wyoming	335,540	335,540
Total	*4,471,815*[iii]	*2,737,557*

Table Notes:

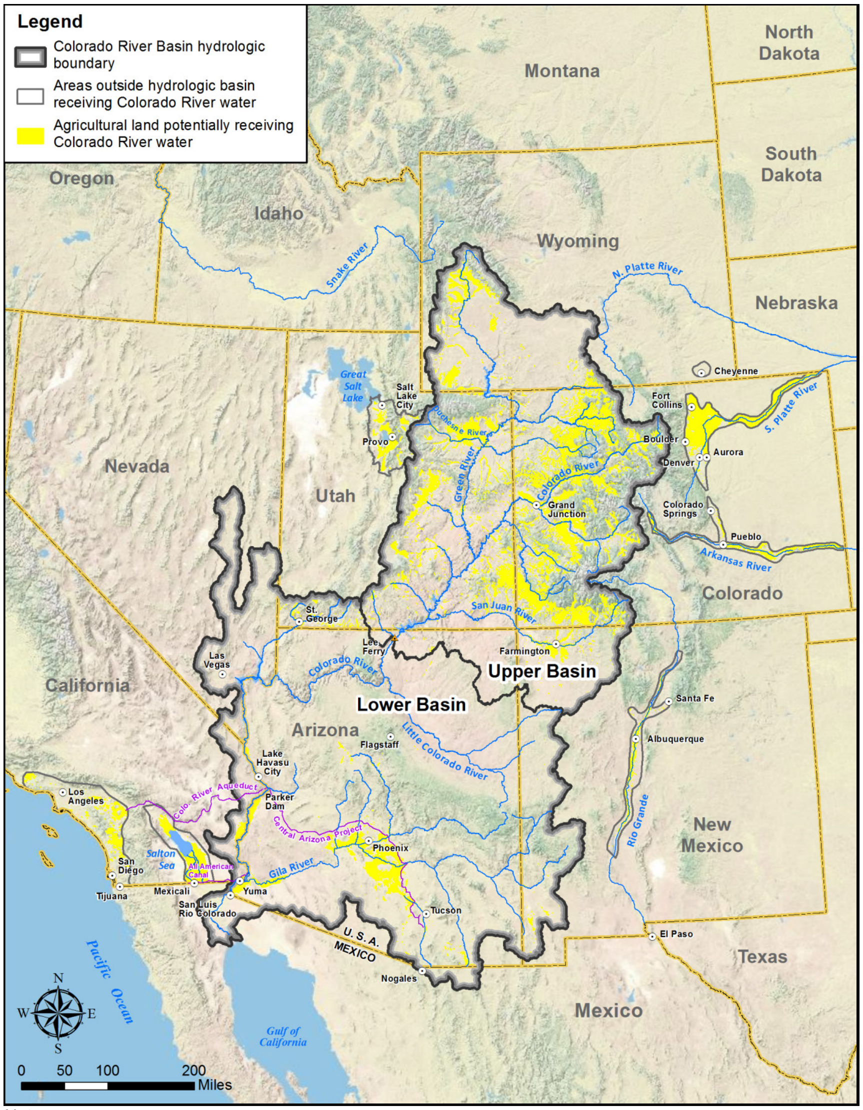
Total acreage is generally exclusive of tribal agriculture acreage except in Colorado. The majority of tribal water use is for agriculture. Basin Study tribal demand for 2015 is approximately 10-15 percent as compared to the basin-wide consumptive use and loss average from the past decade.

[i]Sources: Basin Study (Bureau of Reclamation 2012). Acreage data from 2011. Utah acreage provided by Utah Division of Water Resources. Wyoming acreage modified from Basin Study to reflect areas currently receiving Colorado River water. Acres are generally exclusive of agriculture supplied by sources other than Colorado River apportionment.

[ii]"Equivalent Irrigated Acres." The total acreage was prorated to reflect the portion of supply that comes from the Colorado River when multiple sources are available. For example, if total acreage for a given geography was 100,000 and that area received 40 percent of its supply from the Colorado River, it was assumed that approximately 40 percent of the acreage, or 40,000 acres, would be attributable to the Colorado River supply.

[iii]Acreage presented could potentially receive Colorado River water; however, in many cases Colorado River water is supplemental.

Figure A.5. Agriculture potentially served by Colorado River Water[129]

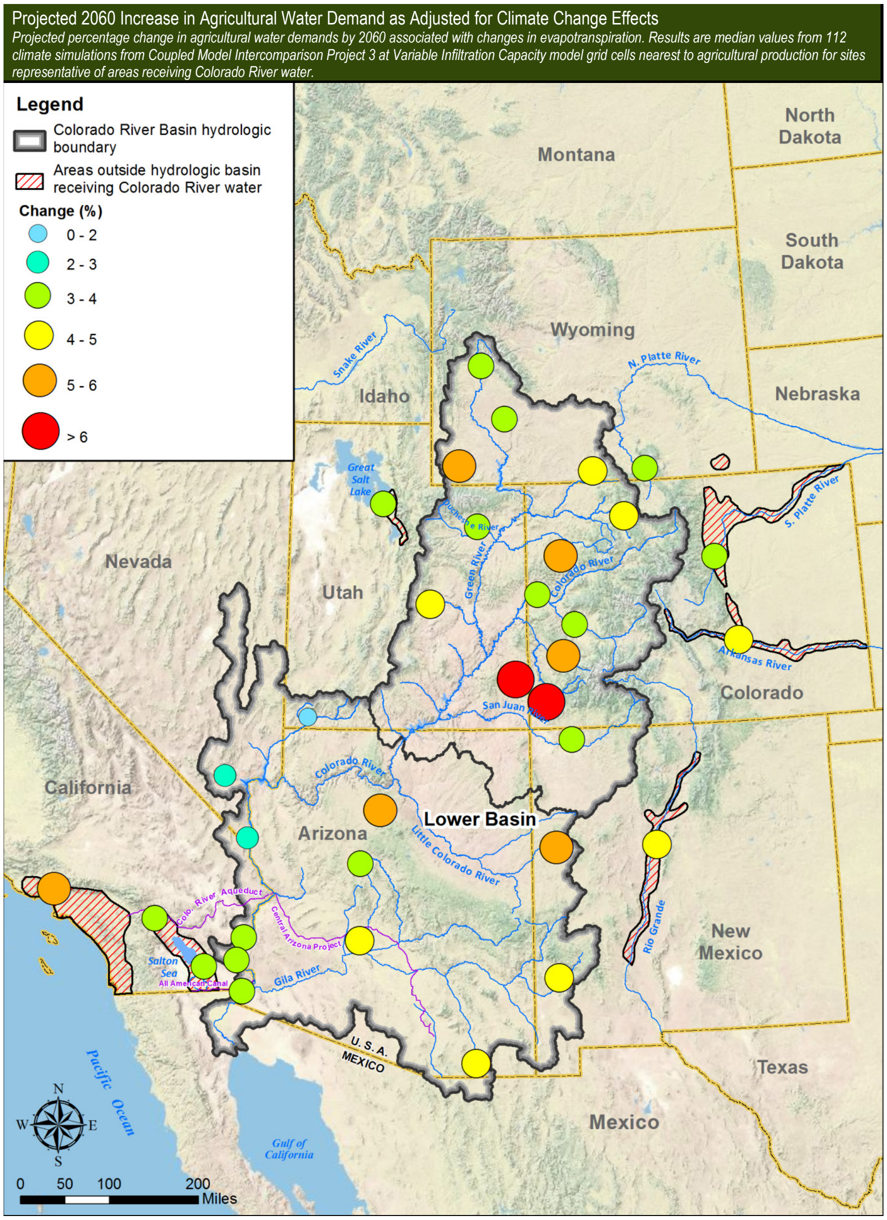


Notes:
1. Irrigated acres from National Land Cover Database; may not reflect all acreage.
2. Some of the agricultural lands shown may not receive Colorado River water or may receive mixed supplies (for example, non-tributary groundwater, diversions from Lower Basin tributaries, or other supplies).
3. Similar to the Basin Study, the scope of the *Moving Forward* effort is limited to the portion of the Basin within the United States (U.S.).

Like many areas of the western U.S., in the Upper Basin, much of the infrastructure—diversions, canals, pumps, irrigation equipment—is old, cumbersome, in dire need of repair, and labor intensive to operate and maintain.[130] These challenges can reduce irrigation efficiency, cause damage to streams, and hamper farm and ranch productivity. While many Lower Basin operations are larger, with newer, more automated infrastructure and laser-leveled fields, there may be opportunities to achieve greater productivity with less water in these operations as well.[131] Tribal agriculture is also in need of investment, as tribes seek to improve existing operations and put their Colorado River rights to beneficial use.[132]

Irrigated agriculture may also be challenged by higher temperatures associated with climate change. For example, Figure A.6. shows a projected 2060 increase in agricultural water demand as adjusted for climate change effects. Given that the Colorado River Basin is already over-allocated, it is unlikely that there will be adequate water to meet such increased irrigation demand.

Figure A.6. Projected 2060 Increase in Irrigation Demand Under Climate Change[133]



Infrastructure upgrades may include simple, low-cost actions such as installing check structures or measurement structures, to more advanced options like replacing seasonal instream push up dams with modern automated headgates and diversion structures with fish passage; adding more precise water measurement systems; lining or piping ditches; improving on-farm irrigation systems; and replacing old turbines and pumps. Operational investments might include consolidating many small ditch companies into larger and more efficient operations; implementing precision agricultural techniques to closely monitor soil moisture and soil health; and increasing precision in scheduling water diversions and deliveries (including deficit irrigation, where viable), and local, intra-district or regional programs that allow for temporary, compensated reductions in water use. Some of these investments may also have river health benefits, such as avoiding the use of push up dams and adjusting the timing of diversions during critical spawning or low flow periods.[134]

Rather than necessarily being targeted solely at reducing consumptive use of water in agriculture, some of these investments are aimed more at making better use of the water already allocated to agriculture. In some cases, the improvements may reduce consumptive use as a side benefit, and the conserved water could then be leased or sold for environmental benefit or other uses. But, overall, the greater benefit of these investments for river health is likely tied to changes in timing, rates, and diversions.

Improving agricultural infrastructure and operations may ***reduce pressure on existing water*** supplies by making operations more efficient, reducing the potential for over-diversion from streams and rivers, and, in some cases, reducing consumptive use. Taken together, these improvements, if implemented at scale over the medium-term, could also help the Basin's agriculture ***adapt to and become more resilient*** to the effects of climate change such as reduced stream flows and higher temperatures. Throughout the Basin, improving yield and profit margins through upgrades targeted at the most productive lands may allow more marginal lands to be returned to native grasses or cover crops (which might, in the future, be able to generate recognized carbon offsets) or used to produce solar or wind energy, helping to ***mitigate climate change and further reduce pressure on water supplies***. Ensuring that agricultural infrastructure and operations are up to the challenges of higher temperatures and reduced flows can help bolster and sustain ***the economic resilience of rural communities*** where irrigated agriculture has been and is a significant part of the economy.

Current State of Knowledge

Several advances in agricultural irrigation infrastructure and operational techniques have been made over the last few decades.[135] These include, but are not limited to:

- Advanced pivot and drip irrigation systems;
- Automated diversion structures and headgates;
- Overall automated monitoring at the irrigation district level via Supervisory Control and Data Acquisition (SCADA)[136] systems;
- New materials for lining[137] and piping irrigation ditches;
- Effective fish passage ladders; and
- Advanced soil moisture sensors and precision irrigation scheduling, including techniques that allow for deficit irrigation.

These modernization options can improve crop yield, productivity, profit margins and reduce adverse effects of outdated or poorly designed diversions. Not all of these approaches are all guaranteed or even intended to reduce consumptive water use (and some changes, such as the switch from flooding to sprinkler or drip irrigation may increase crop consumptive use). In other cases, actions like improving off-farm conveyance structures might reduce evapotranspiration losses. Accounting for that conserved water is an important challenge, however. Results of applying these modernization approaches will vary with geography, soil type, irrigation district/ditch company structure, state laws and regulations and irrigation district/company rules on the fate of conserved water, and many other factors.[138]

Some observers predict that developments in artificial intelligence and machine learning will increasingly "transform" the irrigation industry, leading to increased productivity and decreased water use.[139] Related developments include using the "internet of things" to transmit field level data to cell phones and vast improvements in weather data and forecasts. Of course, these more data-intensive approaches may not make sense for smaller operations.

A.4

Reagan Waskom, the Director of the Colorado Water Institute, sums up the situation and the prospects well:[140]

> *If additional water is not available in the future to meet irrigation needs, yet the demands placed on the food system only grow, the questions before us are: Can we use innovation and technology solutions to stretch limited irrigation water resources? Will technology provide the tools to improve productivity per unit of water; reduce weather risk and increase resiliency; take better advantage of plentiful water in good years and stretch limited water in dry times? Further, can technology help us reduce energy consumption for irrigation, conserve nonrenewable aquifers, better manage drought risk and other water shortage conditions, and reduce labor and input costs?*
>
> *The array of newly available technologies developed for military, medical, communications, and other sectors of the economy are astounding. Remote image and data sensing from satellite and unmanned drones, wireless sensors, robotics and pervasive automation, real-time decision systems, 5G broadband connections, long-term weather forecasts, genetic technologies, global positioning systems, big data systems, to name a few—all hold potential to be added to water resource managers' toolboxes. As a result, we are in the midst of a new agricultural revolution as these innovations are integrated into food systems and irrigation. We see a future where irrigators rely on soil, plant, water, and atmospheric sensors with smartphone apps, integrating data for irrigation decisions that incorporate real-time economic data, input costs, market forecasts, and other variables. 5G broadband connections and low-band spectrum frequency network coverage will increase communication capacity in rural areas, paving the way for the next generation of wireless technology. Precision and variable rate irrigation equipment and controllers combined with precision inputs, genetics, and management will provide the increased "crop per drop" needed to meet future needs and social expectations.*

Applicability in the Colorado River Basin

There does not appear to be an existing comprehensive evaluation of what on-farm and system-level[141] upgrades are needed in the Colorado River Basin.[142] However, through state water plans, applications for federal or state funding, and other processes, agricultural and conservation entities have identified a plethora of opportunities for upgrades that would provide benefits to both producers and the environment.

For example, the Animas Watershed Partnership used USBR Cooperative Watershed Management Program (CWMP) Phase I (planning) funding to identify necessary improvements for both agricultural irrigation infrastructure and water quality. It is now implementing those projects using CWMP Phase II funding.[143] In Eagle County, the Conservation District inventoried irrigation assets for needed improvement, funded in part by a grant from the Colorado Water Conservation Board. Using this model, a diversion inventory is now being performed for the Yampa River Basin. Similar efforts are underway in many areas of the Basin states.

The Tribal Basin Study identified upgrade and modernization opportunities for irrigation on tribal lands.[144] The 2012 Colorado River Basin Study also evaluated several infrastructure and process improvements targeted to agricultural irrigation, but without the level of detail needed to pinpoint where such improvements could be made.[145]

To date, many, but not all, of the Upper Basin projects designed to upgrade agricultural infrastructure have focused on the larger irrigation companies (e.g. Grand Valley, Orchard Mesa and the Uncompahgre systems in western Colorado; the Ferron Canal and Reservoir Company in Utah; and similar examples, as well as several salinity control projects in various areas that have focused

A.4

on conversion from flood and furrow irrigation to sprinklers.)[146] Some examples have been funded through the Upper Basin Endangered Fish Recovery Program, often supplemented by state grant programs such as the Colorado Species Trust Fund.[147] Other examples have arisen from funding through the Colorado Water Plan,[148] the Wyoming Wildlife and Natural Resource Trust and Utah's Watershed Restoration Initiative, among other programs.

Applying upgrades, particularly those that require planning and outside financing, in the many small mutual ditch and irrigation companies that dominate some areas of the Upper Basin will be challenging as many of those ditches do not even have a formal board or governing body. Marshalling the technical and financial resources to help individual producers incorporate new technology and/or make upgrades and process changes will also be challenging. One recent development that may help is that the 2018 Farm Bill authorized irrigation district and similar water management entities to directly receive and administer EQIP funding. Before this change, EQIP funds could only be awarded on a producer-by-producer basis. This provision might help ease the challenges for small irrigation companies seeking to make upgrades.

In the Lower Basin, one high profile example of infrastructure upgrades is the Yuma area, where significant infrastructure and efficiency investments have been made, "largely driven by the transition to winter vegetable production. Most of the many miles of canals, laterals and farm ditches within the Yuma irrigation districts are lined, and laser and GPS land leveling is practiced within Yuma County. Improvements in on-farm irrigation infrastructure, including construction of concrete lined irrigation ditches and high flow turnouts, shortened irrigation runs and sprinkler irrigation systems have improved on-farm irrigation efficiencies, resulting in a reduction in water use."[149] Yuma's favorable growing climate allowed a significant shift away from cotton, sorghum and alfalfa to a multi-crop system based on winter vegetables and durum wheat, melons and short season cotton.

The application of newer innovations has not likely taken hold as fully in the Colorado River Basin as it has in areas like the Central Valley of California, which has faced severe water availability challenges. However, as deep drought persists and all users face constrained supplies, there is ample opportunity to expand the application of both well-tested and more innovative upgrades. The same is likely true for decisions about whether to irrigate marginally productive lands.

Costs and Barriers to Implementation

The costs of upgrading agricultural infrastructure and operations to enhance their productivity and resilience and improve river health will vary widely with the location, type of improvement and economies of scale. Given the state of current infrastructure and the extensive irrigated acreage in the Basin, however, the total cost over the long-term would run into the billions.

For example, the Lower Gunnison Regional Conservation Partnership Program (RCCP)[150] project involves $8 million in federal farm bill funds, matched by funding from the Colorado River District, the state of Colorado, irrigation districts, the federal salinity control program, conservation organizations and other sources, for a total project cost of approximately $50 million to improve agricultural infrastructure, soil health and other operational aspects.

Just installing new, automated headgates and associated equipment can run in the hundreds of thousands to millions of dollars, depending on the size of the diversion.[151] On-farm improvements in irrigation, such as soil moisture monitoring and automated irrigation scheduling require upfront capital investments by individual farmers in the range of thousands to tens of thousands, depending on the sophistication of the system and farm size.

On the other hand, less costly improvements like measurement structures or check structures for maintaining canal or ditch water levels to facilitate better deliver of water to fields represent much less costly measures which, if implemented at scale on a ditch or within a district, could significantly improve water management.

Cost and access to technical assistance for system design and implementation are two substantial barriers to scaling up agricultural infrastructure and operations upgrades across the Basin. There are several federal and state programs that can assist with costs, as discussed below. Several of these programs, however, either require up-front match and/or have complex application guidelines. That is not to say they do not work: they are being applied already throughout the Basin. The challenge is matching the scale of investment to the potential for upgrades, as well as motivating irrigation districts and producers to do the upgrades.

Where irrigation water is generally available and crop value is modest and steady (such as with alfalfa and grass hay), motivating costly upgrades is more difficult. In addition, where farmers generally lease, rather than own the land, motivation for upgrades may be lacking.[152]

But as older systems begin to break down, ditch company managers age out and younger farmers desire more automation, or water availability forces revaluation of operations, more districts and producers may be open to upgrades.

Another important challenge for achieving resilience and environmental benefit is moving from piece-meal, crisis response upgrades to more holistic, proactive plans for entire tributaries or systems. The Lower Gunnison RCPP, and similar projects in other parts of the Basin, like the Verde River, are good examples of entities taking this more holistic approach. But the planning, funding and implementation of these bigger projects require institutional commitment from state and federal funders as well as extensive on-the-ground outreach.

Opportunities: Research, Demonstration and Financing

There are several on-going efforts to upgrade agricultural infrastructure in the Basin, and these deserve continued support and promotion. And there are many more opportunities to make such upgrades that have been identified through on-the-ground work by agricultural producers and conservation organizations working together.[153]

But both strategies could be advanced more rapidly through focusing funding and outreach on the need to make Colorado River Basin agriculture more resilient to climate change, broadening beyond responding to near-term maintenance and operational needs. This may require a more watershed or project-based approach, coordinated among producers, relevant funding agencies and, where appropriate, conservation organizations.

There are several approaches to funding agricultural infrastructure and operational upgrades, as summarized in Figure A.7 below.

Near-term efforts could focus on the Regional Conservation Partnership Program (RCPP) since it is more suitable for watershed scale work. Continuing to build on the RCPP streamlining efforts in the 2018 Farm Bill may be necessary to make this program more readily workable, but it has already been applied several times in the Basin. Full funding of Reclamation's Cooperative Watershed Program (which is currently funded at $20 million of the authorized $28 million) could assist with watershed level planning to explore the full suite of upgrade opportunities at the watershed level.[154] In Colorado, that planning could be combined with or take place in conjunction with stream management plans and updates of Basin Implementation Plans. Similar opportunities to combine state and federal funding likely exist in other Basin states.

Figure A.7. Funding Sources for Agricultural Infrastructure and Operations Upgrades

Program	*Requirements*
Farm Bill Conservation Programs (e.g. RCPP, EQIP, CRP, CREP, PL 566)	Generally, require match; competitive and demand often exceeds funding; application and implementation can be complex.
Bureau of Reclamation general	Focused on off-farm irrigation associated with federal projects and designated Salinity Control Project areas; need generally exceeds available funding; application process can be complex. Also, the RIFIA/WIFIA programs run by USBR and the Environmental Protection Agency may help with portions of project financing costs.
WaterSMART (USBR)	Competitive grant process; generally, requires match. A variety of programs available.
Salinity Control Program	Focused on designated areas of the Basin; has generally focused on canal lining and conversion from flood to sprinkler/pivot; combination of federal and state funding. Program might be more targeted to resilience improvements and better habitat replacement procedures.
State agricultural grant and loan programs	Loans are generally low interest; grant funding limited.
Regional entities	An example is the Colorado River District, which provides grant funding for modest agricultural irrigation infrastructure improvements.
Commercial loans	Agricultural lenders throughout the Basin; interest rates higher than state programs; generally, require collateral.
Fees on irrigators within districts/ ditch companies	Limited by resistance to increased fees, capacity to pay.

A concerted approach to identifying priority watersheds where agricultural infrastructure can be repaired or upgraded in a manner that provides cropping flexibility, eliminates the incentive to irrigate marginal lands, and provides environmental benefits could help guide future public and private sector investment in the Basin's rural communities. Such an approach would need to have leadership from agricultural producers, as well as broad participation from funding agencies and input from other stakeholders.

Tribal lands present an important opportunity for both upgrades and designing new climate resilient irrigation infrastructure and practices. The Tribal Basin Study[155] recommended several possible steps in this direction, including:

- Ensure operations and maintenance fees and project funding for tribal and Bureau of Indian Affairs (BIA)-managed facilities are adequate to maintain irrigation facilities;
- Increase tribal management and oversight of BIA Indian irrigation projects;
- Explore the potential for removing barriers to or expanding contracts authorized under the Indian Self Determination and Education Assistance Act (Public Law 93-638) to allow Partnership Tribes to assume operational control of federally owned irrigation projects;
- Engage outside/independent expertise to conduct economic analysis of Indian irrigation projects where needed to prioritize or evaluate the feasibility of further investment;
- Examine and, if deemed helpful, propose changes to 25 CFR Part 171 to improve tribal participation in BIA irrigation operations;
- Increase efficiency by implementing new technology and farming methods where practicable;
- Seek ways to collaborate with other water users to increase irrigation system efficiencies;

A.4

- Explore ways to work with the financial sector to create specific avenues for Partnership Tribes to better access capital markets; and
- Consider developing a tribal loan program specifically for agricultural infrastructure development, rehabilitation, and storage development.

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A.5 CROPPING ALTERNATIVES & MARKET PATHWAYS

Description

Reducing water consumption through alternative cropping is based on the premise that changes in types of crops under irrigation will reduce consumptive water use, either through (1) shifting from water intensive crops to more water efficient crops or (2) shifting to crops that have similar water efficiency but which have a higher value that can economically justify other agricultural conservation practices to reduce consumptive demand on other acreage. In its most basic conceptual form, this strategy looks to 'switch' from higher water use crops to economically viable, lower water use crops. In practice, identifying and implementing changes to the types of crops produced around the Basin depends on a variety of very local considerations, including suitability of crop alternatives to the region, soil, and climate; practicality and cost of operational and labor changes to produce the new crop; availability of market pathways locally and regionally for the new crop. These practices relate to and are often undertaken in combination with other agricultural and/or water conservation practices (see Upgrading Agricultural Infrastructure & Operations and Regenerative Agriculture sections in this Appendix).

Irrigated agriculture is by far the largest category of water use in the Basin.[156] From 1985 to 2010, more than 85% of water diverted from the River was used for irrigated crops.[157] Grass, pasture, and alfalfa for cattle are the Basin's major crop, followed by wheat, vegetables and fruit, and cotton.[158] Studies have estimated that a significant amount of water could be conserved by implementing changes in the types of crops produced, even without taking land out of production.[159] However, estimating generalized water savings as a result of alternative cropping across the Basin is difficult and fraught with uncertainty because water savings potential varies considerably based on region, climate, the initial crop, the replacement crop, and other factors. Moreover, as discussed below, there are substantial technical, financial, socio-economic and other barriers to widespread adoption of crop switching in the Colorado River Basin, and important considerations related to the appropriate type and amounts of agricultural water conservation. Anne Castle, former U.S. Dept. of the Interior Assistant Secretary for Water and Science stated:

> *Although about 80 percent of Colorado River water goes to agriculture, we would be unwise to assume that we can address shortages solely by removing irrigation water from farms. Retiring too much farmland will harm our economy in the Southwest, our food security and our quality of life. Further improving efficiency, judicious switching to less-thirsty crops, and using science to grow more with less water will be essential, but we must be careful to not destabilize rural economies that are the foundation of the basin.*[160]

This section explores the potential for cropping alternatives and creation of new pathways for farmers to access high-value markets which could help ***reduce pressure on existing water supplies***. Investments in cropping strategies, market pathways, and food systems could also help the Basin ***adapt to on-going climate shifts*** by providing options for agricultural producers experiencing impacts to crop productivity and strengthening food systems to bolster regional food security; ***mitigate climate change*** by exploring ways that cropping strategies, operations, processing, and transportation might reduce and sequester greenhouse gas emissions; and ***increase economic resilience in communities*** by testing and demonstrating the economic viability of alternative crops and new market pathways.[161]

A.5

Current State of Knowledge

Agriculture in the southwest produces "half of the fruits, vegetables, and nuts and most of the wine grapes, strawberries, and lettuce for the United States," and increasing water scarcity and competing water demands raise significant risks for agriculture, rural communities, and food security.[162] Several research efforts and demonstration projects, described further below, have explored options for alternative crops (as well as supporting processing infrastructure and market pathways) to reduce the overall water demand of irrigated agriculture while also keeping important agricultural lands in production. In analyzing a variety of agricultural water conservation scenarios for the Colorado River Basin, Cohen et al. estimated that various combinations of agricultural conservation actions (none of which include taking land out of production) could result in consumptive use savings of 60,000 - 970,000 AF annually.[163] The researchers estimated the following savings for scenarios only involving changes to the types of crops produced:

- 90,000 AF/y or more diversion/consumptive use (cu) savings from substituting 70,000 acres of cotton with wheat;
- 140,000 AF/y or more diversion/cu savings from substituting 74,000 acres of alfalfa with sorghum; and
- 250,000 AF/y or more diversion/cu savings from substituting 74,000 acres of alfalfa with 37,000 acres cotton and 37,000 acres wheat.[164]

Changes in irrigated agriculture's water use in the Colorado River Basin has largely focused on improved efficiency (which does not necessarily reduce consumptive water use) and methods such as deficit irrigation or rotational fallowing.[165] While there are some examples of crop production changes specifically targeted at lower-water use crops in the Basin (see below), there has been little incentive to date for most producers to invest the time, technical resources and money to switch from relatively stable crops such as alfalfa to lower water use alternatives. Thus, there is still uncertainty about practical aspects of alternative crops in the Basin, including identification of alternatives, costs, benefits, and scalability. Incentives may begin to appear in some areas of the Basin, such as Central Arizona and southwestern Colorado, as the extent and frequency of hotter and drier conditions increases, requiring agricultural operations to adjust water use expectations and leading to more opportunities for research, local case studies, and improved knowledge.

Applicability in the Colorado River Basin

As noted elsewhere in this section, the applicability of a resilience investment in crop alternatives and markets, the degree of transferability and scalability of specific crops or practices, and the water and resilience benefits of projects are highly dependent on a variety of very local climactic, physical, operational, market, and other factors. Case studies from in and around the Basin provide examples of some of the crop alternatives and/or market investments that have been researched, piloted, and/or implemented (Figure A.8.).

The Lower Basin in general has more potential for water conservation gains from alternative cropping strategies than the Upper Basin "because the climate there allows for greater crop selection, and because the longer growing season increases the water-use difference between high- and low-consumptive-use crops."[166] In the Upper Basin, a few locations such as the Uncompahgre, Grand Valley, and Dolores basins in Colorado have climates that allow for many different crops, which provides more potential crop switching opportunities.[167] However, throughout most of Upper Basin, shorter growing seasons, higher elevations and generally smaller parcels of farmland limit the possible region-wide water supply gains.

Even where water supply gains may be limited or more difficult to quantify on a regional level, investing in cropping alternatives and developing pathways for farmers to access high-value markets could generate local water-related benefits and other regional resilience benefits. Assessing these benefits must be done on a site-specific basis due to highly localized climate, soil type, governance, and other issues, but case studies and research indicate that some of the linkages and co-benefits may include, for example:

- Changes in timing and quantity of diversions may result in more water in streams when it is needed the most for aquatic health, riparian habitat, and recreation;[168]
- Diversifying cropping and building knowledge about crop alternatives could build adaptive capacity for farmers and rural communities to deal with changes in climate that are likely to impact food and forage production and shift the geographic areas suitable for currently grown crops;[169]
- Lower-water use crops may bring higher returns, which could build economic resilience for agriculture and agriculture-based communities[170] (recognizing that different labor, input, and other costs may also be involved);
- Producing more food (and more diverse food crops) supports local and regional food systems and food security;[171] and
- Supporting new community-driven infrastructure, processing facilities, and local/regional food systems partnerships and infrastructure could develop new market pathways and further bolster social and economic resilience.

Switching to new crops can involve significant costs at the farm level (field preparation, new equipment, additional labor, seed and other input costs). In addition, for conversion at scale in a locality or region, investments in processing, transportation and marketing capacity are likely necessary. Because these costs vary with the type of crop switch, locality, and existing infrastructure, it is not possible to usefully estimate them for a region or the Basin as a whole.

Other barriers to implementation include obtaining the technical assistance often required to evaluate crop suitability; developing and building new markets from scratch; and finding expert partners and investment capital needed for developing processing and/or transport facilities, often in more remote rural areas. In addition, the current dominant crop—alfalfa—is relatively profitable, easy and predictable to grow, and the high-quality alfalfa has a widespread market in the western U.S. and, increasingly, overseas. Additionally, pasture and grass hay production are often tied to local or regional cattle production with well-established marketing and transport infrastructure in place. Thus, the incentives to continue current cropping patterns are strong.

Finally, while there may be water savings possible in converting from water intensive crops to lower water use but higher value crops, there are many factors that go into determining whether those savings are beneficial to river or watershed health. Such a determination depends on, among other factors: the quantity and timing of savings relative to current stream conditions and flow needs; the ability to ensure that savings are not applied to additional crop acreage or diverted by other water right holders; and the permanence of the crop switch.

A.5

Figure A.8. Examples of alternative cropping and market pathways in and near the Colorado River Basin

Over the past 40 years, agricultural operations in ***Yuma, Arizona*** area have transitioned from perennial and full season crops such as cotton, sorghum and alfalfa to **lettuce** and **winter vegetables**.[172] Acreage committed to perennial and full season crops (citrus, cotton, sorghum, and alfalfa) has declined over that period while the number of acres planted to vegetables and multi-crop production systems has increased. Nearly 70% of irrigated acres in Yuma "now support multi-crop production systems that include a winter vegetable crop followed by durum wheat, melons, short season cotton or Sudan grass. The water requirements of these multi-crop systems are typically less than the perennial and full season crops they replaced."[173] Yuma County farms (including both family-run and large company farms) produce 90% of the U.S. supply of winter vegetables, employ tens of thousands of local and migrant workers, and contribute almost $3 billion annually to Arizona's economy.[174]

In the ***Verde Valley in Arizona***, a collaborative partnership between producers, processors, retailers, and a local nonprofit have support switching acreage from alfalfa and corn to **barley**. Barley's consumptive use is less than that of alfalfa or corn in spring months and a key benefit of the switch is timing – growing higher-value barley economically justifies not planting an additional crop in the summer months when streamflow in the Verde River is at its lowest.[175] A new malting facility was piloted to address the limited local market pathways for processing and malting the barley. The facility became Arizona's first commercial malthouse, creating a link to local and regional brewers.[176]

In ***central Arizona***, researchers are testing **guayule**, a perennial hardwood shrub native to northern Mexico and the southwestern US desert, as a renewable, domestically-produced natural rubber alternative.[177] Guayule is drought- and heat-tolerant and requires less water for cultivation than crops currently grown in the region.[178] Building on a key industrial partner's existing research, plant breeding and agronomy, and production with participating growers,[179] research is ongoing to further develop and test guayule and potentially build to commercialization and expansion of guayule cultivation.[180]

Heirloom and historic apple varieties were planted in ***southwestern Colorado*** over 100 years ago but are no longer a substantial component of the farm economy in the region. Apple crops on average consume less water than crops like alfalfa in areas where both are grown in the West, and their potential for increased profitability may also allow producers to generate more income with fewer irrigated acres.[181]

In ***western Nevada*** (outside of the Basin), a local grower working with the Walker Basin Restoration Program developed **organic vegetable** production on land previously used to grow alfalfa hay to test whether the negative regional economic effects from the permanent retirement of a portion of land and water rights previously devoted to alfalfa hay could be offset through partnerships with local producers to convert smaller land area to higher value crops.[182] The project included several conservation strategies, including a smaller irrigated footprint and conversion to sprinkler and drip, in addition to shifting to other crops. Even with significantly less acres in production and higher expenses (fertilizer, herbicide/pesticide, and seed cost), there was a net change of over $4.5M in increased revenue and between 3,250-4,633 acre-feet net reduction in water application over the 5-year pilot. Water savings resulted from both smaller irrigated area and lower per acre water application associated with vegetable and melon crops. Conserved water is targeted for instream flows to help preserve Walker Lake.

Teff seed is being explored as a crop that requires less water than alfalfa, but which may be more profitable.[183] Teff is a warm season grass that needs high temperatures to maximize yield. It can produce 5 to 6 tons of hay per acre over a relatively short growing season and has a consumptive use of approximately 2.5 AF/acre in northern Nevada. Since 2005 its price has closely tracked alfalfa hay.[184] Teff is increasingly embraced as a high-quality horse hay and grown in at least 25 states. It is also used for flour and the global market is growing, although food-grade teff imports have driven down domestic prices. A small number of food companies and start-ups are trying to incorporate teff into everyday American foods.[185] Nevada is emerging as a significant teff state, producing it primarily for cattle and horse forage (although most of that production is occurring in areas of the state outside of the Colorado River Basin).[186]

Sorghum silage has roughly the same yield as corn, yet it uses up to 50% less water.[187] Prices for sorghum silage are becoming more competitive but corn silage has a long history with growers, feedlots, and dairies. Sorghum is a warm season crop, is very drought tolerant, provides a useful rotation with corn and has seen a spike in interest from growers in recent years.[188] Cohen et al. modeled a crop switching scenario with sorghum in Arizona (where there is an existing biofuel plant), Which estimated that shifting 74,000 acres from alfalfa to sorghum could result in consumptive use savings of just over 140,000 AF per year. [189]

A.5

In many areas of the Colorado River Basin, producers, particularly younger farmers, are deeply interested in resource sustainability (including reducing water use) and in growing sustainable, organic and higher value products for local and regional markets—products that generally use less water than alfalfa or pasture.[190] Supporting these efforts with incentives and investments could help create local strong agriculture economies that can adjust to water scarcity and contribute to food security.

Opportunities: Research, Demonstration and Financing

Many efforts are already underway throughout the Basin to reduce irrigation water demand while keeping farms and ranches in production, develop high-value market pathways, and build local food systems and crop diversity. However, these goals are often being worked on as separate issues by different groups and associations without connecting strategies and leveraging available knowledge, partnerships, and funding. In addition to pursuing projects specifically targeted at the water supply benefits, partnerships could be made to provide technical and research assistance to other already-ongoing projects to better understand whether and how those projects designed for non-water related goals influence water supply, climate adaptation, climate mitigation, and economic resilience.

Some aspects of this strategy are well researched and understood, but more work could be done to build connections, support ongoing demonstration projects, and build knowledge around the potential resilience benefits. University agricultural extensions, state departments of agriculture, agricultural associations, and other organizations provide region-specific resources about crops suitability and production. Some research has been conducted specifically related to the water consumption and water conservation potential of various crops, but as noted above those studies are often site-specific. Additional research could be undertaken to:

- Better understand the technical support and resources needed to build capacity and reduce risk for farmers to undertake these types of activities and the role of public/private/philanthropic organizations in providing those resources;
- Identify the local infrastructure and supply-chain gaps in bringing new crops to market;
- Identify market pathways to connect local producers with local and regional processers, distributors, and retailers to build vibrant food systems; and
- Understand the possible co-benefits and trade-offs that might be involved, including the resilience goals as well as wildlife/aquatic/avian species and habitat, recreation, rural communities, Indigenous communities, and vulnerable populations.

While there are many public grant and financing programs available to support other agricultural practices and infrastructure (see Upgrading Agricultural Infrastructure & Operations section of this Appendix), those programs typically do not cover capital, operational costs, or risks associated with switching from one type of crop to another. Importantly, farmers bear the financial risk of testing the new crop and getting it to market. Alternative, new, and/or specialty crops are often not covered by crop insurance or subsidy programs, which in turn may impact a farmer's ability to access credit.[191] The Noninsured Crop Disaster Assistance Program (NAP) and Whole Farm Revenue Protection (WFRP) provide some risk management assistance to farmers,[192] yet the costs and risks of switching to a new crop can still be a strong disincentive to implementing changes. As noted in a report co-authored by Cara Fraver of the National Young Farmers Coalition:

> *Better risk management tools, including not only NAP but also the [WFRP], would create a cascade of benefits to the agricultural sector, particularly for beginning farmers setting out to produce fruits and vegetables. These improvements would increase access to credit, further market*

diversification, and enable more widespread adoption of conservation practices... they would be able to purchase additional land, adopt conservation practices, scale their operations, diversify their production, and start new enterprises.[193]

Private funding could fill an important resource gap and risk management need in implementing these practices. Philanthropy can support research and demonstration projects that answer crop viability questions, build producer knowledge and buy-in, and research the co-benefits of projects. Private investment for a scaled strategy could come in several forms, including partnerships with producers and local organizations in projects that open markets, build capacity for processing, packaging, storage, distribution, or sales, or otherwise attract resources needed for increasing adoption of an alternative crop. Supportive funding streams could potentially come from co-benefits, such as conserved water.

The Verde Valley project (see figure above) is an example of a combination of these financing options and approaches. The crop conversion was supported by The Nature Conservancy and corporate donors with the goal of keeping more water in the Verde River during the months when it needed it the most.[194] Resources and support was also provided to upgrade irrigation infrastructure and protect the land and water from future development through an easement.[195] To solve a regional market-access challenge for the new barley crop, a private enterprise (and registered public benefit corporation) was created to build and operate a local malting facility—creating a new market pathway to connect with local and regional end users.[196]

Similar partnerships and creative solutions could be pursued to continue progress on water-related resilience goals through establishing connections with groups like young farmers, tribal communities restoring food sovereignty and reintroducing Indigenous food production, organizations building local food systems, cities interested in regional food security, and rural communities with economic development priorities and developing new demonstration projects. Working with these groups will leverage existing knowledge and available funding to support these projects and build more support for scaled resilience investments that target co-benefits for farmers, food systems, rural communities, and watersheds.

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A.6 URBAN CONSERVATION & REUSE

Description

Urban water efficiency and conservation programs are highly effective at saving water. They can be and are being used to offset population growth and forestall or prevent the need for additional supplies.[197] The programs can also help businesses reduce overhead and provide jobs. As shown in Figure A.9., there are a variety of different types of water efficiency and conservation measures.

Figure A.9. Water Efficiency, Conservation, and Reuse Actions[198]

Indoor water use efficiency	E.g. high-efficiency toilets, clothes washers, dishwashers, showerheads, and faucet aerators
Outdoor water use efficiency	E.g. smart irrigation controllers, improved irrigation equipment, and real-time irrigation efficiency monitoring
Water utility efficiency	E.g. programs to detect system leaks, energy efficiency audits, and water rate reforms
Water reuse	Reuse through exchange –treated reusable effluent is exchanged with another water user for water that can more readily be diverted and may be of higher quality. Often upstream municipal or industrial users seek non-potable diversions exchanges with downstream agricultural users who can use treated wastewater.[199]
	Non-potable, or reclaimed, water reuse – treated effluent that is further treated to non-potable standards appropriate for the intended use; requires a separate set of “purple pipe” delivery infrastructure
	Indirect potable reuse – treated effluent is discharged to an “environmental barrier,” e.g., lake, stream, groundwater, prior to being diverted, often blended with other supplies, and treated to drinking water standards
	Direct potable reuse – treated effluent is not discharged but rather is kept in the system, often blended with other supplies, and treated to drinking water standards
	Graywater use – this typically occurs at the residential level (single family homes, multi-family communities such as college campuses); involves directing untreated wastewater from indoor uses with low organic matter content, such as showers, tubs, and washing machines to low risk uses such as landscaping and toilet flushing

Investments in urban conservation and reuse may contribute to the resilience of the Basin by ***reducing pressure on existing water supplies*** as populations and water demands continue to grow; ***adapting to climate shifts*** by efficiently using available resources; ***mitigating climate change*** by reducing energy use and emissions implicated in water transportation; and ***increasing economic resilience*** in communities by creating jobs, limiting rising water fees and rates, and limiting the associated impacts of water shortages on health, financial loss, and displacement.[200]

A.6

Current State of Knowledge

While urban water use comprises only about 15% of the total Colorado River water use, it is the fastest growing water demand sector in the Colorado River Basin.[201] From 1990 to 2008, total municipal water deliveries increased by more than 600,000 acre-feet and the number of people relying on Colorado River Basin water rose by about 10 million.[202] From 1985 to 2010, domestic deliveries from public water suppliers increased by 31% in the Upper Basin and by 102% in the Lower Basin.[203] Most of these increases are a result of population growth in metropolitan areas such as Las Vegas, Phoenix, Denver, and San Diego.

Despite these upwards trends in water deliveries and demands, per capita water deliveries dropped an average of at least one percent per year from 1990 to 2008, generating roughly 2 million acre-feet in water savings during that same time period.[204] Several large metropolitan areas reliant in part on Colorado River water are implementing water efficiency, conservation, and reuse programs that have been highly effective at reducing per capita water use and stretching supplies through water recycling even while the customer base and number of service connections increase. The U.S. Bureau of Reclamation's 2015 Moving Forward Report noted that current and planned water conservation and reuse programs were estimated to create more than 700,000 AF/y of additional water conservation and 400,000 AF/y of water reuse.

Of course, there are trade-offs to consider with urban conservation and reuse. Additional M&I water conservation and reuse "may not result in substantial reductions in diversions of Colorado River water because conservation and reuse are typically used to meet future growth or offset or delay the need for future water supplies."[205] There may be impacts to rivers or riparian habitat or downstream water users that rely on existing discharges[206] And there are water quality considerations, including the cost required to purify water.[207]

Implementing conservation programs and rate increases can be a cost-effective way to reduce demand, avoid new infrastructure, and support a growing population, as demonstrated in several case study cities. In Westminster, Colorado, a reduction in water use since the 1980s has saved residents and business 80% in tap fees and 91% in rates compared to rates without conservation.[208] In Aurora, Colorado, water use efficiency mapping saves 44 AF/yr by targeting the top 200 most inefficient customers at an annual cost of around $63,729, with an estimate unit water cost of $1,448 AF/yr.[209]

Jobs and economic benefits associated with expanding urban water efficiency and conservation are well documented. Water efficiency and conservation programs such as indoor water use efficiency (e.g. high-efficiency toilets and other appliances), outdoor water use efficiency (e.g. smart irrigation, turf removal), and utility efficiency (e.g. leak detection, water rate reform) provide significant job and economic benefits: "[d]irect investment on the order of $10 billion in water efficiency programs can boost U.S. GDP by $13 to $15 billion and employment by 120,000 to 260,000 jobs."[210]

A.6

Applicability in the Colorado River Basin

Water providers in major metropolitan areas that receive Colorado River water have been investing in conservation and reuse programs over the past 30 years. From 1990 to 2000, each urban region of the Basin reduced the GPCD by an estimated 100-315% (Figure A.10.).[211]

Figure A.10. 5-Year Annual Average, 2008-2012: Water use and trends for major metropolitan areas[212]

Major Metro Area	*Population Served*	*Annual Water Delivery (AF)*	*Percent Colorado River Water (%)*	*Climate Index: Potential Evapo-transpiration minus Precipitation (inches)*	*GPCD (% reduction from 1990, 2000)*	*Residential[i] (%)*	*CII[i] (%)*
Front Range	2,461,600	491,300	46	28	178 (22%, 18%)	79.4	14.6
Wasatch Front	978,600	245,200	27	29	224 (NA, 15%)[ii]	70.6[iii]	21.3[iii]
Middle Rio Grande	685,800	117,000	36[iv]	43	152 (38%, 24%)	68.8	22.2
Southern Nevada	1,932,900	493,400	91	86	228 (33%, 26%)	55.7	25.5
Central Arizona	4,725,100	1,029,800	46	68	195 (14%, 15%)	60.0	30.4
Coastal Southern California	17,983,400	3,422,200	34	34	170 (11%, 10%)	70.2	26.0
Salton Sea Basin	464,000	166,300	NA	65	314 (15%, 24%)	NA	NA

Table notes:

[i]Residential and CII use may not sum to 100 percent due to other uses.

[ii]GPCD values and percent reductions developed from 5-year averages centered around 1990, 2000, and 2010. Percentage reductions from 1990 represent the change over 20 years, while percentage reductions from 2000 represent the change over 10 years.

[iii]2010 values, data not available for the 5-year period.

[iv]2009-2012 average, data not available for 2008

Reuse of water is a major demand management strategy throughout the Colorado River Basin. It is important to note that at the customer/water user level, reuse does not reduce demand, but it does help decrease the need for additional supplies by stretching existing supplies to meet increasing demand. A total of 708,800 AF was identified as M&I reuse supply in the 2012 Basin Study (Figure A.11.).[213] In 2012, reclaimed water comprised between 9-12% of the total M&I water supply in Coastal California, Central Arizona, and Front Range urban areas.[214] Water reuse strategies differ in various parts of the Basin (Figure A.12.). The majority of reuse goes towards beneficial uses such as groundwater recharge, agricultural uses, and environmental restoration (e.g. wetlands, riparian corridors, and urban streams). Expanding use of recycled water in municipal areas is an effective strategy for supporting riparian and flow restoration efforts, and for reducing energy use and greenhouse gas emissions.[215]

Figure A.11. M&I Reuse in the 8 major metropolitan regions as a snapshot in time from 2012[216]

State	Major Metropolitan Areas	M&I Reuse: Non-Potable Reuse Water AF	M&I Reuse: Indirect Potable Reuse Water AF	M&I Reuse: Total M&I Reuse AF	M&I Reuse: Total M&I Reuse %	Total Reuse for All Uses as % of Reusable Supply
WY	Cheyenne	600	0	600	4	9
CO	Front Range	19,300	44,300	63,600	12	80
UT	Wasatch Front	1,500	0	1,500	0.6	1
NM	Middle Rio Grande	1,300	0	1,300	1	100
NV	Southern Nevada	17,500	200,400	217,900	45	99
AZ	Central Arizona	95,000	0	95,000	9	95
CA	Coastal Southern California	179,200	134,900	314,100	9	24
CA	Salton Sea Basin	8,700	0	8,700	6	65
Total		*328,400*	*379,600*	*708,800*		

Table Note: Table presents reclaimed water that is delivered by municipal providers for M&I purposes only. Values do not represent the full amount of reclaimed water that may be used by industrial users, agricultural users or put to other beneficial purposes.

Figure A.12. Examples of Water Reuse – Southern California, Central Arizona, and Colorado's Front Range

Southern California

In southern California, the Metropolitan Water District is designing and implementing a Regional Recycled Water Program in partnership with the Sanitation District of Los Angeles County to purify water for recharge and recovery in groundwater basins.[217]

The City of Los Angeles announced a plan in February 2019 to recycle 100% of wastewater currently discharged to the ocean from the Hyperion Wastewater Treatment Plant by 2035 to increase groundwater recharge.[218]

Arizona

The City of Tucson uses reclaimed wastewater for irrigating parks, golf courses, and open spaces, as well as for specifically designed wetland, river, and riparian restoration projects, among other applications. The city notes that using reclaimed water for irrigation instead of potable drinking water can save enough water every year for 60,000 families (~50,000-70,000 AF/y).[219] As an example of environmental projects, Tucson Water is directing 3,150 AF/y of reclaimed water to the Santa Cruz River to restore flows through a historic and culturally important portion of the city.[220]

The City of Phoenix uses reclaimed water to maintain parks, recharge groundwater aquifers, and enhance riparian areas, among other applications. The City of Phoenix partnered with the U.S. Army Corps of Engineers from 2007-2012 to restore 700 acres in and around the Salt and Gila Rivers. Wastewater is pumped to the Tres Rios project where it circulates through wetlands before it is discharged back to the Salt River. There are over 150 different species of birds and animals, as well as a diverse range of riparian vegetation species that have been restored to this reach of the Salt River.[221]

Colorado Front Range

Colorado Springs has been using reclaimed water for parks, campuses, and golf course irrigation for over 50 years. Water is also reused at the Drake Power Plant, which is scheduled for closure in 2035.[222]

Denver Water has been increasing direct reuse and has a goal of attaining 17,500 AF/yr of recycled water that can be used for parks, golf courses, and the Denver Zoo.[223]

Aurora Water has been using reclaimed water for over 50 years and developed the groundbreaking Prairie Waters indirect potable reuse project.[224] That system and other infrastructure has been instrumental in the regional Water Infrastructure and Supply Efficiency Partnership (WISE) project where Denver and Aurora share reusable return flows with South Metro communities.

A.6

As a step towards identifying priority regions for increased water conservation and efficiency efforts, the Moving Forward report compiled conservation and reuse targets for key providers (Figure A.13.).[225] These providers serve more than 28 million people, which represents almost 85% of the population that receives water for M&I purposes.[226]

Figure A.13. Conservation Targets among the major urban water providers in the Basin[227]

Agency or Management Area	*Population Served (2010)*	*Projected Population Served (2030)*	*GPCD Reduction Target*	*Baseline Year*	*Target Year*	*Best Management Practices Target*
Denver Water (2014)	1,310,000	1,733,900	22% (165 GPCD)	2002	2016	
Colorado Springs Utilities (2008)	445,700	626,400	19%* (149* GPCD)	2010	2050	No
Aurora Water (City of Aurora, 2007)	325,100	456,900	10% (140 GPCD)	2002	2030	
Jordan Valley Water Conservancy District (2014)	585,400	762,200	25% (191 GPCD)	2000	2025	Yes
Metropolitan Water District of Salt Lake and Sandy (2014)	385,300	464,100	25% (228 GPCD)	2000	2025	No
Albuquerque Bernalillo County Water utility Authority (2013)	606,800	809,400	10% (135 GPCD)	2011	2024	No
Southern Nevada Water Authority (2009)	1,956,900	2,422,700	20%* (199 GPCD)	2009	2035	No
Phoenix Active Management Area	3,701,600	5,197,300	*Conservation requirements in the Third Management Plan has been met. New requirements have been proposed in the Fourth Management Plan, which will go into effect on January 1, 2023.*			
Tucson Active Management Area	835,600	1,059,600	*Conservation requirements in the Third Management Plan has been met. New requirements have been set in the Fourth Management Plan.*			
Metropolitan Water District of Southern California (2014)	17,977,900	20,753,600	20% (145 GPCD)	1995-2005	2020	Yes

*Estimated values based on water plan documents because specific values were not provided.

Costs and Barriers to Implementation

The cost of urban water conservation measures will vary depending upon the type of measure implemented. Some of the measures may cost more than they save over time, thus municipalities have to weigh the water savings with the implementation costs.[228] Some water reuse strategies will require additional toxicological or epidemiological analyses, monitoring, infrastructure, and risk assessments.[229] Figure A.14. provides an example of the costs of residential water conservation and efficiency measures in California. A negative cost means that the measure saves more money over its lifetime than the cost to implement it.

A.6

Figure A.14. Residential water conservation and efficiency measures[230]

Efficiency Measure	*Potential Statewide Water Savings (acre-feet per year)*	*Device Water Savings (gallons per device per year)*	*Cost of Conserved Water ($ per acre-foot)* Low	High	*Notes*
Toilet	290,000	4,700	-$630	-$190	3.5 gpf to 1.28 gpf
		680	$1,200	$4,600	1.6 gpf to 1.28 gpf
Showerhead	170,000	1,400	-$3,000	-$2,800	2.5 to 2.0 gpm
Clothes washer	270,000	7,100	-$760	-$190	
Dishwasher	11,000	410	$12,000	$19,000	
Landscape conversion	870,000 – 2,000,000	19 – 25	-$4,500	-$2,600	$2 per square foot
			$580	$1,400	$5 per square foot

Table Note: All values are rounded to two significant figures. Potential statewide water savings based on Heberger et al. (2014). Device water savings for landscape conversions are based on converting a square foot of lawn to a low water-use landscape. Because outdoor water savings are influenced by climate, the authors used a simplified landscape irrigation model to characterize water savings in five cities: Fresno, Oakland, Sacramento, San Diego, and Ventura.

One barrier is that when municipalities enact conservation measures, they reduce customer demand, which in turn reduces the revenue a municipality receives from customers. The municipality may therefore have a harder time implementing upgrades and repairs and other necessary items with lower revenues. Another barrier is that urban conservation can harden demand, such that some municipalities may no longer be able to reduce demand when faced with shortages. Additionally, implementing certain programs like reuse may require changes to state law or city regulations. Moreover, a key component to all the efficiency and conservation measures is education—making the case to the public and officials about the costs and benefits of the strategies.

Opportunities: Research, Demonstration and Financing

Urban conservation and reuse are well-demonstrated and are taking hold throughout the Basin and adjacent areas that use Colorado River water. With urban areas expected to continue to grow, urban conservation and reuse efforts will be critical to supporting additional water demands and reducing stress on reservoirs and ecosystems. To implement these measures, municipalities will require adequate financing to support the implementation of indoor and outdoor efficiency measures, build reuse infrastructure, and engage in public education campaigns. Efforts to standardize data and report on water use may be helpful for coordinating conservation and reuse programs among the Colorado Basin states.

There are a number of federal programs that could potentially providing funding for conservation and reuse efforts. For example, Congress has specifically authorized water reclamation, reuse, and recycling project financing through Title XVI of the Reclamation Projects Authorization and Adjustment Act.[231] TXVI projects are structured as “partial de facto grants” with federal-local cost-share arrangements. Other financing sources include Bureau of Reclamation’s WaterSMART Water Energy and Efficiency Grants and various EPA grant programs.[232]

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A.7 INDUSTRIAL CONSERVATION & REUSE

Description

Industrial water use in the Basin includes power plant cooling, mining, snow making, food and beverage manufacturing, semiconductor and electronics manufacturing, data centers, chemicals and pharmaceuticals, oil and gas extraction, and other industries. Commercial, Industrial, and Institutional (CII) users can account for up to 30-40% of the total M&I use in areas with large institutional and industrial users.[233] By changing practices and modifying or updating equipment to reduce water use and increase energy efficiencies, industries can generate significant water and energy savings, and lead the way in promoting socially and environmentally responsible water management efforts in the Basin. Industrial conservation and reuse can help ***mitigate climate change*** by changing energy demands such that emissions can be reduced, ***reduce pressure on water supplies*** by implementing water efficient practices and/or offsetting water use, ***adapt to climate shifts*** through planning and implementing sustainable water and energy practices, and ***increase economic resilience*** by supporting water smart economic development.

Current State of Knowledge

Awareness of drought and climate change has grown in recent years and many sectors are beginning to recognize the link between water risk and business risk. Various initiatives such as the CEO Water Mandate and Ceres Connect the Drops are encouraging companies to assess and understand the physical, regulatory, and reputational risks that can arise from water issues.

Corporations are now more informed on water issues and display a willingness to engage and collaborate in finding solutions for the communities in which they operate. For example, in recent years, corporations and business interests in the Basin voiced their support for federal and state legislation authorizing the 2019 Colorado River Drought Contingency Plans and today are actively participating in conversations with local leaders about water management issues.

In addition, many corporations have made overall commitments to enhance the sustainability of their operations and promote environmental stewardship. According to the Pacific Institute, many companies are setting measurable water targets, such as reduction in total water withdrawals or percent increase in overall water use efficiency, as part of their water stewardship strategy.[234] Corporate water stewardship action generally falls into three categories: (1) water management in direct operations; (2) value chain engagement; and (3) collaboration in local watersheds.[235]

Three areas where industrial conservation practices could potentially provide hydrologic and other climate adaptation benefits and where companies have been engaging in water and energy efficiency improvements are: data centers, cooling systems, and reuse practices.

DATA CENTERS

Data centers have significant environmental footprints, using large amounts of electricity and water for cooling. In recent years these centers have grown exponentially across the United States, driven by demand for cloud computing services and high rates of data consumption. Phoenix and surrounding cities are home to one of the most attractive data center markets due to the availability of land, lower construction costs, and tax incentives. According to CBRE, as of 2018 70 MW of capacity was under construction with another 240 MW planned.[236] Promoting transparency, sustainability, and innovation in the growing data center market in the western states is of critical importance. Data centers use water for the generation of electricity and for on-site operations.

The national average Water Usage Effectiveness (WUE) for data centers is 1.8 L/kWh (0.46 gallons/kWh) for on-site use, although water use will vary by data center in accordance with size, cooling technology, and water reuse and other sustainability practices.[237] The national average for electricity generation for the centers is 7.6 L/kWh (2.0 gallons/kWh) using thermoelectric and hydroelectric plants. Water consumption can be around 80-130 million gallons annually for centers that have 15 MW of IT capacity.[238] Switching to or implementing from the beginning efficient energy and water systems can reduce the water consumption rate. As discussed below, some data center companies are implementing net water positive operations, showcasing the water conservation possibilities.

COOLING SYSTEMS

Many industries use wet-cooling systems to cool buildings and dispose of waste heat. These include hospitals, office complexes, and university campuses. Cooling towers are one of "the largest use[s] of water in institutional and commercial applications, comprising 20 to 50 percent or more of a facility's total water use."[239] However, as with data centers, newer, zero-water dry cooling systems can be used to replace the older systems in a variety of industries. The switch can cut water use, reduce demands on municipal water supplies, and conserve energy. By switching to more efficient cooling systems, these facilities in the Basin could provide significant water savings and also generate cost savings for the companies. AT&T found that efficiency investments in cooling towers could provide up to 40% in water savings.[240] In one plant studied, AT&T found that a $4,000 investment in free air cooling resulted in $40,000 in savings annually.

REUSE

Water reuse in industries is expected to increase in the coming years as energy and water costs, water risk, and social responsibility steer companies towards more sustainable practices. Industrial applications for reclaimed municipal wastewater are projected to grow 72 percent by 2027.[241] Reuse can mean either reusing the water previously used in the facility or using treated water instead of direct potable water from municipalities. Reuse practices can conserve potable water supplies and/or reduce water diversions if water can be recycled in the facility's operations. There are a variety of industries that can reuse water including power generation, mining, automotive, and food and beverage. There are tradeoffs to consider with reuse, as water that is normally discharged by facilities may be providing environmental benefits such as recharging groundwater or supporting river flows or wetlands, depending upon the facilities' location and discharge system.

Applicability in the Colorado River Basin

There are a number of existing data centers in the Basin,[242] and more are expected to come. This presents an opportunity to engage in discussions with the corporations regarding best water and energy management strategies. For example, Google is expected to open new centers in Henderson, Nevada and Mesa, Arizona. The water use at the Mesa plant is estimated to be 4,480 AF/y.[243] Microsoft is planning to open two plants in Arizona, in Goodyear and El Mirage. The water use at the Goodyear facility is estimated to be 5,600 AF/y.[244] Data centers are coming up with solutions to reduce their water consumption.[245] CyrusOne in Chandler, Arizona claims to be "net water positive." They are using patented technology to reduce consumptive water use and have established a partnership with Bonneville Change the Course program to restore water flows in excess of what the data center uses in a year.[246] Microsoft announced in September 2020 their commitment to be water positive in their direct operations by 2030, reducing the amount of water used per megawatt of energy for operations and replenishing water in the water-stressed regions they operate.[247]
For its Arizona data centers, Microsoft plans to use adiabatic cooling, which uses air for cooling when temperatures are below 85 degrees, and an evaporative cooling system when temperatures are higher. They claim that the system uses up to 90% less water than other water-based cooling methods. Microsoft is partnering with First Solar to use solar energy at the centers, which could

also save water in comparison to power from water-cooled power plants. They are also working with the Gila River Water Storage LLC to generate long term storage credits for El Mirage and Goodyear to balance Microsoft's future water use, and with the Nature Conservancy on water conservation efforts in the Verde River.[248]

There are likely thousands of facilities using cooling towers in the Basin. In the Phoenix metropolitan area alone, there are 12,000 cooling towers.[249] Implementing new technology, upgrades, or designing buildings with lower water use systems can all result in significant water savings. For example, Dynamic Water Technologies sells technology than can help companies cycle their cooling tower water. Increasing the cycles saves water; a 109-ton cooling tower running 1,610 hours per year can save around 160,000 gallons of water a year by increasing its cycle by one.[250] When implemented at Scottsdale Fashion Square, the technology helped increase the number of water cycles from 3.55 to 6.99.[251]

Measures such as water reuse have been in place for several years in nearly all Basin States. In eight major metropolitan areas in the Basin, a total of around 709,000 AF of M&I water supply was derived from reclaimed water in 2012.[252] Early 2012 Basin Study estimates indicated that reuse of industrial wastewater had the potential to create 40,000 AF/y by 2035 and through 2060.[253] There are a variety of ways that industries can engage in reuse practices in the Basin. For example, in Arizona, Frito-Lay was the first U.S.-based food processing plant to produce water up to drinking water standards for reuse in its food operation.[254] The plant uses a 650,000 gallon per day process water treatment and recovery system that recycles up to 75 percent of the process water. This reuse has decreased the company's annual water use by 100 million gallons.

Costs and Barriers to Implementation

There are a number of barriers to implementing water and energy efficiency projects in industries, including costs, technical complications, and ability to meet an acceptable return on investment. Regulations have also hindered some efforts because the process such as for reuse permitting varies state by state and the regulations are not always up to date with the latest technological advances. The cost to implement conservation efforts will vary considerably based on the type of facility, type of water or energy systems being utilized, and type of upgrades or changes contemplated. A notable challenge has been adequately assessing and understanding the "value of water" for a particular business or stakeholder. While some companies may clearly understand this concept, in the face of relatively low water prices it is challenging to convince all business sectors to invest in water management if the only factor in determining return on investment is water savings.[255]

There is a need for accountability and transparency to demonstrate the costs and benefits and encourage other industries to enact conservation practices. Frequent water audits can help large industrial water users identify problems and quantify savings. There are a variety of tools and resources to help. For example, the American Water Works Association offers free water audit software.[256] The City of Boulder has developed a tool for conducting a water conservation assessment for commercial, industrial, institutional facilities.[257] The Environmental Defense Fund and the Global Environmental Management Initiative have a WaterMAPP tool to help facilities assess water efficiency.[258] The Natural Resources Defense Council also has model state legislation for utility water loss audits.[259] It is unclear the extent to which companies are applying water reduction strategies to their operations in the Basin. In a recent assessment, Business for Water Stewardship (BWS) analyzed 67 companies in the food and beverage, hospitality, energy, and technology sectors based in Arizona and Colorado and found that few had quantified goals, and even fewer tracked the volumetric outcomes of their efforts.[260] Therefore, it is important to continue to develop tools and processes that will allow companies to assess and measure their risk exposure as well as the effectiveness of their mitigation efforts.

Opportunities: Research, Demonstration and Financing

In recent years corporate users have begun to recognize water risk as a key factor affecting their operations, profitability, supply chains, and reputation. To address this risk and reduce pressures from consumers and investors, many corporations are actively engaging and promoting corporate water stewardship initiatives. These initiatives can provide additional water savings and create durable investment opportunities in the Basin. The momentum surrounding corporate water stewardship is likely to continue and will also help implement demand management, technology, and reuse projects more broadly.

Actions that conserve water in direct operations may be easier and faster to promote and grow than strategies that involve other stakeholders such as value chain engagement and collaboration in local watersheds. However, all areas are important and may provide additional benefits to a broader group of companies and stakeholders creating greater impact and sustaining a thriving community. In some situations, scaling up may also require investment in entities such as non-profits that are able to educate and build relationships where needed and provide risk measurement tools.

In order for businesses to implement upgrades, redesign systems, or invest in offsets, they have to justify the costs to executives and, in certain circumstances, to shareholders. Pilot projects can help justify the return on the investment cost for conservation projects. Incentives through tax credits or deductions for businesses to engage in sustainable practices like water conservation or reuse implemented at the federal or state level could help encourage corporate action. Additionally, the ability to cover a portion of the costs with federal funding may also incentivize action. Potential funding sources for certain projects may be found in the Bureau of Reclamation's Title XVI Water Reclamation and Reuse program which provides funding for projects that reclaim and reuse municipal, industrial, domestic or agricultural wastewater and impaired ground or surface waters in the 17 Western States and Hawaii.[261] Additional federal funding is available for M&I projects not covered by Title XVI both through Reclamation's WaterSMART Water Energy and Efficiency Grants and from various Environmental Protection Agency grant programs.

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A.8 COAL PLANT RETIREMENT WATER

Description

For over 50 years, coal-fired power plants have provided electricity to communities and industry in various regions of the Colorado River Basin. While historically these plants provided relatively cheap and reliable power, they increasingly cannot compete financially with cleaner energy sources, such as solar and wind. Moreover, state policies to reduce emissions, such as the Colorado Pollution Reduction Roadmap,[262] and similar policies in other Basin states, are also driving coal plant closures. With coal plant retirement, there is growing interest in how and whether the plant's water rights may become available for purchase or reallocation to other purposes, including system benefit, environmental uses, and instream flows.[263] Securing water from retiring coal plants could potentially provide a host of benefits for the surrounding communities and Colorado River system. Coal plant retirement can help increase the resilience of the Basin by ***mitigating climate change*** through the reduction of greenhouse gases. Finding appropriate mechanisms to dedicate coal plant water to system or environmental benefit could help the Basin ***adapt to climate change*** while repurposing the water supplies to other uses, and where appropriate, could ***reduce pressure on existing supplies***. Mitigation transition funds could be required to avoid adverse local impacts in communities dependent on coal or coal-fired power plants.

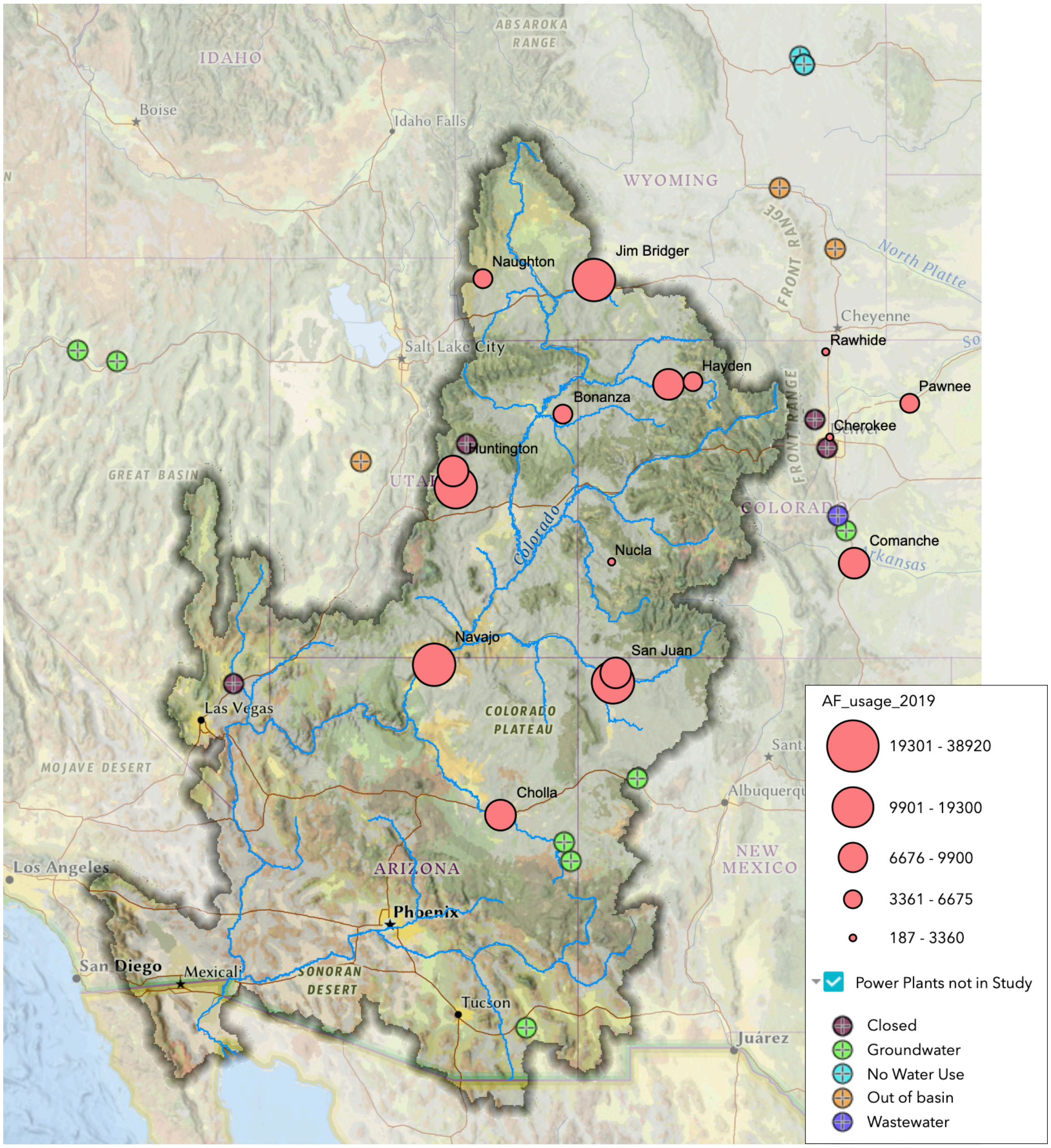
Current State of Knowledge

The coal industry has been in steep decline in the US for the past decade and during 2019, coal-fired power plants closed their doors at the second-fastest rate on record.[264] From 2011 to mid-2020, 95 gigawatts of coal capacity were closed or converted to another fuel source, and 25 gigawatts are expected to be shut down by 2025.

These closures could be a significant source of water rights, which have been previously used primarily for cooling purposes and may be available for other uses. As many plants have not yet decided what will happen with their associated water rights, there is an opportunity to engage early in the decision-making process with the owners and other stakeholders.

Each and every transaction to secure those water rights will be extremely unique. Through a preliminary review of the water rights for coal-fired power plants in the Colorado River Basin (see Figure A.15. below), it is evident that the amount and source of the water rights varies considerably among the different plants. The volume of water that would be available to generate system reliability or instream benefits is dependent on the historic consumptive use of the plant. The varying water diversion locations of the plants will also affect the types of transactions that could occur. Moreover, the regulatory context for such transactions will vary widely by state.

Figure A.15. Map of Coal Plant Water Usage in the Colorado River Basin[265]



Applicability in the Colorado River Basin

According to an initial inventory of coal-fired power plants in the western United States, out of 22 coal plants in the Colorado River Basin area (including those supporting major cities on the Front Range of Colorado), all but a few have either recently closed or are expected to reduce or close operations by 2042 (Figure A.16.).

Figure A.16. List of Coal Plants in the Colorado River Basin.[266]

Coal Plant	*State*	*Plant Owner*	*Scheduled for Closure*
Apache Generating Station, Unit 3	AZ	Arizona Electric Power Cooperative	None
Cholla Power Plant	AZ	Arizona Public Service (Units 1 & 3), PacifiCorp (Unit 4) (Unit 2 closed in 2015)	2025 (Units 1 & 3); 2020 (Unit 4); (Unit 2 closed 2015)
Coronado Generating Station	AZ	Salt River Project	2032
Navajo Generating Station	AZ	Salt River Project, Arizona Public Service Co., NV Energy, and Tucson Electric Power; U.S. is a participant	Closed in 2019
Springerville Generating Station	AZ	Tucson Electric Power (Unit 1 & 2); Tri-State (Unit 3); Salt River Project (Unit 4)	2027 (Unit 1); 2032 (Unit 2); (None for Unit 3 & 4)
Comanche Generating Station	CO	Xcel Energy	2022 (Unit 1); 2025 (Unit 2); (None for Unit 3)
Craig Generating Station	CO	Salt River Project, Xcel Energy, Platte River Power Authority, and Tri-State (Units 1 & 2); Tri-State (Unit 3)	2025 (Unit 1); 2028 (Unit 2); 2030 (Unit 3)
Hayden Generating Station	CO	Xcel Energy, Salt River Project, PacifiCorp	2030 (Unit 1); 2036 (Unit 2)
Martin Drake Power Plant	CO	Colorado Springs Utilities	2023 (Units 2 & 3) (Unit 1 closed 2017)
Nucla Station	CO	Tri-State Generation and Transmission	Closed in 2019
Rawhide Energy Station	CO	Platte River Power Authority	2030
Ray D Nixon	CO	Colorado Springs Utilities	2030
Escalante Generating Station	NM	Tri-State Generation and Transmission	2020
Four Corners Generating Station	NM	Arizona Public Service majority owner, partial ownership by Public Service Company of New Mexico, Salt River Project, and Tucson Electric Power	2031
San Juan Generating Station	NM	Public Service Company of NM (Unit 1, 50% Owner)	Proposed 2022 (Units 1 & 4); (Unit 2 & 3 closed in 2017)
Bonanza Power Plant	UT	Deseret Electric Power Cooperative	2030
Hunter Power Plant	UT	PacifiCorp	2042
Huntington Power Plant	UT	PacifiCorp	2036
Intermountain Power Plant	UT	Intermountain Power Agency	2025
Sunnyside Cogeneration Power Plant	UT	ACI Energy	Unknown
Jim Bridger Power Plant	WY	PacifiCorp	2023 (Unit 1); 2028 (Unit 2); 2037 (Units 3 & 4)
Naughton Power Plant	WY	PacifiCorp	2020 (Unit 3); 2025 (Units 1 & 2)

A.8

A recent analysis in the Upper Basin found coal plants averaged 162,000 AF/y of consumptive use 1991-2018.[267] Upper Basin coal plant consumptive use peaked in 2006 at 170,000 AF/y, but by 2018, consumptive use fell to 144,000 AF/y. Total consumptive use in the Upper Basin is around four million AF/y, so it is estimated that closing all the plants and dedicating that consumptive use to non-consumptive system reliability purposes could reduce Upper Basin consumptive use by around four percent.[268]

There are a variety of creative transactions that could secure water rights from closing coal plants. The water might be used for environmental purposes, such as augmenting flows for fish and recreation. For example, in western Colorado, Craig Station water rights could provide instream flows for the Yampa River downstream of Craig and benefit both fish species and seasonal flows. This reach is designated as critical habitat for four species of fish listed for protection under the Endangered Species Act: Colorado pikeminnow, razorback sucker, bonytail and humpback chub.[269] Flows can fall to low levels in the summer, so coal plant water could augment those flows.[270] Coal plant water might also be used for bolstering system resilience by, for example, increasing reservoir storage. Other uses for coal plant water rights might include lease backs or water sharing with agricultural and municipal communities.

Cost and Barriers to Implementation

The cost of acquiring retired coal plant water will vary greatly depending on the location of the plant, competing buyers, the amount of water involved in the transaction, and whether the water is available for purchase or lease. Analyses conducted on other water transfer costs may provide a general estimate of the cost to lease or purchase the water rights from a closing coal plant. Note that the possibility of a demand management program/compensated compact security program as a new highest and best use is likely to shift the price of water in the future. Apart from the upfront cost of acquiring the water rights, there are also long-term costs to consider including administrative costs, potentially new diversion infrastructure, transition assistance for communities affected by the plant closure, and monitoring costs. Securing financing for purchases or leases will be a challenge.

Leases. On behalf of The Nature Conservancy, WestWater Research conducted an analysis of 204 environmental water leases in the Colorado River Basin during the period of 2010-2020 (159 were in the Upper Basin and 45 were in the Lower Basin).[271] The analysis found average lease rates of $35/AF in Utah, $56/AF in New Mexico, $58/AF in Colorado, and $155/AF in Arizona. These leases were for environmental purposes. In the System Conservation Pilot Program, agricultural water leases in 2018 averaged $150/AF of consumptive use. A WestWater analysis conducted for the Colorado Water Bank Working Group found that annual water leases in Colorado for a wide variety of purposes have ranged from $29/AF to $375/AF of consumptive use, with an average rate of $143/AF. [272]

Purchases. For a review a purchases, a WestWater analysis[273] identified 15 water rights sales on the West Slope of Colorado between 2003-2013. The sellers consisted of agricultural producers, land developers, and municipalities. The buyers were municipalities, water and sanitation districts, land developers, and environmental conservation interests. Prices ranged widely from $1,700/AF of consumptive use to $28,500/AF of consumptive use (with an average of $10,618/AF). Most of the sales involved a relatively small volume of water (average of 151 AF of consumptive use) – which would likely not be the case for transactions involving coal plant water. Water sold for transmountain diversion to urban centers attracted a premium price, averaging $17,143/AF, more than double the average price of water right transfers that stay within the basin (average price $8,245/AF.) For sales within the basin, those involving water in the upper reaches of tributaries priced significantly higher than those further downstream and closer to the Colorado state line (which averaged $2,137/AF). This is of significance because the plants that are currently scheduled for closure in Colorado are closer to the state line and may therefore have a lower price point.

Legal, procedural, and approval processes for transferring water rights to instream flows or system use vary by state and can be challenging to complete. Two key hurdles are 1) uncertainty about whether power plant water rights can be transferred to system use or environmental use and 2) a need to identify what jurisdictional and/or stakeholder approvals might be needed. Legal and policy challenges include:

- Whether, to what extent, and for what period of time the Law of the River (as interpreted by the Basin States) permits water to legally qualify for compact compliance "credit" for Upper Basin states;
- Whether and to what extent state law within each Upper Basin State defines compact compliance as a "beneficial use," legally authorizing each Upper Basin State the diversion, storage, administration, and subsequent use of water for compact compliance purposes;
- Whether and to what extent state law within each Upper Basin State allows for transfers and changes of use; and
- Whether Basin state instream flow legislation is sufficient to ensure that water may be left in streams, or may diverted, stored and later released to streams to generate environmental benefits. This question encompasses whether, in what amounts, and over what reaches water left in or released to streams may be diverted or "exchanged on" by other water users both within the state in which the water is left in the stream and in subsequent states.

These challenges may impede acting quickly on investments in water rights from closing coal plants, which in turn creates a risk that the water may be purchased by others before these issues could be resolved. Competing sources for the water could include local farmers or users outside of the region (for example selling Western Slope water to the Front Range).[274] Slow action could also undermine the historic consumptive use available for transfer because the plant may be using less water, and thus have a lower consumptive use able to be transferred by the time a transfer is ready.

Opportunities: Research, Demonstration and Financing

In order to incentivize the transfer of water from closing coal plants to system benefit or environmental purposes, it may be worth pursuing efforts to clarify outstanding legal and policy issues and simplify and streamline legal processes that impact the desirability of transferring water rights from power plant use to system benefit or environmental purposes. It may also be worth pursuing specific opportunities with closed or retiring coal plants by engaging with the plant owners to discuss potential water right transfers. Securing water from retiring coal-fired power plants could create these co-benefits for communities:

- Lease back programs to agriculture communities;
- Water sharing plans with communities;
- Generating funds through transactions that can be invested in just energy transitions in affected communities; and
- Creating transactions that include NGO support for converting retired plant locations to renewable energy installations—and opening those opportunities to the agricultural community such that marginal lands could be enrolled in the program, generating additional water for conservation and economic benefits for agriculture.

A.8

At present, there are few (if any) ready funding sources that exist to support this investment. Some possibilities include the Endangered Fish Recovery Program, as funding for purchasing water comes through the Bureau of Reclamation and U.S. Fish and Wildlife Service appropriations. However, the federal agencies would not own the water outright, so funding would likely only be able to be used for leases. Another possibility is funding from philanthropic funds or impact investment funds.[275]

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A.9 REDUCING DUST ON SNOW

Description

Dust on snow has significant hydrologic implications for snow melt and streamflow in the Colorado River Basin and is a key and important linkage between land management, climate change, and water supply throughout the western United States. Along with air temperature, dust (and the minerals and particles contained in the dust) deposited on snow affects snowmelt because it absorbs sunlight to warm snow.[276] Dust deposition on mountain snow cover in the Upper Colorado River Basin accelerates melting, shifts the timing of snowmelt and runoff, impacts peak runoff, and reduces total yield.[277] Key sources of dust in the Basin appear to be from livestock grazing, off highway vehicle use, energy development, fire, and drier soils due to drought and increased temperatures.[278] Federal lands appear to be a prominent source of dust.[279] Actions that can be taken to reduce dust and implement a comprehensive dust management strategy include:[280]

- Reducing the intensity or extent of land-use activities that produce dust;
- Implementing restoration or reclamation strategies that promote ecosystem resilience to wind erosion;
- Accounting for landscape variability in planning dust-producing land uses and targeting restoration/reclamation actions to maximize dust abatement; and
- Encouraging research and monitoring.

Given the regional connections between land disturbance and management and the hydrologic implications of dust on snow, actions that reduce dust generation could ***build adaptive capacity to ongoing climate shifts***. If implemented at scale, reduction in dust emissions could help protect runoff and streamflow dynamics that would help ***reduce pressure on water supplies***. This section presents recent research on dust on snow dynamics, as well as estimates of water supply yields from reducing dust on snow. Note that the majority of initial research reviewed is focused on the impacts of dust on snow. There is considerably less information on the range of current dust mitigation projects that are in the design or implementation phase.

Current State of Knowledge

As noted above, dust deposition on mountain snow cover in the Upper Colorado River Basin accelerates melting, shifts the timing of snowmelt and runoff, impacts peak runoff, and reduces total yield.[281] There is a significant relationship between land degradation in the deserts of the Colorado Plateau and the Great Basin, the amount of dust on snow, and the rate of snowmelt and stream conditions. Studies have confirmed the relationship between changes in snowmelt and the rates at which steam rises, driven by absorbed solar radiation from dust on snow.[282]

Dust loading has increased since agricultural development and land disturbances intensified in the mid-1880s. From 1950 to 2000, the dust deposition rates were the highest of the last 11,000 years.[283] Spring winds carry dust from the Colorado Plateau, Sonoran Desert, Mojave Desert and the Great Basin Desert to the headwater areas of the Colorado River, aided by the natural erosional landscapes.[284]

Increasing aridity, extreme weather events, and drought are predicted to increase wind erosion, dust generation and transport, and the amount and duration of dust on snow.[285] As evidence of climate impacts, the onset of the spring dust season has occurred earlier by 1 to 2 weeks over the last 20 years.[286]

The 2012 Basin Study estimated that the potential yield of reducing dust on snow would be about 280,000 AF/y by 2035 and 400,000 AF/y by 2060.[287] Basin Study estimates were based on several scientific studies that evaluated the relationship between total dust concentrations and the rate and timing of snow melt. More recent studies have further verified the hydrologic implications of dust on snow. Notably:

- "The dust-advanced loss of snow cover (days) is linearly related to total dust concentration at the end of snow cover... Dust radiative forcing also causes faster and earlier peak snowmelt outflow with daily mean snowpack outflow doubling under the heaviest dust conditions."[288]
- Snow cover duration can be shortened by 18 to 35 days from Colorado Plateau dust. The frequency and intensity of dust deposition increases in drought years.[289]
- "Peak runoff at Lees Ferry, Arizona has occurred on average 3 weeks earlier under heavier dust loading and that increases in evapotranspiration from earlier exposure of vegetation and soils decreases annual runoff by more than 1.0 billion cubic meters or ~5% of the annual average."[290]
- Large-scale impacts of dust on snow can, in some cases, reduce regional water supplies by ~5%.[291]

In addition to affecting water yields and timing, dust on snow can adversely affect alpine biological communities[292] and changes in flow can affect riverine species and habitats. Dust also adversely affects public health by elevating the level of particulate matter (PM_{10}).[293]

There are numerous research efforts focused on tracking and quantifying dust-on-snow accumulation, patterns, and impacts,[294] and PM_{10}. However, there is considerably less information, research, and/or communications on the restoration efforts needed or occurring to reduce dust on snow and/or mitigate the effects of drought, dry croplands, wind erosion, and soil degradation at a scale that can reduce dust on snow.

Applicability in the Colorado River Basin

Key to any mitigation strategy for dust on snow in the Basin is knowing the locations where the greatest amount of dust is coming from. As shown below in Figure A.17., dust on snow emanating from federal lands is particularly prominent:

Figure A.17. Dust Emission Sensitivity and Ownership in Western US Drylands[295]

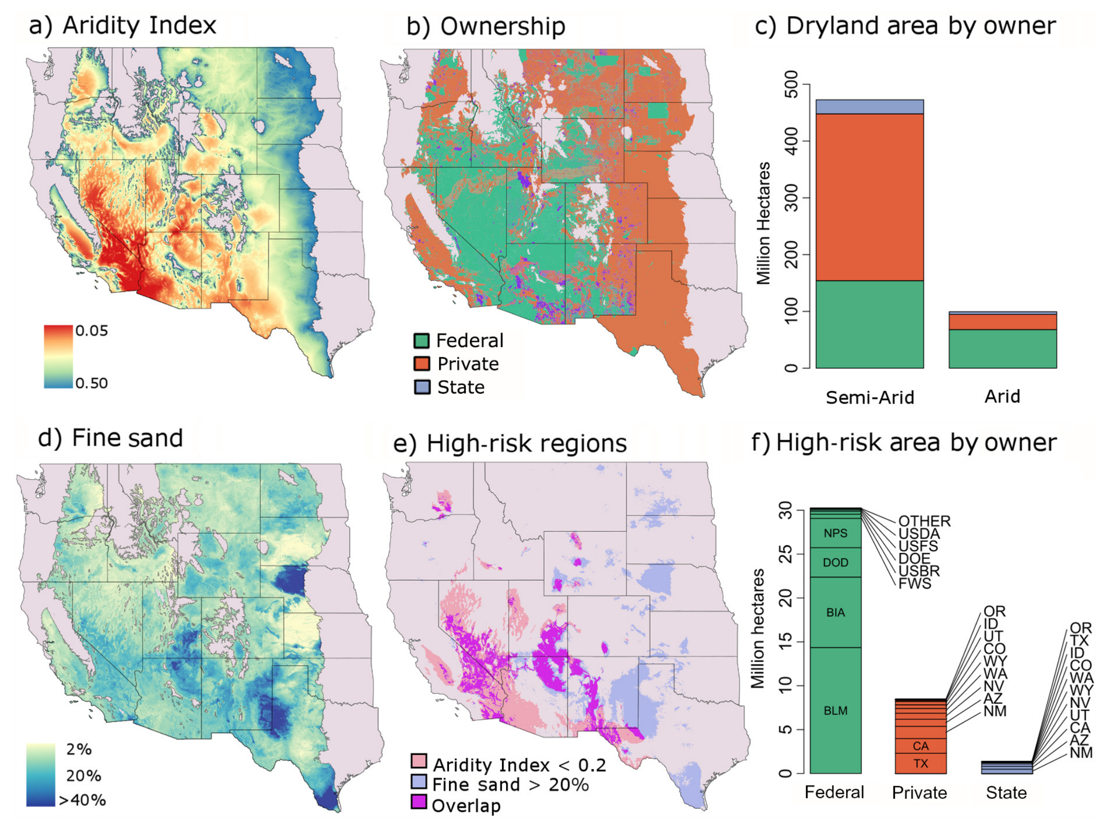

Fig. 1. Dust emission sensitivity and ownership in western US drylands. Aridity index (AI) calculated as total annual precipitation divided by potential evapotranspiration (PPT:PET) for regions with AI $\leq$ 0.5 (a). Dryland surface area according to ownership type (Federal, State, or Private) and aridity (semi-arid 0.5–0.2 and arid <0.2; b and c). Percent fine sand (particles 100–250 µm) content by mass of soil fines (<2 mm) in dryland surface soil (d). Regions to be considered as high risk for dust emissions based on prevalence of fine sands and aridity (e). Tabulated areal ownership of land in the highest risk category (fine sand >20% and AI < 0.2) by agency for federal land and state by private and state-owned land (f). Soils with higher percentages of fine sand have been shown to be more susceptible to eolian destabilization when a site is disturbed (Marticorena and Bergametti 1995, Okin et al. 2006, Belnap et al. 2007, Field et al. 2010). The fine sand map was created using a quantile regression forest with same predictor database as Ramcharan et al. (2018) by training with georeferenced samples in the U.S. National Cooperative Soil Survey soil characterization database. Details of the mapping and soil modeling are in Supporting information. BLM, Bureau of Land Management; BIA, Bureau of Indian Affairs; DOD, Department of Defense; NPS, National Park Service; FWS, Fish and Wildlife Service; USBR, US Bureau of Reclamation; DOE, Department of Energy; USFS, US Forest Service; USDA, US Department of Agriculture (exclusive of USFS).

Land management and restoration actions to reduce dust would likely best be primarily focused on desert regions of the Colorado Plateau and the Great Basin.[296] Actions would need to take place over a large expanse of area of at least 10,000 square miles to be effective,[297] which means working with institutional landowners (I.e., federal, state or tribal governments).

Interventions appropriate for the Basin include stabilizing desert soils, limiting off-road vehicle use, restoring abandoned croplands, and planting native grasses and vegetation on degraded rangelands.[298] A primary goal of improving desert lands would be minimizing wind erosion over large areas, which would have cascading benefits to local agriculture, air quality, and quality of life.[299]

Reclamation highlighted a relatively large portion of the Colorado Plateau and the Great Basin as appropriate places for dust management practices.[300] In the 2012 Basin study, they prioritized areas of the Colorado Plateau based on the high amounts of dust emissions and potential greater yield per acre of management than other areas.[301]

Costs and Barriers to Implementation

Reclamation estimated costs for dust control based on conversion of land to native grasses using practices similar to U.S. Dept. of Agriculture Conservation Reserve Program enrollment.[302] Likely costs might include clearing lands, reseeding with native seeds, vegetation maintenance, and land protection policies and designations. Reclamation estimated an average cost of $15/acre/year.[303] Implemented over an area of 10,000 square miles, the cost per acre-feet would be around $500.[304] In the Basin Study, Reclamation assumed that a first phase of a dust control program would target areas of the Colorado Plateau that are generating the most dust emissions and would produce greater yield per acre of management. Reclamation estimated cost per acre-feet per year of water savings at $200.[305]

However, costs are uncertain given that, as noted elsewhere, there is less information, research, and/or communications on the restoration efforts needed or occurring to reduce dust on snow and mitigate the effects of drought, dry croplands, wind erosion, and soil degradation. Land restoration and reclamation costs are generally estimated to range from $175 to over $600 per acre.

One of the most significant challenges for reducing dust on snow is coordinating and driving "the widespread adoption of practices to minimize wind erosion over large areas."[306] Target lands might span a variety of federal, state, and tribal land ownership. Reclamation noted that a dialog is needed among relevant federal agencies and appropriate Landscape Conservation Cooperatives to better understand the origins and mitigation options[307] and that implementation is most likely to be accomplished by promoting financial, regulatory, and educational measures at both federal and state levels.[308]

Coordinating with land managers – particularly the Bureau of Land Management (BLM) – may be a major challenge and opportunity. Since key sources of degradation and dust include certain allowable uses on public lands like livestock grazing, off-highway vehicles use, and oil and gas development, working with BLM to manage those sources in addition to implementing restoration will be important.

Studies, coordinated planning, permitting, and layers of approval would also be needed. Reclamation's Basin study estimated that land restoration activities may involve approximately 5 years to evaluate strategies and potential effectiveness, 5 years for permitting and policy actions, and 5 years for the first phase of implementation. An additional 10 years should be expected for more distributed and complex land protection and restoration actions.[309] However, with willing participants, the increased understanding of dust on snow's adverse effects and growing pressure on the water resources of the Basin, it may be possible to implement large-scale demonstration practices faster.

Opportunities: Research, Demonstration and Financing

Restoring the degraded and drought prone, arid lands that generate dust in Nevada, Utah, and Arizona will likely result in significant reductions in dust on snow. Because the federal government owns a large portion of the land in those states, there are opportunities to engage with federal agencies to implement dust reduction strategies. For example, BLM is the owner of a large portion of the land in the dust generating hot spots and livestock grazing and energy development are key sources of dust. Thus, a top dust mitigation strategy could be restoring grazing lands and improving energy development practices on BLM lands. Energy development on federal lands and its links to climate change will likely be a prominent issue over the next several years. Additionally, as the Forest Service also owns a decent portion of the land in the hot spots and fires are key causes of dust, forest management is also a top mitigation strategy. There may be opportunities to engage in stewardship contracts with the Forest Service and BLM for projects that may help mitigate dust generation.

Actions taken to reduce dust overlap with many of the other strategies discussed in this report, including Natural Distributed Storage, Forest Management & Restoration, and Regenerative Agriculture. Of course, dust emissions and impacts on snow and public health are important considerations in evaluating potential trade-offs of other resilience projects. For example, other water conservation and demand reduction projects could reduce inflows to downstream saline lakes, expose lake beds, and exacerbate dust on snow issues. Large-scale renewable energy projects are often developed on desert public lands and have the potential to generate significant amounts of dust, among other land and habitat degradation concerns. Thus, it will be important to consider the dust on snow effect in implementing other resilience projects and in trying to link dust mitigation activities with the other strategies. Large scale projects, or at a minimum more coordination among individual projects, will be necessary to appropriately address the dust on snow challenge in the Basin.

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A.10 COVERING RESERVOIRS & CANALS

Description

A significant amount of water in the Colorado River Basin is lost each year through evaporation from storage and conveyance infrastructure. Reducing evaporation from reservoirs and canals, such as through shade balls, chemical mono-layers, or other methods, throughout the Basin could improve overall system efficiency, reduce system losses, resulting in additional water supply availability, reducing pressure on existing water supplies and helping the Basin adapt to on-going climate shifts. Those system benefits could also create economic resiliency benefits by saving utility and public costs on water transportation, water augmentation, and water treatment costs, and by potentially creating distributed sources of renewable energy if solar panels are placed over water surfaces.

Although estimating evaporation rates is challenging and depends on a variety of factors,[310] researchers at the University of Colorado at Boulder estimate that annual evaporation losses in the Colorado River Basin as a whole are about 1.5 million acre feet, or approximately 10 percent of the total natural flow in the Basin.[311] It is estimated that reducing evaporation from the major reservoirs and canals could result in a potential savings of 200,000 AF/y from controlling evaporation with reservoir covers and 200,000-850,000 AF/y from controlling evaporation on reservoirs and major canals with chemical covers.[312]

Although the largest potential savings from reducing evaporation would be associated with the Basin's largest reservoirs, covering those reservoirs would also involve the largest costs and potentially the largest barriers and environmental impacts. However, examples and research indicate that covering reservoirs and canals might cost-effectively provide water savings and other co-benefits, particularly when applied to non-major canals and reservoirs in the Basin. This concept relates to and may have some overlap with agricultural and municipal infrastructure efficiency (see Upgrading Agriculture Infrastructure and Urban Conservation sections in this Appendix).

Current State of Knowledge

A variety of methods have been explored for controlling evaporation from reservoirs and other water surfaces as shown in Figure A.18.

Figure A.18. Various methods for limiting evaporation from water surfaces.[313]

Physical	Floating covers can be continuous (i.e., plastic sheets) or modular (i.e., shade balls, floating discs). Continuous covers are an impermeable barrier; they can reduce evaporation over 95%. Modular covers do not completely cover the surface. In tests they have reduced evaporation by 43-80%, depending on the type of cover.
	Shadecloths are suspended by structures over the water surface. Economically used on small reservoirs. Depending on material, they can reduce evaporation by 80-90%, plus they can reduce maintenance costs and water quality by limiting the growth of aquatic plants and preventing birds and animals from entering the reservoir.
	Solar photovoltaics installed over canals can reduce evaporation. The setup can offer natural cooling for the panels, and in one study photovoltaics installed over canals had better efficiency compared to ground panels.
	Thermal mixing by injecting a bubble plume into the cold deep layer of a reservoir can lower the surface temperature and reduce evaporation. This method works best in deep reservoirs with a marked natural thermocline and a relatively large volume of cold water for mixing. Additional benefits could include improving water quality, increasing levels of dissolved oxygen in water, increasing fish habitat, and reducing algal growth.
Chemical	Chemical mono-layers are single molecular layers of insoluble (or almost insoluble) compounds that, when applied to water, form an invisible film that can be used to cover a reservoir and block evaporation. Chemical layers can reduce evaporation by approximately 30%. The compounds are effective only a few days at a time.
Biological	Palm fronds can be used to cover water surfaces and could reduce evaporation by 26-58%. Palm fronds could be beneficial covers for open water surfaces because they do not have harmful effects on water quality and can withstand hot weather conditions in arid regions.
	Floating plants can reduce evaporation, but water transpired by the plants needs to be taken account to estimate their effectiveness.
	Wind breakers established by planting trees to reduce wind speed across the water body can result in 1.1-5.6% reduction in evaporation.

In one review of these various methods, researchers concluded that:[314]

- Physical methods can save a large percentage of water (70-95%), and while their capital costs are high, maintenance costs are relatively affordable;
- Chemical methods can save a small percentage of water (20-40%), their capital costs are not high, but maintenance costs are significant, and the influence of surface area is significant in the effectiveness (i.e., wave action and temperature affect the film);
- Biological covers can significantly decrease evaporation, but water used for transpiration must be considered; and
- Reducing the exposed area of water surface will reduce/avoid evaporation, that could mean considering deeper reservoirs and storing water in underground storage.

It is important to note that many studies have been performed over small artificial surfaces, as opposed to actual reservoirs, and the effectiveness of the various methods depends heavily on atmospheric conditions and other factors.

In the Colorado River Basin, much of the research on reducing evaporation has primarily focused on the two largest system reservoirs (Lake Powell and Lake Mead). In 2008, the seven Basin States commissioned a series of technical evaluation papers on options for long-term augmentation of the Colorado River system and as part of that study, options were evaluated for reducing evaporation on Lake Mead and Lake Powell. That evaluation estimated that chemical covers would lead to a 15% decrease in the evaporation rate of the two reservoirs, which would result in water savings of up to

270,000 AF/y.[315] The Bureau of Reclamation included an evaluation of strategies for reducing evaporation from the reservoirs in the 2012 Basin Study. Figure A.19. shows estimated water savings for three evaporation reduction strategies.

Figure A.19. Range of potential water water savings of three strategies for reducing evaporation.[316]

	Potential Yield by 2035 (afy)	*Potential Yield by 2060 (afy)*
Solar Panel Canal Covers	18,000	18,000
Solar Panel Reservoir Covers	200,000	200,000
Chemical Type Covers on Canals and Reservoirs	200,000	850,000

Reclamation recently funded work to update evaporation rate equations.[317] It is unclear whether/how Reclamation or other Basin stakeholders are using this updated methodology to recalculate estimated water savings.

There are a number of environmental considerations with this strategy. Higher reservoir levels may provide higher quality habitat for fish and other aquatic species. However, chemical covers could negatively impact fish, aquatic species, avian species, riparian habitat, and vegetation and reduce overall quality. Lower evaporation rates could raise water temperatures, which could negatively affect aquatic species. There are also water costs to consider for the water used to produce the covers. For example, the Los Angeles Department of Water and Power covered the Los Angeles Reservoir with shade balls in 2015. MIT conducted a study to see how much water was used to produce the balls and found that the balls would need to be used for an extended period of time in order to offset the water production cost, and even then, other potential negative effects such has effects on aquatic life and water quality may not be offset during wetter periods when the ball's efficiency drops.[318] Additional studies would be needed to understand and quantify the potential negative impacts on water quality, public health, recreation, wildlife, and ecosystem health and function.[319]

Applicability in the Colorado River Basin

Simply based on the expansive storage and conveyance infrastructure across the Basin, there could potentially be a variety of places where a strategy to cover reservoirs and canals and reduce evaporation could be implemented. The key is to identify the most impactful and cost-effective opportunities.

As described above, much of the existing literature focuses on the major system reservoirs, and while the potential supply gains of covering or otherwise reducing evaporation at Lakes Powell and Mead are high, so too are the potential costs and trade-offs. Evaporation from both reservoirs amounts to about 15 percent of the annual Upper Basin allocation of water resources and is approximately 5-6 times the annual water usage of a medium-sized city in the United States. Using municipal water rates in Denver as a benchmark, the estimated value of that evaporated water is up to $370 million annually.[320] Any method for reducing evaporation at the reservoirs would require substantial time, cost, and resources (see next section), and could involve trade-offs for recreation and environmental values (as noted above).

Some other basin infrastructure that could be evaluated for covering strategies include:[321]

- Upper Basin reservoirs (Aspinall Unit, Flaming Gorge, Fontenelle, Navajo)
- Lower Basin reservoirs (Lake Havasu, Lake Mojave)

- Large canal systems (Colorado River Aqueduct, All American Canal, Central Arizona Project) (According to the Central Arizona Project (CAP), the average annual evaporation loss from the CAP system is approximately 4.5 percent, or 16,000 acre-feet from the aqueduct and 50,000 acre-feet from Lake Pleasant.[322])
- Interconnected system reservoirs and canals (Central Utah Project system, Salt & Verde system, southern California reservoirs)

Additionally, there may be an opportunity to focus on covering smaller-scale municipal and irrigation canal infrastructure, because these are common in the Colorado River Basin and are eligible for several federal grant programs (see financing information in Opportunities section below; see also Upgrading Agricultural Infrastructure & Operations and Urban Conservation & Reuse sections in this Appendix).

Costs and Barriers to Implementation

Costs for implementation depend on a variety of factors, particularly the covering method and size and jurisdiction of the targeted reservoir or canal. L.A. Dept of Water and Power's experiment to cover the 175-acre L.A. Reservoir in 2015 with shade balls cost $32 million, which the agency paid for from existing funds. The purpose of the project was more related to water quality protection than reducing evaporation (avoiding toxic bromate production), but evaporation was also studied, and the project decreased evaporation by over 80%.[323] Between savings associated with reduced treatment costs and the evaporation benefit, the project will pay back half of its implementation cost over its 10-year lifetime.[324]

Various covering options have been evaluated for the CAP canal system. Reclamation studied the possibility of covering the CAP aqueduct during the original project evaluation but found the cost to be prohibitive – covering the canal would have quadrupled the $4 billion original project cost.[325] The Central Arizona Project described the costs and barriers associated with covering CAP system canals with photovoltaic panels, noting that the water supply savings that might be achieved would be modest in the context of the enormous cost involved.[326] CAP noted several challenges:

- Cost of the solar project, including additional costs of the structures needed to suspend the panels over the canal, which is quite wide (80 ft for much of the canal);
- Additional electrical transmission facilities would be needed to move the power onto the electrical grid;
- It would be more difficult to maintain the canal, since the suspended panels would interfere with access to the canal itself and the mounting infrastructure would take up space on the O&M roads along the canal; and
- Compared to solar projects constructed on vacant land near transmission systems, it would be very expensive and impractical.

The Basin Study evaluated the cost of solar panel covering options and chemical-type covering options on system reservoirs and canals, with the following estimated costs and implementation timeframes: (Figure A.20.).[327]

Figure A.20. Range of estimated costs and time frame for three evaporation reduction strategies.[328]

	Estimated Cost ($/afy)	*Years before Available*
Solar Panel Canal Covers	15,000	10
Solar Panel Reservoir Covers	15,000	18
Chemical Type Covers on Canals and Reservoirs	100	15-25

Solar covering options have a high implementation and maintenance cost but could generate revenues or offset other system operational costs from the energy produced. The Basin Study referenced cost numbers from a solar company that determined that 3 acres of photovoltaic covers had a capital cost of $5 million and could generate 1 MW of power.[329] Assuming photovoltaic panels have a 15-year life and are amortized at 4.125%, the annual cost of a $5 million installation is roughly $450,000/year.

For chemical covers, the 2012 Basin Study estimates that costs would include airplanes, fuel, pilots, aircraft maintenance, and the chemical product. Assuming chemical application every 10 days and two planes per application, annual O&M costs could total $38 million.[330] Amortizing the cost of planes (purchasing or leasing) in addition to other costs, a rough unit cost could be around $100/AF.

Extensive feasibility studies, permitting, and layers of approval would also be needed, particularly for any actions on the large system reservoirs. The 2012 Basin study estimated that it would take approximately 10 years to implement a physical cover option, which would include steps to evaluate feasibility, plan, permit, and construct a project.[331] For chemical covers, the Basin Study acknowledged that considerably less is known about these strategies. As a result, feasibility studies in combination with pilot projects on smaller reservoirs would be needed to more fully understand the impacts, benefits, costs, and design requirements. Conservatively, Reclamation estimated in the Basin Study that it may take at least 15 years for full-scale implementation.

Opportunities: Research, Demonstration and Financing

There may be great potential in implementing covers on a mid- to smaller scale (i.e., the municipal level rather than the Lake Mead level). These opportunities would most likely be present in the Lower Basin, where there are higher temperatures and regional/municipal “grey” infrastructure facilities. This approach would avoid covering facilities like reservoir lakes or natural infrastructure conduits that support wildlife and habitat.

Although they come with potentially high up-front implementation costs and challenges, these projects could make economic sense particularly when factoring in various co-benefits like water quality improvement. More research is needed to better understand the potential co-benefits and possible trade-offs of a project such as impacts to aquatic species and wildlife.

A variety of existing grant programs provide money for system efficiency projects, including activities like piping and improving agricultural and municipal infrastructure. Depending on the scale of the project and owner/operator of the infrastructure, funding and financing may include: Farm Bill Conservation Programs (RCPP, EQIP, CRP, CREP, PL 566) and Bureau of Reclamation and EPA grants and financing programs (WaterSMART, WIFIA, RIFIA). Regional infrastructure projects with multi-benefits could be good candidates for innovative public-private partnerships and financing like green bonds.

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