



— BUREAU OF —  
RECLAMATION

# Water Reliability in the West - 2021 SECURE Water Act Report

## **Mission Statements**

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# **Water Reliability in the West - 2021 SECURE Water Act Report**

*Prepared for:*

United States Congress

*Prepared by:*

United States Department of the Interior  
Bureau of Reclamation

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Jackson Lake Dam, Wyoming

A vertical photograph on the left side of the page shows a scenic mountain landscape. In the foreground, there is a dense forest of evergreen trees. A road winds through a grassy field towards a large, calm blue lake. In the background, rugged mountains rise under a clear blue sky.

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# Executive Summary

The Bureau of Reclamation (Reclamation) is the largest wholesaler of water in the country. Reclamation delivers water for municipal, agricultural, tribal, and environmental water uses, including providing one out of five farmers in the Western United States (West) with irrigation water for 10 million acres of farmland that produce 60 percent of the Nation's vegetables and 25 percent of its fruits and nuts.

The Omnibus Public Land Management Act of 2009 (Public Law 111-11), Subtitle F of Title IX of the Act (Science and Engineering to Comprehensively Understand and Responsibly Enhance [SECURE] Water Act) recognizes that changes to temperature, precipitation (rainfall and snowfall), and the timing and quantity of snowpack and runoff pose a significant challenge to the protection and use of water resources. Every 5 years, Reclamation submits a report to Congress under the SECURE Water Act that analyzes projected risks to water supplies in the West using the best available science and highlights collaborative efforts to mitigate those risks. This Water Reliability in the West - 2021 SECURE Water Act Report (2021 Report) provides a West-wide assessment of expected changes to water supplies, uses, and demands; highlights progress; and describes actions taken to increase water supply reliability since the 2016 SECURE Water Act Report.

Reclamation has a broad range of programs and projects that help increase the reliability of water and power deliveries. Our activities include science and research, planning, infrastructure sustainability, efficient hydropower production, and on-the-ground actions to increase reliable water supplies to meet water demands. These activities are undertaken in collaboration with our customers, stakeholders, and partners.

In the West, competing demands for water for farms, cities, Tribes, the environment, recreation, hydropower, and other uses can lead to conflict. Conflict escalates particularly during droughts, which are expected to be more frequent and severe with climate change. Fostering strong relationships is essential to carry out Reclamation's everyday operations, conduct long-term planning efforts, and avoid unnecessary conflicts.

Reclamation operators and planners rely on information about precipitation, snowpack, streamflow, temperatures, water demands, and groundwater to make informed decisions. Reclamation's 2021 West-Wide Climate and Hydrology Assessment (2021 Assessment) builds on our 2011 and 2016 West-wide assessments of future temperature and precipitation change by using several complementary approaches, including analyses based in paleohydrology derived from tree rings (dendochronology) that help answer this question: *"If droughts in the distant past were to occur today, how would water systems perform?"*

With our Federal, State, Tribal, and local partners, we address challenges resulting from climate change and shifting demographics. We use a multi-faceted approach to support reliable water and hydropower deliveries; to help maintain healthy ecosystems; to protect federally-listed fish, wildlife, and plants, as well as designated critical habitat; and to manage risks (e.g., droughts, floods, and fires). Implementing the SECURE Water Act has served as a catalyst for collaboration and innovation, improving our understanding of climate change impacts to water resources and our ability to address those impacts.

# Introduction

## About this Report

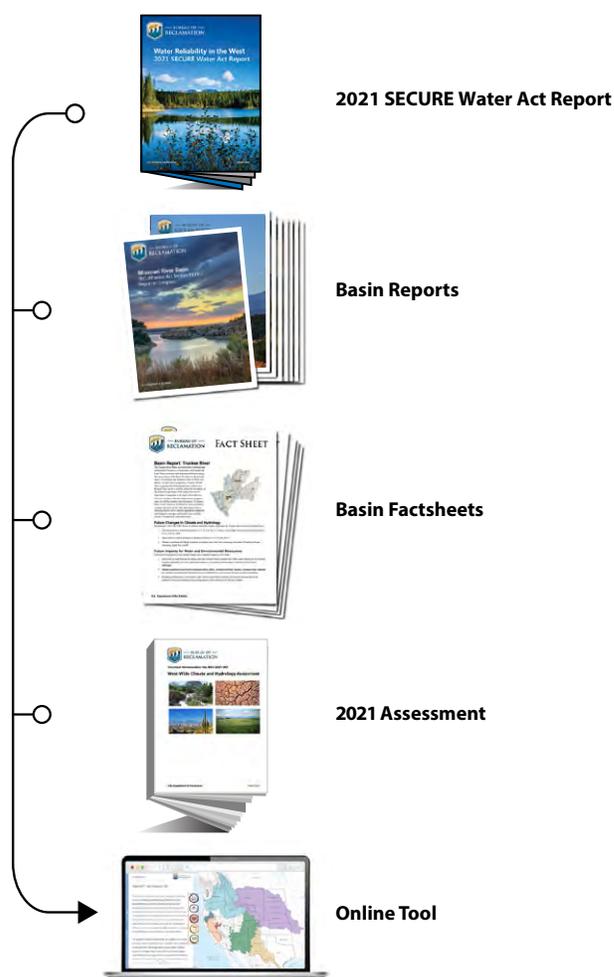
Safe and secure water supplies are a continuing fundamental pursuit for life in the West. This 2021 Report provides an assessment of climate change impacts to water uses in the West and adds a new set of West-wide information based in paleohydrology. This report describes our collaborative actions taken to increase the reliability of water and power deliveries since 2016, including: science and research, planning, infrastructure sustainability, efficient hydropower production, and on-the-ground actions to meet needs for irrigation, municipalities, power, Tribes, and the environment.

This 2021 Report summarizes the more detailed information in associated documents, which will be available after March 2021 on our climate website, <https://www.usbr.gov/climate/secure>, where all SECURE Water Act Reports are available.

**Basin Reports** and **Factsheets** for each of the eight major Reclamation river basins identified in the SECURE Water Act provide more in-depth discussions of changes and innovative actions within that basin to help ensure sustainable water and power deliveries.

The **2021 Assessment** evaluates impacts to water supply and demand based on future projections and paleohydrology.

The **Online Tool** will pull the more detailed information together in an easy-to-use format and provide additional examples of how Reclamation is increasing the reliability of water and power deliveries.



## The SECURE Water Act

The 2009 SECURE Water Act recognizes that adequate and safe supplies of water are fundamental to the health, economy, security, and ecology of the United States. The Act further recognizes that changes to temperature and precipitation, as well as the timing and quantity of snowpack and runoff, pose a significant challenge to the protection and use of water resources.

Section 9503 of the SECURE Water Act authorizes Reclamation to:

- Coordinate and collaborate with others to use the best available science to assess changes to water supplies
- Assess the risks from climate change to water supplies in each major Reclamation river basin
- Analyze how such changes will impact various water uses and services
- Develop appropriate mitigation strategies
- Monitor water resources to support these analyses

The SECURE Water Act requires Reclamation to submit a report to Congress every 5 years, addressing the elements of Section 9503(c), including:

(c)(1) – each effect of, and risk resulting from, global climate change with respect to the quantity of water resources located in each major Reclamation river basin

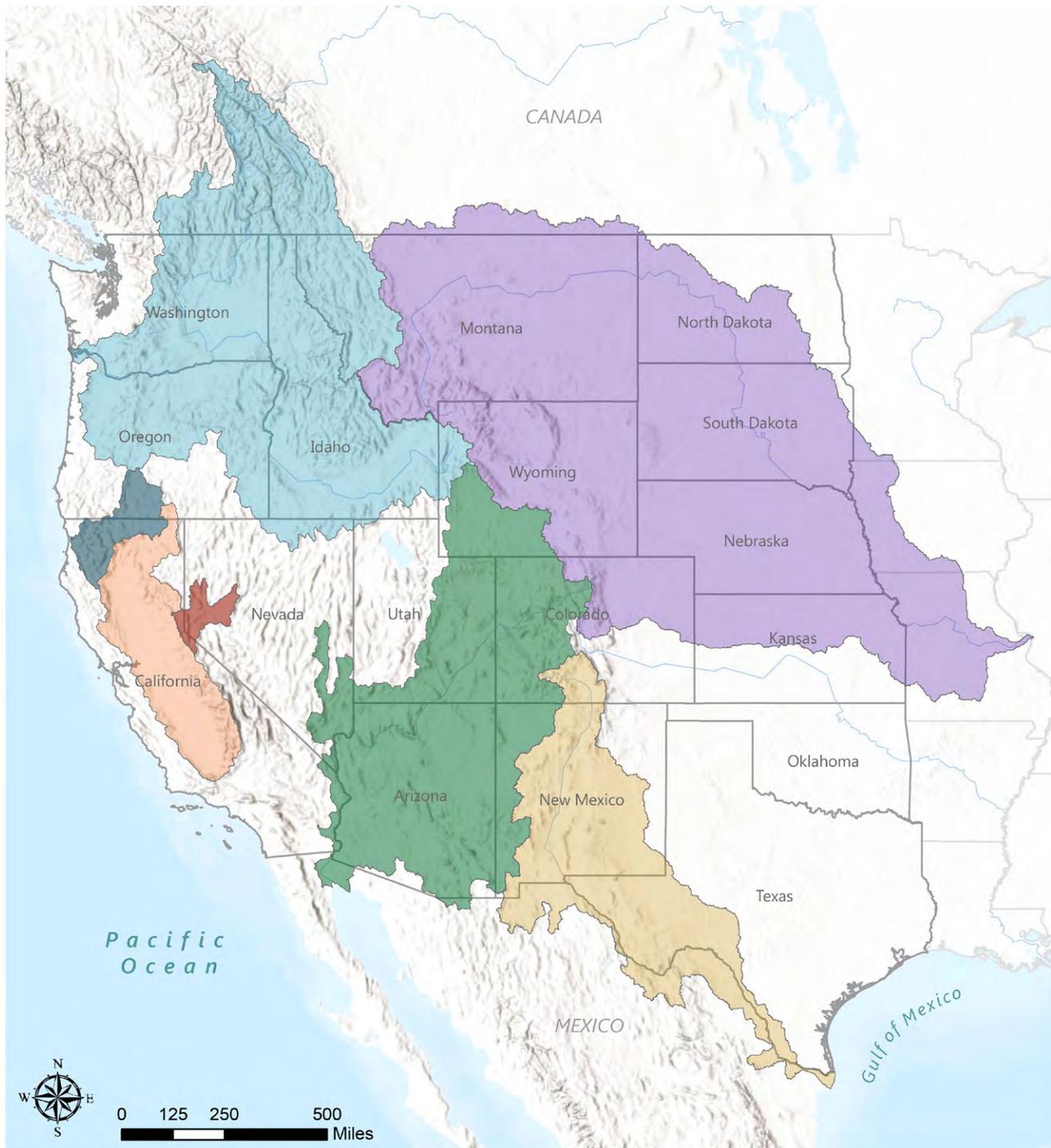
(c)(2) – the impact of global climate change with respect to the operations of the Secretary of the Interior in each major Reclamation river basin

(c)(3) – each mitigation and adaptation strategy considered and implemented by the Secretary of the Interior to address each effect of global climate change

(c)(4) – each coordination activity conducted by the Secretary of the Interior with the United States Geological Survey, National Oceanic and Atmospheric Administration, United States Department of Agriculture, or any appropriate State water resource agency

(c)(5) – the implementation by the Secretary of the Interior of the monitoring plan developed under subsection (b)(5).

**Reclamation has submitted two prior reports under the SECURE Water Act, in 2011 and 2016. This 2021 Report provides a West-wide assessment of projected changes to water supplies and demands and highlights progress and actions taken to increase water supply reliability since the 2016 Report.**



#### Legend

 Colorado River Basin	 Missouri River Basin	 Truckee and Carson River Basins
 Columbia River Basin	 Rio Grande Basin	 State Boundary
 Klamath River Basin	 Sacramento and San Joaquin River Basins	

Eight major Reclamation river basins are identified in the SECURE Water Act. The SECURE Water Act identifies the Sacramento and San Joaquin River Basins as separate reporting basins. However, these two basins are discussed jointly in this report because the water management issues within each basin are closely interrelated.

## ABOUT RECLAMATION



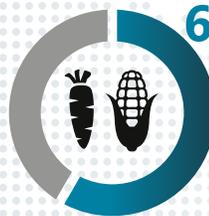
Reclamation was established in 1902 and is best known for the dams, powerplants, and canals it constructed within the 17 Western States. Today, Reclamation is the Nation's largest wholesale water supplier, operating 338 reservoirs with a total storage capacity of 140 million acre-feet. Reclamation supports customers, stakeholders, the States, Tribes, and others by providing reliable water and power deliveries and helping to meet the competing needs of a multitude of partners for limited water resources in the West.

RECLAMATION PROVIDES  
**water**

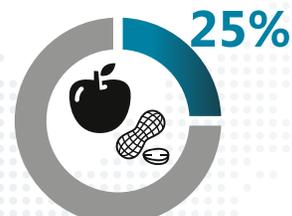
— to —  
**140,000**  
Western farmers



**10 Million**  
acres of farmland irrigated  
by Reclamation water



The percent of the Nation's vegetables, fruits, and nuts grown with Reclamation water



**2<sup>nd</sup>**  
largest producer of  
hydroelectric power in the  
United States



**53**  
powerplants owned and operated by  
Reclamation, generating over 40 billion  
kilowatt-hours each year, on average





At the Nathaniel Washington Power Plant, a crane lowers a new turbine runner into Generating Unit 22 on June 12, 2020. This powerplant is a feature at Grand Coulee Dam, Columbia Basin Project in Washington State.

## How Reclamation Uses Information about Changing Conditions

To operate reservoirs, deliver water and power to customers, and develop water management strategies, Reclamation relies on observations and future projections of water supply and demand, based on information about temperature, precipitation (rainfall and snowfall), snowpack, streamflow, water demands, and groundwater. Climate change influences these conditions—increasing the uncertainties in our planning. Projections of changes to water supply and demand can help water managers make informed decisions.

Reclamation's 2021 Assessment uses multiple approaches that leverage projections, stream gages, and paleohydrology. Collectively, these analyses illustrate potential future conditions.

**Temperature:** Temperatures are projected to increase over the West during the 21<sup>st</sup> century from the last decade of the 20<sup>th</sup> century. Projected temperature increases become greater with time.

**Precipitation:** Precipitation is projected to increase over the northwestern and northcentral portions of the United States and decrease in southwestern and southcentral areas. Projections of future precipitation are more variable and less certain than those for future temperature.

**Snowpack:** Snowpack is projected to decrease for almost all locations in the West.

**Streamflow (runoff):** Timing and quantity of streamflow are projected to continue to change as temperature and precipitation levels change. On average, snowmelt is projected to occur sooner, shifting streamflow earlier in the year.

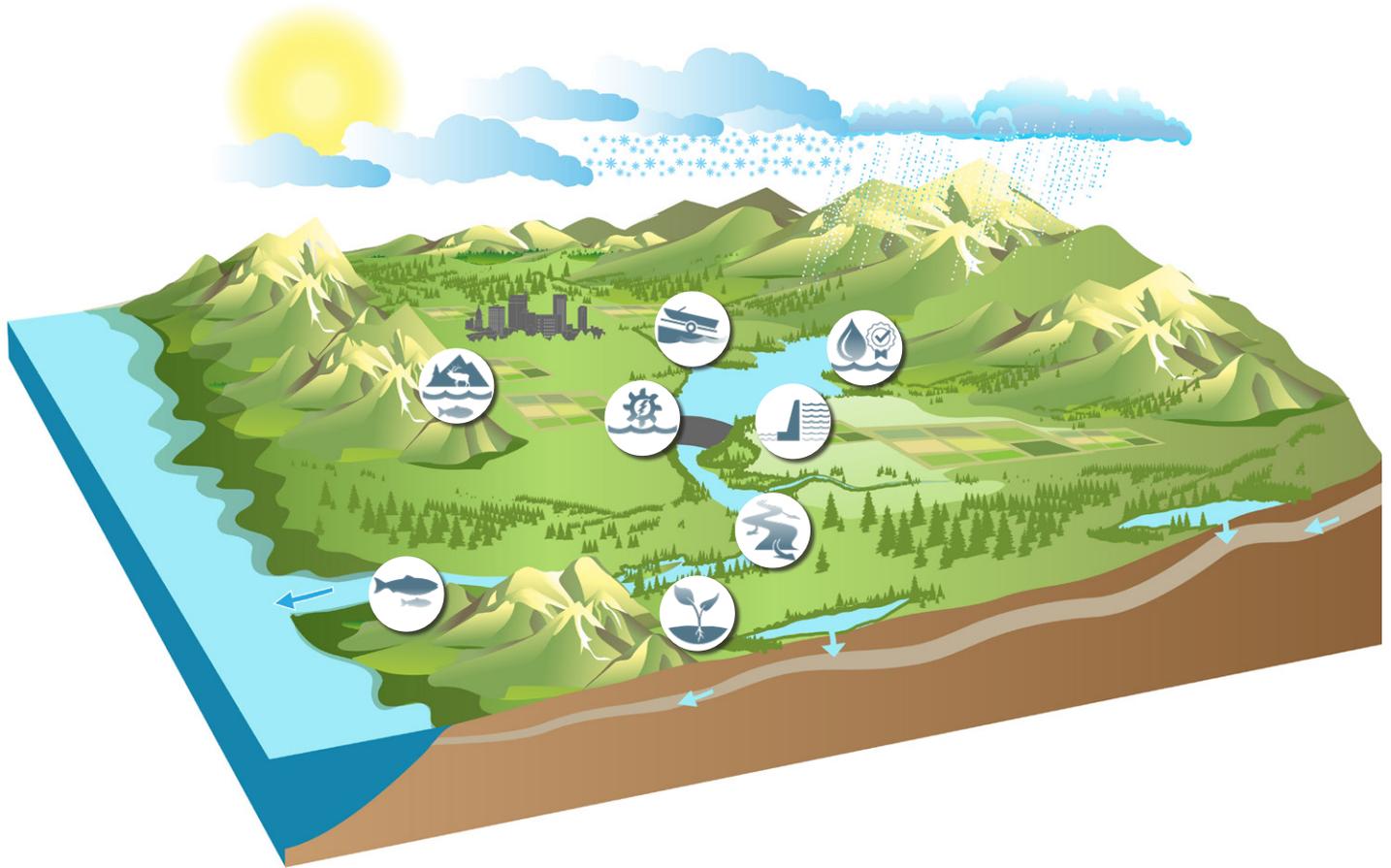
**Droughts:** The duration, severity, and frequency of droughts are projected to increase in the future compared to droughts of the distant past.

**Water demands:** Increased temperatures and longer growing seasons are projected to result in increased evaporation and irrigation water requirements. The 2021 Assessment examined turfgrass in urban centers across the West.

**Groundwater:** The amount of water infiltrating into the groundwater system is projected to mirror changes in precipitation with some decreases from increased evapotranspiration. However, unique local precipitation characteristics, topography, land use, and aquifer properties have considerable influence as well.

Understanding how these changing conditions impact water uses that are central to Reclamation's mission helps us develop innovative approaches to meet these challenges. The following sections provide a more detailed discussion of potential climate change impacts (including uncertainties associated with climate change projections) and innovations and strategies to maintain reliable water and power deliveries as conditions change.

# Climate change information helps water managers understand impacts to water uses.



Increasing temperatures, decreasing snowpack, changes to the volume of precipitation, and changes to runoff timing and volume across the West are projected to affect numerous aspects of water management:



**Water Deliveries**



**Hydropower**



**Water Quality**



**Endangered, Threatened, or Candidate Species**



**Recreation**



**Flood Control Management**



**Fish and Wildlife Habitat**



**Ecological Resilience**

# Innovations in Collaboration and Science

**Coordinate and collaborate with others to use the best available science to assess changes to water supplies.**

Changing hydrologic conditions and demographics along with competing demands for water are increasingly impacting our water supply and delivery systems. Consistent with the SECURE Water Act, Reclamation coordinates and collaborates with Federal, State, and local agencies; Tribes; non-governmental organizations; customers; and stakeholders to ensure access to the best available science to support reliable water and power deliveries. This section highlights some innovative approaches leveraging collaboration and science to address water management challenges now and in the future.

## Coordinating and Partnering

In the West, competing demands for water can lead to conflict, particularly during droughts, which are expected to become more frequent and severe with climate change. Identifying successful and often complex water management strategies requires input and cooperation with a multitude of customers, partners, and stakeholders. Therefore, collaboration is central to Reclamation's role in Western water as a leader and facilitator to address critical water management issues. Reclamation delivers water and power to customers, interacts closely with State and local agencies, and works as a partner with Tribes to support the United States' Indian Trust responsibilities.

## Managing for Drought in the Colorado River Basin

The current drought in the Colorado River Basin has persisted since 2000, leading to great concerns about the long-term reliability of basin water supplies. The period from 2000 through 2020 was the driest 21-year period in the Colorado River Basin in more than 100 years of record-keeping and one of the driest in the past 1,200 years based on paleohydrology data.

With drought conditions remaining unabated and the likelihood of continued population growth in the Southwest, the challenges of maintaining a reliable water supply for 35 to 40 million people and meeting future needs in this over-stressed and highly variable basin are compounded.

### WaterSMART Basin Study Program

WaterSMART (Sustain and Manage America's Resources for Tomorrow) basin studies help identify long-term water supply and demand imbalances and develop strategies to address those imbalances. Non-Federal partners cost-share to evaluate the impacts of climate change and identify a broad range of potential strategies to address current and future shortages.

Reclamation has initiated 3 new basin studies since 2016, bringing the total to 27 basin studies in 15 Western States since the program's start in 2009. Of the 27 basin studies, 17 are complete and 10 are still underway. These strong relationships with non-Federal entities across the West have built a technical foundation that directly contributes to many collaborative follow-on efforts, including eight water management pilots, two basin study updates, and many other efforts.

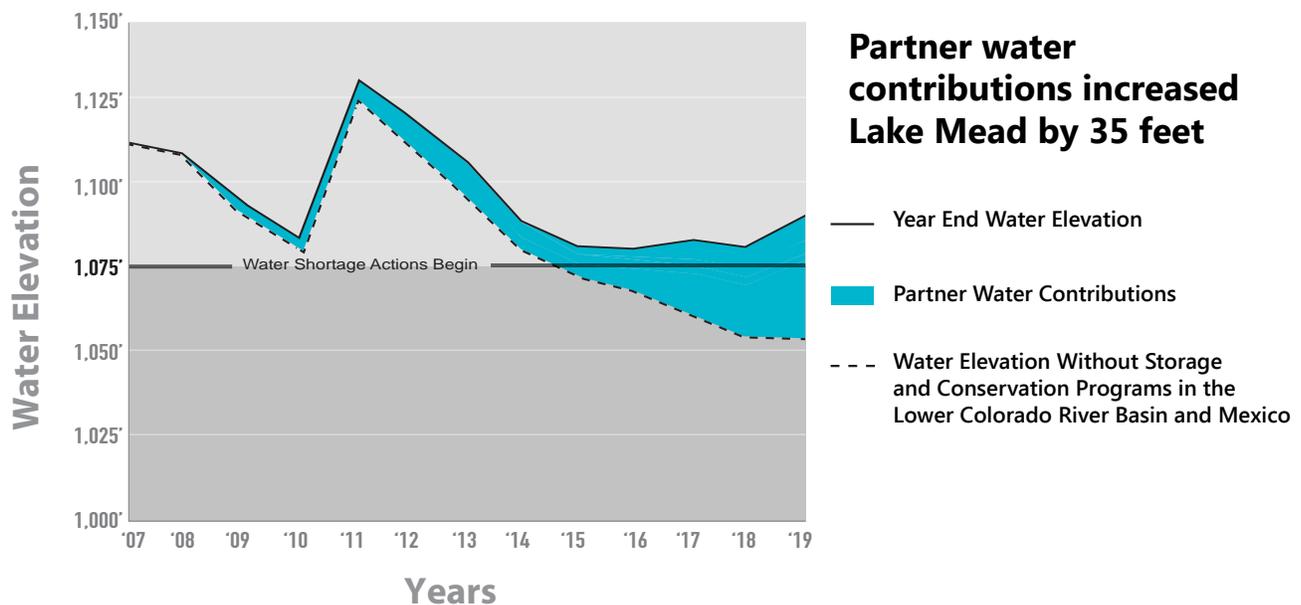
On May 20, 2019, the Department of the Interior, Reclamation, and representatives from the seven Colorado River Basin States signed the Colorado River Drought Contingency Plans at Hoover Dam, ensuring a greater likelihood of sustainable operation of the Colorado River System through December 31, 2026. This required tremendous collaboration, coordination, and compromise by the Basin States, Tribes, non-governmental organizations, and Mexico.

As Commissioner Brenda Burman stated: “This is an historic accomplishment for the Colorado River Basin. Adopting consensus-based drought contingency plans represents the best path toward safeguarding the single most important water resource in the Western United States” (Reclamation 2019 [DCP]).

In the Colorado River Basin, the benefits of collaboration to address water supply issues are evident. As a result of voluntary water conservation and storage activities by Reclamation, the Basin States, Tribes, and Mexico since 2007, approximately

3 million acre-feet has been conserved in Lake Mead, increasing its elevation by approximately 35 feet. This additional water stored and conserved in Lake Mead has effectively kept the Lower Colorado River Basin out of a shortage condition.

Signers of the Drought Contingency Plans were able to collaboratively work with partners to develop these complex plans because of the relationships and technical foundation built through multiple efforts to respond to the on-going drought and to address future water management challenges. An early effort, the Colorado River Basin Water Supply and Demand Study finalized in 2012, laid some of this groundwork. The study confirmed that, in the absence of timely action, there are likely to be significant shortfalls between projected water supplies and demands in the basin in coming decades. Nevertheless, continued action is needed as drought conditions persist and Lake Powell and Lake Mead remain at risk of declining to critically low elevations.



Lake Mead water elevation during the ongoing Colorado River Basin drought (figure shows 2007-2019).

## Providing Water Supplies for Tribal Communities

The Navajo-Gallup Water Supply Project is the cornerstone of the Navajo Nation's Water Rights Settlement Agreement in the San Juan River Basin in New Mexico. Parts of the project have been completed, including the Carson/Huerfano public water system, which started to deliver potable water from the Cutter Lateral Water Treatment Plant on October 27, 2020. When fully completed, the project will include over 300 miles of pipeline, 2 water treatment plants, 19 pumping plants, and several water storage tanks. The project will provide a reliable and clean drinking water supply for 43 Chapters within the Navajo Nation, the southwestern portion of the Jicarilla Apache Reservation, and the City of Gallup. These areas currently rely on rapidly depleting groundwater supplies, some of which are of poor quality. Furthermore, it is estimated that more than 40 percent of Navajo households across the reservation rely on water hauling to meet daily water needs.

Building trust and support for this project among the Tribal communities has been critical. Reclamation leads committees to discuss design and construction-related issues, develop consensus with project participants on decisions, and plan for future operation and management. Many local Tribal community members have been hired to work on the construction projects. Reclamation has also supported traditional blessing ceremonies conducted by medicine men at major milestones of the project to underscore the spiritual and religious aspects of water and highlight what this project means to the Navajo people.

## Aligning Federal Goals, Research, and Actions for Hydropower

Hydropower provides an important source of renewable energy that can add to the flexibility of the power grid. To help position Federal agencies to meet the Nation's need for reliable and affordable renewable hydropower, Reclamation, the U.S. Department of Energy's Water Power Technology Office, and the U.S. Army Corps of Engineers (USACE) signed a Federal Hydropower Memorandum of Understanding (MOU) at Hoover Dam on August 24, 2020. The MOU provides for a collaborative working relationship that prioritizes similar goals and aligns ongoing and future renewable energy development efforts among the three agencies. The MOU identifies a number of topic areas to be considered by the agencies including: Asset Management, Value of Hydropower, Workforce, Water Supply Reliability, and Environmental Outcomes. Related to water supply reliability, the agencies intend to work together to share information and identify areas of collaboration and to understand and build resilience into water-energy systems. Reclamation intends to leverage the MOU to deliver value to our power customers and stakeholders.



Hydropower at Hoover Dam, Arizona and Nevada.



Blessing ceremony for the Navajo-Gallup Water Supply Project's Cutter Lateral Water Treatment Plant near the community of Dzilth-Na-O-Dith-Hle on the Navajo Reservation, New Mexico on October 22, 2018.



Signing the Hydropower Generation Memorandum of Understanding at Hoover Dam, Nevada, on August 24, 2020.

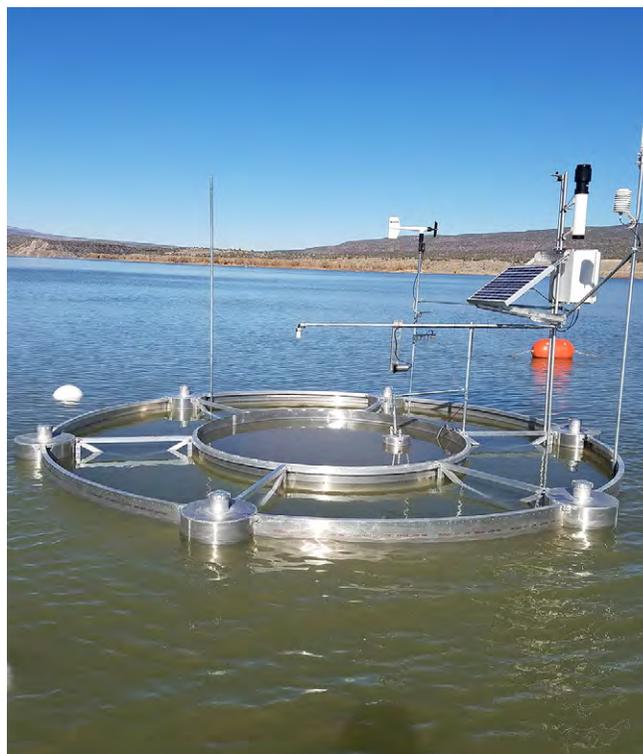
## Using the Best Science and Tools

Reclamation develops and uses the most up-to-date science, technologies, and information to carry out our mission, including fulfilling water supply contracts, operating reservoirs for multiple purposes, and complying with environmental requirements. This includes continuing to improve our forecasting tools, modeling capabilities, hydrologic data, and more. As hydrologic conditions become more variable with climate change, innovations in science and tools will help Reclamation and water managers in the West to identify and adapt to changing conditions.

## Addressing Open-Water Evaporation from Reclamation Reservoirs

Open-water evaporation is one of the largest losses of water in the Southwestern United States, especially during hot dry summers. Evaporation will increase as temperatures rise. Through collaboration with local partners, Reclamation's Albuquerque Area Office is piloting innovative methods to track and reduce these losses. Modernized, floating evaporation pans that mimic reservoir conditions and eddy covariance towers are being deployed at several reservoirs where evaporation losses affect water operations, including Cochiti Lake, Elephant Butte Reservoir, and Caballo Reservoir in New Mexico, as well as at Lake Powell in the Colorado River Basin.

A floating evaporation monitoring pan has also been deployed within the Pueblo of Zuni in western New Mexico to support Indian Water Rights Settlements. These real-time measurements are being used to support reservoir operations that can reduce total evaporative losses.



Floating evaporation pan on Cochiti Lake, New Mexico, November 2017.

**“These projects are a result of the mindset central to Reclamation’s work: every drop of water matters—even the upward drops we cannot see. It is certainly impressive to experience the level of collaboration required to address such complex and dynamic issues working alongside well-established experts and innovators.”**

*Andrew Gelderloos  
Hydrologist with Reclamation’s Albuquerque Area Office*

## Using Improved Forecasting Tools to Address Variable Conditions

Reservoir managers work to optimize water storage to meet designated needs, while maintaining enough available space in the reservoir for flood control management. Historically, water control manuals have dictated the amount of reserved flood control space based on local, historical weather patterns and decades-old estimates of flood potential that do not account for changing hydrological conditions. In some cases, this has required reservoir releases to maintain space in the reservoir—even when forecasts indicate dry weather and lower flood risk. However, advances in forecasting provide a new opportunity for forecast-based reservoir operations, where infrastructure design, management objectives, and forecasting skills align. For example, improved forecasting and a new auxiliary spillway have combined to support forecast-based reservoir operations at Folsom Dam, part of the Central Valley Project near Sacramento, California.

In June 2019, USACE and Reclamation signed an updated Folsom Dam Water Control Manual for Folsom Dam and Lake that allows more accurate release decisions based on weather forecasts and uses the new auxiliary spillway more efficiently. The auxiliary spillway, constructed adjacent to the dam in the fall of 2017, has gates that are 50 feet lower

in elevation, making large flood releases possible without waiting for water levels to reach the main gates of Folsom Dam.

While forecast-based reservoir operations depend on specific characteristics of the reservoir system and the availability of skillful forecasts, Reclamation is collaborating with others to explore these opportunities where possible. For example, Reclamation has contributed to ongoing efforts in California, led by the USACE, Scripps Institution of Oceanography - UC San Diego, and local reservoir operating entities. These forecast-informed reservoir operations (FIRO), have focused on USACE's Lake Mendocino in northern California. More FIRO locations have been recently identified but are still in the early stages of evaluation.



Folsom Dam, Central Valley Project, California, December 2016.

**As forecasting tools and infrastructure have improved, water managers have recognized that changes to historic reservoir operating procedures may be possible and use of forecast-based reservoir operations is gaining momentum. As described by a Reclamation reservoir operator, “Forecast-informed flood management for reservoir operation is a significant paradigm shift from the prior century mindset.”**

*Randi Field  
Hydraulic Engineer with Reclamation's Central Valley Office*

# West-Wide Climate and Hydrology Summary

Assess the risks from climate change to water supplies in each major Reclamation river basin.

Reclamation's 2021 West-Wide Climate and Hydrology Assessment (2021 Assessment) investigates changes in climate and hydrology across the West using approaches that align with the 2011 and 2016 Reports and new techniques, data, and analyses that provide a richer assessment of future changes to support water management in the West. The 2021 Assessment relies on the best available information and well-vetted methods, using approaches documented in peer-reviewed literature. However, uncertainties still exist, including those associated with climate projections and assessing hydrologic impacts, as discussed in more detail below. This work is performed by Reclamation's Technical Service Center in partnership with the United States Geological Survey (USGS), University of Arizona, Columbia University, Desert Research Institute, National Center for Atmospheric Research, Aspen Global Change Institute, and in collaboration with Reclamation Regions and Area Offices. This section provides an overview of what is contained in the 2021 Assessment.

## Future Projections

The climate change analysis in the 2021 Assessment summarizes projections of future temperature, precipitation, snowpack, and streamflow across the West. Maps (shown on the next page) show changes in temperature and precipitation projected to occur around the mid-21<sup>st</sup> century (2040 - 2069), relative to a baseline of 1970 - 1999. Under scenarios with higher greenhouse gas concentrations, increases in temperature are more severe (warmer, more red) than in scenarios with lower greenhouse gas concentrations, shown as differences between maps in right and left columns. In both the higher and lower scenarios, average temperatures are projected to increase across the West and annual precipitation is projected to increase in the Northwest, particularly in the Columbia and Missouri River Basins, and decline in the Southwest. In most river basins, snowpack is projected to decline as more winter precipitation falls as rain and warmer temperatures melt snow sooner.

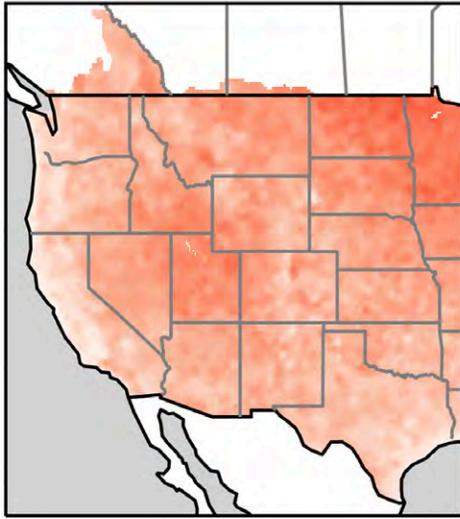
In some high elevation regions, snowpack may increase due to a projected increase in winter precipitation. Throughout the West, seasonal streamflow is projected to occur earlier in the year, as shown on page 22.

## Climate Change Scenarios

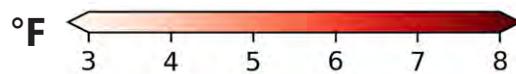
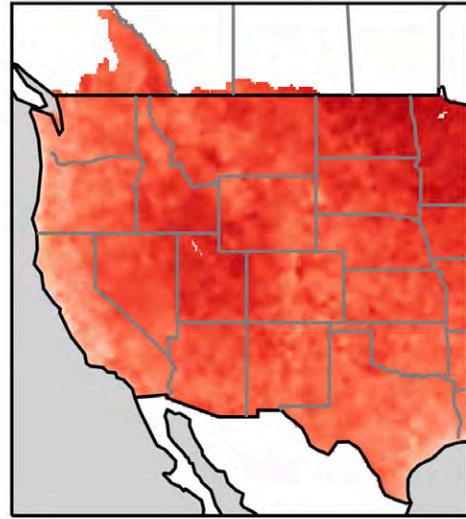
In these analyses, as in 2016, global climate models from a contemporary Coupled Model Intercomparison Project Phase 5 (CMIP5) are used. This prominent, multi-model experiment provides future climate change scenarios referred to as Representative Concentration Pathways (RCP)—a set of four pathways developed for CMIP5 for the climate modeling community as a basis for long-term and near-term modeling experiments that inform the Intergovernmental Panel on Climate Change Assessment Report 5. The four RCPs, commonly referred to as RCP2.6, RCP4.5, RCP6.0, and RCP8.5, represent a range of potential future conditions that vary based on greenhouse gas concentrations over the 21<sup>st</sup> century.

## Temperature Increases

Lower scenario (RCP4.5)

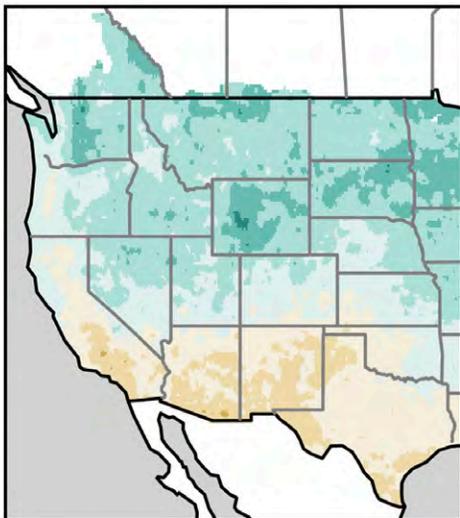


Higher scenario (RCP8.5)

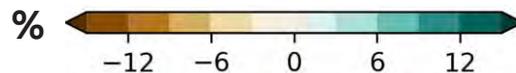
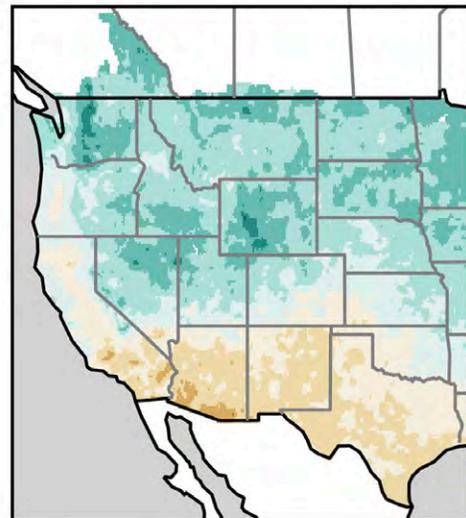


## Precipitation Changes

Lower scenario (RCP4.5)



Higher scenario (RCP8.5)



Maps show average annual temperature increases and average percent changes in precipitation across a lower scenario (RCP4.5) and a higher scenario (RCP8.5) for the period 2040 - 2069 relative to 1970 - 1999 using the LOcalized Constructed Analogs (LOCA) downscaling approach (described on page 19). Methods and models used to develop the figure are the same as in the Fourth National Climate Assessment (NCA4). These maps convey an average across 32 global climate models; differences among models and other methodological choices vary considerably. There is greater uncertainty in projections of future precipitation than with projections of future temperature.

In 2017, the United States Global Change Research Program (USGCRP) released the Fourth National Climate Assessment (NCA4). The USGCRP is mandated by Congress to coordinate Federal research and investments to understand the forces shaping the global environment. The NCA4 identified RCP4.5 and RCP8.5 as the core scenarios representing an appropriate range of future conditions, stating “NCA4 focuses on RCP8.5 as a ‘higher’ scenario, associated with more warming, and RCP4.5 as a ‘lower’ scenario with less warming. Other RCP scenarios (e.g., RCP2.6, a ‘very low’ scenario) are used where instructive, such as in analyses of mitigation of science issues” (USGCRP 2018).

Reclamation has consistently relied on a broad range of possible climate scenarios when assessing the risks and impacts from climate change, considering each as equally likely to best characterize the range of possible futures. Scenarios contained within the 2016 Report are incorporated in the 2021 Assessment, which remains a state-of-the-art assessment of potential future climate and hydrology using RCP2.6 through RCP8.5.

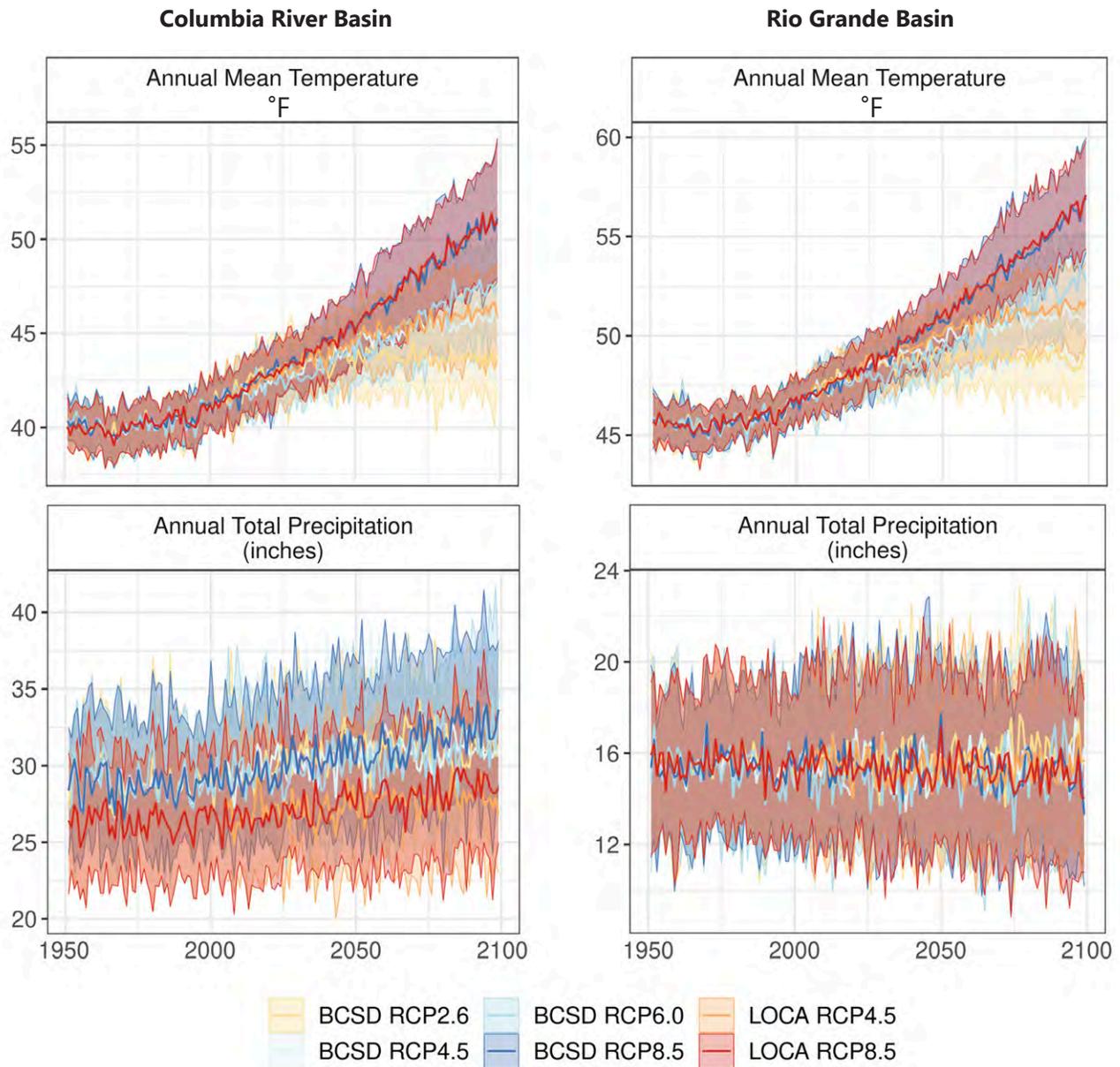
Additionally, the 2021 Assessment employs guidance provided by NCA4 and further evaluates potential outcomes from RCP4.5 and RCP8.5, including additional downscaling methodologies as described on page 19 of this report.

Reclamation’s use of a range of RCPs—without assigning probabilities to any individual climate modeling experiment—reflects Reclamation’s commitment to understand uncertainties associated with future projections and identify a fuller range of possible outcomes consistent with the current state of the practice in water resources climate impact assessments. Consistent with this approach, Reclamation has been collaborating since 2007 with both Federal and non-Federal partners to provide climate scenarios of locally relevant climate and hydrology data with recent updates also informed by NCA4. This Downscaled CMIP5 Climate and Hydrology Projections archive continues to be a primary data resource for users and, as of August 2020, has served projections to over 4,500 users—collectively issued through approximately 85,000 requests.



Collaborators for the Downscaled CMIP5 Climate and Hydrology Projections archive, which hosts most of the datasets used in the 2016 and 2021 Assessments.

## Future Projections of Temperature and Precipitation across Climate Scenarios



The figure above shows Coupled Model Intercomparison Project Phase 5 (CMIP5) projections using Bias Corrected Spatial Disaggregation (BCSD) and LOcalized Constructed Analogs (LOCA) distributions of annual mean temperature and total precipitation projections across Representative Concentration Pathways (RCP) for two major Reclamation basins: the Columbia River Basin in the north and the Rio Grande Basin in the south. BCSD and LOCA are two statistical downscaling methods (described on the next page). In each figure panel, the heavy line is the median value for each year across the range of projections. The shaded area is the annual time series of 10<sup>th</sup> to 90<sup>th</sup> percentiles.

## Downscaling Climate Model Projections

Future projections of temperature and precipitation are typically developed at a global spatial scale that requires an additional post-processing step, commonly referred to as “downscaling,” before they can be used in local impact assessments. Numerous different techniques have been developed by Reclamation, other Federal agencies, academic institutions, and others. Reclamation has primarily developed and relied upon statistical techniques and has continuously evaluated sources of uncertainty that can be identified and attributed to the complex analyses that are required to simulate future climate at local scales. Different downscaling methodologies can lead to different projections of future climate.

In the 2021 Assessment, Reclamation is adding the statistical downscaling approach referred to as Localized Constructed Analogs (LOCA), to the Bias Correction and Spatial Disaggregation (BCSD) statistical downscaling approach presented in the 2016 Assessment. In general, broad trends of climate and hydrologic variability West-wide are similar using either of these two downscaling methods. There are, however, geographic differences in climate (e.g., precipitation and temperature) and hydrology (e.g., annual runoff) projections using information from the LOCA and BCSD datasets. These differences reflect the uncertainties associated with methodological choices and data sets; accordingly, one projection cannot be characterized as any more likely than the other.

Differences between LOCA and BCSD climate and hydrology are largely attributable to different observed temperature and precipitation datasets used for bias correction; differences in spatial resolution of the downscaled variables; and differences in their respective choice of temporal resolution (e.g., daily or monthly). More generally, differences in hydrologic modeling approaches—including choices for model configurations, how simulated water is directed to streams, and whether additional post-processing has occurred—can also contribute to or exacerbate differences between simulated hydrologic variables such as streamflow (see 2021 Assessment, Chapters 2 and 3).

Both LOCA and BCSD datasets have been used extensively by the climate and hydrology modeling communities, including in the NCA4 and in previous SECURE Water Act Reports. Reclamation presents results from CMIP5 LOCA and BCSD as part of an all-encompassing dataset that characterizes the uncertainty in simulated hydrologic variables from which risks and impacts to water resources can be evaluated and appropriate adaptation strategies developed.

Continuing to introduce and test different methodologies allows Reclamation to better understand the uncertainties and to better support the risk assessment process that water managers must engage in to plan for the future.

## Basin-Specific Future Projections

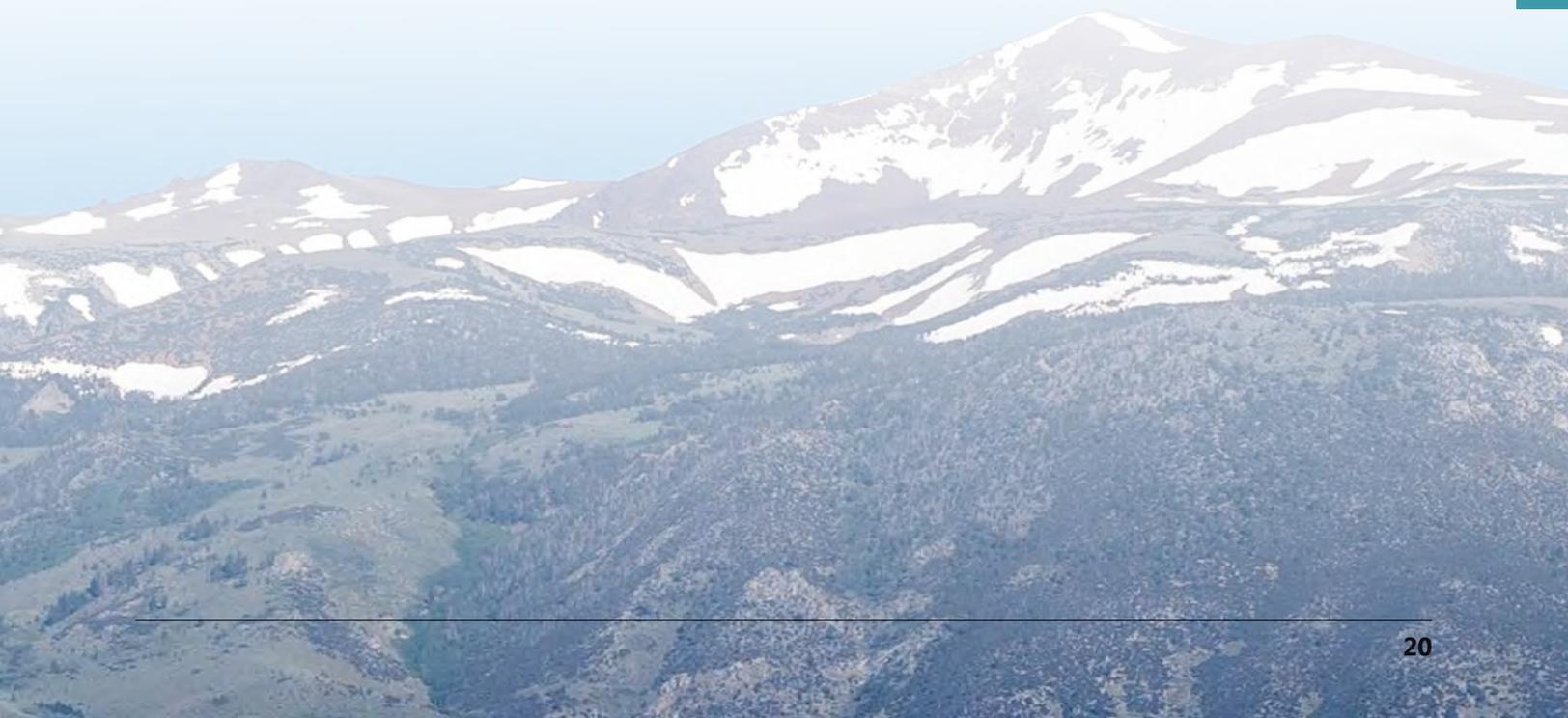
Future climate and hydrology projections were evaluated at specific locations (see the figures on the next two pages) for the 2020s, 2050s, and 2070s. These changes are consistent with those found West-wide, namely increasing temperatures, declining snowpack, and earlier streamflow—all becoming more pronounced in later decades. The magnitudes of change differ depending on location. For example, in the 2070s, projected snow declines for the Truckee River at Truckee River at the Nixon gage are between 39 percent and 74 percent, whereas projected declines for the Rio Grande at Elephant Butte Dam are between 7 percent and 40 percent.

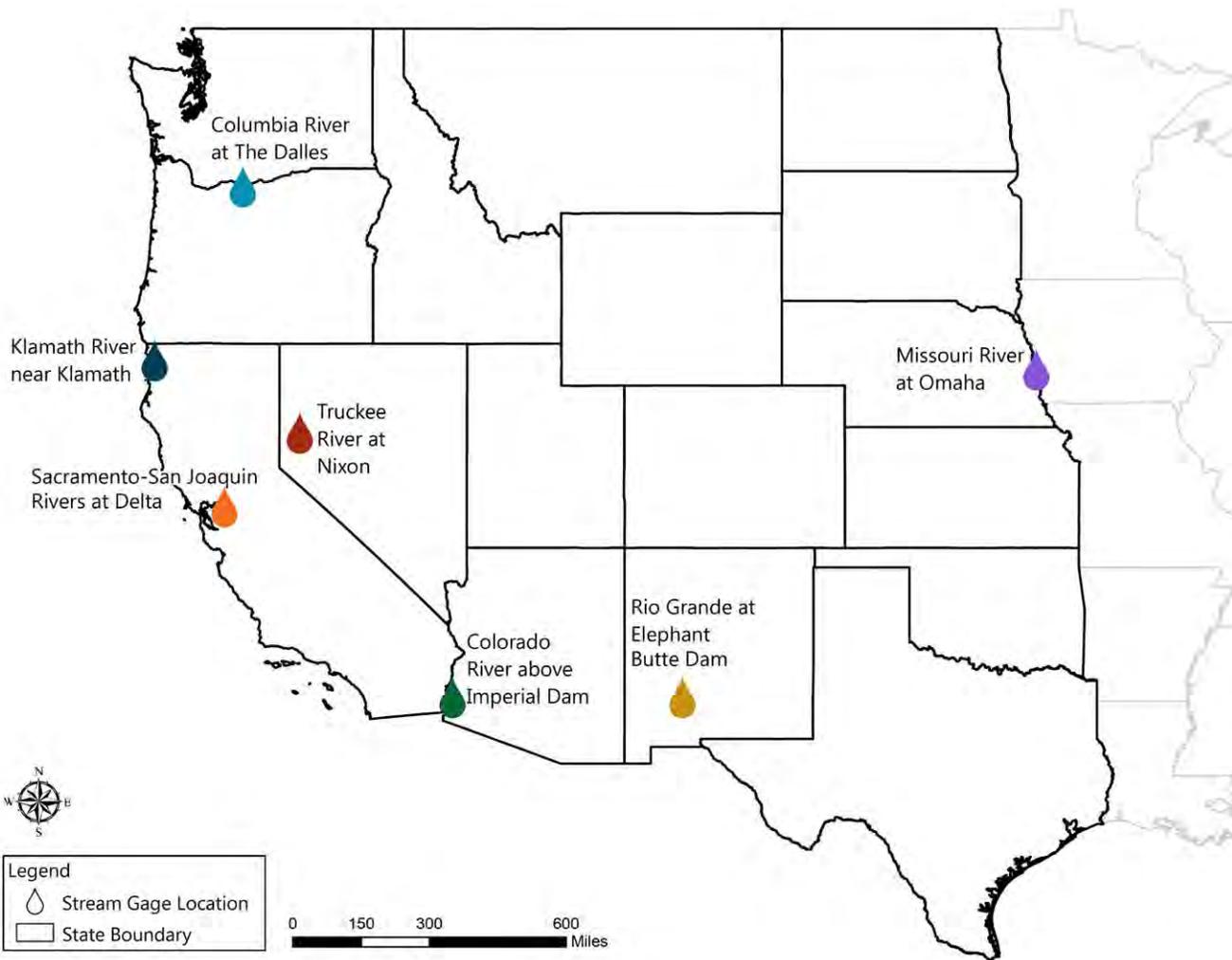
Many locations are likely to experience increased streamflow during December through March (winter) and decreased streamflow during April through July (late spring). For example, the

Truckee River at Nixon may experience increased winter streamflow of 104 percent to 296 percent and decreased late spring runoff of 21 percent to 51 percent. The Rio Grande at Elephant Butte Dam may experience a decrease of 4 percent to an increase of 25 percent in runoff in the winter, and a decrease in late spring runoff between 3 percent and 28 percent (see 2021 Assessment, Chapter 3). In these examples, the ranges are from LOCA downscaled projections that span the 25<sup>th</sup> to 75<sup>th</sup> percentiles of 64 future hydroclimate projections encompassing RCP4.5 and RCP8.5 from future decades relative to 1990 - 1999 and can be compared to BCSD results as shown on page 22.

Key findings on future climate and hydrology projections are consistent with, and reinforce, findings in the 2016 report. The climate projection dataset used in this assessment is also the primary source of data in the NCA4.

**Basins throughout the West are projected to experience increasing temperatures, snowpack declines, and earlier seasonal peak runoff. The magnitude of impacts becomes greater with time and varies based on location.**

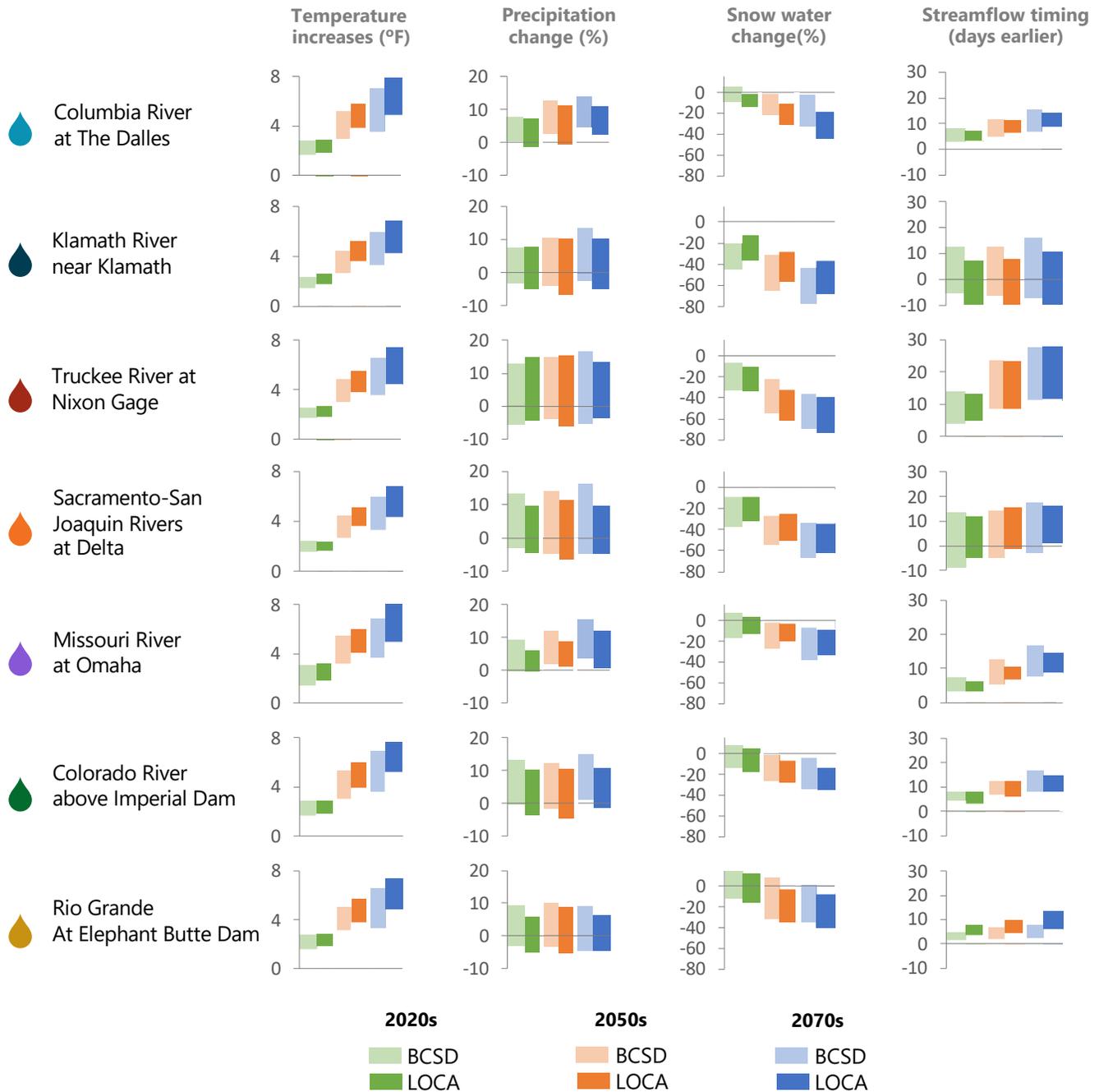




General locations of stream gages across the West where climate change impacts are summarized on the next page. Note, water drop colors on all figures correspond with the colors used to identify the major Reclamation river basins on the map on page 4.

## Change to Climate Change Projections in Basins Across the West Over Time

Values below represent the mid-range (the 25<sup>th</sup> to 75<sup>th</sup> percentiles) of future hydroclimate projections from future decades relative to 1990 - 1999. These include values from the 2016 Report using BCSD with RCP2.5, RCP4.5, RCP6.5, and RCP8.5 (displayed as lighter shades on the left), and from LOCA projections using RCP4.5 and RCP8.5, on the right. Additional results for these and 36 other locations, including streamflow magnitudes, are in the 2021 Assessment, Chapter 3. BCSD projections largely overlap with LOCA projections, however differences vary by basin.

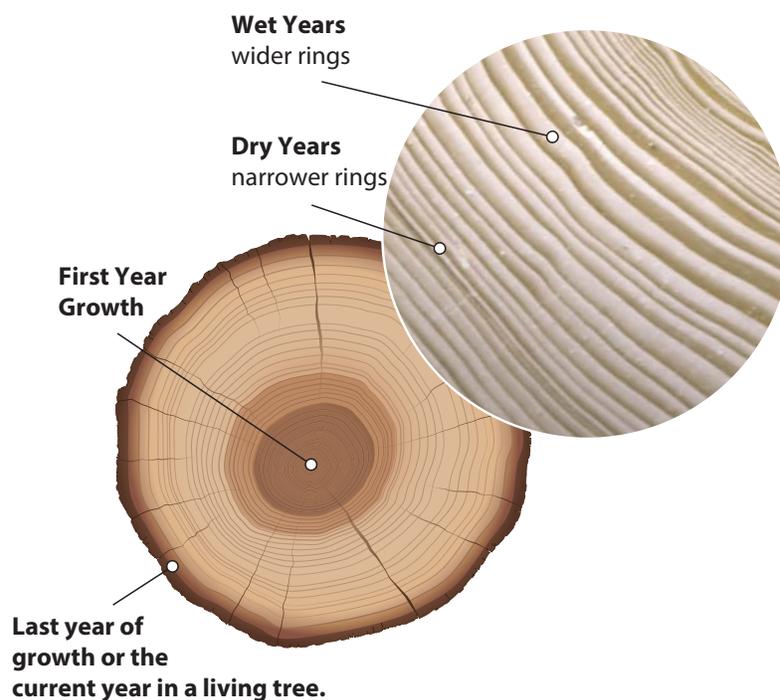


## Paleohydrology

Reclamation is incorporating paleohydrology to inform long-term planning in addition to using projections of future climate in the 2021 Assessment. Paleohydrology uses tree-ring reconstructions to understand wet and dry conditions centuries before stream gages were installed. The reconstructions provide information that complements and adds value to contemporary projections of future climate and hydrology.

Paleohydrology has been useful in informing water management and planning in basin-specific studies supported by the WaterSMART Basin Study Program. These longer records inform water managers whether droughts in the distant past were similar to or more severe than observed droughts in the past century. This is especially useful as observations, including stream gages, go back only a hundred years in most cases, capture a limited number of extreme events, and may not contain the full range of droughts and wet periods that have occurred over past centuries.

**By developing West-wide analyses that incorporate paleohydrologic data, Reclamation provides water managers access to longer histories and regionally consistent approaches to more comprehensively evaluate future risks.**

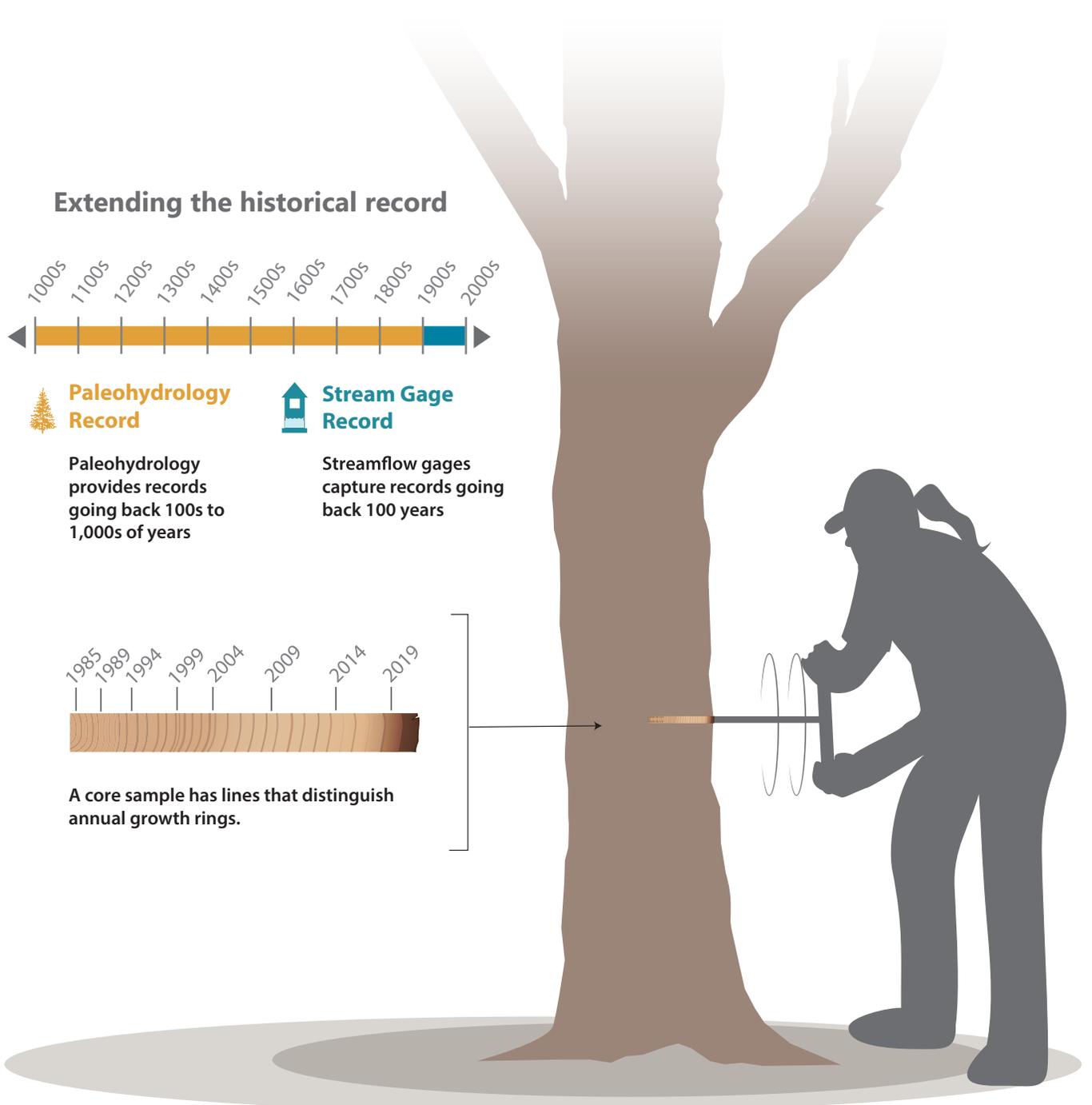


Each tree records information about its environment by growing more in wet years (wider rings) and less in dry years (narrower rings). In a watershed, trees will have similar patterns, and scientists can use this information to reconstruct historical streamflow conditions from tree-ring data.

# What is Paleohydrology?

Paleohydrology provides insights into how water supply has varied over the past 1,000 years going back far beyond the stream gage record (referred to in this analysis as the observed historical period). Using tree-ring reconstructions and other methods, paleohydrology helps us understand historical variations in wet and dry conditions, and by extension, streamflow.

In the 2021 Assessment, paleohydrology serves as another tool in the Reclamation toolkit, as water managers work to mitigate risks inherent in water resources planning.



## West-Wide Drought Analyses

Knowing more about the occurrence of drought events will help farmers, ranchers, municipalities, businesses, and other decision-makers prepare for and adapt to changing conditions. New to the 2021 Assessment, Reclamation's West-wide drought analyses provide a framework for drought planning and help managers develop water management alternatives with adequate lead times. Reclamation and study partners developed information and tools based on paleohydrology reconstructions to evaluate dry and wet period characteristics and analyze chances of shifting between wet states or dry states, which help inform how these changes might happen in the future.

In addition, two sets of information, drought duration and drought severity, can inform decision-making, especially when understood together. The examples shared here reveal that, compared to the distant past, climate model projections indicate an increase in drought duration and severity. Climate models also project that drought duration and severity will be more variable in the future for most of the West.

Climate scenarios (e.g., RCP4.5 or RCP8.5) are projected to influence how long future droughts last. Increases in drought severity are projected under both lower and higher scenarios as locations (indicated by dark orange) are likely already reaching water limited conditions. Additionally, the length of a drought influences its severity, and therefore these measures should be interpreted alongside each other. The maps on the next page illustrate this analysis. More detail on methodologies and associated uncertainties are in the 2021 Assessment.

This drought analysis uses the Palmer Drought Severity Index (PDSI) to identify droughts (defined below). Historically, drought severity as measured by PDSI has ranged from -1 to -2. This PDSI range is defined as Abnormally Dry, leading to "short-term dryness slowing planting, growth of crops or pastures" (United States Drought Monitor 2020). In the future, in some locations the range increases to -2 to -3 PDSI. This range, defined as Moderate Drought, leads to "some damage to crops, pastures; streams, reservoirs, or low wells; some water shortages developing." Variability in drought severity, as measured by the standard deviation, is higher under RCP8.5 than lower scenarios (see the 2021 Assessment, Chapter 4).

Droughts can be defined in many ways. Water managers use the two definitions shared here to help track hydrometeorological conditions and water supply, which are important to water management during dry periods.

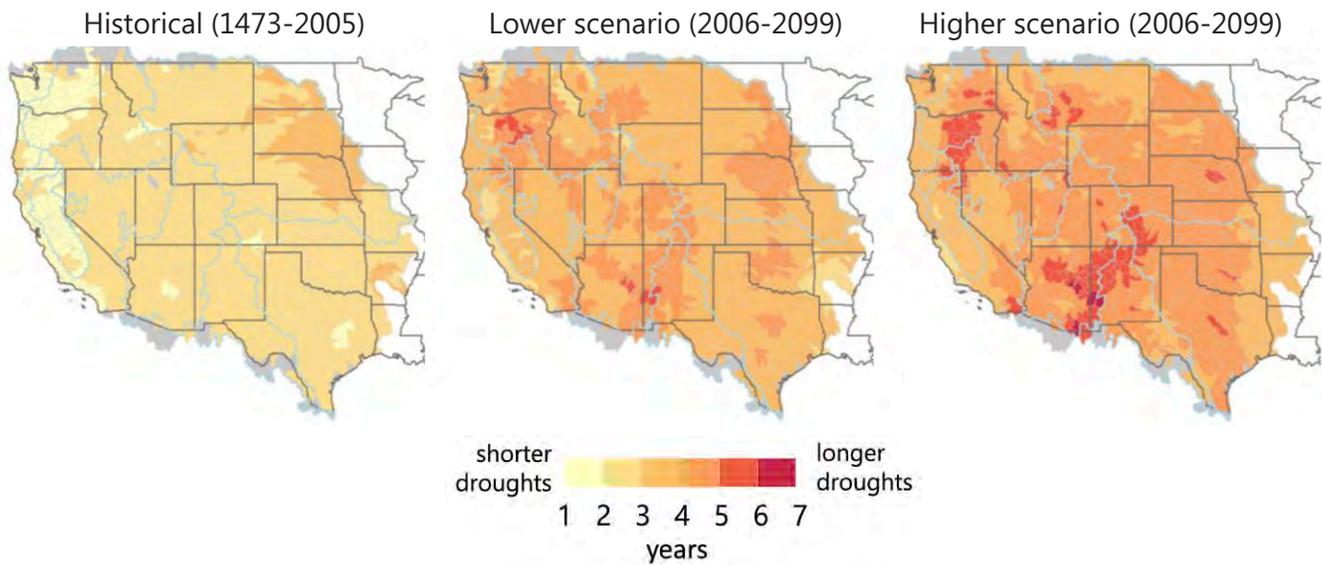
### **Palmer Drought Severity Index (PDSI):**

This common hydrometeorological measure of drought has been used to describe conditions for agriculture since the 1960s and underlies tools like the United States Drought Monitor (2020). PDSI integrates temperature, precipitation, and soils information and can be used to evaluate both paleohydrology and future projections. In the 2021 Assessment, PDSI is useful in spatial analysis of droughts going back to 1473. Reclamation also applied the PDSI water-balance model to develop future projections of PDSI from 2006-2099 (see 2021 Assessment, Chapter 4).

The PDSI data were broadly defined over two periods: an historical period (1473-2005) and a projection period (2006-2099). For highlights from these analyses, see figures on the next page.

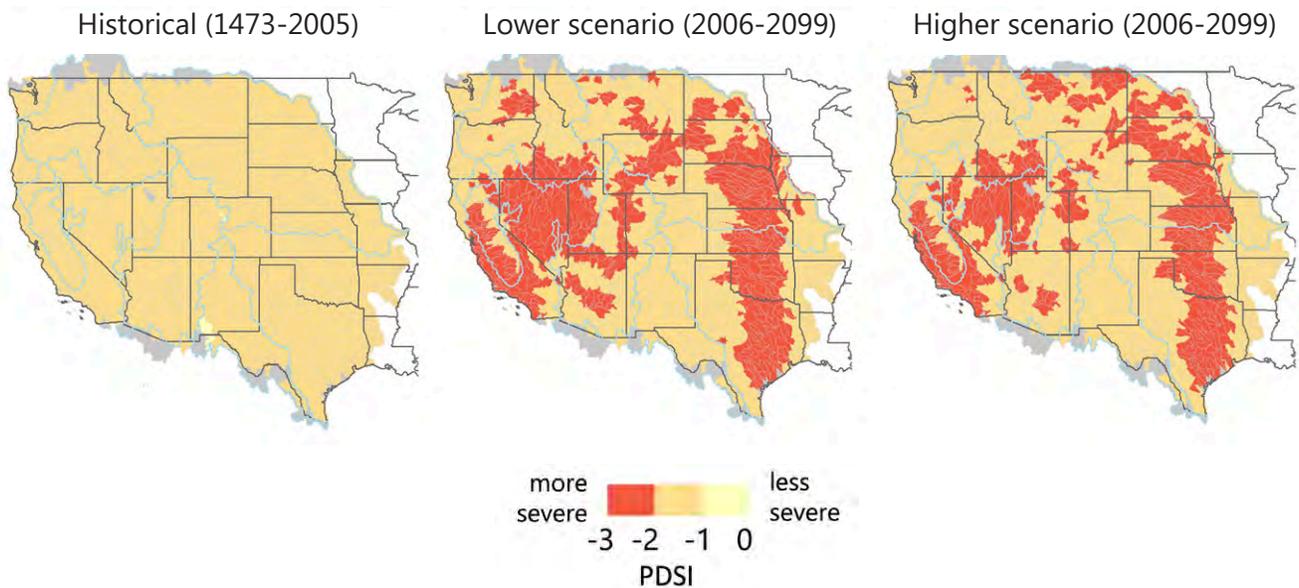
**Largest cumulative deficit droughts:** This measure identifies severe droughts when the cumulative volume of water below the long-term median (50<sup>th</sup> percentile) streamflow was most severe. This measure was used to identify the three largest droughts between 1685-1977, the period common to all available streamflow reconstructions (see 2021 Assessment, Chapter 6).

## Average Drought Duration Projected to Increase



Droughts, defined as PDSI values less than or equal to zero, historically last an average of 1 to 4 years (yellow and light orange). In the future, these conditions are projected to last longer (orange and red) under both the lower and higher scenarios.

## Average Drought Severity Projected to Increase



Historically, drought severity, including the paleo and observed historical period, is between PDSI values of -1 and -2. In the future, droughts are projected to become more severe (darker orange) in portions of the West under both the lower and higher scenarios.

## Water Supply Reliability Assessments

*If droughts in the distant past were to occur today, how would water systems perform?*

Paleo-reconstructed streamflow was used to explore the impact of the largest paleo droughts in the past 300 years on water systems throughout the West. In the 2021 Assessment, water systems models were run using paleo-reconstructed streamflow with current operating approaches to help stress-test water systems and prepare water managers for possible risks to water deliveries. This approach can also be used to evaluate impacts to hydropower, recreation, fish and wildlife habitat and species, ecological resiliency, and flood control management. Knowing how existing systems would handle droughts that occurred over a longer historical record can help water managers determine whether changes are needed or increase operators' confidence in the safety and reliability of current operations.

Reclamation, with support from study partners, analyzed impacts for locations within each major Reclamation basin, including the Truckee and Carson Rivers, Rio Grande, Colorado River, and Klamath River Basins, as well as subbasins within the Columbia River Basin (Boise River), the Missouri River Basin (Upper Missouri River upstream of Fort Peck Reservoir), and Sacramento and San Joaquin River Basins (Sacramento River at Shasta Lake and San Joaquin River at Millerton Lake). This evaluation focused on the three largest cumulative-deficit droughts from the reconstructed streamflow record dating back to 1685. Future drought events and paleo-reconstructed flood events were also evaluated (see 2021 Assessment, Chapter 6).

Whether and by how much observed historical droughts (here, since 1900) differ from those in the paleo-reconstructed period (1685 to approximately 1900) varied across river basins. In addition, the length of the droughts evaluated varies across locations. It is important to consider both duration and severity when evaluating the impacts of droughts.

The 1930s drought in the observed historical period and the 1770s drought in the paleo-reconstructed period were significant throughout the West and were included in the analysis for most of the modeled basins.

The performance of each system—whether paleo droughts were more or less severe than what had been experienced in the observed historical period—depended on the basin. In the Columbia River Basin (Boise River), paleo droughts were much more severe and longer than observed historical droughts. In the Colorado River, Rio Grande, Truckee and Carson Rivers, and the Upper Missouri River Basins, paleo droughts were comparable to observed historical droughts. In the Klamath River Basin, the 1930s drought was the largest, but the three paleo droughts were longer and more severe than the other identified droughts in the observed historical period. In the Sacramento and San Joaquin River Basins, observed historical droughts were both longer and more severe than the paleo droughts dating back to 1685. In many parts of the West, there may be more extensive droughts prior to 1685 that were not evaluated in the 2021 Assessment. Paleo droughts prior to 1685 were evaluated in studies such as the Colorado River Basin Water Supply and Demand Study (Reclamation 2012) and the Upper Missouri River Basin Impacts Assessment (Reclamation 2020).

In these two studies, longer time periods reveal droughts that were similar to, or more severe than, those analyzed in the 2021 Assessment using a measure that considers both drought length and magnitude.

The complex interaction between inflow, storage, water demands, and operating policies were evaluated in the 2021 Assessment. The impact of a drought on the managed system depends in part on the magnitude and duration of the drought, but also on the size of the system's reservoirs relative to their inflow, and the extent of carryover storage. To illustrate the wide range of impacts, reservoir storage at the end of the year for selected basins is shown on the next page. For example, Lake Mead and Lake Powell have the combined capacity to store approximately three times their annual inflow, which allows these reservoirs to store water in wet years to meet demands in drought years.

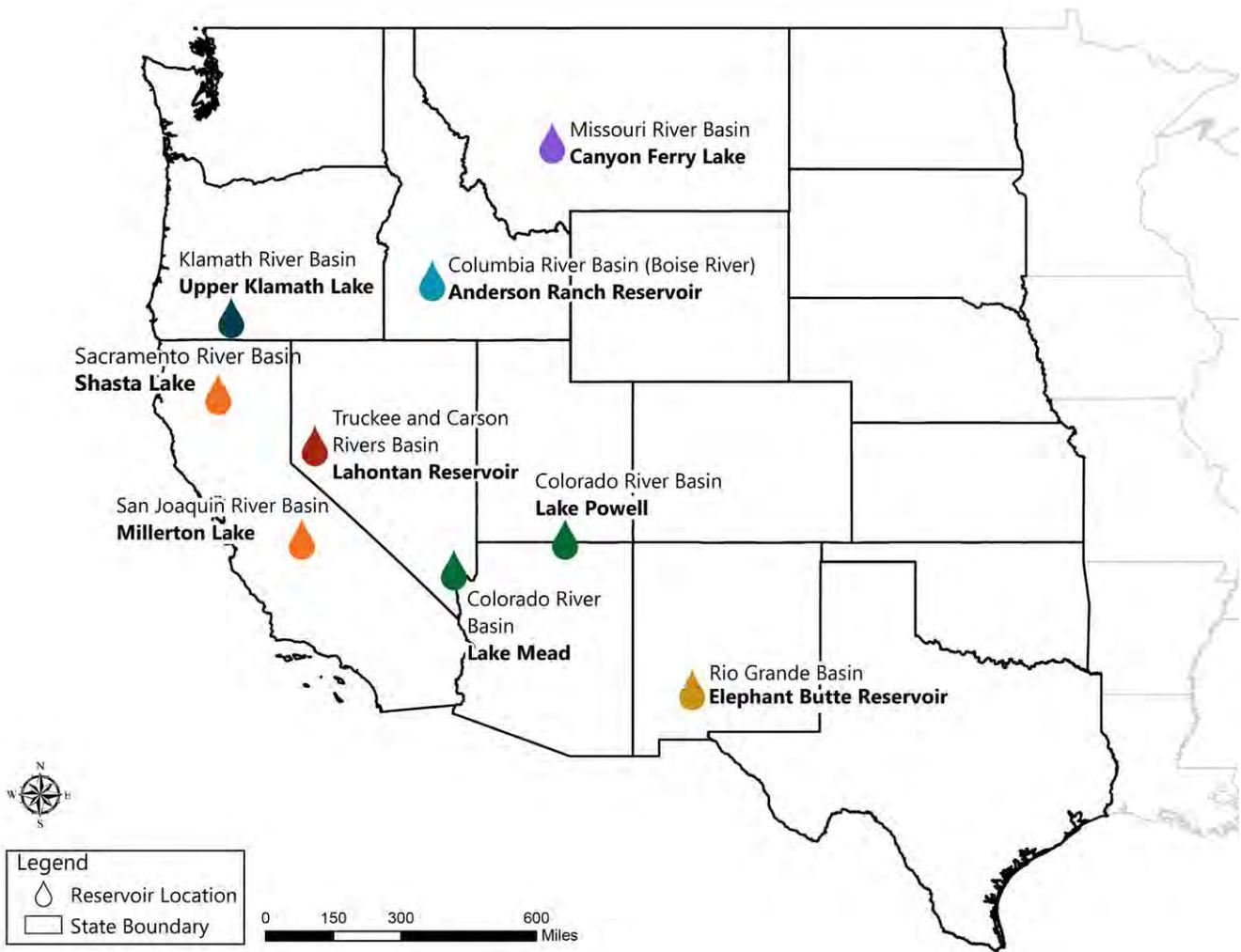
In another example, Upper Klamath Lake has limited ability to provide carryover storage, and operating policies allow for a relatively small amount of active storage in comparison to the lake's total capacity, so drought conditions may not have a clearly visible impact on storage. In the Upper Missouri River Basin, 11 percent of the active storage of Canyon Ferry Reservoir is unallocated, which serves as a buffer against the impact of drought.

Anderson Ranch Reservoir in the Columbia River Basin (Boise River), which can store a little less than its average annual inflow, experiences more impact to storage during paleo droughts than during observed historical drought events. At Shasta and Millerton Lakes, observed historical droughts

had a larger influence on their end-of-September storage than paleo droughts, giving confidence to the ability of those systems to withstand a greater variety of droughts.

As these examples illustrate, metrics such as end-of-September storage may be consistently evaluated across reservoirs, but local context is important for interpreting the results in each basin.

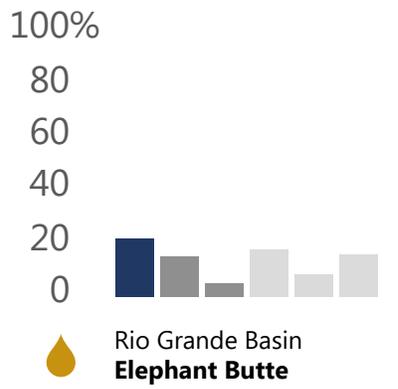
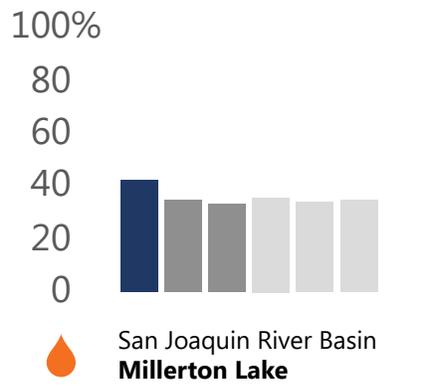
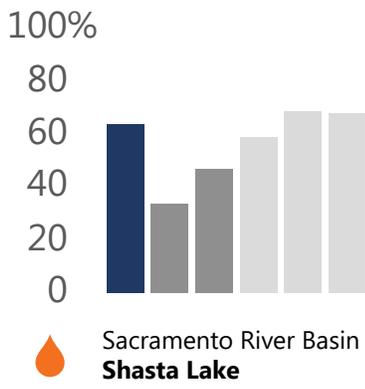
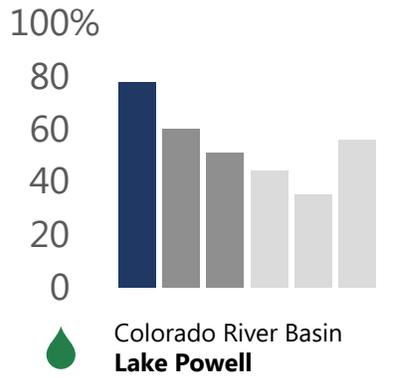
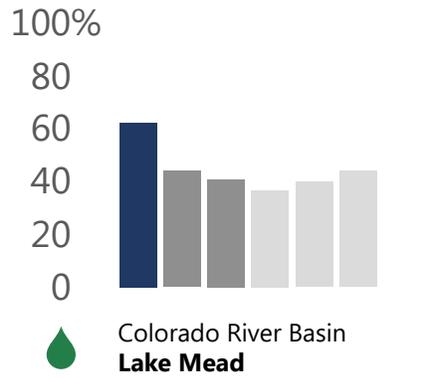
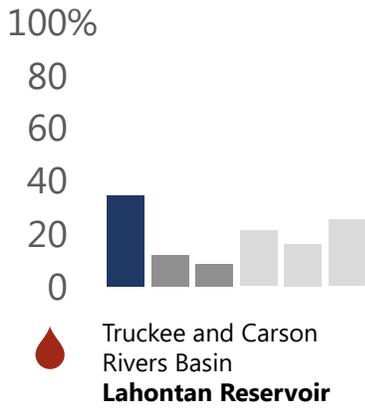
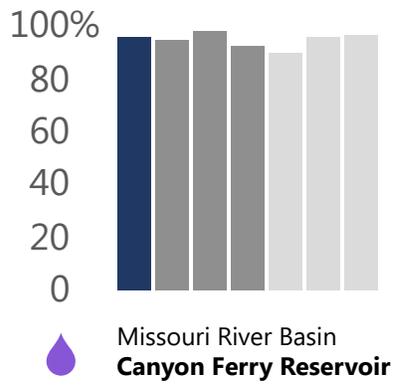
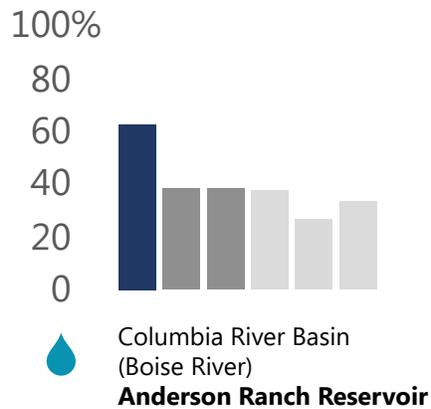
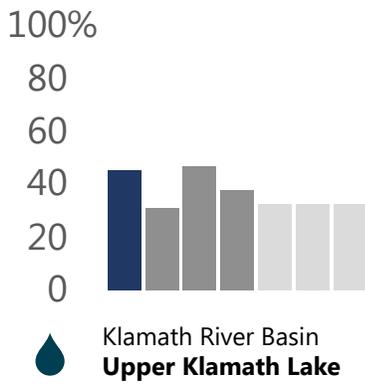
To evaluate a reservoir's ability to meet its management objectives, another analysis in the 2021 Assessment evaluated reservoir inflow, outflow, and reservoir storage data. The research focused on five reservoirs to identify severe, sustained, and seasonal droughts covering both paleohydrologic and observed periods. The analysis showed that the minimum active storage pool at which restrictions are imposed is generally a large fraction (about 60 percent) of the active storage capacity and represents a strategy that imposes restrictions while maintaining a relatively large fraction of storage in order to hedge against droughts (see 2021 Assessment, Chapter 5).



Map of reservoir locations across the West where paleo droughts were compared to droughts in the observed historical period, shown on the next page.

## West-Wide Reservoir Storage at End of Water Year

The average reservoir storage as a percent of reservoir capacity on September 30 across the basins examined for the historical baseline period (historical time period over which water planning is done—dark blue), historical drought events (gray), and paleo drought events (light gray). In some river basins, only two droughts in the observed historical period were evaluated. In other river basins, three historical droughts were evaluated. Comparing the paleo drought events (light gray) to droughts in the observed historical period (gray) shows that in some basins paleo droughts were more severe (see 2021 Assessment, Chapter 6).



■ Baseline    
 ■ Historical drought    
 ■ Paleo drought

## Urban Water Demands

Irrigated turfgrass is one of the largest irrigated crops in the United States (Milesi et al. 2005). To understand how it will respond to future changes, Reclamation and partners conducted an urban landscape irrigation demand analysis, which complements the agricultural demand analysis conducted in the 2016 SECURE Water Act report. In 68 urban areas across the West, water demands were estimated using an evapotranspiration and irrigation water requirement model representing grass varieties such as Bermuda and Kentucky Bluegrass. The analysis, comparing historical values to projected future changes, found significant increases in both estimated evapotranspiration (from +8 percent to +36 percent) and net irrigation water requirements per acre (from +9 percent to +54 percent) by the 2080s. These increases are largely driven by higher temperatures and longer growing seasons, which could stress water supply systems at times of the year when historical demand for water is low. Precipitation increases in some regions provided some offset—but were typically not enough to compensate for total increases in turfgrass water demand (see 2021 Assessment, Chapter 7).

## Groundwater

Groundwater is an unseen, yet critical, water resource for many communities throughout the West. Given unique aquifer properties, local precipitation, topography, and land use; groundwater resources in any particular location are challenging to assess. Since a consistent West-wide analysis was impractical, climate change impacts on groundwater were evaluated through a synthesis of groundwater projects done in collaboration with the USGS and basin study partners over the last 5 years.



The 2021 Assessment illustrates eight case studies that evaluate impacts of climate variability and change to groundwater resources, providing examples of strategies used to assess future changes and highlighting established approaches to hydrology modeling and decision support analysis. Generally, as wet areas get wetter and dry areas get drier, the amount of water recharging the groundwater system will reflect those changes, yet change may be buffered or accentuated by increased evapotranspiration. There are, however, nuances based on location and recharge type (e.g., diffuse or focused recharge). For example, more focused recharge events might increase with precipitation intensity or shifts in precipitation seasonality, even if overall precipitation amounts decline. This work summarizes evaluations of natural changes to groundwater and does not encompass acknowledged impacts to groundwater due to irrigation pumping and other uses (see 2021 Assessment, Chapter 8).

## Uncertainty

The 2021 Assessment employs a collection of evaluation tools and techniques that update the consistent West-wide data developed for earlier SECURE Water Act Reports. These analyses reveal new ways of understanding future change and showcases the type of evaluations that are possible. These analyses are designed to take advantage of the best available information and techniques, following methods documented in peer-reviewed literature and supported by collaborations with leading researchers in other Federal agencies and research institutes across the United States.

There are a number of analytical uncertainties, including uncertainties associated with climate projection information and assessing hydrologic

impacts. Differences between downscaling methods are described in detail in the technical memorandum (Vano et al. 2020).

The 2021 Assessment also employs new analyses to better understand future change. A diversity of techniques collectively provides a more robust analysis, especially when different techniques reveal similar conclusions. For example, future climate projections and paleohydrology provide complementary information that both help to understand and prepare for conditions outside those experienced in the past century. Future projections rely on a suite of models—global climate models, downscaling methods, and hydrology models—to reveal how increases in greenhouse gas concentrations influence climate and hydrology processes. In contrast, paleohydrology reconstructions use tree rings to better understand climate of the distant past—analyzing tree-ring cores, correlating those cores to stream gage records, and estimating what this reveals about past climate. Both analyses require different tools and models, which have associated uncertainties. Yet, collectively both reveal scenarios and likelihoods which extend our understanding, allow a more informed risk-based decision-making framework, and can help promote more resilient planning. And, while these multiple methods can help to further reveal what we know, it is also important to recognize the need to explore alternative planning paradigms to consider decision-making under deep uncertainty.

Overall, the collection of techniques and their respective uncertainties used in the West-wide analyses are explained throughout the 2021 Assessment and discussed in relation to one another in Chapter 9.

# Impacts to Water Uses

Analyze how changes will impact various water uses and services.

Ongoing and future changes in climate and hydrology are projected to have multiple anticipated impacts to water uses. See the 2021 Assessment for a detailed analysis. The impacts described below are identified in various basin studies, see References.



## Water Deliveries

*Projected increases in temperatures, decreases in snowpack, and runoff occurring earlier in the year—with a corresponding reduction in supply in summer months—make supplies less predictable and water deliveries more difficult to manage.*

Water supplies are increasingly stressed by rapid urban growth, a vital agricultural industry, and environmental needs and obligations. Changing hydrology, including projections of more frequent and more severe droughts, increased temperatures leading to evaporation losses and increased irrigation requirements, and changes to the timing and quantity of runoff, brings added water management challenges. Shifts in runoff timing, longer growing seasons, and greater reliance on limited water storage may increase the potential for water supply shortages (e.g., the Upper Deschutes River Basin Study [2019] noted an increased reliance on stored water during the summer due to lower natural flows). End-of-water-year storage is projected to decrease in areas, including the reservoirs analyzed in the Upper Missouri River Basin Impacts Assessment (2019) and the Sacramento-San Joaquin Basins Study (2016).



## Water Quality

*Anticipated warming water temperatures, sea level rise, and more wildfires will likely impact ecosystem health. Changes in precipitation and runoff will likely affect pollutant transport into and within water bodies.*

Across the West, increasing wildfire risks increase water quality issues as fire scars may lead to increased ash, large debris, and sediment washing into rivers and reservoirs. In the Sacramento-San Joaquin Rivers Delta, salinity is affected by both sea level rise, as ocean temperatures increase, and by changes in Delta outflow, allowing more sea water intrusion into the Delta. In the Missouri River Basin, water quality characteristics have also changed over the past several decades as a result of land use practices, increased urbanization, atmospheric deposition of pollutants, and dam construction and regulation.



## Recreation

*Reduced reservoir levels and river flows could have negative implications for flow and water-dependent recreational activities.*

Climate change may cause fluctuations in water depth and surface acreage, which may affect recreation use and economic value in complex ways. The Rio Chama Economic Study (forthcoming) is finding that higher water levels typically provide greater recreational value. In the Rio Grande Basin, drying wetlands could diminish wildlife watching opportunities, drought conditions could lead to reduced game populations for hunters, and changes in runoff flow and timing could shorten fishing seasons in headwater streams.



## Fish and Wildlife Habitat

*Projected changes to the timing and volume of streamflow, increasing severity and duration of floods and droughts, increasing temperatures, and increasing wildfires create challenging conditions for species and habitat.*

As air and water temperatures increase, the timing and magnitude of streamflow change—impacting ecosystems. The Missouri Headwaters Basin Study (Reclamation and the Montana Department of Natural Resources and Conservation 2019) investigated ongoing efforts by the National Drought Resilience Partnership and Reclamation to mitigate impacts of severe drought. The study found that implementation of voluntary instream flow targets for water conservation during drought could provide multiple benefits without substantial impacts to irrigation water users.



## Hydropower

*Hydropower production faces challenges from longer, more severe droughts and floods, and runoff occurring earlier in the year—decreasing supplies when demand is highest during summer months.*

Increasing temperatures, earlier runoff, and lower summer flows may reduce hydropower operational flexibility. Communities dependent on hydropower may encounter power supply and demand imbalances as hydrologic changes could reduce generation capacity during the late-summer periods when energy demands are anticipated to increase.

The effect of prolonged drought on hydropower generation is also still uncertain. Even with efficiency improvements, impacts to hydropower generation are anticipated to continue in the Colorado River Basin with over 20 years of drought. Projections indicate a 0.5 to 2.5 percent loss in power generation from year-to-year over the next 5 years at Hoover Dam.



## Endangered, Threatened, or Candidate Species

*Terrestrial, freshwater, and marine organisms are responding to climate change by altering individual characteristics, the timing of biological events, and their geographic ranges.*

Warmer conditions may result in increased stress on fish such as the silvery minnow in the Rio Grande and the Lahontan cutthroat trout in the Truckee River Basin. These warmer conditions may require increased water demands for instream flows for ecosystems. Changes in ambient temperatures and seasonality shifts in streamflow could alter the timing of breeding patterns of aquatic species. The Truckee River Basin Study (2015) stated that any impacts on Pyramid Lake elevations could affect cui-ui and Lahontan cutthroat trout spawning and the quality of lake habitat for these listed species.



## Flood Control Management

*Precipitation changes are projected to occur, interacting with warming to cause larger and more frequent floods, even in areas where total precipitation is projected to decline.*

More operational flexibility may be needed to manage increased risks from flooding. Reservoirs in the Pacific Northwest could experience more floods due to a combination of warming and increased winter precipitation leading to increased rain-on-snow events. The Crooked River Reservoir Operations Pilot Study (2020) estimated the potential impacts of climate change on flood control operations on the Crooked River in Oregon. The study found that the wetter climate change scenario resulted in an additional 22 days of flows above flood stage and increased potential for surcharge compared to current conditions. In many Missouri River Basin reservoirs, the average number of spring days per month above flood pool elevation is expected to increase, while the average number of summer days per month above flood pool elevation is projected to decrease, as described in the Missouri Headwaters Basin Study (Reclamation and the Montana Department of Natural Resources and Conservation 2019).



## Ecological Resilience

*Warmer temperatures and changes in precipitation affect the resilience of ecosystems in watersheds, which we rely on for ecosystem services, including water supplies.*

As climate change increases the magnitude of disturbances in our natural systems, more ecosystems are approaching—or crossing—resilience thresholds, and therefore changing in basic character. For example, projected climate changes with increased temperatures and decreased available moisture could profoundly affect upland forests throughout the West, adding stress to already disturbed systems. These forests accumulate the snowpack that many of Reclamation's projects depend on for water supply. Resilience thresholds for many of these forests are being surpassed, resulting in extensive loss of forests to bark beetle and other infestations, as well as to growing intensity and size of wildfires. These forest losses expose areas with snow accumulation to increasing sunlight, leading to decreases in snowpack and spring runoff. Resilience thresholds are also being approached within our river systems, through increasing temperatures, which decrease oxygen and lead to fish kills, as well as increasing river drying and impacts to riparian systems.

# Strategies to Support Reliable Water and Power Deliveries

## Develop appropriate mitigation strategies.

Reclamation works with a multitude of customers, stakeholders, and other partners to address vulnerabilities to increased risks of drought as well as changes to precipitation, runoff, and increased temperatures that will build resilience to climate change in Western river basins. For example, Reclamation supports reliable water deliveries through hundreds of ongoing construction activities, a range of water management improvements—from water reuse to software maximizing the amount of power produced with available water supplies—and building partnerships across the West to maintain streamflow for fish and improve habitat. Reclamation also incorporates climate change information into risk assessments for infrastructure and drought planning, and improved decision support tools to manage risks from wildfires. This section highlights example actions supporting four strategy areas, including:



**Water Delivery**



**Habitat, Ecosystems,  
and Recreation**



**Hydropower**



**Risk Management**

**“We have had a wonderful partnership with the Federal government in breathing new life back into a project that some said would never happen. In the past few months, we have begun to roll up our sleeves and begin the real work of completing the Arkansas Valley Conduit. The Bureau of Reclamation has shown a new level of energy toward getting this project done and the District is more than ready to do its part.”**

*Jim Broderick  
Executive Director, Southeastern Colorado Water Conservancy District*



## Actions to manage risks to water deliveries from variations in hydrology, including risks from floods, droughts, and water supply variability.

### Water Delivery Strategies

Since 1902, Reclamation's assets have provided secure, reliable water deliveries for irrigation, people, and the environment; generated energy efficiently to meet our economic needs; ensured outdoor recreation opportunities; and fulfilled our commitments to Tribal Nations in the 17 Western States. As Reclamation and its local customers, partners, and stakeholders face challenges from climate change and shifting demographics, we are taking a multi-faceted approach to support reliable water deliveries, including: construction activities, water management improvements, diversifying supplies through water reuse, and conjunctive use of ground and surface water.

#### Maintaining Reliability through Construction

Reclamation has approximately 350 active construction activities, including new delivery systems and storage, dam safety projects, recreation rehabilitation activities, and other major replacements and repairs. Most of Reclamation's facilities are more than 50 years old, and some dams are more than 100 years old. Preventive maintenance programs, capital improvement planning, and substantial investment in major rehabilitation and replacement all contribute to maintaining infrastructure.

#### Bringing Safe Drinking Water to Rural Colorado

Now in the final design stage, the Arkansas Valley Conduit, once completed, would provide a safe, long-term water supply to as many as 50,000 people in 40 rural communities along the Arkansas River in Southeastern Colorado. Drinking water now delivered to about 5,200 people in the area does not meet National Primary Drinking Water Regulations due to naturally occurring radionuclides in current groundwater sources, and 17 communities are under state enforcement orders. This project will allow water providers to deliver safe, affordable drinking water and support future growth.

#### Increasing Safety from Flood Events

Reclamation crews raised Stampede Dam, near Truckee, California, by 11.5 feet, constructed two small dikes, and reconstructed the spillway to better control outflows during large floods—in less than 2 years and under \$22 million. Investigations indicated a need for this project to prevent potential overtopping of the dam, which could lead to potential failure of both Stampede Dam and Boca Dam 6 miles downstream that could impact the City of Reno and surrounding areas.



Downstream face of Stampede Dam, California, showing the 11.5-foot-high crest raise (Reclamation).

## **Supporting New Construction with New Authorities**

Water storage is an important component of building resiliency in the face of growing water demands and climate variability. The Water Infrastructure Improvements for the Nation (WIIN) Act, Public Law 114-322, enacted in December 2016, authorizes a new funding model for construction. This allows Reclamation to require non-Federal cost contributions to be paid upfront—in contrast to the financing model requiring Reclamation to fund all project costs, with repayment over time by beneficiaries. Under WIIN Act Section 4007, Congress has appropriated over \$600 million to date for water storage projects and multiple projects are underway.

One of these projects, raising the existing Cle Elum Dam by 3 feet in Washington, is the first new water storage project in the Yakima River basin in more than 80 years and will provide an additional 14,600 acre-feet of storage capacity, increasing reliability for existing users and improving instream flows for fish.

WIIN Act funding has also been used to finalize a number of studies identifying more water storage in the West. This includes the North-of-Delta Off-Stream Storage Investigation, documenting the potential costs and benefits of the Sites Reservoir Project in northern California. The proposed reservoir, to be located 81 miles northwest of Sacramento, would store water diverted from the Sacramento River for future releases to beneficiaries throughout the state. The reservoir would increase northern California's water storage capacity by up to 15 percent and provide water supply, flood protection, environmental, and recreational benefits.

The Sidney Water Users Irrigation District in northeastern Montana will use a WaterSMART Water and Energy Efficiency Grant to convert 12,200 feet of an earthen canal to pipeline and install flow meters, which is expected to save 1,312 acre-feet a year of water that is now lost to seepage and inefficient conveyance. This area has experienced heightened drought conditions in recent years, and low flows in the Yellowstone River have caused water shortages during peak irrigation months. The closed pipeline will also facilitate future on-farm improvements, including installing pivot sprinkler systems to replace traditional flood irrigation.

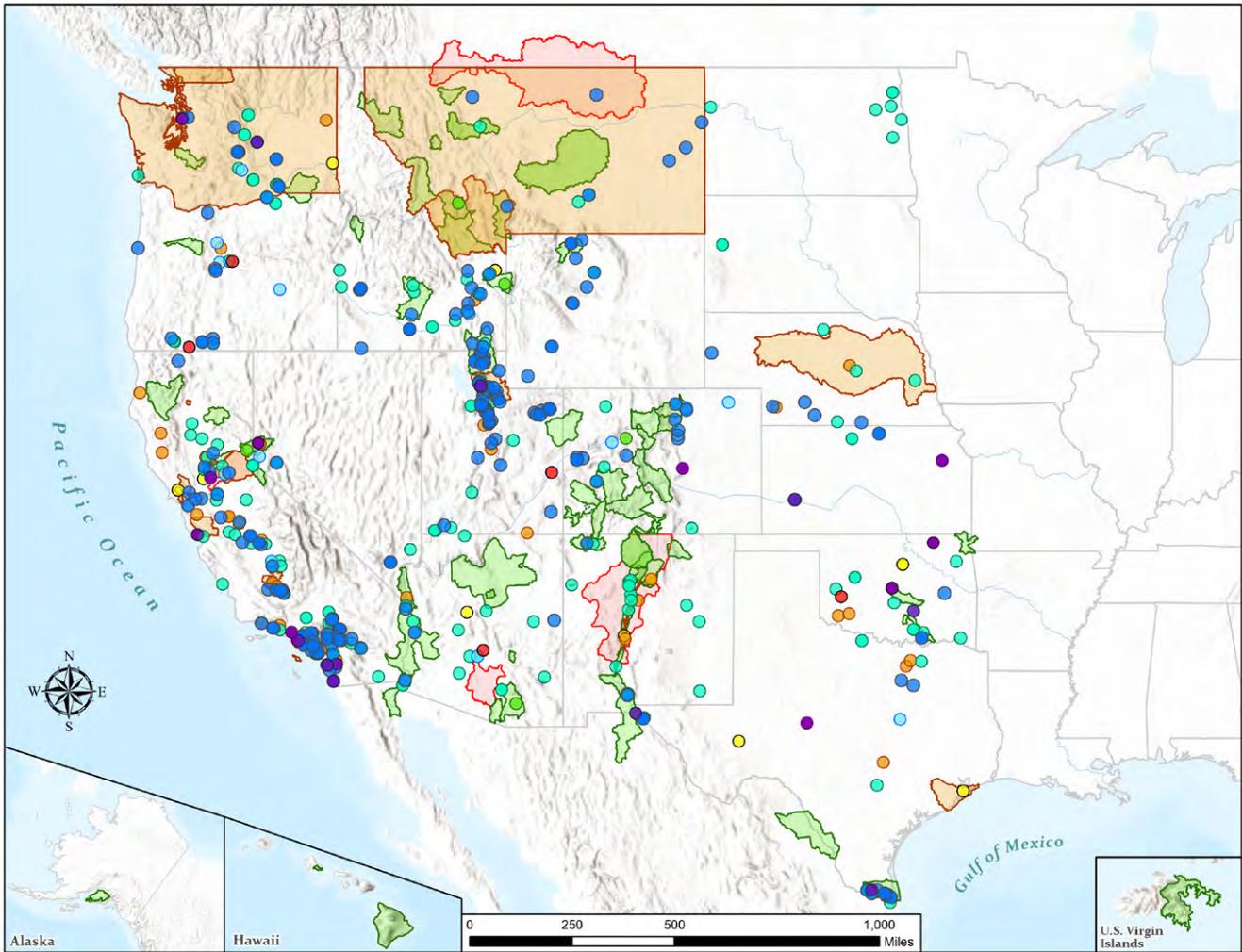
## **Increasing Supplies through Water Management Improvements**

### **WaterSMART**

Since 2016, Reclamation has leveraged \$365 million in Federal funding with \$1.1 billion in non-Federal cost-share funding for 749 WaterSMART projects, as shown on the map on the next page. These projects support a wide range of water management activities, including water delivery system improvements, drought contingency plans, restoration planning by watershed groups, water reuse and recycling projects, and more. Through WaterSMART, Reclamation provides cost-shared financial assistance to water managers on a competitive basis for projects to conserve water, increase the production of hydropower, develop water marketing strategies, and mitigate the risk of water conflicts.

### **Pilot System Conservation Program**

The Pilot System Conservation Program in the Colorado River Basin demonstrated that cost-shared conservation projects provide a viable contribution to water savings, and the lessons learned are being applied to possible future demand management. In the Lower Colorado River Basin, agricultural, municipal, and tribal projects in Arizona, California, and Nevada conserved more than 165,000 acre-feet of water in Lake Mead from fiscal year (FY) 2015 to FY2018. In the Upper Colorado River Basin, projects conserved about 47,000 acre-feet through 2018 (Reclamation 2020 [PSCP]).



**WaterSMART Projects Funded Since 2016**

Since 2016, Reclamation has funded 749 WaterSMART projects, with \$365 million in Federal funding and \$1.1 billion in non-Federal funding. These include a mix of planning activities and on-the-ground improvement projects with multiple benefits. For example, the Water and Energy Efficiency Grant projects funded since 2016 are expected to save more than 430,000 acre-feet of water per year, once completed. An interactive tool that includes detailed information on all projects funded under WaterSMART is available at <https://www.usbr.gov/watersmart/>.



## Diversifying Water Supplies through Water Reuse

Water recycling is often drought-resistant, since sources such as treated municipal wastewater continue to be available during periods of water shortage. Reclamation provides grant funding through the Title XVI Water Reclamation and Reuse Program (Title XVI) for projects that reclaim and reuse wastewater and impaired ground and surface water. Since 1992, Reclamation has allocated more than \$761 million in Title XVI Program funding. This funding, along with non-Federal cost-shares, has resulted in more than \$3.4 billion in total investments in reuse projects. Projects funded through this program delivered over 411,000 acre-feet of recycled water in 2019. For example, the El Paso Water Utilities Public Service Board, in Texas, is constructing the first large-scale, direct-to-distribution potable reuse project in the United States that will produce 13,000 acre-feet of water per year, saving surface and groundwater. This project is tentatively expected to be completed in 2028.

In California, the Pure Water Monterey Title XVI Project is expected to produce up to 8,200 acre-feet of water for a reliable, drought-resistant supply for communities in Monterey County. Existing water sources for the area are limited by extended droughts, habitat needs, and groundwater adjudication and overdraft. The Pure Water Monterey project includes collection and conveyance facilities and an advanced water treatment plant. The project will treat secondary effluent from a local wastewater treatment plant, municipal urban runoff, stormwater, and agricultural wash water.

The treated water will be used to recharge the Seaside Groundwater basin, precluding seawater intrusion, and will be used as a drinking water source and for agricultural irrigation. The project will receive \$19.6 million in Title XVI funding from FY2018 through FY2020, which will be leveraged with more than \$59 million in non-Federal cost shares.

## Using Groundwater and Surface Water Connections to Manage Supplies

In addition to water conservation and reuse, managing ground and surface water conjunctively can also provide flexibility to prevent water shortages.

Water can be stored underground. For example, in the Yakima River Basin, Reclamation is partnering with the Yakama Nation, irrigation districts, and the Washington Department of Ecology to evaluate diverting water from the Yakima River during the non-irrigation season into canals, allowing the water to seep and travel through the shallow aquifer back to the river to augment supplies in the late summer and fall.

Groundwater and surface water can be marketed to provide flexible supplies. For example, in the Upper Red and Upper Washita basins in Oklahoma, ongoing basin studies are carefully evaluating conditions that best predict the onset of critical drought periods, which can inform voluntary “dry-year lease” agreements. Under a dry-year lease agreement, the owner of a surface water permit could pay a groundwater user to curtail pumping at specific times to protect the surface water right.

The **2016 WIIN Act** amendments to the Water Desalination Act of 1996 provide a new opportunity for ocean or brackish water desalination project sponsors to compete for Federal funding. Since the passage of the WIIN Act, Reclamation has allocated \$42 million in funding to plan, design, and construct eligible projects.



## Actions to support reliable hydropower deliveries, optimize hydropower generation, support operations under variable hydrologic conditions, and improve cost-competitiveness.

### Hydropower Strategies

As the second largest producer of hydroelectric power in the United States, Reclamation supplies 40 million megawatt-hours (MWh) of electricity each year on average. This hydropower is used to support water deliveries from Reclamation facilities and is marketed to power customers, providing revenues for project repayment.

Hydropower production faces challenges from longer, more severe droughts and floods as well as changes to the timing of runoff. In some Western river basins, including the Colorado River and Upper Rio Grande Basins, lower flows and reservoir levels as well as higher water demands associated with climate change are anticipated to decrease hydropower production.

Improving generation capability, flexibility, and reliability to ensure that each drop of water creates as much power as possible is part of Reclamation's overall strategy to respond to the impacts of climate change. Reclamation uses advanced decision support tools to maximize the amount of power produced with available water supplies and new technologies to better maintain hydropower plants and decrease outages.

#### Optimizing Hydropower Generation

Reclamation's hydropower decision support tool, HydrOS, uses innovative algorithms to maximize powerplant output, given water input. Thus, Reclamation powerplants need less water to meet power output requirements, conserving water. Reclamation's Technical Service Center, in coordination with the USACE, developed HydrOS, which is configurable to all Reclamation hydropower plants.

HydrOS is a proven means to enhance Reclamation hydropower capabilities and value, ensuring Reclamation hydropower remains a long-term, cost-competitive energy resource. Between FY2013 and FY2019, HydrOS was deployed at four Reclamation facilities: three control centers (Black Canyon in Idaho, Casper in Wyoming, and Glen Canyon in Nevada) and one stand-alone powerplant (Elephant Butte in New Mexico). HydrOS has improved plant efficiencies by 1.75 percent, on average, equating to over 100,000 MWh in incremental generation in FY2019. In FY2020, Reclamation deployed HydrOS at our largest facility, Grand Coulee Dam west of Spokane, Washington.

#### Hydropower provides an important source of renewable, carbon-neutral energy.

Production of hydropower is a non-consumptive use of water. Water replenished by snowmelt and rainfall flows through a turbine that generates power and then continues downstream where it remains available to water users. Hydropower is uniquely suited to provide both firm (consistently available) power and dispatchable (on-demand) grid support services to transmit electricity in a safe, reliable manner.

## Maintaining Hydropower System Infrastructure

Hydropower turbines can be damaged when required to operate during flood and drought conditions.

Machine Condition Monitoring (MCM) systems monitor equipment in real time, preventing wear and decreasing maintenance needs and costs by reducing the destructive operation of machinery during less than ideal conditions. Across Reclamation, 35 units now use this technology, and 39 more installations are planned. An MCM system analysis performed in 2019 found that investing almost \$1 million resulted in \$12 million in benefits—a twelve-fold return on investment.

At the Judge Francis Carr Powerplant near Shasta, California, MCM is used to monitor for problems when adverse water flow conditions harm the turbine blades. By using the data this system provided, operators at Judge Francis Carr Powerplant have been able to decrease cavitation and delay generator outages—increasing the service life of the powerplant. The MCM system's flexibility and expandability will allow it to be adapted to meet future monitoring needs as conditions change.



Jim DeHaan of Reclamation's Technical Service Center installing a cavitation monitor at the Judge Francis Carr Powerplant near Shasta, California (Reclamation/John Germann).



Cavitation damage to the runner blade of Judge Francis Carr Unit 2 in 2013 near Shasta, California (Reclamation/John Germann).



## **Actions to support fish and wildlife habitat, meet Endangered Species Act requirements, and maintain flow-dependent ecological resiliency.**

### **Habitat, Ecosystems, and Recreation Strategies**

Reclamation helps maintain healthy ecosystems and protect federally-listed fish, wildlife, plants, and designated critical habitat affected by Reclamation facilities through a range of programs and activities. Reclamation and its non-Federal recreation partners also work together to manage more than 240 developed recreation areas. Changes to the timing and volume of streamflow, increasing severity and duration of floods and droughts, and increasing temperatures can create challenging conditions for species, habitat, and recreation activities. These conditions raise the importance of efforts to protect habitat, ecosystems, and recreational uses.

#### **Understanding Hydrology to Protect Endangered Species and Habitat**

Collaboration and transparency are critical to the success of Reclamation's efforts to support Endangered Species Act-listed species and habitat. A common understanding of the hydrology can provide a vital foundation for habitat conservation. For example, a water system operations model developed for the Upper Deschutes Basin Study in Oregon provided a basis for more specific analyses conducted to inform the Habitat Conservation Plan that has recently been developed for the basin. As a result of work done in the basin study to create scenarios of current and future conditions—and improved working relationships developed during those efforts—stakeholders in the planning process started with a common understanding about water operations in the basin. This shared understanding has helped different basin interests work toward strategies to improve streamflow for ecosystem benefits while also recognizing the challenges facing irrigated agriculture.

#### **Managing for Competing Uses**

Reclamation and our partners have developed creative approaches on the Rio Grande to address competing demands for water by irrigators and for Endangered Species Act-listed species, such as the silvery minnow. To mimic the flow pulses that historically occurred naturally on the Rio Grande, Reclamation works with water management partners, including USACE, the State of New Mexico, irrigation districts, Tribes, and municipalities to engineer pulses that create overbank flows in key river reaches to support the spawning of the endangered Rio Grande silvery minnow, without significant impact to irrigators.

In extremely low snowmelt runoff years, such as 2020, Reclamation and the Middle Rio Grande Conservancy District cooperate to use the irrigation diversion structures along the river to pass flow pulses through the Middle Rio Grande. These innovative water operations support silvery minnow spawns in the river and allow biologists to capture eggs to raise in hatcheries so that minnows can be released back to the river during better flow conditions.

## Working Together with Watershed Groups

Reclamation's Cooperative Watershed Management Program (CWMP) supports watershed groups to encourage diverse stakeholders to form local solutions for water management. Since 2012, Reclamation has provided \$7.7 million in Federal funding to support 85 projects by watershed groups to conduct watershed group development, watershed restoration planning, and watershed management project design. These restoration plans cover 200,000 square miles of watershed area. Reclamation has also provided funding for on-the-ground watershed management projects, representing \$2.4 million in collaboratively developed watershed management solutions, including non-Federal cost share contributions.

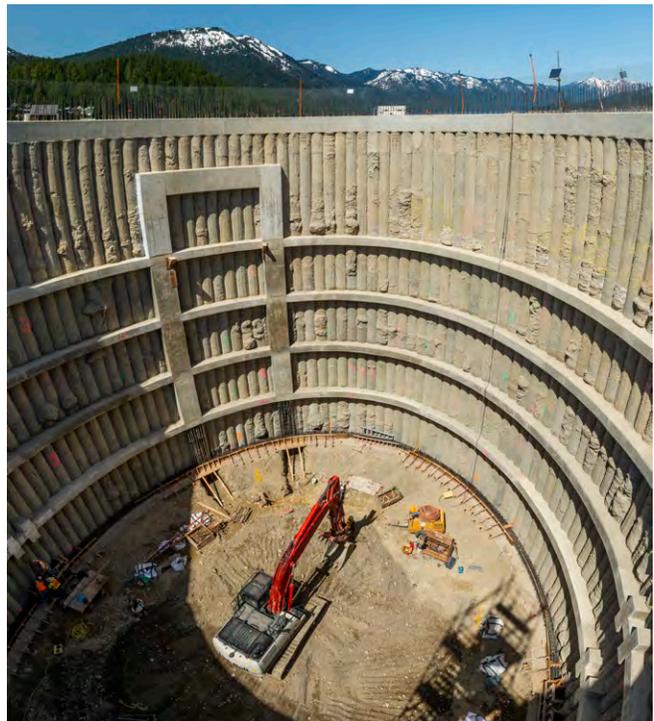
## Protecting Fish through Infrastructure Improvements

Reclamation is improving fish passage to help protect fish as potential increases in temperature and decreases in summer streamflow create challenging conditions. These efforts include the Nation's largest horizontal fish screen, completed in September 2020 at Derby Dam near Reno, Nevada. The \$34-million fish screen is a critical investment to modernize the dam to provide reliable water supplies for irrigation customers and restore historic spawning habitat for the threatened Lahontan cutthroat trout.

An innovative helix fish passage design, similar to the spiral ramp in a parking garage is now being installed at Cle Elum Dam in the Yakima Basin in Washington. The new structure will provide permanent fish passage at the facility and support the reintroduction of sockeye that the Yakama Nation and Washington Department of Fish and Wildlife are leading.



New horizontal fish screens at Derby Dam. The dam is part of Reclamation's Newlands Project and is 115 years old. It was one of the first Reclamation projects approved for construction and is part of a system that provides water to 57,000 acres of cropland in the Lahontan Valley in western Nevada.



Panoramic view of the secant at Cle Elum Dam, Washington State. The secant is a very large oval-shaped hole that is stabilized by a concrete wall. It was built in preparation to construct the helix fish passage structure.



Floating Marina on Lake Pleasant, Arizona (Getty Images).

## Managing for Recreation Uses

Reclamation manages almost 8 million acres of land and water, most of which is available for public outdoor recreation, and hosts over 240 developed recreation areas. It is estimated that Reclamation's recreation areas draw more than 45 million visits annually, supporting local economies. In FY2019, Reclamation had a direct economic contribution of \$2.26 billion to the recreation sector and a total economic contribution of \$5.22 billion, including supporting 35,000 domestic jobs (DOI 2020).

Reduced reservoir levels and river flows could have negative implications for these recreational activities. Reclamation is adjusting to changes by providing adaptable recreation infrastructure.

The Missouri Headwaters Basin Study (Reclamation and the Montana Department of Natural Resources and Conservation 2019) showed that, generally, lower pool elevations in reservoirs and lower streamflow in the summer months will lead to decreased access to boat ramps for recreation and, on average, more unusable days.

At Scorpion Bay Marina on Lake Pleasant, north of Phoenix, Arizona, for example, fluctuating reservoir levels impaired access to the marina. In response, Reclamation's managing partner, Maricopa County, and their concession operator built an innovative floating system that allows the entire marina to react to fluctuating reservoir levels.



## Actions to manage risks to water users from variations in hydrology, including risks from floods, droughts, and water supply variability.

### Risk Management Strategies

Because accurately predicting extreme events at a particular location is not possible, water managers must consider a range of future conditions to assess risks—including droughts, floods, and fires—and identify strategies to mitigate those risks. The potential for increased frequency and intensity of droughts and floods brings additional challenges to water infrastructure and management.

#### Addressing Drought Risks

Proactively preparing for and better understanding drought risks are strategies that can build resilience as the severity, duration, and frequency of drought increases. Severe droughts can last decades, like the one in the Colorado River Basin, where a historic drought has continued since 2000, and Reclamation's September 2020 modeling results indicate increased likelihood of reaching the first ever declared shortage conditions in the Lower Colorado River Basin before 2025 if the drought persists.

#### Planning for Drought

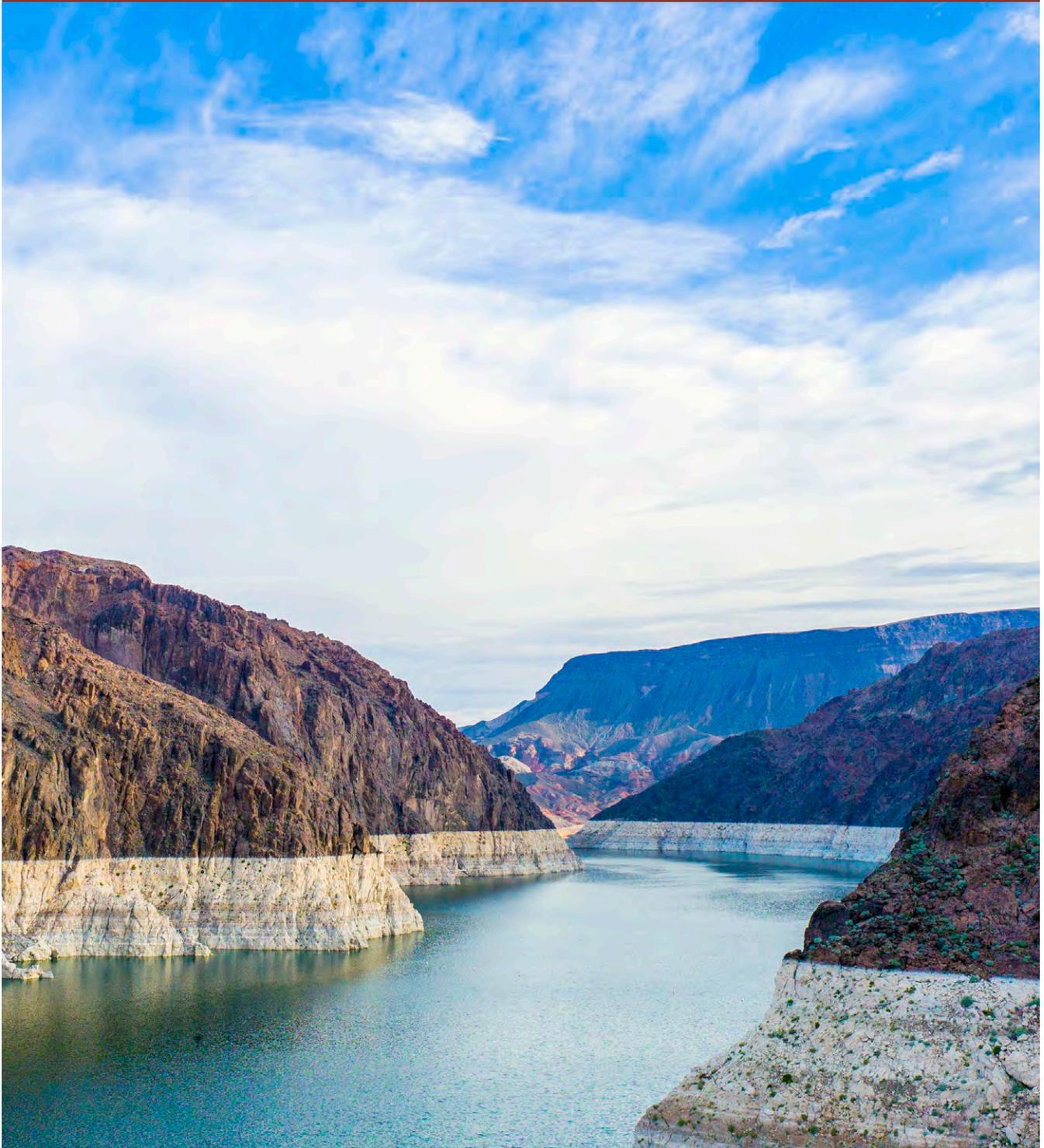
In recent years, Washington State has had record low snowpack followed by hot, dry summers resulting in “snowpack droughts” which pose challenging conditions for communities, farms, and the environment.

After the most extreme drought in recent decades, the Washington State Department of Ecology updated its 1992 Washington State Drought Contingency Plan under the WaterSMART Drought Response Program in 2018. This new drought framework prioritizes early action before water supplies reach critical levels and identifies multiple drought indicators. Historically, reliance on the State's legal definition of drought limited agencies from taking certain actions until water supplies were less than 75 percent of normal and hardship to water users was anticipated. In the spring of 2020, the Washington State Legislature adopted several of the key recommendations from the drought plan into State law. This new two-stage drought system allows Washington State to issue a drought advisory when water supply conditions are below normal but not yet at a level where hardship is anticipated.

**“The WaterSMART program was instrumental in helping us to bring together our partner agencies and stakeholders to accomplish that work. With this legislation, the Department of Ecology has been put in a better position to support long-term projects which help water users reduce their vulnerability in times of drought. As our climate warms, and snowpack droughts hit with greater frequency, this resilience will become even more critical.”**

*Laura Watson  
Washington Department of Ecology Director*

**Building on the planning approaches developed through the Basin Study Program, all WaterSMART drought plans are required to incorporate climate change projections in evaluating drought risks.**



Low reservoir levels at Lake Mead. Colorado River Basin along Nevada/Arizona border.

## Increasing Reservoir Operations Flexibility to Respond to Drought

The Washita Reservoir Operations Pilot Study (2018) demonstrates how climate projections and paleohydrology can support more flexible reservoir operations for drought management. In the Washita pilot study, Reclamation developed reservoir inflow reconstructions going back 600 years to capture past wet and dry cycles for Foss and Fort Cobb Reservoirs in Oklahoma. The analysis showed that the drought scenarios based on tree-ring reconstructions were more severe than scenarios based on the observed droughts over the 90-year period of record—meaning that the actual risks of drought were greater than previously understood.



Foss Reservoir in Oklahoma taken in March 2015, at the end of the recent drought. Picture shows three intakes, two of which are dry. The top of the third intake can just be seen through about six inches of water, signaling a potential need to take emergency action to access the lowest pools of the reservoir.

With stakeholder input, Reclamation selected several drought scenarios based on this analysis to provide benchmarks for real-time delivery of municipal and industrial water supplies during drought. The resulting model can be used to quantify the extent to which water deliveries would need to be curtailed to avoid emergency drought response under different drought scenarios.

## Incorporating Climate Change into Dam Safety Assessments

Because the risk of dam failure often depends on the risk of flooding, appropriately characterizing the probabilities of extreme floods is crucial. Based on the results of a 2015 Reclamation Dam Safety Office pilot study for Friant Dam in California that explored the potential impacts of climate change, a supplementary climate change analysis is now included in the flood hazard section of dam safety review reports. This analysis includes a summary of the projected monthly and annual streamflow changes for each Reclamation facility, developed from historical and future streamflow projections based on downscaled climate change information. This screening level information, about when and where the largest and smallest median increases in average monthly streamflow are projected to occur, helps prioritize more detailed levels of analysis.

### Investigating How Drought Impacts Infrastructure

Extended periods of low reservoir levels can lead to increased animal burrowing into certain dams and earthen embankments. Increased drying and freeze-thaw cycles can also harm dams. Reclamation is reviewing our entire inventory of dams to identify infrastructure degradation after periods of extended reservoir drawdowns and to formulate strategies to improve the drought resiliency of our physical structures (e.g., enhanced monitoring of dams after atypical periods of reservoir drawdown).



Smoky skies from the Elkhorn Complex fire near Shasta Dam, California. View shows the dam's switchyard, warehouse, and visitor center, September 9, 2020 (Reclamation/Amy Holland).

## Managing Risks from Increasing Wildfire

Over the past 20 years, the size and severity of wildland fires in the West have markedly increased. Post-fire debris flow and sedimentation from upstream fires can have adverse and costly impacts to Reclamation's existing infrastructure and reservoir storage capacity. A recent USGS report projected that increases in the frequency and magnitude of wildfires will significantly increase rates of sedimentation in watersheds in the West within the next 33 years. In almost 9 out of 10 of the watersheds assessed by the USGS, sedimentation could increase by at least 10 percent. In some watersheds, erosion and sedimentation could increase by 1,000 percent (Sankey et al. 2017).

Reclamation is developing geographic information system (GIS)-based mapping tools to provide information in real-time about the proximity of fires to Reclamation infrastructure. A West-wide map was developed in the summer of 2020 to assess risk during an unprecedented season of wildfires in the West. In Reclamation's Columbia-Pacific Northwest Region, more detailed mapping is underway that, once completed, will display near real-time national fire perimeters, satellite heat signatures, and detailed asset and lands information (mapped jurisdictional lands, restoration sites, bridges, etc.). This map will help staff quickly identify potential impacts to our infrastructure, including post-fire sediment influx. This effort will help coordinate with downstream agencies for large fires that could create substantial sediment influx outside of the burned footprint.

# Next Steps

Monitor water resources to support these analyses.

Implementing the SECURE Water Act has served as a catalyst for collaboration and innovation—improving our understanding of climate change impacts to water resources and our ability to address those impacts. In carrying out the assessments specified in the Act, Reclamation has developed consistent, West-wide approaches to assess climate change risks and impacts to water resources as well as tools and information applicable Reclamation-wide. Working together with stakeholders, Reclamation has built on West-wide assessments, basin studies, and past SECURE Water Act reports to conduct site-specific analyses and identify potential strategies to improve water reliability. These analyses have also provided a foundation for collaboration across other Federal agencies, and with universities and research institutes to develop the best available science. The next report in 2026 will build on past SECURE Water Act efforts to provide additional tools and information to support reliable water and power deliveries into the future.

## Building Science to Support Resiliency

Similar to the 2011 and 2016 SECURE Water Act Reports, this 2021 report includes an analysis of future temperature, precipitation, snowpack, and runoff changes developed using future hydroclimate projections across the West. This analysis provides a consistent set of information across past reports, while incorporating the best science available now. In addition, the 2021 Assessment adds an important new West-wide set of information based in paleohydrology.

Looking at the past can better inform the future. For example, the drought risk framework, based in paleohydrology, will help water managers better understand natural variability and provide valuable historical context and information about the nature of droughts.

## Looking Ahead to 2026

Looking forward to the next SECURE Water Act Report in 2026, Reclamation will focus on expanding the analysis to include new sets of information to inform water management in the West.

### **The paleohydrology analysis provides several tools for water managers to assess the risk of future drought, including:**

- A consistent set of streamflow reconstructions based on paleohydrology across the major Reclamation river basins;
- Methods for incorporating streamflow reconstructions in current water operations models to provide context from the past to assess future risks to water supply and demand; and
- A framework for assessing the severity, duration, and frequency of drought and to understand probabilities of going into or coming out of drought.



Columbia Basin Project, Washington State.

Reclamation will perform a deeper analysis of pluvial (wet) periods based on the paleohydrology data sets developed for this report. Additionally, the impacts of climate change to ecological resiliency and groundwater recharge and discharge can be analyzed to better understand how these impacts can be addressed. And the latest science will be incorporated to support risk analyses that can be used to build resilience to climate change.

Current efforts by Reclamation to develop common datasets and to make data, methodologies, and decision support tools more widely accessible across Reclamation will inform and benefit future efforts. Through the Reclamation Information Sharing Environment, rolled out in 2020, Reclamation has made a selection of our water related data available in open formats online and has created a centralized data portal with query tools and downloadable data. Reclamation also works with partners through the AgriMet program to maintain a cooperative network of agricultural-based weather stations across the West, providing crop consumptive water use data to a variety of users to support efficient irrigation practices.

A new GIS program established in 2019 will make Reclamation's geospatial data more accessible through a centralized data portal and increase our ability to develop maps and other tools using geospatial data. Similarly, a new Internal Applied Science Program is funding new modeling, forecasting, and decision support tools to help all Reclamation offices use the latest available data and tools effectively. Improving the consistency and availability of data across Reclamation will improve our ability to assess climate change risks and impacts across the West. Reclamation also recognizes the need to explore alternative planning paradigms to consider decision-making under deep uncertainty.

The many collaborative efforts included in this report are the result of work performed by a vast network of Reclamation offices; non-Federal customers, stakeholders, and partners; and Federal agency partners. Sharing this information with Congress and the public serves as an opportunity to showcase products, tools, and information that can benefit Reclamation and our collaborators to help us be more prepared to face the challenges of tomorrow together.

## Acronyms

°F	degree Fahrenheit
2021 Report	Water Reliability in the West - 2021 SECURE Water Act Report
2021 Assessment	Reclamation's 2021 West-Wide Climate and Hydrology Assessment
BCSD	Bias Corrected Spatial Disaggregation
CMIP5	Coupled Model Intercomparison Project Phase 5
CWMP	Cooperative Watershed Management Program
FIRO	forecast informed reservoir operations
FY	fiscal year
GIS	geographic information system
LOCA	LOcalized Constructed Analog
MCM	Machine Conditioned Monitoring
MOU	Memorandum of Understanding
MWh	megawatt-hour
NCA4	Fourth National Climate Assessment
PDSI	Palmer Drought Severity Index
RCP	Representative Concentration Pathway
Reclamation	Bureau of Reclamation
SECURE	Science and Engineering to Comprehensively Understand and Responsibly Enhance
SECURE Water Act	The 2009 Omnibus Public Land Management Act of 2009 (Public Law 111-11), Subtitle F of Title IX of the Act
Title XVI	Title XVI Water Reclamation and Reuse Program
USACE	United States Army Corps of Engineers
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
WaterSMART	Sustain and Manage America's Resources for Tomorrow
West	Western United States
WIIN	Water Infrastructure Improvements for the Nation

## Websites

Climate Change: <https://www.usbr.gov/climate>

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: <https://gdo-dcp.ucllnl.org>

Hydropower Program: <https://www.usbr.gov/power>

Reclamation Information Sharing Environment: <https://data.usbr.gov>

Reservoir Operations Pilots: <https://www.usbr.gov/watersmart/pilots>

WaterSMART Basin Studies: <https://www.usbr.gov/watersmart/bsp>

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