TEN STRATEGIES FOR CLIMATE RESILIENCE IN THE COLORADO RIVER BASIN

This report was authored by Martin & McCoy and Culp & Kelly, LLP, on behalf of American Rivers, Environmental Defense Fund, National Audubon Society, The Nature Conservancy, Theodore Roosevelt Conservation Partnership, Trout Unlimited, and the Western Resource Advocates. The authors gratefully acknowledge the extremely helpful information and input from these organizations in developing and preparing this report. All opinions and errors are the responsibility of the authors.

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Across the world, water users and managers, scientists, local communities, entrepreneurial innovators, and non-governmental organizations are looking for ways to increase the long-term resilience and health of river basins that supply critical water needs for humans, agriculture, industry and the environment. These efforts are driven by many factors, including the need to reverse historic degradation, improve watershed health and reduce hydrologic vulnerability to climate change.

Positioned along the spine of the Rocky Mountains, across the Colorado Plateau, and within the Sonoran and Mojave Deserts, the Colorado River Basin is uniquely vulnerable to a wide range of hydrological, ecological, social, and economic impacts from climate change. These impacts directly affect the reliability and durability of water supplies that support cities, agriculture operations, tribal communities, forests, rivers, groundwater tables, and numerous other human and natural systems.

Traditionally, well-tested and widely implemented water conservation efforts have largely been carried out in the periphery of Colorado River management efforts, like the development of the 2007 Interim Guidelines, the Drought Contingency Plans and various state water planning efforts that focus on traditional demand/supply analyses and water management solutions. While these efforts are essential, they are developed and implemented with a focus on the management, movement, and use of water and therefore do not typically or sufficiently include or consider broader economic, environmental, and social risks from changing climate dynamics. By focusing solely on managing water supply and demands within the context of drought and climate change, there may be missed opportunities to explore multi-faceted strategies that could adapt to, respond to, and mitigate the steady, compounding, and extreme risks of climate change to economies, communities, landscapes, and water resources.

This report seeks to bring to light the potential for investigating, testing, and scaling-up ten investment strategies aimed at preparing the Basin for long-term rising temperatures, high variability in precipitation patterns, and increased drying, all of which are projected to occur even if efforts to limit climate change are taken seriously over the next few decades. The strategies range from well-demonstrated, to emerging, to theoretical but largely untested concepts. By presenting an integrated exploration of these strategies, this report aims to move the conversation from a focus on water management to a focus on climate resilience to increase the Basin's capacity to adapt to climate change while also protecting water supplies, increasing economic agility, and mitigating carbon emissions where possible.

As on-the-ground pilot projects and implementation experience continue to inform how the strategies can provide cost-effective and meaningful results, developing cross-sector partnerships and basin-wide funding for such investments will be necessary to implement the strategies at a scale commensurate to the challenge. While it is too early to say definitively how such a coordinated funding approach might be sourced and governed, this analysis highlights just some of the existing federal and state programs that could be applied in a coordinated fashion with a clear water-related climate resilience goal for the Colorado River Basin. Philanthropic and private funding could be used to match or leverage these federal and state dollars. Development of such a coordinated approach to water-related climate resilience funding is particularly timely for several reasons:

1. Congress, the federal administration and several Basin states are focused on bolstering climate mitigation and climate resilience, and water and watershed resilience can and should be at the cutting edge of those efforts (Office of the President 2021);

2. The Basin States, Tribal governments, and most major water providers and users in the Basin acknowledge the risks associated with climate change and are beginning to look for ways to address those risks;

3. Over the next few years, the operational guidelines for the Colorado River will be renegotiated, and the effects of climate change will be central to that negotiation. While the guideline negotiations are not necessarily the forum for structuring investments in the types of strategies discussed in this report, the guidelines process brings a clear focus to the challenges facing the Basin and may serve to motivate a more coordinated approach to resilience; and

4. Most importantly, there is no time to waste. The effects of climate change, as experienced in a year like 2020, are here now. Many of the resilience strategies will take time to be scaled-up and produce results across the Basin's watersheds.

1.0 PURPOSE AND CONTEXT

Climate change poses severe risks to the economic and environmental health of the Colorado River Basin. Federal and state agencies and water users are increasingly recognizing these risks and examining steps to deal with projected variability and increased scarcity in water supply through more flexible water management strategies.[1] Current measures—including demand management, system conservation, intentionally created surplus (ICS), and reservoir operation—will be vital in the short-term to prevent shortages and increase drought response capacity.

Although these flexible mechanisms will help to manage systemic water risks in the near term, they ultimately represent just a first step. Whatever the Basin's short-term challenges, the past decade has provided a window to the more significant on-going and future challenges likely to result from the combined impacts of continued growth in demands, the natural variation of precipitation and runoff, and the increasingly noticeable effects of climate change and other landscape-level factors.

This report seeks to bring to light the potential for investigating, testing, and scaling-up ten integrated investment strategies aimed at preparing the Basin for long-term rising temperatures, high variability in precipitation patterns and increased drying, all of which are projected to occur even if efforts to limit climate change are taken seriously over the next few decades. To support this inquiry, ten proactive investment strategies for medium- and long-term responses to the acute and progressive risks of climate change in the Colorado River Basin are examined:

- Forest Management & Restoration
- Natural Distributed Storage
- Regenerative Agriculture
- Upgrading Agricultural Infrastructure & Operations
- Cropping Alternatives & New Market Pathways
- Urban Conservation & Re-Use
- Industrial Conservation & Re-Use
- Coal Plant Retirement Water
- Reducing Dust on Snow
- Covering Reservoirs & Canals

Each investment strategy is described and assessed within the context of four resilience questions:

1. Could the investment help the Basin ***adapt to on-going climate shifts?***

2. To what extent would the investment ***reduce pressure on existing water supplies?***

3. Would the investment help ***mitigate climate change?***

4. Could the investment ***strengthen economic resilience in communities?***

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The next section, Section 2, provides definitions and context for the four resilience questions. Section 3 explores the current state of the four resilience questions by providing background on climate shifts both progressive and acute, hydrologic risks across the Colorado River Basin with a focus on water supply, the need and opportunity for climate mitigation activities, and economic and social risks. Section 4 provides an overview of the research process and a short summary of each investment strategy. Section 5 summarizes various financing options, and Section 6 offers conclusions and strategic next steps. The Technical Appendix contains more detail on each of the strategies, including a summary of the approach and current knowledge; how it might be applied in the Colorado River Basin; costs and barriers to implementation; and opportunities for further research, demonstration, and financing.

2.0 RESILIENCE QUESTIONS

There is a direct connection between a warming atmosphere and water supply challenges with implications for the ecology and human systems of the Colorado River Basin. Climate change is the main driver of hydrologic change in the Colorado River Basin, with intensifying impacts on hydrologic, social, and economic systems. The future of the Colorado River Basin depends on actions taken to adapt to climate change impacts, to balance water supplies and demands, and to mitigate greenhouse gas emissions where possible.

To make the case for an integrated climate adaptation and water management approach, this report explains some of the climate change dynamics and impacts in the Basin. In response to those impacts, ten integrated strategies are proposed that can strengthen the Basin's capacity to respond to changing conditions from multiple angles. Each of the ten strategies are qualitatively described within the context of four resilience questions that provide a conceptual evaluation perspective to compare and highlight each strategy.

1. Could the investment help the Basin ***adapt to on-going climate shifts?***

As defined by the International Panel on Climate Change, adaptation is a process of adjusting to current and future conditions in an effort to minimize harm and create beneficial opportunities (Field, Barros, and Intergovernmental Panel on Climate Change 2014). Adaptation is an inherently iterative risk management process that includes identifying vulnerabilities, planning for projects and actions, pursuing implementation, monitoring results, and revising further actions (Lempert et al. 2018). The strategies proposed in this report have the potential to build adaptive capacity in municipal sectors, agricultural operations, and federal, state, and tribal rangelands and forests.

2. To what extent would the investment ***reduce pressure on existing water supplies?***

This resilience question takes a more traditional focus on augmenting supply, improving watershed yield, or reducing demand as pathways to increasing the buffer between current conditions and a future crisis. The Bureau of Reclamation's 2012 Colorado River Basin Water Supply and Demand Study (Bureau of Reclamation 2012) presented a detailed analysis of options and strategies to reduce consumptive use and resolve supply and demand imbalances. The ten strategies explored here build from the foundational work in the Basin Study and the subsequent 2015 Moving Forward report (Bureau of Reclamation 2015b) by positioning water supply benefits in the context of climate change and economic resiliency actions.

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3. Would the investment help *mitigate climate change?*

Mitigation refers to measures that have the potential to reduce the extent and pace of future climate change by limiting and preventing greenhouse gas emissions and enhancing activities that remove gases from the atmosphere (Field, Barros, and Intergovernmental Panel on Climate Change 2014; Martinich et al. 2018). While global-scale reductions in greenhouse gas emissions are necessary to address the magnitude, speed, and scale of climate change dynamics, watershed-scale actions explored in this report can reduce regional contributors to carbon emissions and foster local practices that remove carbon dioxide from the atmosphere while also generating economic, social, and ecological benefits (Martinich et al. 2018).

4. Could the investments *strengthen economic resilience in communities?*

Uncertainties around the extent of climate change impacts on the biophysical environment can also lead to uncertainties and disruptions in social and economic systems. This report brings an intentional focus to discussing the ways in which the strategies may foster and increase economic resilience by bolstering the sustainability or profitability of existing economic sectors or creating new jobs and business linked to restoration and/or infrastructure improvements.

3.0 CLIMATE AND ECONOMIC RISK

Key Terms*

Acute Climate Extremes
The occurrence of a weather or climate event either above or below the range of historically observed thresholds.

Progressive Climate Change
An on-going shift in the mean state of the climate that persists for an extended period of time.

Adaptation
A process of adjustment to current and expected climate conditions with the aim of moderating harm at the minimum, and optimally creating beneficial opportunities.

Mitigation
Actions that limit or prevent greenhouse gas emissions and enhance activities that remove gases from the atmosphere.

Resilience
The capacity for a system (human and natural) to anticipate, absorb, accommodate, or recover from the impacts of a hazardous event in a timely, efficient, and equitable manner.

*Adapted from Field et al 2014

The foundational water management framework, policies, infrastructure, and socio-economic systems in the Colorado River Basin were built on climate patterns and expected annual weather cycles that are both progressively and abruptly changing. Over the past two decades, the Colorado River Basin has experienced an ongoing decline in stream flows, record-setting heat, some of the driest years ever recorded, and previously unimaginable catastrophic fires. The scale and pace of climate-related changes affect the availability and reliability of water supplies, agricultural operations and supply chains, rural and urban water demands, energy use, and watershed health. At an even deeper level, changing climate dynamics illuminate a need to proactively adapt current legal, economic, and social systems to respond to heightened levels of risk and bolster the Basin's overall resilience.

In this report, the term *risk* is used primarily to refer to the potential climate-change impacts that result from two drivers of climate change: (1) extreme events that dramatically eclipse previous records and historic expectations and (2) progressive deviations from historic trends.

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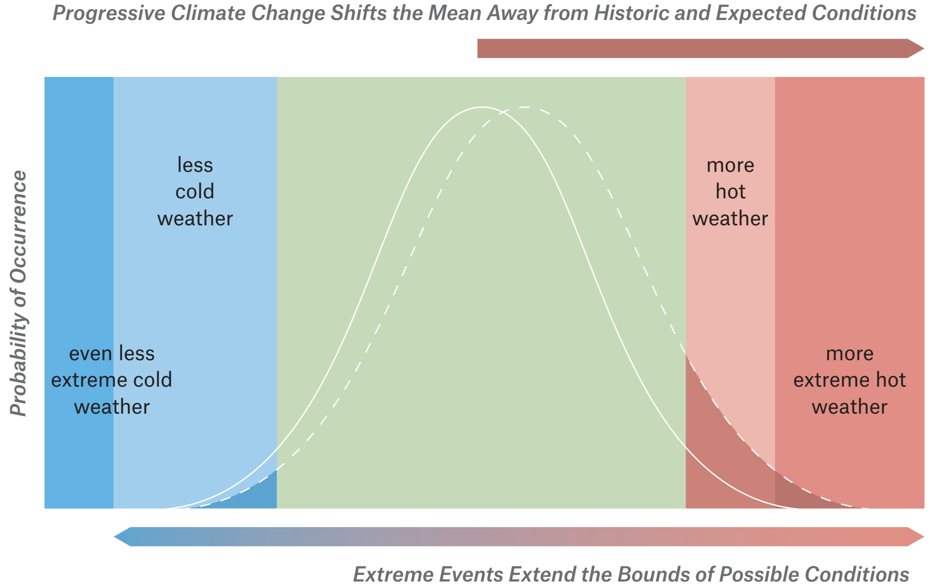
Figure 1. As global and Colorado River Basin temperatures rise, extremely hot weather pushes the boundaries of what is possible while progressive increases in temperature shift the mean away from historic trends and expectations (Adapted from Field, Barros, and Intergovernmental Panel on Climate Change 2014).



Distinguishing between progressive change and acute extreme events helps align adaptation responses to the type of risk (Figure 1). For example, an extreme temperature event can create dangerous, if not deadly, impacts on vulnerable populations, crop viability, and forest fire potential at levels previously not experienced. Simultaneously, progressive shifts towards overall hotter temperatures place pressure on water and energy systems to keep up with rising irrigation needs, municipal supply demands, and energy consumption.

Both progressive shifts in climate conditions and extreme events increase hydrologic, social, and economic risk to municipalities, agriculture, industry, and watershed health throughout the Basin and require innovative strategies to proactively respond and adapt (Bennet 2021). The ten investment strategies explored in this report provide ways to respond and adapt including supporting adaptation measures, reducing pressure on water supplies, increasing the capacity to mitigate climate change, and bolstering economic resilience.

3.1 CLIMATE CHANGE IN THE COLORADO RIVER BASIN

Temperature

The range of annual temperature variation is one of the largest drivers that determines regions that are most suitable for livability and agriculture, including in the Colorado River Basin. Rising temperatures contribute to more intense droughts, reduced soil moisture, increasingly heavy downpours, and reduced snowpack throughout the Colorado River Basin (Lall et al. 2018). Under a business-as-usual climate change scenario, the global band of habitable temperatures will shift more quickly and significantly than it has over the past 8,000 years, forcing both adaptation and migration (Xu et al. 2020). There are many unknowns about how agriculture and populations will shift in the Basin, given projections that portions of the Lower Colorado River Basin could experience extreme temperatures above 95-degree Fahrenheit for half of the year (Liu, Stanturf, and Goodrick 2010; Lustgarten 2020; Frisvold 2016; Thiel 2013). If population continues to grow in the hottest parts of the Basin, water supply efficiency, accessibility, and availability will become even more important.

Recent studies on temperature have found that beginning in the early 1970s, both the Upper and Lower Basins have experienced strong positive increases in temperatures, with a maximum shift above the long-term mean of about 1.1 degree Celsius (Tillman, Gangpadhyay, and Pruitt 2020). Modelling results point to continued increases in temperatures above the historical median, with steady warming in decadal average temperatures through the end of the century (Tillman, Gangpadhyay, and Pruitt 2020).

Precipitation

Winter and summer precipitation patterns are shifting significantly across the Basin. Snowpack, a key component of the Colorado River Basin's water budget, has been declining across 90% of snow monitoring sites in the western United States, in tandem with increasing evapotranspiration rates from snow sublimation (Mote et al. 2018; Knowles et al. 2015). Currently, snowmelt-derived runoff contributes roughly two-thirds of the inflow into the major storage reservoirs in the Basin, and the contribution of snowmelt to total runoff is likely to decrease by one third for the western United States (Li et al. 2017).

3.1

Summer precipitation is a key contributor to streamflows and aquifer recharge in the Lower Basin. Typically, the North American Monsoon provides approximately 70% of the total annual rainfall for the Lower Basin and northern Mexico states (Sheppard et al. 2002). The monsoon is critical for soil moisture, groundwater recharge, ecosystem functions, rangeland grazing, and agriculture in Arizona and New Mexico. Climate researchers project changes in monsoon patterns, with significant declines in early season precipitation (June-July) and occasionally, though variable, increased precipitation later in the monsoon season (September-October) (Truettner et al. 2019; Cook and Seager 2013).

Recent research finds that precipitation in the Upper Basin is projected to increase through the end of the century, potentially rising to 6% above the 1951-2015 historical period by mid-century and by 9% at the end of the century (Tillman, Gangpadhyay, and Pruitt 2020). Conversely, the Lower Basin is expected to see precipitations at or less than the historical period (1951-2015) (Tillman, Gangpadhyay, and Pruitt 2020). Figure 2 illustrates expected trends in both temperature and precipitation for the Upper and Lower Basins through the end of the century (Tillman, Gangpadhyay, and Pruitt 2020).

Aridification

Climate change-induced changes in temperature combined with precipitation shifts, is placing the current drought on the trajectory of a mega-drought (Williams et al. 2020) and shifting the baseline to a permanently more water-scarce environment ("aridification") (Colorado River Research Group 2018). The risk of long-term and persistent "hot drought" conditions throughout the Colorado River Basin is significant where rising temperatures are projected to reduce streamflow from 20% at mid-century to 35% by the end of the century (Udall and Overpeck 2017; McCabe et al. 2017).

Observed and ongoing changes in climate have influenced fire potential across the globe and in the Colorado River Basin (Liu, L. Goodrick, and A. Stanturf 2013; Liu, Stanturf, and Goodrick 2010) and have resulted in significant and extreme recent fire events. The compounding influence of increased temperatures, lower soil moisture, reduced precipitation, and dense forest fuel loads is sparking "very large fires," defined as the top 5 or 10% of the largest fires in a region's history (Barbero et al. 2015). Very large fires have increased across the western United States in the past decade and set new upper bounds on the speed, magnitude, and longevity of fires, shifting what previously seemed impossible

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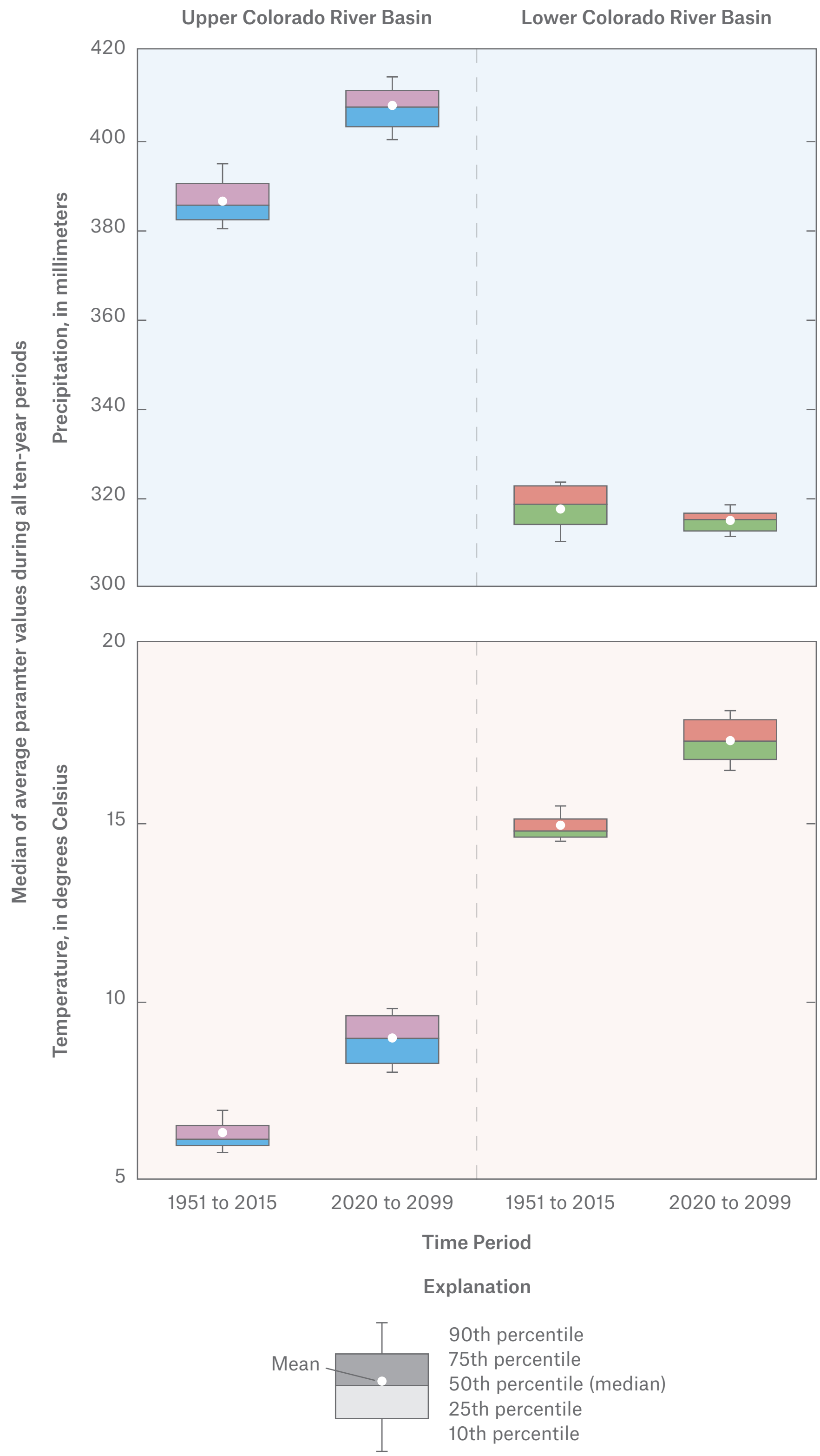
into the realm of the frighteningly possible. Extreme fires, such as those seen in 2020, re-define the scale and possibility of very large fires in the region and increasingly threaten and affect homes and communities, inflict severe ecological damages, lead to direct and indirect impacts on human health, and have rippling economic repercussions.

Figure 2. Precipitation and Temperature trends through 2100 in the Upper and Lower Basins (adapted from Tillman, Gangpadhyay, and Pruitt 2020).



3.2

CLIMATE DRIVEN IMPACTS ON COLORADO RIVER BASIN WATER SUPPLY

Progressive climate-induced streamflow changes are increasingly well documented in the Basin. Overall conditions in the Basin have been drier and warmer in the 21st century relative to the 20th century, reflected in diminished streamflows, reduced snowpack, decreased summer precipitation, declines in aquifer recharge, and higher temperatures (Williams et al. 2020). Between 2000 and 2014, the first 14-years of an on-going drought, annual total Colorado River flows averaged 19% below the 1906-1999 average, while Upper Basin streamflow declined by 16.5% from 1916-2014 (Xiao, Udall, and Lettenmaier 2018; Udall and Overpeck 2017; Kuhn and Fleck 2019). Over 50% of the decreasing runoff trend from 1906-2014 can be linked to basin-wide warming which has contributed to decreased snowpack, higher evapotranspiration rates, and lower soil moisture (Xiao, Udall, and Lettenmaier 2018).

In some years, shifts in summer rains may result in an overall reduction in precipitation in the Lower Basin, adding pressure to groundwater supplies as surface water supplies diminish. During drought conditions from 2004-2013, groundwater depletion exceeded the rate of depletion in Lake Mead and Lake Powell, indicating that groundwater is a significant contributor to Basin water use (Castle et al. 2014). Recent modelling suggests that over the next 80 years, groundwater infiltration and aquifer recharge will be consistently less than the previous 65 years (1951-2015), which would significantly impact Lower Basin water supplies (Tillman, Gangpadhyay, and Pruitt 2020).

As climate-induced streamflow changes are unfolding, the past three water years, from 2018-2020, have also been a case study in intersecting extreme and acute climate events in the Colorado River Basin. In water year 2018, precipitation and streamflows throughout the Basin ended at record- or near-record low levels, accompanied by record- or near-record high average temperatures and evaporative demand. In September of 2018, stream flow gages throughout the Upper Basin recorded their lowest September monthly flows on record (Western Water Assessment 2020). The year registered as one of the top five driest and hottest years on record for Arizona, Colorado, and Utah (Western Water Assessment 2020; National Weather Service 2020).

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The start of water year 2019 moved quickly from the hot and dry conditions of the previous water year to above-normal precipitation and snowpack levels in the Upper Basin and substantial rain and snow in the Lower Basin that improved drought conditions. Spring and summer run-off bolstered reservoirs and led to storage levels between 110-125% above average in some Upper Basin states by fall (Western Water Assessment 2020). However, despite abundant winter precipitation, a drier than average summer season diminished regional soil moisture values to below average levels (Harpold and Molotch 2015). Low soil moistures are further exacerbated by diminished summer monsoon and precipitation events that deliver fewer storms to infiltrate and hydrate soils. Extremely dry soils with low moisture content in the Upper Basin further diminish runoff, weaken vegetation, and heighten wildfire risk.

Water year 2020 began with higher than average reservoir storage in the Upper Basin, while Lake Mead elevation levels sat comfortably above shortage tiers. Strong storms brought significant snowfall to the Colorado River headwaters and upper portions of the Rocky Mountains. However, by July 2020, conditions shifted rapidly and the summer of 2020 broke records for soaring temperatures with little to no precipitation. In Colorado, the heat broke high temperature records across the state, with 75 days in Denver and 98 days in Pueblo eclipsing 90 degrees. Arizona recorded the highest number of days ever where temperatures exceeded 110 degrees. The relentless high temperatures were a result of a high-pressure dome over the Lower Basin and the persistent and excessive heat wave qualified as an extreme climate event (Machemer 2020; Livingston and Freedman 2020).

The six-month period from April to December 2020 was one of the driest periods on record in the Basin. Within that six-month period, the four months from August to December registered as among the driest of those months on record, bested only by August 2002 and September 2018. Conditions in early 2021 resembled 2002, 2012, 2013 and the beginning of 2018, which are four out of the five driest years on record.[2]

3.3 CLIMATE CHANGE MITIGATION

In order to avoid the most severe risks of climate change, rapid reductions of carbon dioxide and other greenhouse gases to "net zero" will be required at the global, national, and regional scales. Limiting global warming to the 2°C threshold set in the Paris Climate Agreement will require investment in a broad range of reductions in many sectors across the globe, with a focus on developing and implementing solutions that benefit local economics, communities, and ecological systems (Martinich et al. 2018). While achieving this goal is daunting, and federal action is currently lagging in the U.S., proactive investment in solutions at the state or regional levels can be a testbed for the robustness of land-based mitigation activities.

A comprehensive portfolio of solutions needs to include zero-carbon energy production, energy efficiency solutions, nature-based climate solutions, low-carbon food production, and low-carbon water storage and distribution. When implemented at scale across the entire U.S., nature-based climate solutions such as forest management and restoration, agricultural and grassland management, and wetland management could contribute to a 21% reduction in annual emissions for the U.S. (Fargione et al. 2018). Several of the investments outlined in this report could contribute to mitigation potential in the Colorado River Basin to varying degrees, especially if implemented at scale.

Progressive climate shifts are also likely to impact the permanence of carbon stored in biomass around the globe (Fargione et al. 2018). Climate change feedback loops increase the likelihood of large landscape-scale disturbances, such as fires, which have measurable and degrading effects on global emissions. The summer of 2020 showcased the dangerous consequences of compromised forest health and extreme fire. The three largest fires in Colorado history occurred in 2020. The East Troublesome, Cameron Peak, and Pine Gulch fires together burned over 600,000 acres. Over 4 million acres burned in California in 2020—more than double the record set in 2018. In addition, five of the largest six fires in California's modern history occurred in 2020. Greenhouse gases generated by the U.S. economy in 2020 decreased by 9.2%, bringing total emissions to about the same level as 1983 (Mufson 2020). Those national gains–which came at a steep cost to the U.S. economy (Mufson 2020)—were negated by roughly 30% due to the carbon dioxide and other pollutants released into the air from the record-setting extreme fires along the west coast and in the Rocky Mountains (Mufson 2020).

3.4 ECONOMIC & SOCIAL RISKS

Economic risks from climate change include, but are not limited to, increased water costs, lower labor productivity, reduced crop productivity, impacts to public health, and increases in insurance premiums. Extreme climate events and progressive climate impacts already cost billions of dollars in the United States annually and the total costs of these events are rising (Davenport and Smialek 2020; Lustgarten 2020; Oreskes and Stern 2019). "Climate change is water change"[3] and the bulk of these costs are associated with water-related impacts such as floods, droughts, hurricanes, and wildfires that can all be linked to changes in the hydrologic cycle.[4]

Despite the fact that the Basin is largely landlocked, sea level rise also poses an economic risk to the Basin, because as coastlines are eroded and flooded people move inland, including to communities in the Basin. Migrating populations will seek places that can offer affordable housing and employment. A recent modelling study projects that the Phoenix metropolitan area will be among the top regions in the U.S. for population migration from coastal cities (Hauer 2017). Maricopa County, which encompasses Phoenix metropolitan-area cities, is already one of the fastest growing counties in the Nation,[5] even with the escalating temperatures and increasing aridity. This paradox highlights the trade-offs in population responses to climate change. Populations may be faced with trading one risk (sea level rise) for another (extreme heat).

Relatedly, the impacts and risks associated with climate change disproportionately affect vulnerable people and communities (or *populations of concern*), including people and communities with low income, communities of color, immigrant groups, Indigenous peoples, older adults, persons with preexisting medical conditions, and others (Gamble et al. 2016; IPCC 2014). People living in at-risk areas including impoverished urban areas, isolated rural areas, floodplains, or coastlines, "are more vulnerable not only to extreme weather and persistent climate change but also to social and economic stressors" (Gamble et al. 2016). Indigenous people, especially those who live in geographically isolated and/or impoverished communities, are likely to experience "greater exposure and lower resilience to climate-related health effects" (Gamble et al. 2016). The National Congress of American Indians (NCAI) established a Climate Action Task Force to "document, inform, and support the climate action efforts of tribal nations and organizations" and advocate for policies and funding to support climate actions (National Congress of American Indians 2019). In the Navajo Nation,"[r]ising temperatures and declining rainfall have made groundwater the principal drinking water source for many residents," which leaves those residents and communities even more exposed and vulnerable to climate risks and related social, economic, and health consequences,[6] challenges also faced by other tribal communities. The Navajo Nation's Climate Adaptation Plan identifies water security, overgrazing, and land use management and planning as three of the six priority areas related to climate vulnerabilities and adaptation strategies (Tom, Begay, and Yazzie 2018).

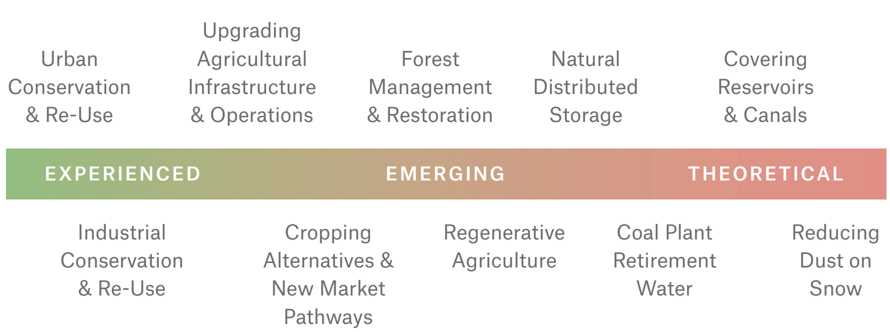
4.0 OVERVIEW OF INVESTMENT STRATEGIES

Throughout the world, water users and managers, scientists, local communities, entrepreneurial innovators, and non-governmental organizations are looking for ways to increase the long-term resilience and health of the basins that supply critical water needs for humans, agriculture, industry and the environment (Field, Barros, and Intergovernmental Panel on Climate Change 2014; Reidmiller et al. 2018). These efforts are driven by many factors, including the need to reverse historic degradation, improve watershed health and reduce hydrologic vulnerability to climate change. Similar efforts are beginning to develop in the Colorado River Basin (Snider 2020), but they have largely been carried out in the periphery of efforts like the development of the 2007 Interim Guidelines, the Drought Contingency Plans and various state water planning efforts that focus on traditional demand/supply analyses and water management solutions.

While well-tested and widely implemented water conservation efforts are essential, they are developed and implemented with a focus on the management, movement, and use of water and therefore do not typically or sufficiently include or consider broader economic, environmental, and social risks from changing climate dynamics. By focusing solely on managing water supply and demands within the context of drought and climate change, there may be missed opportunities to explore multi-faceted strategies that could adapt to, respond to, and mitigate the steady, compounding, and extreme risks of climate change to economies, communities, landscapes, and water resources.

There is potential for investigating, testing, and scaling-up investment strategies aimed at preparing the Basin for long-term rising temperatures, high variability in precipitation patterns and increased drying, all of which are projected to occur even if efforts to limit climate change are taken seriously over the next few decades. The ten strategies explored in this report range from well-demonstrated, to emerging, to theoretical but largely untested concepts (Figure 3).

Figure 3. Range of Application and Implementation Experience for Each Strategy in the Colorado River Basin



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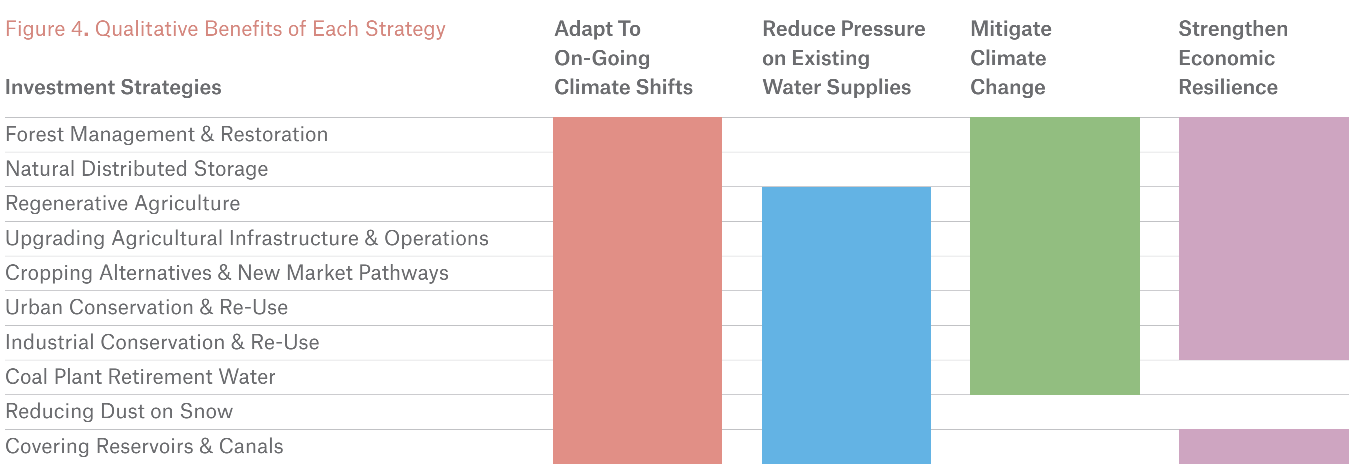
The research began with an extensive literature review on each strategy. Information was gathered from the Bureau of Reclamation's 2012 Colorado River Basin Water Supply and Demand Study, (Bureau of Reclamation 2012) the 2015 Moving Forward Report (Bureau of Reclamation 2015a), the 2018 Tribal Water Study (Ten Tribes Partnership 2018), peer-reviewed studies, agency reports, and white papers. Following the initial compilation of literature, on-the ground experience from various conservation programs, applied academic research, and implementation data from water management agencies in the Basin was compiled and integrated into summaries for each strategy. Taken together, the investment strategies represent a diverse set of actions that could be implemented at multiple geographies and timescales, industries, agriculture, NGOs, and management agencies to build resilience to moderate and acute levels of hydrologic risk and progressive and extreme climate impacts.

Overall, the research revealed that benefits and implementation costs are predominately site-specific, making it challenging, if not impossible at this time, to precisely and accurately quantify the economic, environmental, and social benefits and total costs at a basin-scale. Recognizing this limitation, the final research step made an effort to qualitatively conceptualize the expected benefits of each strategy to a) adapt to climate shifts, b) reduce pressure on water supplies, c) mitigate climate change, and d) increase economic resilience (Figure 4).

Sections 4.1 through 4.10 present a high level overview of each strategy. A companion Technical Appendix provides a detailed discussion and a comprehensive reference list for each strategy. The Technical Appendix was developed from a thorough literature review and on-the-ground knowledge of a broad range of contributors, and serves as the knowledge base for the main report as well as each summary.

It is challenging to precisely and accurately quantify benefits that could result from scaling up these strategies in applicable regions of the Basin since benefits are site specific and effectiveness data is limited or non-existent (with the possible exception of urban and industrial conservation efforts). Similarly, it is not possible to accurately estimate total costs necessary to scale such strategies in applicable areas of the Basin (though it could potentially run into the billions over a decade or more). The analysis also identified plenty of barriers to scaling up these strategies.

Figure 4. Qualitative Benefits of Each Strategy



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Brief Summary of Barriers to Scaling Up Investment Strategies

Forest Management & Restoration: Cultural, statutory, jurisdictional and cost barriers to changing forest management practices; lack of funding for preventative actions and restoration; still developing science on best approaches for improving watershed yield; potential for litigation from opponents.

Natural Distributed Storage: Additional demonstrations needed to fully document potential benefits for and impacts to ranching profitability; water rights and permitting complications; getting watershed level consensus on projects and pursuing research and monitoring on the hydrologic benefits.

Regenerative Agriculture: More research on applicable practices needed; multi-year gap between investment and financial benefit; increased labor and equipment costs; agricultural finance structures favor conventional practices; no market premium for products from regenerative operations.

Upgrading Agricultural Infrastructure & Operations: Incentives to change practices or upgrade systems sometimes lacking; more comprehensive watershed approaches need additional funding; need to focus on improvements to most productive lands to sustain value proposition of investments.

Cropping Alternatives & New Market Pathways: Incentives to switch from traditional crops may be lacking; need for marketing and processing facilities and critical mass of producers to justify those investments; up front capital costs, risk mitigation, and technical assistance needs; and uncertainties regarding trade-offs, including implications for avian and wildlife species.

Urban Conservation & Re-use: Conservation can reduce water utility revenues if programs not properly structured; opposition to some forms of re-use; incentives to change may be lacking in overbuilt systems.

Industrial Conservation & Re-use: Technical complications for some strategies; potentially high costs; and lack of incentives for change.

Coal Plant Retirement Water: Complex economic and social issues associated with plant closures and long decision timelines; legal and regulatory hurdles in repurposing coal plant water; competing uses for coal plant water.

Reducing Dust on Snow: More research on where and what interventions would be most effective; source of financing unclear; need to work with willing institutional landowners to get to scale; potential opposition to practice changes.

Covering Reservoirs & Canals: Largely untested except on smaller scale; physical methods have high capital costs; chemical methods have high maintenance costs; potential for adverse environmental and recreational effects; legal and permitting issues.

Despite the barriers, these ten strategies offer a means of responding and adapting to progressive and extreme climate events, and reducing hydrologic, social, and economic risk for municipalities, agriculture, industry, and watershed health. Efforts taken to reduce the barriers can help pave the way to climate resilience in the Colorado River Basin.

4.1

adapt
mitigate
strengthen

FOREST MANAGEMENT & RESTORATION

Resilience Benefits:
Well managed 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 against watershed degradation, severe wildfire, and other climate change impacts. 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.

Investment Summary:
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" (IPCC 2014). Forest restoration, on the other hand, means engaging in practices that regain ecological integrity from degraded systems. 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.

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 which has prevented fires from clearing small trees and bushes. Logging that removes mainly large, older trees, and leaves surface fuel increases the fire hazard and fire severity. Insects and disease along with 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.

4.1

A number of entities are working on forest restoration projects in the Basin, including Denver Water, the Salt River Project, the Indigenous Peoples Burning Network, Blue Forest, and the Mountain Studies Institute, among others. It has however been difficult to implement forest management and restoration practices at the needed ecological scale because of the high cost of management ($1,000-$4,000+ an acre), jurisdictional challenges in implementation, a culture of fire suppression, and concerns around litigation, among other challenges.

To advance forest management and restoration efforts, support for the development of science to improve understanding of where and how forest management activities can increase snowpack, increase snowmelt duration, water retention, watershed resilience, improve flows/hydrographs, reduce the risk of high-severity wildfires, and provide net carbon storage will be necessary, along with financing and stakeholder support to implement projects and bring the actions to scale.

4.2

adapt
mitigate
strengthen

NATURAL DISTRIBUTED STORAGE

Resilience Benefits:
This strategy has the potential to build adaptive capacity in ecosystems and ranching operations to cope with ongoing climate shifts. Investments in natural distributed storage could also have important 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.

Investment Summary: As used in this report, 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 a range of identifiable characteristics.

Natural distributed storage projects primarily use natural materials that are appropriate to the specific site and landscaping setting, and largely rely on natural riverine, wetland, hydrologic, or ecological processes. They can result in aquifer recharge, transient floodplain water retention, or reconnection of historic floodplains to stream channels. Projects are generally designed to produce two or more environmental benefits, including (1) stream flow timing changes that are beneficial to watershed health, (2) fish and wildlife habitat or migration corridor restoration, (3) floodplain reconnection and inundation, or (4) 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, channelization and stabilization of rivers, and the extirpation of beaver and the removal of their dams during the 19th and 20th centuries. 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.

4.2

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. 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).

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. However, demonstration projects so far have indicated that there is enormous potential in this strategy. Natural distributed storage restoration methods are considered to be relatively low-cost, but most of the existing cost information relates to smaller, reach-scale projects. Larger-scale projects would involve greater resources, time, and coordination, but could facilitate better prioritization across basins and watersheds and could link up with related projects to deal with “core” issues such as roads or grazing practices upstream that are causing sedimentation issues downstream.

4.3

adapt
reduce
mitigate
strengthen

REGENERATIVE AGRICULTURE

Resilience Benefits:
Regenerative agriculture offers an opportunity to enhance resilience in the Colorado River Basin. It can contribute to climate change mitigation by reducing greenhouse gas emissions and sequestering carbon. It can boost adapation 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. Enhanced water-holding capacity in soils can also reduce the need for irrigation, thereby limiting pressure on existing water supplies. Regenerative agriculture can help ensure 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.

Investment Summary:
Regenerative agriculture is a broad term that focuses on restoring and improving soil health biodiversity through farming and grazing practices that rebuild organic matter and biodiversity with the aim of increasing soil moisture, water retention, and carbon sequestration. Regenerative agricultural practices, broadly defined, include, but are not limited to, no-till agriculture, use of cover crops, diverse crop rotations, rotating crops with livestock grazing, and intensive grazing rotation.

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; reinstituting Indigenous farming cultures; water scarcity; and the potential for carbon markets to offer payments for increased storage of carbon in soils. Several studies project that widespread application of regenerative agriculture techniques could draw down enough carbon to significantly counter global emissions, in addition to the co-benefits of healthier soils, improved crop and rangeland yields, increased water retention, and improved biodiversity. 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.

4.3

In the Colorado River Basin, there are three areas where regenerative practices could potentially provide hydrological resilience, economic resilience, and climate change mitigation benefits: (1) rangeland restoration and stewardship, particularly on lands in federal, state or tribal ownership; (2) improved soil health in irrigated grass and hay pasture operations; and (3) increased use of cover crops in farming operations. These practices are already being implemented in some areas of the Basin, though on a sporadic basis, and much more research is needed to quantify benefits. State agricultural departments in Colorado, New Mexico and Utah have established healthy soils programs and the issue is a priority for many of the NRCS state-level offices in the Basin. There are also partnerships among agricultural producers, universities, and others examining the use of regenerative practices, such as the Colorado Collaborative for Healthy Soils. Opportunities to further this strategy include coordinated federal, state and/or tribal funding and support of regenerative agriculture demonstrations; market and/or tax incentives that favor regenerative practices; and addressing the substantial financing barriers to conversion from conventional to regenerative practices.

4.4

adapt
reduce
mitigate
strengthen

UPGRADING AGRICULTURAL INFRASTRUCTURE & OPERATIONS

Resilience Benefits: 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 potentially reducing consumptive use. The improvements may 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.

Investment Summary: Much of the Basin's irrigation infrastructure, particularly in the Upper Basin is old, cumbersome, in dire need of repair, and labor intensive to operate and maintain. These challenges 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. Tribal agriculture is also in need of investment, as Basin Tribes seek to improve existing operations and put their Colorado River rights to beneficial use.

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 collapsing 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; increasing precision in scheduling water diversions and deliveries (including deficit irrigation, where viable), and creating local, intra-district or regional programs that allow for temporary, compensated reductions in water use.

4.4

The costs of upgrading agricultural infrastructure and operations to enhance their productivity and resilience and improve river health vary widely with the location, type of improvement and economies of scale. Given the state of current infrastructure and the extent of irrigated acreage in the Basin, however, the total cost over the long-term could be quite high, though there are targeted and less costly measures that could lead to measurable improvements.

There are several on-going efforts to upgrade agricultural infrastructure in the Basin and there are more opportunities that have been identified through on-the-groundwork by agricultural producers and conservation organizations working together. A key approach to this strategy will be to develop comprehensive, watershed-level infrastructure improvement plans that can obtain grant or loan financing and that produce benefits at scale: to producers, watersheds and local economies. Several such planning efforts have been in the works or are being contemplated and support for these collaborative efforts will be critical.

4.5

adapt
reduce
mitigate
strengthen

CROPPING ALTERNATIVES & NEW MARKET PATHWAYS

Resilience Benefits:
Investments in alternative crops and creation of new pathways for farmers to access high-value markets could help reduce pressure on existing water supplies and generate resiliency benefits including: adapting to on-going climate shifts by providing options for agricultural producers experiencing impacts to crop productivity and strengthening regional food systems and security; mitigating climate change by exploring how cropping strategies, operations, processing, and transportation might reduce and sequester greenhouse gas emissions; and increasing economic resilience by testing and demonstrating the economic viability of new crops and market pathways.

Investment Summary:
Identifying and implementing changes to the types of crops produced around the Basin depends on a variety of 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; and other factors. Alternative crops could result in reduced water consumption either through (1) shifting from water intensive crops to more water efficient crops or (2) shifting to crops that have comparable water efficiency attributes, but which have a higher economic value that can justify conservation practices to reduce consumptive demand on other acreage. These practices relate to and are often undertaken in combination with other agricultural and/or water conservation practices (see Upgrading Agriculture Infrastructure & Operations and Regenerative Agriculture strategies).

Irrigated agriculture is the largest category of water use in the Basin. From 1985 to 2010, more than 85% of water diverted from the River was used for irrigated crops. Grass, pasture, and alfalfa for cattle are the Basin's major crops, followed by wheat, vegetables and fruit, and cotton. Studies suggest that a significant amount of water could be conserved by changing the types of crops produced without taking land out of production. However, estimating generalized water savings is difficult because water savings potential varies based on region, climate, the initial crop, the replacement crop, and other factors. Moreover, crop switching can involve significant costs at the farm level (field preparation, new equipment, additional labor, seed and other input costs). Scaling up will require investments in processing, transportation, marketing capacity, and legal costs to develop new market pathways.

4.5

While there are some examples of cropping changes specifically targeted at lower water use crops in the Basin, there has been little incentive for producers to invest the time and resources to switch from relatively stable crops such as alfalfa to lower water use alternatives. Incentives may begin to appear as drier conditions become more frequent, requiring agricultural operations to adjust water use expectations and leading to more opportunities for research, case studies, and improved knowledge. Water supply benefits could be significant and investing in cropping alternatives and new market pathways could provide benefits to local streams and habitats as well as local and regional food systems and food security.

Given the potential resilience and economic benefits, it would be useful to encourage existing and new explorations of crop alternatives and creation of new markets. There are several initiatives and university research efforts to build upon, as well as policy recommendations to resolve financing and other barriers.

4.6

adapt
reduce
mitigate
strengthen

URBAN CONSERVATION & RE-USE

Investment Summary:
Urban water efficiency and conservation programs are highly effective at saving water. They can and are being used to offset population growth and forestall or prevent the need for additional supplies. The programs can also help businesses reduce overhead and provide jobs. There are a variety of different types of water efficiency and conservation measures. These include indoor and outdoor measures (e.g. low-water use toilets and showers, and smart irrigation), water utility measures (e.g. programs to detect leaks and audits), and reuse (e.g. direct and indirect potable reuse).

Resilience Benefits:
Investments in urban conservation and re-use may contribute to the resilience of the Basin by mitigating 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.

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. Despite upward 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 two million acre-feet in water savings during that same time period. 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. 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.

4.6

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. Municipalities will also have to weigh the other potential implications such as reduced revenue from reduced demand, hardening of demand, and any changes required in state law to enact certain measures like reuse. There are also various factors to consider with urban water reuse strategies, such as impacts to rivers or riparian habitat or downstream water users that rely on discharges, and water quality considerations.

Urban conservation and re-use activities 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 re-use efforts will be critical to support additional water demands and reduce stress on reservoirs and ecosystems. To implement these measures, municipalities will require adequate financing and rate structures to support the implementation of indoor and outdoor efficiency measures and re-use infrastructure and engage in public education campaigns.

4.7

adapt
reduce
mitigate
strengthen

INDUSTRIAL CONSERVATION & RE-USE

Resilience Benefits:
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 re-use can help mitigate climate change by changing energy demands such that emissions can be reduced, limiting pressure on water supplies by implementing water efficient practices and/or offsetting water use, adapting to climate shifts through planning and implementing sustainable water and energy practices, and increasing economic resilience by supporting water smart economic development.

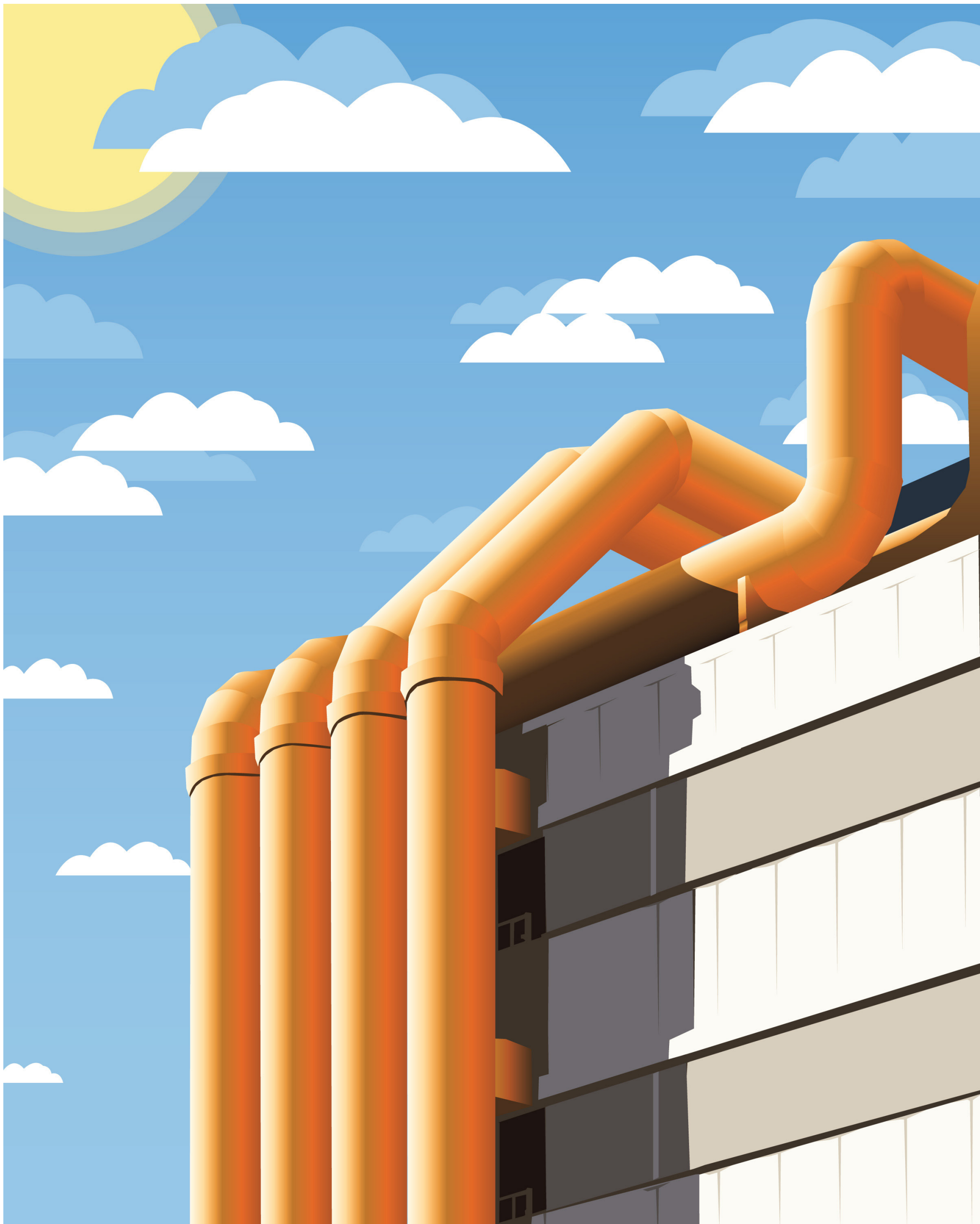
Investment Summary:
Industrial water use in the Basin includes power plant cooling, mining, snow making, food and beverage manufacturing, semiconductor and electronics manufacturing, data centers, chemicals and pharmaceuticals, and oil and gas extraction. Commercial, Industrial, and Institutional (CII) users can account for up to 30-40% of the total M&I use in areas with large institutional and industrial users. Awareness around drought and climate change has grown in recent years and many industrial 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. In addition, many corporations have made overall commitments to enhance the sustainability of their operations and promote environmental stewardship.

Areas where industrial conservation practices could potentially provide hydrologic and other climate adaptation benefits and where companies have been engaging in water and energy efficiencies, include data centers, cooling systems, and reuse practices. Data centers have significant environmental footprints, using large amounts of electricity and water for cooling. However, some data centers are coming up with solutions to reduce their water consumption, including engaging in reuse, and attempting to be net water positive. Apart from data centers, other industries use wet-cooling systems to cool buildings and dispose of waste heat. These include hospitals, office complexes, and university campuses. Used in many institutional and

4.7

commercial facilities, cooling towers are a significant aspect of facilities' water use (constituting 20-50% of total use). Newer, zero-water dry cooling systems exist which 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.

There are several barriers to implementing industrial water and energy efficiency projects, including costs, technical complications, and difficulty in meeting returns on investments. To implement upgrades or redesign systems, businesses must justify the costs to executives and, in certain circumstances, to shareholders. A suite of actions that could be taken to incentivize companies to implement water conservation and re-use practices include engaging with companies early in the building design planning process and implementing pilot projects to help justify the return on the investment. To assist with cost justifications, potential opportunities at the federal or state level include providing incentives through tax credits or deductions for businesses to engage in sustainable practices like water conservation or reuse.



4.8

adapt
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mitigate

COAL PLANT RETIREMENT WATER

Resilience Benefits:
Coal plant retirement can help increase the resiliency 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 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.

Investment Summary:
For over 50 years, coal-fired power plants have provided electricity to communities and industries 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, and similar policies in some other Basin states, are also driving coal plant closures. With coal plant retirement, there is growing interest in how and whether the plants' water rights may become available for purchase or reallocation to other purposes, including system benefits, environmental uses, and instream flows. Securing water from retiring coal plants could potentially provide a host of benefits for the surrounding communities and Colorado River system. According to an initial inventory of coal-fired power plants in the western United States, there are 22 coal plants in the Basin (including those supporting major cities on the Front Range of Colorado) that either recently closed or are expected to reduce or close operations by 2042.

4.8

There are a variety of creative transactions that could secure water rights for augmenting flows for fish and recreation. For example, in western Colorado, Craig Station rights could provide instream flows for the Yampa River downstream of Craig and benefit both fish species and seasonal flows. The water may 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.

There are a number of challenges to implementing this investment strategy. Securing financing for purchases or leases could be difficult. Costs 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. Additionally, the legal, procedural, and approval processes for transferring water rights to instream flows or system use vary by state and can be challenging to complete. 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.

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 some specific opportunities with closed or retired coal plants by engaging with the plant owners to discuss potential water right transfers, and with the state and communities surrounding the plant to design potential water transactions, exchanges and/or economic mitigation strategies.

4.9

adapt
reduce

REDUCING DUST ON SNOW

Resilience Benefits: 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 support basin water supplies.

Investment Summary: 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. 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. Federal lands appear to be a prominent source of dust.

Dust loading has increased since agricultural development and land disturbances intensified in the mid-1880s. Spring winds carry dust from the Colorado Plateau, Sonoran Desert, Mojave Desert, and the Great Basin Desert, aided by the natural erosional landscapes. A comprehensive dust-management strategy could include a combination of:

(1) reducing the intensity of land-use activities that produce dust;
(2) implementing restoration or reclamation strategies that promote ecosystem resilience to wind erosion;
(3) accounting for landscape variability in planning dust-producing land uses and targeting restoration/reclamation actions to maximize dust abatement; and (4) encourage research and monitoring.

4.9

Restoring the degraded and drought prone arid lands primarily in Nevada, Utah, and Arizona that generate dust will be key in reducing dust on snow. A top mitigation strategy could be restoring BLM-managed grazing lands and improving energy development practices. Additionally, as the Forest Service 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. As such, dust on snow mitigation strategies tie in with several other strategies in this report, including Regenerative Agriculture (for example, stewardship rangeland contracts may be an option for work on federal, state, and tribal lands if there were institutional support), Forest Management, and Natural Distributed Storage. In the context of dust on snow, however, large scale projects, or at a minimum more coordination among individual projects, will be needed.

Potentially appropriate interventions for the Basin include stabilizing desert soils, restoring abandoned croplands, and planting native grasses and vegetation on degraded rangelands. 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.

4.10

adapt
reduce
strengthen

COVERING RESERVOIRS & CANALS

Resilience Benefits: This concept focuses on physical solutions to reduce evaporation such as covering reservoirs and conveyance systems with, for example, shade balls or solar panels. Reducing evaporation from reservoirs and canals throughout the Basin could improve overall system efficiency and result in more water supply availability, reducing pressure on existing water supplies. It may also help the Basin adapt to on-going climate shifts and increase economic resiliency by improving or installing infrastructure now to reduce system loss and protecting drinking water quality (thereby also reducing costs) and generating renewable energy over water surfaces where appropriate.

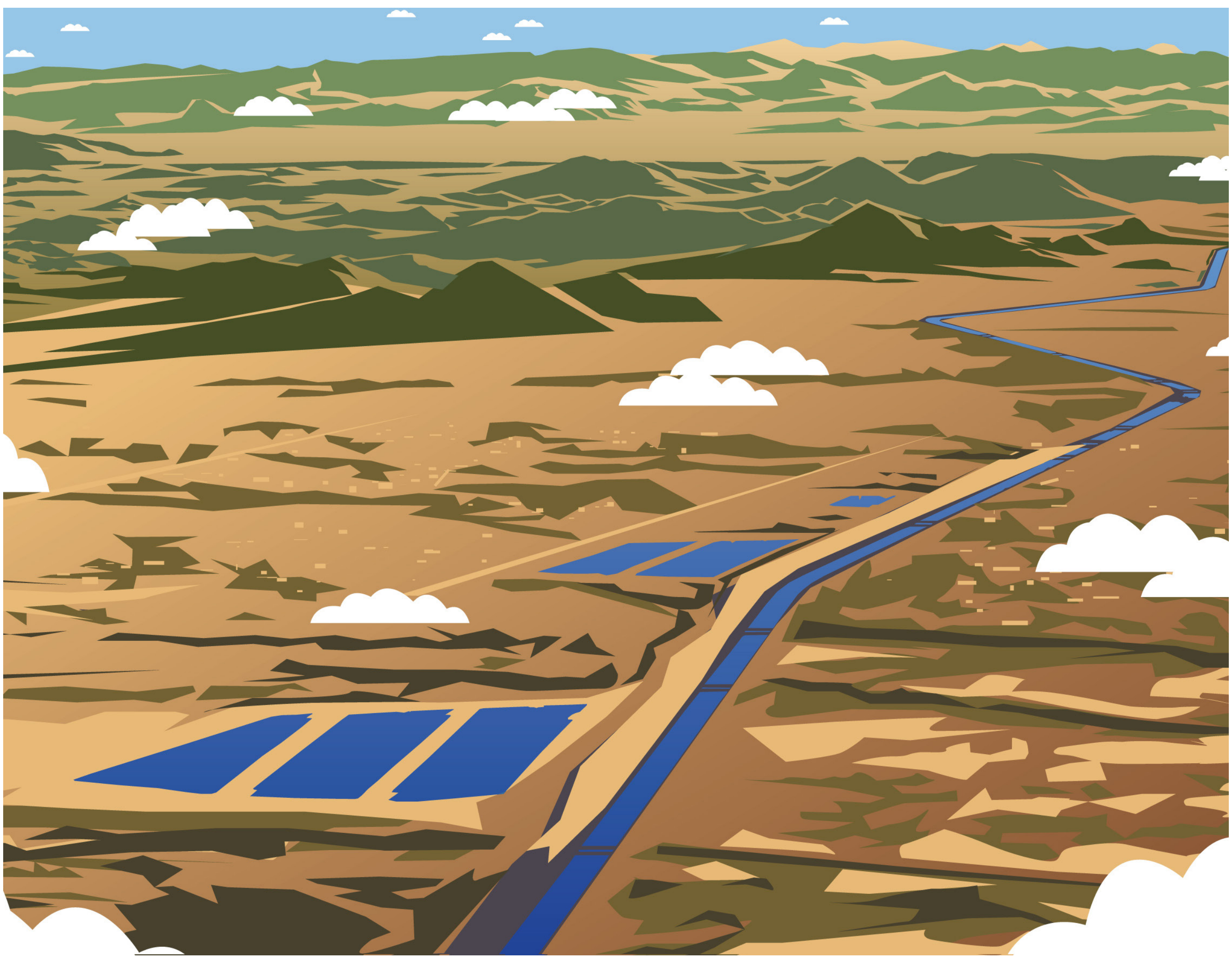
Investment Summary: A significant amount of water in the Colorado River Basin is lost each year through evaporation from storage and conveyance infrastructure. Estimating evaporation rates from reservoirs and canals is challenging and depends on a variety of factors. However, researchers at the University of Colorado at Boulder estimate that annual evaporation losses in the Colorado River Basin as a whole are about ten percent of the total natural flow in the Basin. Methods used to control evaporation from reservoirs and other water surfaces include physical methods (floating covers, shadecloths, solar photovoltaics, etc.), chemical methods (mono-layers), and biological methods (floating plants, wind breakers, etc.). It is estimated that reducing evaporation from the major reservoirs and canals could result in the following potential savings: 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. For example:

- Physical methods may yield 70-95% savings. Initial capital costs are high, though maintenance costs are lower in the longer term.
- Chemical methods could produce 20-40% savings. Capital costs are not high, but maintenance costs are significant, and the influence of surface area conditions (e.g. wave action and temperature) significantly impacts the degree of effectiveness.
- Biological covers can significantly decrease evaporation, but with a trade-off in transpiration needs of the cover vegetation.

4.10

While the most significant potential savings from reducing evaporation would be associated with the Basin's largest reservoirs, covering those reservoirs would also involve the steepest costs and the largest barriers, including environmental impacts to birds, fish habitat, and water quality, as well as impacts on recreation, among other feasibility challenges.

Pursuing smaller scale projects in the Lower Basin, where temperatures are higher and project scale is more feasible, might provide water savings and other co-benefits. Smaller-scale municipal, community water system, and irrigation canal system projects are common in the Colorado River Basin and are eligible for several federal grant programs. In this regard, this concept relates to and may have some overlap with agricultural and municipal infrastructure efficiency (see Upgrading Agricultural Infrastructure & Operations and Urban Conservation & Re-use strategies).



5.0 SUMMARY OF FINANCING OPPORTUNITIES

Developing a comprehensive, basin-wide, diversified financing approach is an essential and immediate next step in deploying a basin-wide climate resilience effort. While the contours and design of such a financing approach is beyond the scope of this report, there are a variety of federal, state, philanthropic, and private funding programs and mechanisms that currently provide support for the kinds of projects that would be integral to a climate resilience strategy. This section broadly summarizes those programs and mechanisms, identified in each summary and described in greater detail in the Technical Appendix, primarily focusing on existing funding opportunities related to water and conservation.

There are several robust and significant federal programs that can be utilized for many of the strategies discussed in this report. U.S. Department of Agriculture (USDA) Farm Bill conservation programs (i.e., Environmental Quality Incentives Programs, Grassland Reserve Program, Soil Health and Income Protection Program, Regional Conservation Partnership Program, and Conservation Innovation Grants, among others) support restoration and improvement projects for farms, grasslands, and forests. U.S. Bureau of Reclamation programs such as WaterSmart and the Cooperative Watershed Management Program provide funding to municipalities, utilities, Tribal governments, irrigation districts, and watershed groups for conservation and efficiency programs. The U.S. Forest Service and the USDA Farm Bill initiatives provide funding through the Shared Stewardship Strategy and Good Neighbor Authority (respectively) for partnerships with states, counties, and tribes to support watershed and forest restoration projects. Federal programs can provide substantial funding over longer-terms and could provide important foundational funding within an integrated climate resilience effort for the Colorado River Basin, if they were operated in a coordinated fashion for that purpose.

There are also multi-agency collaborative efforts that provide support for source water protection, water quality, watershed and river restoration. The Colorado River Basin Salinity Control Program, a federal program administered and coordinated by the multi-state, multi-agency Colorado River Basin Salinity Forum, provides funding for salinity control projects across the Basin and there may be opportunities to update the approach of that program to both reduce salinity and address resilience. The National Water Quality Initiative is a joint effort between the Environmental

5.0

Protection Agency (EPA), USDA, and state water quality agencies to reduce nonpoint pollution in priority watersheds. EPA also administers Clean Water Act Section 319 funds, which support states and tribes in developing and implementing conservation and monitoring systems that address erosion, run-off, and river degradation. The National Fish and Wildlife Foundation, in partnership with states and philanthropic foundations, provides support for landscape level projects focused on river and riparian restoration efforts.

State-based programs provide funding to landowners, non-profits and community organizations for localized activities focused on forest and watershed health restoration, water quality improvement projects, river and riparian restoration, and water conservation and efficiency efforts. Some of these programs and granting agencies include: the Wyoming Department of Environmental Quality, Colorado State Forest Service, Colorado Department of Natural Resources, Utah Watershed Restoration Initiative, Arizona Water Protection Fund, Arizona Department of Environmental Quality, New Mexico Environment Department, Nevada Division of Environmental Protection, Nevada Division of Forestry, California Watershed Restoration Grants, and California Climate Investments.[7]

Philanthropic funds are also a source of innovative and effective financing for research and novel implementation projects. Philanthropic foundations can provide support for matching funds needed for federal and state granting programs and national and local non-profits to develop and implement restoration and conservation projects, often in partnership with private landowners, irrigation districts, municipal water supply providers, academic institutions, and other watershed-focused organizations.

Public-private partnerships have emerged as a potential opportunity for leveraging financing for water conservation, watershed restoration, and carbon resilience and sequestration projects that reduce risks to business operations and markets. Groups like Blue Forest Conservation,[8] the Salt & Verde Alliance, & Yampa River Water Fund[9] leverage multiple funding sources to protect forests and watersheds for drinking water and river flows.

"Green bonds" could provide a way to fund projects with climate resilience or other specific environmental benefits. Green bonds allow debt issuances by cities, corporations, or other entities for projects that meet certain defined sustainability, climate, or other criteria and are structured as traditional, tax-exempt or taxable municipal bonds. There are no uniform metrics for which types of "green" activities can qualify, but renewable energy, energy efficiency, and water infrastructure have traditionally been the use of proceeds. While traditionally green bond issuances receive no credit premium from traditional bond issuances, some investors believe that investing in sustainable water management can improve the risk profile of a municipality. In these instances, it may be possible for municipalities to layer in investor capital, state revolving funds, and concessionary capital in order to make innovative projects more affordable, or which otherwise would be ineligible for traditional funding. Expanding this concept to a Joint Powers Authority Green Bond would allow two or more public authorities (such as local municipal or county governments) to work together to create a regional financing solution to a regional water resource challenge. Over the past several years, green bonds have grown from a niche market to a nearly $100 billion per year market.

6.0 CONCLUDING INSIGHTS AND NEXT STEPS

Future water management in the Colorado River Basin will be significantly influenced by climate change and the resulting challenges will be most effectively addressed in the longer run through strategies that increase adaptive capacity while also managing water scarcity, ensuring healthy rivers, strengthening economic resilience in the face of uncertainty and change, and where possible, contributing to climate change mitigation. This is a departure from many water management conversations that focus on supply solutions, which are important and necessary, but are themselves insufficient to make strides towards addressing the root driver of hydrologic impacts, which is climate change.

This analysis examined several strategies to build resilience and adaptation in the Basin to impacts from both progressive and extreme climate change. The strategies range from the well-demonstrated (urban and industrial conservation and some of the more standard agricultural infrastructure and operational improvements) to the emerging (regenerative agriculture, forest management, natural distributed storage, coal plant water retirement, crop switching) to the relatively unapplied/untested (covering reservoirs, reducing dust on snow).

While there are multiple paths forward, three near-term next steps seem particularly relevant:

1. Identify and implement **demonstration projects** and **shovel-ready investments** that generate place-based and regional benefits and build knowledge on the applicability, scalability and co-benefits of each investment.

2. Design a **financing strategy** for a diversified and coordinated project portfolio to support the implementation and monitoring of on-the-ground projects within each of the strategies.

3. Develop an **action-oriented research scope** for project implementation that builds knowledge about the outcomes of the ten strategies, including water supply gains, adaptive benefits, and climate mitigation potential.

6.0

As on-the-ground pilot projects and implementation experience continue to inform how the strategies can provide cost-effective and meaningful results, developing cross-sector partnerships and basin-wide funding for such investments will be necessary to implement the strategies at a scale commensurate to the challenge. While it is too early to say precisely how such a coordinated funding approach might be sourced and governed, this analysis highlights just some of the existing federal and state programs that could be applied in a coordinated fashion with a clear water-related climate resilience goal for the Colorado River Basin. Philanthropic and private funding could be used to match or leverage these federal and state dollars. Development of such a coordinated approach to water-related climate resilience funding is particularly timely for several reasons:

1. Congress, the federal administration and several Basin states are focused on bolstering climate mitigation and climate resilience, and water and watershed resilience can and should be at the cutting edge of those efforts (Office of the President 2021);

2. The Basin States, Tribes, and most major water providers and users in the Basin acknowledge the risks associated with climate change and are beginning to look for ways to address that risk;

3. Over the next few years, the operational guidelines for the River will be renegotiated, and the effects of climate change will be central to that negotiation. While the guideline negotiations are not necessarily the forum for structuring investments in the types of strategies discussed in this report, the guidelines process brings a clear focus to the challenges facing the Basin and may serve to motivate a more coordinated approach to resilience; and

4. Most importantly, **there is no time to waste.** The effects of climate change, as manifested in a year like 2020, are here now. Many of the resilience strategies will take time to be scaled-up and produce results across the Basin's watersheds.

6.0

Opportunities to Pursue Resilience Strategies for the Colorado River Basin

Forest Management & Restoration: Support the advancement of science to improve understanding of where and how forest management can increase snowpack retention, benefit watershed resilience and provide other benefits. Continue exploration of and support for forest management efforts that test new financing mechanisms and/or seek to resolve jurisdictional issues and operate at scale.

Natural Distributed Storage: Explore large-scale demonstrations of natural distributed storage approaches in key watersheds, including strong monitoring protocols. Engage with policymakers to clarify funding opportunities for natural distributed storage projects.

Regenerative Agriculture: Develop a coordinated strategy with federal, state, and tribal government agencies to promote regenerative agriculture demonstrations and research. Expand support that connects interested producers to technical and financial resources for scaling up regenerative practices. Help conventional finance sources find flexibility to support regenerative practices by willing producers.

Upgrading Agricultural Infrastructure & Operations: Expand support for development of comprehensive, collaborative watershed plans that focus on multi-benefit agricultural infrastructure and operational improvements. Inventory and prioritize upgrades in key watersheds. Explore more innovative financing options for multi-benefit upgrades.

Cropping Alternatives & New Market Pathways: Provide incentives, technical support, and catalytic financing for willing producers to explore new crops and to help develop marketing pathways. Continue and build upon current cropping alternative endeavors, university research, and other efforts to develop lower water use crops.

Urban Conservation & Re-Use: Continue to emphasize need for urban conservation and support municipal efforts to do so via financing, rate structures and other measures.

Industrial Conservation & Re-Use: Engage with water intensive industries early in building planning and design to promote more efficient systems. Implement demonstrations with willing partners. Explore tax incentives or other financial mechanisms to promote industrial conservation and reuse.

Coal Plant Retirement Water: Explore legal and policy aspects of dedicated retired coal plant water rights to system resilience, environmental benefit or other uses. Engage with plant owners, communities and other water users to explore possible uses and transactions for water rights associated with closed or retiring coal plants.

Reducing Dust on Snow: Develop a public lands management strategy that helps reduce dust generation in key areas that are linked to dust on snow. Link private lands management and regenerative practices with priority areas for reducing dust on snow.

Covering Reservoirs & Canals: Develop smaller scale evaporation pilots, particularly in the Lower Basin. Explore opportunities for underground vs. surface storage.

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NOTES

1. Several of these strategies are discussed and evaluated in the U.S. Bureau of Reclamation's recent report looking at the effectiveness of the 2007 Interim Operating Guidelines for Lakes Powell and Mead (https://www.usbr.gov/ColoradoRiverBasin/).

2. U.S. Bureau of Reclamation Upper Colorado River Basin Operations, available at: https://www.usbr.gov/uc/water/crsp/cs/gcd.html

3. (American Rivers Podcast and Quote from Brad Udall, October 8, 2019. Available at: https://www.americanrivers.org/2019/10/climate-change-is-water-change)

4. For data on climate extremes by region or zip code see https://www.climate.gov/maps-data/dataset/us-climate-extremes-index-graph-or-map.

5. U.S. Census Bureau - https://www.census.gov/quickfacts/maricopacountyarizona

6. The COVID-19 pandemic has highlighted the stark disparity in health and economic consequences for minority and Indigenous communities. Navajo Nation has been significantly affected by the pandemic, exacerbated by issues related to access to clean and reliable water supplies. (Harris 2020)

7. A recent federal legislative proposal from U.S. Senator Michael Bennet, developed in concert with various Colorado-based interests, proposes allocating $ 60 billion to a grant program and coordinated federal funding to support such climate resilience strategies in the western U.S., including many of the strategies described in this report. See, https://www.bennet.senate.gov/public/index.cfm/2020/12/bennet-unveils-bill-to-dramatically-scale-up-forest-and-watershed-restoration-across-the-west.

8. See: www.blueforestconservation.com

9. See: https://www.yampariverfund.org

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