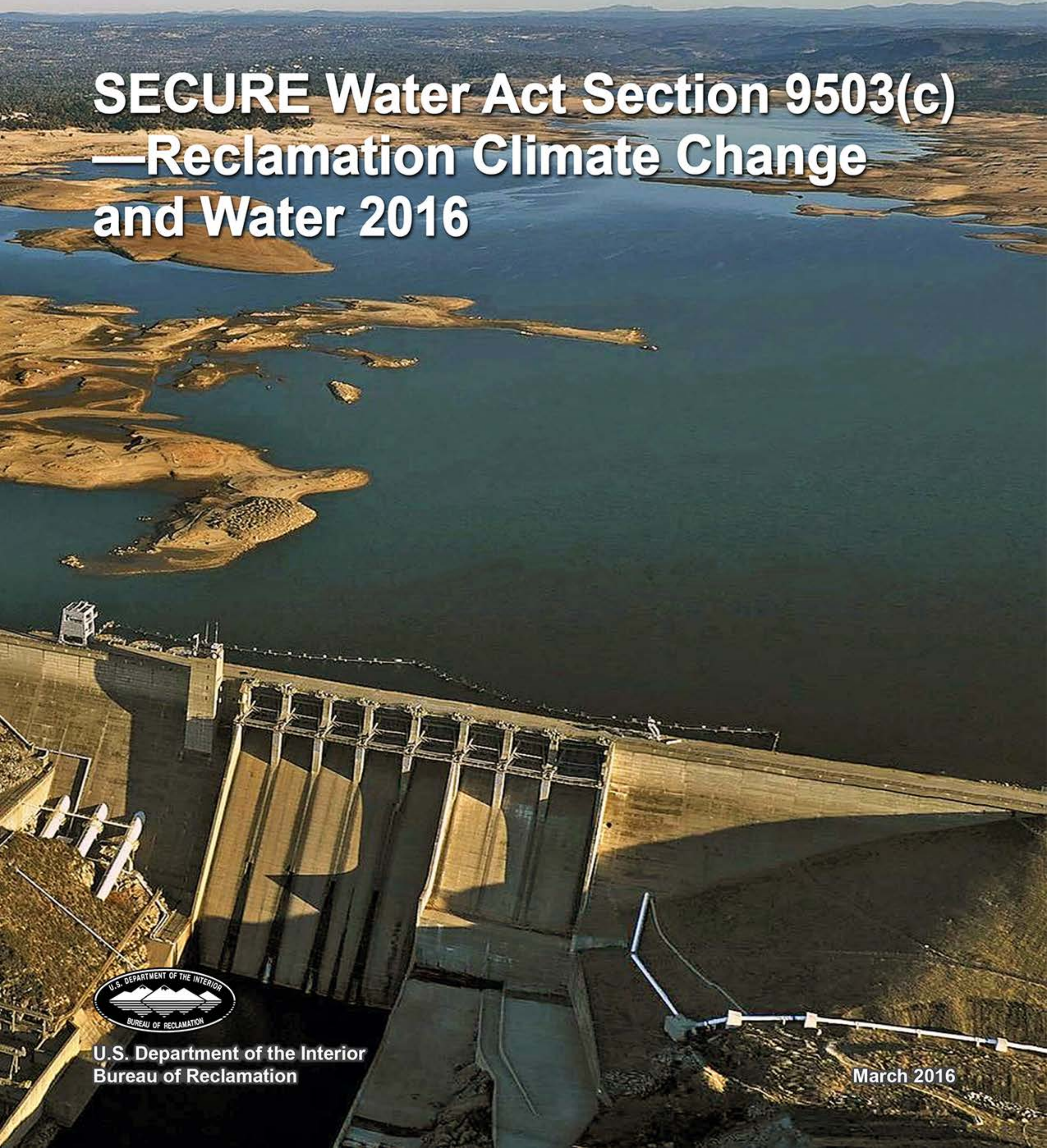
RECLAMATION

Managing Water in the West

SECURE Water Act Section 9503(c) —Reclamation Climate Change and Water 2016



U.S. Department of the Interior
Bureau of Reclamation

March 2016

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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.

On the cover: Folsom Dam, California. The Bureau of Reclamation reduced flows out of Folsom Lake to conserve Sacramento region's water supply during the month of August 2015, as water levels at the reservoir neared historic lows.

SECURE Water Act Section 9503(c)—Reclamation Climate Change and Water 2016

Prepared for

United States Congress

Prepared by

U.S. Department of the Interior
Bureau of Reclamation

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Bureau of Reclamation
Policy and Administration
Denver, Colorado

March 2016

Authors and Technical Writers in Alphabetical Order:

Pamela S. Adams
Donald M. Anderson
Levi D. Brekke, Ph.D., P.E.
Jennifer E. Cuhaciyan
Katharine G. Dahm, Ph.D., P.E.
Subhrendu Gangopadhyay, Ph.D., P.E.
Ronald Ganzfried
Christina M. Gomer
Katrina A Grantz, Ph.D.
Vickie R. Hawkins
Jobaid Kabir, Ph.D., P.E.
Deena Larsen
Dagmar K. Llewellyn
Dean T. Marrone
Peter L. Martin
Arlan V. Nickel
Jessica E. Peters
James R. Prairie, Ph.D.
Tom Pruitt
David Raff, Ph.D., P.E.
Eric L. Rothwell
Michael K. Tansey, Ph.D.
Lee E. Traynham, P.E.
Kelly D. Vick

Bureau of Reclamation Reviewers and Contributors in Alphabetical Order:

Ryan S. Alcorn
Collins K. Balcombe
Gerald T. Benock
Kelly M. Bridges
Jason M. Cameron
Gwendolyn W. Christensen
Bill D. Cole, P.E.
Art Coykendall
Michelle H. Denning
Christopher J. Eder
Marketa M. Elsner, P.E.
Amanda Q. Erath
Patrick J. Erger
David R. Felstul
Joshua E. German
William P. Goettlicher
Cynthia L. Gray
Carri A. Hessman
Anna N. Hoag, P.E.
Steven C. Hvinden
Jerome L. Jackson
Carly S. Jerla
Genevieve R. Johnson
Jennifer Johnson
Nadira Kabir, Ph.D., P.E.
Shana M. Kaplan
Charles T. Kittner
Darion T. Mayhorn
Yvette R. McKenna
Mary L. Mellema
Stephanie R. Micek
Avra O. Morgan
Joel G. Murray
Michael J. Neuman
Kenneth C. Nowak, Ph.D.
Lori Postlethwait
Michael M. Relf
John A. Rice, Ph.D.
John E. Roache
Brandi R. Rose
Ethan K. Rutledge
Noe I. Santos
Thomas R. Scott
Jack Simes
Marla Simpson
Karen M. Weghorst
Debra L. Whitney
Malcolm M. Wilson

External Reviews and Contributors in Alphabetical Order:

Jeff Arnold, Ph.D. - U.S. Army Corps of Engineers
Breton W. Bruce - U.S. Geological Survey
Martyn P. Clark, Ph.D. - National Center for Atmospheric Research
Melinda S. Dalton - U.S. Geological Survey
Ethan Gutmann, Ph.D. - National Center for Atmospheric Research
Sonya A. Jones - U.S. Geological Survey
Shih-Chieh Kao, Ph.D. - Oak Ridge National Laboratory
Paul T. Koski - Bonneville Power Administration
Brian P. Kuepper - Bonneville Power Administration
Sara G. Larsen - Western States Water Council
Thomas K. Patton - Western Area Power Administration
Gregory T. Pederson Ph.D. - U.S. Geological Survey
Christopher P. Weaver, Ph.D. - U.S. Global Change Research Program
Andrew W. Wood, Ph.D. - National Center for Atmospheric Research
Lauren E. Hay, Ph.D. - U.S. Geological Survey
Timothy R. Green - U.S. Department of Agriculture, Agricultural Research Service

Acronyms and Abbreviations

°C	degrees Celsius
°F	degrees Fahrenheit
AF	acre-feet
AFY	acre-feet per year
BA	Biological Assessment
BCSD	bias corrected and spatially downscaled
BGNDRF	Brackish Groundwater National Desalination Research Facility
BWRCSC	Bill Williams River Corridor Steering Committee
CCAWWG	Climate Change and Water Working Group
cfs	cubic feet per second
CIRES	Cooperative Institute for Research in Environmental Sciences
CMIP	Coupled Model Intercomparison Project
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
COPCO	California Oregon Power Company
CRBIA	Columbia River Basin Impact Assessment
CUP	Central Utah Project
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CVWD	Coachella Valley Water District
DBBC	Deschutes Basin Board of Control
DNRC	Montana Department of Natural Resources and Conservation
DOE	Department of Energy
DOI	Department of the Interior
DWPR	Desalination and Water Purification Research
DWR	California Department of Water Resources
EIS	Environmental Impact Statement
ENSO	El Niño/Southern Oscillation
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESRL	Earth System Research Laboratory
ESU	Evolutionarily Significant Units
FCRPS	Federal Columbia River Power System
GHG	Greenhouse gas
GNEB	Good Neighbor Environmental Board
GPCD	gallons per capita per day
GWh	gigawatt hours
GWRP	Groundwater Resources
IBWC	International Boundary Water Commission
ICS	Intentionally Created Surplus
IID	Imperial Irrigation District
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
KHP	Klamath Hydroelectric Project
kWh	kilowatt hours
LBAO	Lahontan Basin Area Office
LCC	Landscape Conservation Cooperatives
M&I	municipal and industrial
MAF	million acre-feet
MCD	Master Conservancy Districts
Mexico	United Mexican States
Mitigation Commission	Utah Reclamation Mitigation and Conservation Commission
MOU	Memorandum of Understanding
MRRIC	Missouri River Recovery Implementation Committee
msl	mean sea level
MW	megawatt
MWA	Mojave Water Agency

MWD	Metropolitan Water District of Southern California
NCAR	National Center for Atmospheric Research
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Survey
NOAA Fisheries	NOAA National Marine Fisheries Service
NPS	National Park Service
NRC	National Research Council
NWC	National Water Census
NWR	National Wildlife Refuge
OCAP	Operating Criteria and Procedures
OCR	Office of the Columbia River
OWRB	Oklahoma Water Resources Board
PDO	Pacific Decadal Oscillation
Pick-Sloan Program	Pick-Sloan Missouri Basin Program
PNCA	Pacific Northwest Coordination Agreement
PSCP	Pilot System Conservation Program
RCPP	Regional Conservation Partnership Program
Reclamation	Bureau of Reclamation
RGRWA	Rio Grande Regional Water Authority
RMJOC	River Management Joint Operating Committee
RPA	reasonable and prudent alternatives
SWP	California State Water Project
TAF	thousand acre-feet
TCID	Truckee-Carson Irrigation District
TDG	total dissolved gas
TMT	Technical Management Team
TMWA	Truckee Meadows Water Authority
TRIT	Truckee River Basin Recovery Implementation Team
TROA	Truckee River Operating Agreement
TWDB	Texas Water Development Board
U.S.	United States
UKL	Upper Klamath Lake
USACE	U.S. Army Corps of Engineers
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WACCIA	Washington Climate Change Impacts Assessment
WaDE	Western Data Exchange
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WAUSP	Water Availability and Use Science Program
WCRP	World Climate Research Program
WestFAST	Western Federal Agency Support Team
WRWUA	Weber River Water Users Association
WSWC	Western States Water Council
WWCRA	West-Wide Climate Risk Assessment

About this Report

This report is being submitted by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act (Subtitle F of Title IX of P.L. 111-11). This 2016 SECURE Water Act Report to Congress is organized into ten complementary chapters:

- **Chapter 1: West-Wide Overview**: Highlights findings from basin-specific studies to provide a West-wide perspective on anticipated impacts to water resources due to climate change and corresponding adaptation strategies considered through collaborative studies.

- **Chapter 2: Hydrology and Climate Assessment**: Provides a summary of the projected hydrology and climate, impacts to water supply and demand, climate monitoring, research, and coordination.

- **Chapters 3–10: River Basin Summary Chapters**: Chapters 3 through 9 each provides a summary discussion for one of the eight major Reclamation river basin identified within the SECURE Water Act, and Chapter 10 presents a separate discussion for other western river basins not listed in the Act. Each river basin summary chapter includes information on the river basin setting, implications for various water and environmental resources, adaptation strategies, and coordination activities.
    - **Chapter 3: Colorado River Basin**
    - **Chapter 4: Columbia River Basin**
    - **Chapter 5: Klamath River Basin**
    - **Chapter 6: Missouri River Basin**
    - **Chapter 7: Rio Grande Basin**
    - **Chapter 8: Sacramento and San Joaquin River Basins**[1]
    - **Chapter 9: Truckee River Basin Summary**
    - **Chapter 10: Other Western River Basins**

See Figure ES-1 for a map of the river basins listed in the SECURE Water Act and Figure ES-2 for a diagram of the report structure. This report summarizes studies completed in the last 5 years that focus on current and future water supply and demand and identify a range of potential strategies to address projected imbalances.

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[1] The SECURE Water Act identifies the Sacramento and San Joaquin Rivers as separate reporting basins. However, these two basins are discussed jointly in Chapter 8, given the interwoven aspects of water management in these basins.

The studies referenced in this report are technical assessments and do not provide recommendations or represent a statement of policy or position of the Bureau of Reclamation, the Department of the Interior, or the collaborative funding partners. This report does not propose or address the feasibility of any specific project, program or plan. Nothing in the report is intended, nor shall the report be construed, to interpret, diminish, or modify the rights of any study participants under applicable law. Nothing in the report represents a commitment for provision of Federal funds.

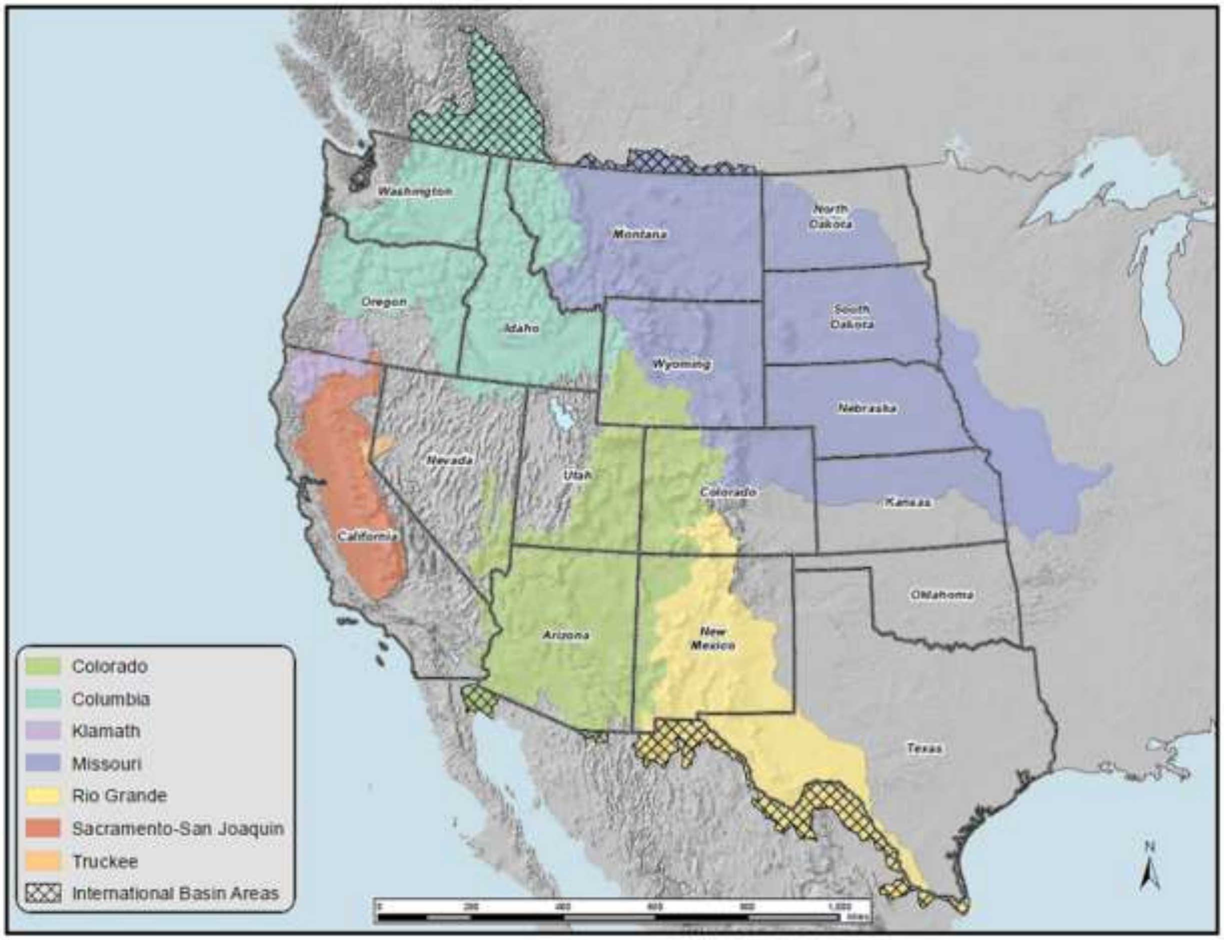


Figure ES-1. Eight major Reclamation river basins listed in the SECURE Water Act. Note that the Act identifies the Sacramento and San Joaquin Rivers as separate reporting basins, but these two basins are discussed jointly in this report given the interwoven aspects of water management within them.

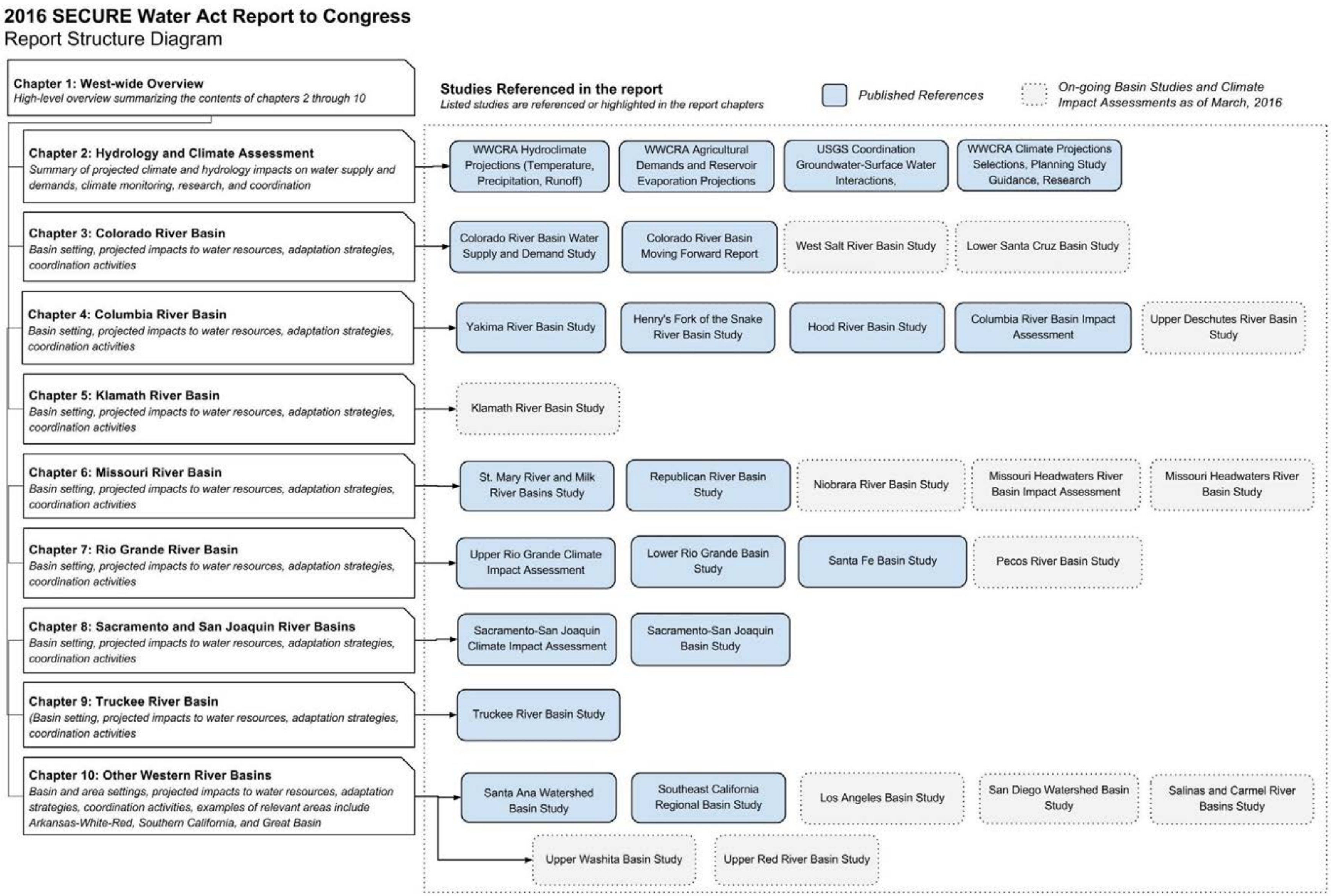


Figure ES-2. 2016 SECURE Report to Congress report structure diagram and key references.

RECLAMATION

Managing Water in the West

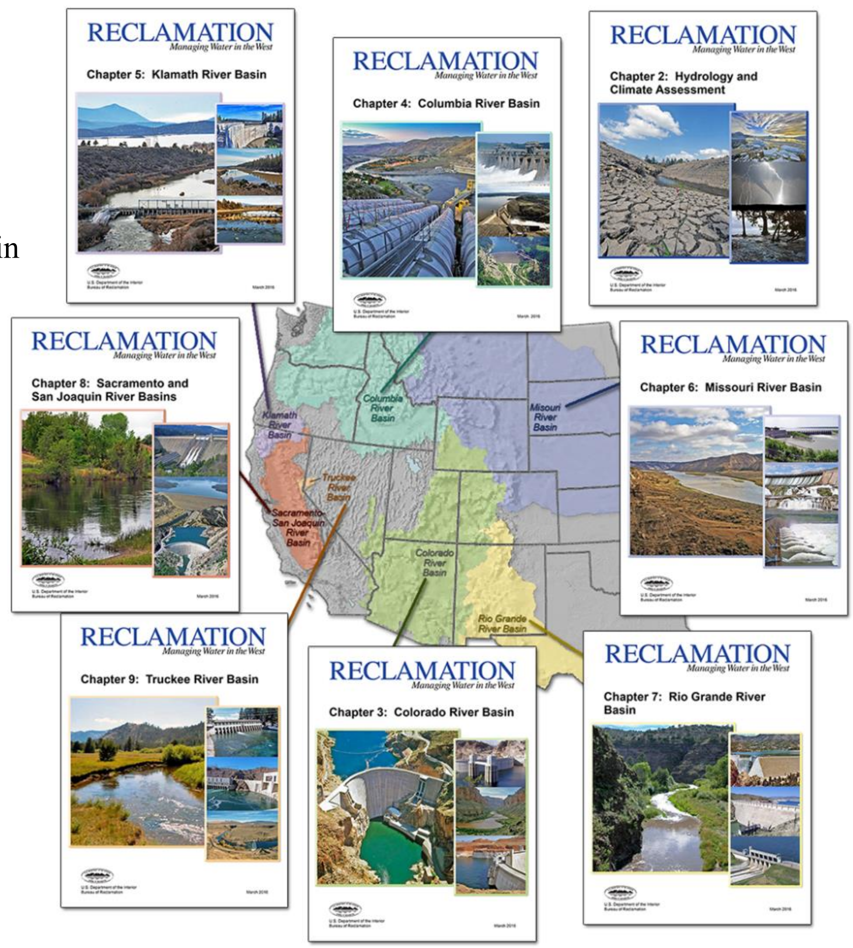
Chapter 1: West-Wide Overview

U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This overview chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act (Subtitle F of Title IX of P.L. 111-11). The 2016 SECURE Water Act Report builds upon the first SECURE Water Act Report, submitted to Congress in 2011,[2] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West by identifying additional impacts of climate change and adaptation strategies throughout western river basins. These strategies are developed in coordination with Reclamation stakeholders and customers through the Sustain and Manage American Resources for Tomorrow (WaterSMART) Basin Studies and additional programs and activities.



This chapter provides a West-wide summary of the information presented in Chapters 2 through 10 of this SECURE Water Act Report to Congress, including highlights in the following areas:

- Identification of the key climate change risks and anticipated impacts to western water resources—those relevant West-wide, as well as those specific to certain western basins;
- Discussion of strategies being considered and implemented to mitigate and adapt to these climate change impacts; and

An overview of Reclamation's coordination activities with western partners to address emerging water-management challenges associated with climate change.

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[2] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: http://www.usbr.gov/climate/SECURE/docs/SECUREWaterReport.pdf.

This chapter is organized as follows:

- **Section 1** provides relevant background information on the implementation of the SECURE Water Act by the Department of the Interior (DOI) and Reclamation.
- **Section 2** summarizes information on the projected effects of climate change on the hydrology of the Western United States.
- **Section 3** addresses the effects of, and risks resulting from, global climate change in terms of anticipated impacts on water supplies and water operations. This includes a discussion of impacts to water deliveries; hydropower; recreation; flood management; water quality; groundwater management; watershed integrity; and fish, wildlife, and ecological resources.
- **Section 4** addresses mitigation and adaptation strategies considered by Reclamation and its western partners to address the anticipated impacts of climate change on water resources.
- **Section 5** highlights accomplishments in implementing Reclamation's Climate Change Adaptation Strategy. Relevant examples are included to summarize coordination activities conducted by Reclamation with fellow Federal agencies, State water resource agencies, and other western stakeholders. In particular, this section focuses on activities undertaken since delivery of the SECURE 2011 Report to Congress.

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1 Introduction

1.1 About Reclamation

The Bureau of Reclamation (Reclamation), established in 1902, is best known for the dams, powerplants, and canals it constructed within the 17 Western United States (U.S.). Today, Reclamation is the largest wholesaler of water in the Nation. It provides more than 10 trillion gallons of water each year for municipal use and provides water to approximately 10 million acres of irrigated farmland that collectively produce 60 percent of the Nation's vegetables and 25 percent of its fruit and nuts. Reclamation also is the largest producer of hydroelectric power in the Western U.S. Its 53 powerplants generate more than 40 billion kilowatt-hours of electricity annually, enough to serve some 3.5 million households and produce nearly a billion dollars in power revenues.

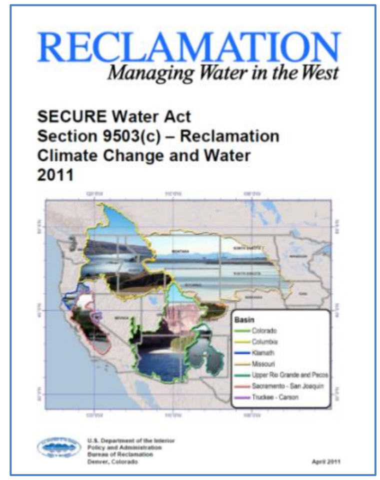
Reclamation's mission is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. As the largest manager and wholesaler of western water, Reclamation has a responsibility to consider potential risks to western water supplies, and to help implement measures that ensure water will be managed as effectively and sustainably as possible.

A growing risk to effective western water management is climate change. In recent decades, climate science has highlighted a broad suite of future challenges for managing western water, in addition to risks already posed by natural variations in climate and pressures associated with growing populations. This includes impacts to water supplies, water demands, and environmental conditions that have the potential to affect Reclamation's ability to fulfill its mission. In light of these challenges, Reclamation is working with its western partners to identify appropriate forward-looking adaptive actions that add resiliency and reliability to water-management planning and practices.

1.2 About Section 9503 of the SECURE Water Act

The Omnibus Public Land Management Act of 2009 (Public Law 111-11) was enacted on March 30, 2009. Subtitle F of Title IX of that legislation, known as the SECURE Water Act, recognizes that climate change poses a significant challenge to the protection of adequate and safe supplies of water, which are fundamental to the health, economy, security, and ecology of the United States. Section 9503 of the SECURE Water Act authorizes Reclamation to coordinate and partner with others to ensure the use of best available science, to assess specific risks to water supply, to analyze the extent to which water supply risks will impact various water-related benefits and services, to develop appropriate mitigation strategies, and to monitor water resources to support these analyses and assessments.[3] The SECURE Water Act also directs Reclamation to submit reports to Congress, 2 years after enactment and every 5 years thereafter, describing progress in carrying out those activities.

1.3 The 2011 SECURE Water Act Report to Congress



In 2011, Reclamation published the *SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water 2011 Report to Congress*. That report assessed climate change risks and how those risks could impact water operations, hydropower, flood control, and fish and wildlife in the Western U.S. It represented the first consistent and coordinated assessment of risks to future water supplies across eight major Reclamation river basins, and identified several increased risks to Western U.S. water resources during the 21st century. Specific projections cited in the report include:

- A temperature increase of 5–7 degrees Fahrenheit (°F) during the 21st century;
- A precipitation increase over the northwestern and north-central portions of the Western U.S., and a decrease over the Southwestern and South-central areas; and
- A decrease across much of the West in April 1st snowpack.

The 2011 SECURE Water Act Report to Congress used the World Climate Research Programme (WCRP) global climate projections developed through its Coupled Model Intercomparison Project (CMIP), which are released roughly every 5 to 7 years. The 2011 SECURE Water Act assessment was developed using hydrologic projections featured in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment and developed as part of the WCRP CMIP Phase 3, referred to here as CMIP3 Projections (i.e., the contemporary projections available in 2011). The report noted that projected changes in temperature and precipitation are expected to impact the timing and quantity of streamflows in all western basins, which would impact water available for farms and cities, hydropower generation, fish and wildlife, and other uses such as recreation.

This 2016 SECURE Water Act Report to Congress was developed using the most current hydrologic projections featured in the IPCC Fifth Assessment and developed as part of the WCRP CMIP Phase 5, referred to here as CMIP5 Projections. The difference between CMIP3 and CMIP5 projections is relatively minor when assessing the range of basin-scale potential future climatic and hydrologic conditions.

[3] The SECURE Water Act also authorizes the Department of Energy (Section 9505) and the Department of Interior's United States Geological Survey (Sections 9507 and 9508) to assess and report on the impacts of climate change on national hydropower production and water data enrichment, respectively.

Figure 1–1 illustrates the relative similarity of CMIP3 and CMIP5 projections when assessing the full range of future conditions for key water supply indicators assessed in this report.

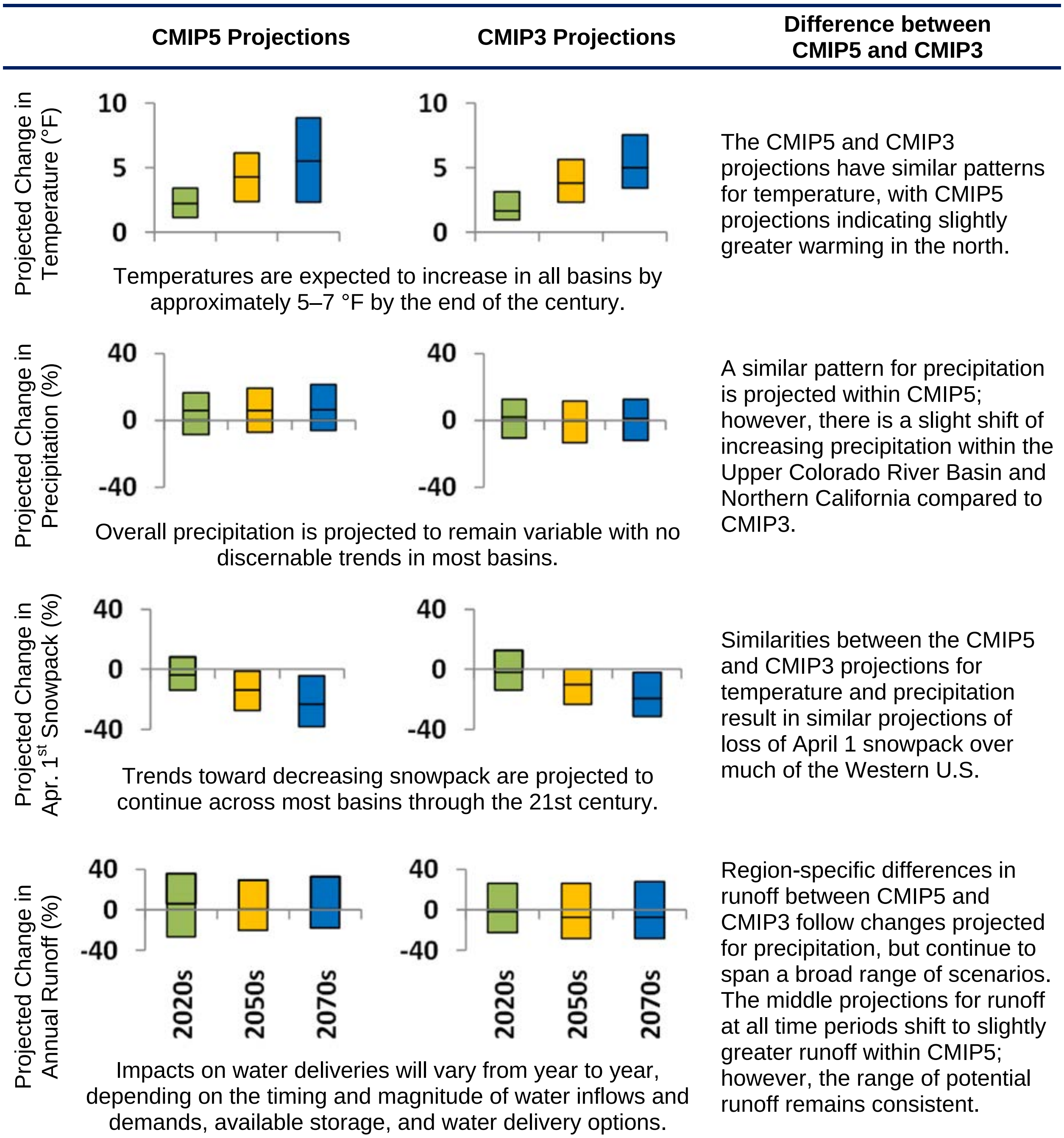


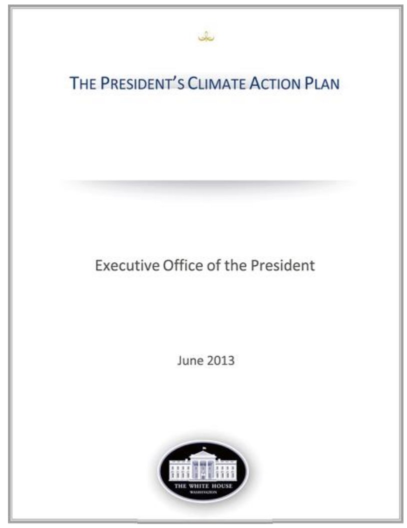
Figure 1–1. Comparison of CMIP3 and CMIP5 projections for temperature, precipitation, April 1st snowpack, and annual runoff relative to the 1990s for the 2020s, 2050s, and 2070s.

Bars represent the 10th (bottom of the box), 50th (middle black line), and 90th (top of the box) percentile projections for CMIP3 and CMIP5 for the Colorado River Basin at Imperial Dam.

This report takes advantage of the best available datasets and modeling tools, follows methodologies documented in peer-reviewed literature, and provides a consistent update to the assessment presented in the 2011 SECURE Water Act Report. The report also acknowledges the uncertainties in future hydroclimate possibilities. (See Section 2.2 of this chapter and additional discussions in chapter 2 of the report.)

1.4 Subsequent Federal Action on Climate Change

At the time of the 2011 SECURE Water Act Report, Reclamation was already working with stakeholders across the West to build a sustainable water strategy to meet the Nation's water needs. Since 2011, additional Federal actions have been taken to address risks associated with climate change. Listed are some of the key actions implemented by the President, by the Department of the Interior (DOI), and by Reclamation:


THE PRESIDENT'S CLIMATE ACTION PLAN

Executive Office of the President

June 2013

- **The President's Climate Action Plan**. In June 2013, President Obama released his *Climate Action Plan*, which provides a blueprint for steady national and international action to slow the effects of climate change. The plan includes efforts to identify vulnerabilities of the water supply sector to climate change, prepare for future flood risks, and manage drought through activities such as a National Drought Resilience Partnership. In March 2014, as follow-up to this plan, the Obama Administration kicked-off the *Climate Data Initiative* to more effectively disseminate the Federal Government's extensive, freely available, climate-relevant data resources.

- **DOI's Climate Change Adaptation Policy** (523 DM1). This policy, issued in December 2012, articulates and formalizes the Departmental approach to climate change adaptation and provides guidance to DOI bureaus and offices for addressing climate change impacts on the Department's mission, programs, operations, and personnel. It also establishes clear Departmental leadership responsibilities for climate change adaptation implementation, and directs Reclamation and other bureaus to participate in relevant Departmental workgroups.

- **DOI's Climate Change Action Plan**. Annually, DOI publishes a plan for addressing concerns related to climate change. DOI's 2013 Plan focused on assessing the Department's climate change-related vulnerabilities. Its 2014 Plan further assessed the Department's work to address climate change through implementation of Executive Order 13653 ("Preparing the United States for the Impacts of Climate Change," signed November 1, 2013) and DOI's *Climate Change Adaptation Policy*.

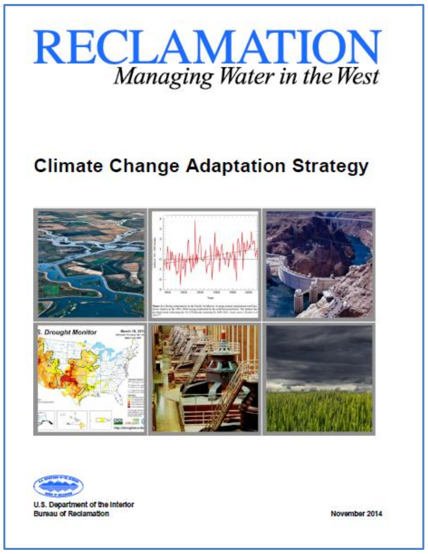
- **Reclamation's Climate Change Adaptation Policy** (CMP P16). In March 2015, Reclamation adopted an overarching policy establishing how

Reclamation addresses climate change impacts to its mission, facilities, operations, and personnel, in accordance with Departmental Policy 523 DM1. Among other things, this policy specifies that Reclamation will develop appropriate climate adaptation strategies to address impacts to land, water, natural, energy, cultural, and tribal resources; to Reclamation facilities and assets; and to personnel.

1.5 Reclamation's Climate Change Adaptation Strategy

In November 2014, Reclamation published its Climate Change Adaptation Strategy to build on existing actions and identify new activities that extend climate change adaptation efforts across Reclamation's mission responsibilities. Reclamation has made significant progress in assessing the impacts of climate change to water resources and implementing on-the-ground actions to mitigate impacts. The strategy highlights additional actions that are necessary to use information about future climate change to make decisions now about how best to operate Reclamation reservoirs, prioritize investments in new or improved facilities, and protect species and habitat in a changing climate. The strategy identifies four primary goals to improve Reclamation's ability to consider climate change information in agency decision making:

- **Goal 1 - Increase Water Management Flexibility:** Increase flexibility in reservoir operations, water conservation, efficiency, and reuse to maximize the efficient use of available water supplies and existing water infrastructure.

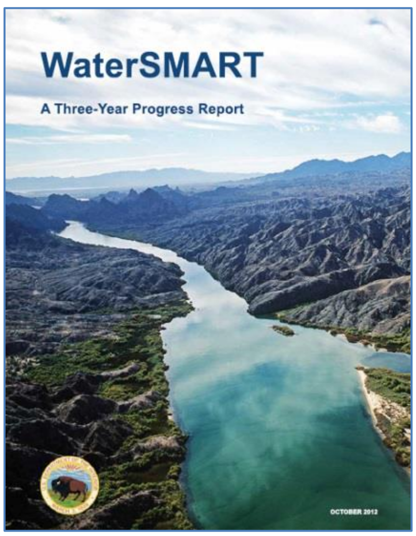


- **Goal 2 - Enhance Climate Adaptation Planning:** Develop capabilities, tools, and guidance to incorporate climate change information across Reclamation's planning processes. These enhanced planning efforts will help Reclamation understand and address climate change impacts to the delivery of water and power, to infrastructure, and to ecosystems and habitat affected by Reclamation projects.
- **Goal 3 - Improve Infrastructure Resiliency:** Improve infrastructure resilience, reliability, and safety to prepare for increased intensity and frequency of floods and droughts. Ultimately, Reclamation will include climate change considerations within evaluations of infrastructure safety as well as in setting priorities for operations and maintenance of existing facilities.
- **Goal 4 - Expand Information Sharing:** Collaborate with stakeholders to support mutual climate adaptation efforts through sharing data and tools.

The President's Climate Action Plan and Reclamation's Climate Change Adaptation Policy both identify the continued development of sound science, water management planning and conservation, and increasing the resiliency of infrastructure as critical actions to prepare the United States for the impacts of climate change. Highlights and accomplishments in implementing Reclamation's Climate Change Adaptation Strategy are provided in Section 4 of this chapter.

1.6 Reclamation's WaterSMART Program and Activities Addressing the SECURE Water Act

WaterSMART (Sustain and Manage American Resources for Tomorrow) was established in February 2010 by DOI as a broad framework for Federal collaboration with States, tribes, local governments, and nongovernmental organizations to work toward secure and sustainable water resources. Reclamation has implemented the climate change adaptation activities authorized under Section 9503 of the SECURE Water Act through the **Basin Study Program**, which is part of WaterSMART. The Basin Study Program includes three complementary activities that represent a comprehensive approach to incorporate the best available science into planning activities for climate change adaptation:



- **Basin Studies:** Reclamation partners with basin stakeholders to conduct comprehensive studies to define options for addressing future water demands in river basins in the West where imbalances in supply and demand exist or are projected. These studies are comprehensive technical assessments that identify current or future imbalances between water supply and demand resulting from climate change and other stressors. In response to the identified imbalances, the studies assess options and strategies for addressing future water demands.
- **West-Wide Climate Risk Assessments (WWCRA):** WWCRAs complement the Basin Studies by developing key data on climate-induced risks and impacts to Reclamation's operations (including climate projections and baseline water supply, water demand, operational, and environmental response analyses) to provide a foundation for future Basin Studies as well as for project-specific applications. WWCRAs also generate important information, tools, and guidance that support the integration of climate information into planning activities, consistent with Reclamation's Climate Change Adaptation Strategy.
- **Landscape Conservation Cooperatives (LCC):** LCCs provide tools for analyzing and addressing climate change impacts for use in Basin Studies.

> The LCCs are partnerships of governmental (Federal, State, tribal, and local) and nongovernmental entities. The primary goal of the LCCs is to bring together science and resource management to inform strategies for adapting to climate change and other stressors within an ecological region or "landscape." Each LCC functions in a specific geographic area; the series of LCCs together form a national network. Reclamation and the Fish and Wildlife Service co-lead the Desert and Southern Rockies LCCs.[4]

Through WaterSMART, Reclamation also works with an array of partners to cost-effectively develop new water sources and make the most of existing supplies. In addition to the Basin Study Program, WaterSMART includes grants for water and energy improvement projects (**WaterSMART Grants**); water reclamation and reuse projects that provide flexibility during water shortages by diversifying the water supply (**Title XVI Program**); a comprehensive approach to drought planning and implementation actions that address water shortages (**Drought Response Program**); support for the water sustainability efforts of collaborative watershed groups (**Cooperative Watershed Management Program**); smaller-scale water conservation planning and improvements (the **Water Conservation Field Services Program**); and a program to identify resilient infrastructure investments that take into account potential effects of climate change while continuing to support healthy watersheds (**Resilient Infrastructure Program**).

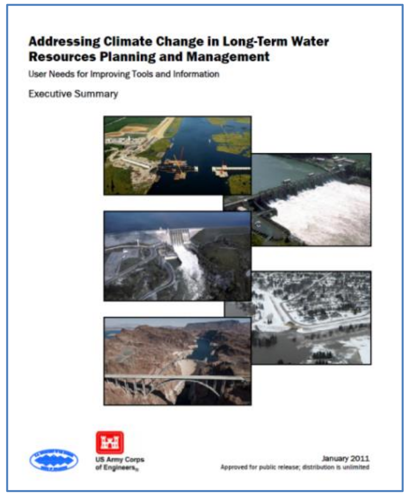
Also under DOI's WaterSMART program, the U.S. Geological Survey (USGS) supports science activities that include developing estimates for components of the water budget; assessing groundwater resources; working with stakeholders to address water resource issues in basins that are experiencing water conflicts; enhancing the nation's streamflow and groundwater networks; and understanding drought impacts. In addition the USGS provides funding to States to participate in the National Groundwater Monitoring Network and to improve water use data through the Water Use Data and Research program.

Reclamation is also actively engaged with research partners to develop and share information for a common understanding of climate change impacts to water resources in the West. The **Science and Technology Program** is a Reclamation-wide competitive, merit-based applied research and development program focused on innovative solutions for water and power challenges in the Western U.S. Reclamation's Research and Development Office also manages the **Desalination and Water Purification Research Program**, which funds research projects to develop and pilot test new clean water treatment technologies that can make degraded water supplies available for consumptive use. Clean water

[4] Reclamation also participates in the other LCCs located in the 17 Western States, which include the Great Northern LCC, North Pacific LCC, Great Basin LCC, California LCC, Plains and Prairie Potholes LCC, Great Plains LCC, and Gulf Coast Prairie LCC. Currently, Reclamation is a steering committee member on the Great Northern LCC.

technologies developed in this program are implemented through complementary research projects under the WaterSMART Title XVI Program.

Reclamation partners with the U.S. Army Corps of Engineers (Corps), USGS, the National Oceanic and Atmospheric Survey (NOAA), and others through the Climate Change and Water Working Group (CCAWWG) to identify mutual science needs for short-term water management decisions and long-term planning. These programs are fundamental to developing new information for adapting to climate change by assessing the current state of knowledge, identifying where gaps exist, and finding opportunities to address those gaps.



Many of the activities carried out as part of WaterSMART are leveraged by partner participation to implement adaptation strategies identified in Basin Studies. Sections 4 and 5 of this chapter include further discussion of these activities, including how they fit within Reclamation's Climate Change Adaptation Strategy and accomplishments to date.

2 Climate and Hydrology

Climate change poses a fundamental challenge to Reclamation's mission and the national economy. The effects of climate change are already being felt across the West. As a result, Reclamation and its water management partners must be prepared to respond to shifts in the baseline of what is considered "normal" for drought, floods, water availability, and water demands over coming decades. Observed and projected changes to western climate and hydrology are summarized in Chapter 2 of this report. Key observations and projections relevant to western water management include the following:

- Temperature increases have resulted in decreased snowpack, differences in the timing and volume of spring runoff, and an increase in peak flows for some Western U.S. basins. Observed increases in mean annual temperature have been approximately 2 °F (1.1 degrees Celsius [°C]) since 1900. Continued warming of roughly 5 to 7 °F (3 to 4 °C), depending on location, is projected over the course of the 21st century. (See Figure 1–2).
- Precipitation changes are also expected to occur, interacting with warming to increase the duration and frequency of droughts and resulting in larger and more numerous floods, varying by basin. The increased intensity of droughts and floods raises concerns about infrastructure safety, the resiliency of species and ecosystems to these changes, and the ability to maintain adequate levels of hydropower production.

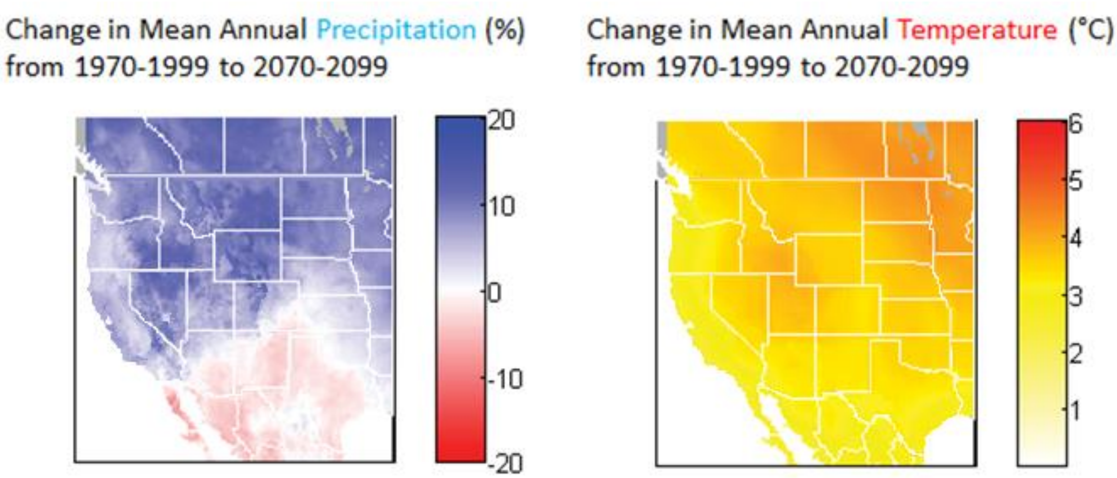


Figure 1–2. Projected changes to temperature and precipitation in the latter 21st century.

Figure represents the median change from a large collection of WCRP's Coupled Model Intercomparison Project phase 5 climate projections spatially downscaled over the U.S. Temperatures are shown to increase throughout the West by 2–5 °C. Mean annual precipitation is largely expected to increase for much of the Western U.S. with the exception of the Southwest, where precipitation is expected to decrease by between 5 and 20 percent.

The impacts to snowpack and runoff affect the timing and availability of water supplies. More variation in hydrology will make it more difficult for Reclamation to address competing demands for water. Key trends related to runoff include the following:

- Winter runoff is projected to increase over the West Coast basins from California to Washington and over the north-central U.S., but little change to slight decreases are projected over the area from the Southwestern U.S. to the Southern Rockies.
- Summer runoff is projected to decrease substantially over a region spanning southern Oregon, the Southwestern U.S., and the Southern Rockies. However, north of this region warm-season runoff is projected to change little or to increase slightly.
- Projected increases in annual precipitation in the northern tier of the Western U.S. could counteract decreases in warm-season runoff, whereas decreases in annual precipitation in the southern part of the Western U.S. could amplify the effect of decreases in warm-season runoff.

2.1 West-Wide Climate Risks to Water Supplies

It is expected that annual and seasonal natural runoff will continue to reflect the continuing changes to the climate. It is not possible to infer water management impacts from these natural runoff changes alone. Water management systems across the West have been designed to operate within envelopes of local hydrologic variability, handling annual and seasonal variations typical for their specific localities. As a result, their physical and operating characteristics vary in terms of storage capacity and conveyance flexibility. The ability to use water storage resources to control future hydrologic variability and changes in runoff seasonality is an important consideration in assessing potential water management impacts due to natural runoff changes.

The impacts of climate change on water resources give rise to difficult questions about how best to operate Reclamation facilities to address growing demands for water and hydropower now and how to upgrade and maintain infrastructure to optimize operations in the future. Figure 1–3 summarizes key risks to western water supplies identified in Reclamation's WaterSMART Basin Study Program. Additional information on impacts to water resources specific to each western river basin, including the strategies to address potential water shortages, is included in Chapters 3 through 10.

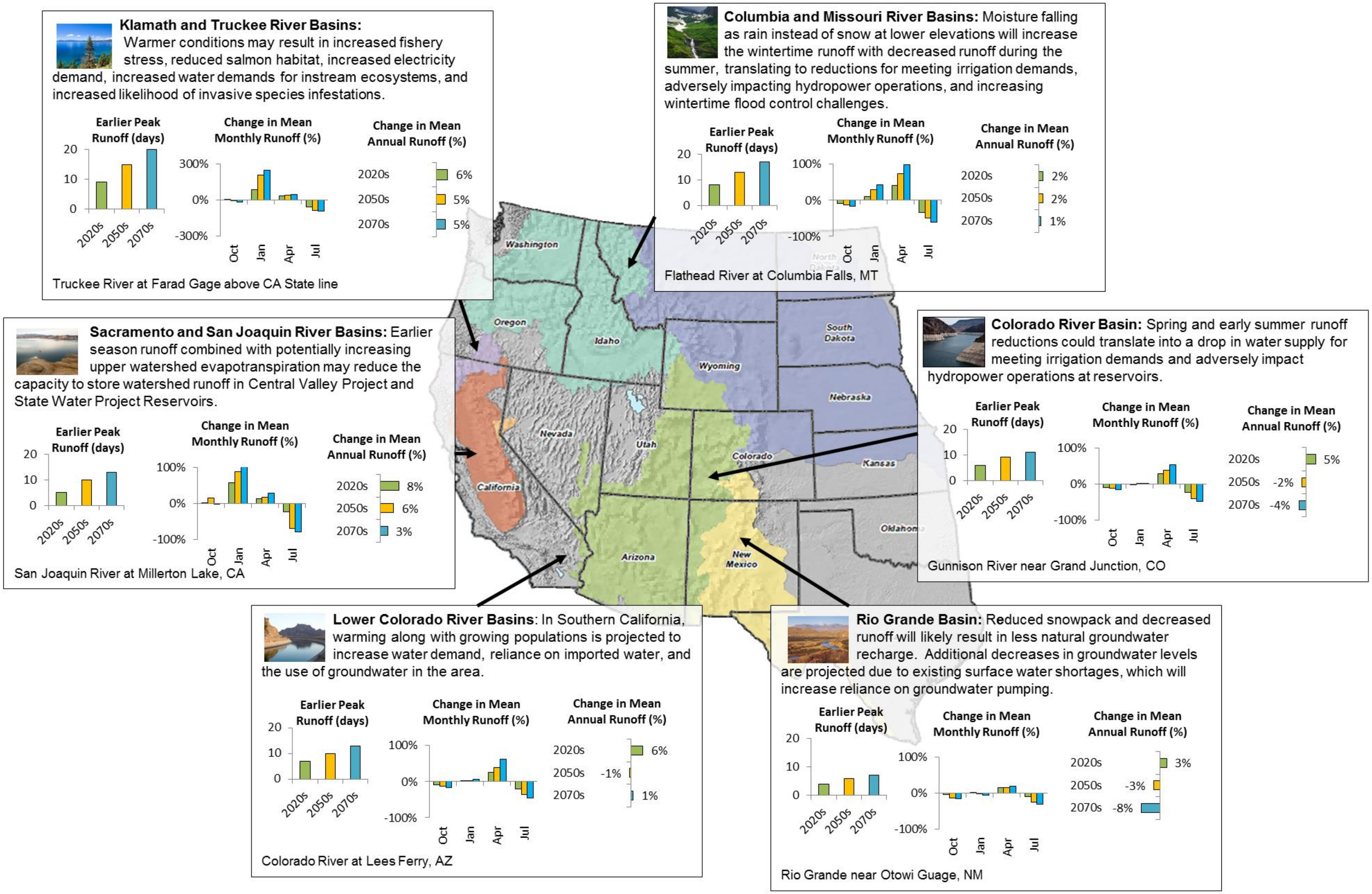


Figure 1–3. Projected climate impacts to water resources in western river basins.

2.2 Uncertainties in Climate and Water Projections

This report summarizes analyses on potential future climate and hydrologic conditions in the Western U.S. The information presented is gathered from Reclamation studies as well as other peer-reviewed literature and reflects the use of best available datasets and data development methodologies. While this report summarizes potential future climate and hydrologic conditions based on the best available datasets and data development methodologies, its characterization of future hydroclimate possibilities implicitly reflects several uncertainties.

- Uncertainties arise characterizing future global climate forcings such as greenhouse gas emissions, simulating global climate response to these forcings, correcting global climate model outputs for biases, spatially downscaling global climate model outputs to basin-relevant scales, and characterizing the hydrologic response to projected climatic changes within specific regions or basins.
- The impacts of climate change on water resources are evident; however, it is important to acknowledge the uncertainties inherent within climate change science and how they contribute to making climate adaptation a difficult challenge. Projections of future climate change contain uncertainties that vary geographically and depend on the weather variable of interest (e.g., temperature, precipitation, and wind).
- Trying to identify an exact climate change impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. As an example, it is not possible to say with certainty whether climatic change makes a particular flood or drought event exactly twice as likely to occur; however, current science may provide enough evidence to judge whether such an event is more or less likely to occur overall.

The concept of risk management in the face of uncertainty is one that is becoming well recognized for climate change adaptation. Notwithstanding these uncertainties, the Third National Climate Assessment identifies viable decision support tools currently available to support the incorporation of climate information into resource management decisions, including risk assessments, targeted projections for high-consequence events such as floods and droughts, and vulnerability assessments. In spite of the uncertainties, Reclamation and its stakeholders have identified a number of possible adaptation strategies, which are presented within this report.

3 Impacts to Water Management

In many regions of the West, projected climate-driven changes in water supply (quantities and timing), along with increased demands for water, are expected to strain the ability of existing infrastructure and operations to meet water needs – not only for consumptive uses such as agricultural, municipal, and industrial activities, but also for hydropower, flood control, fisheries, wildlife, recreation, and other largely nonconsumptive water-related benefits.

This section provides an overview of anticipated impacts to specific categories identified by the SECURE Water Act for analysis: water deliveries; hydropower; recreation; flood management; fish, wildlife, and ecological resources; and water quality. In addition, this section addresses anticipated impacts to groundwater management and watershed integrity, as these also impact the effectiveness of managing water supplies to provide multiple public benefits.

3.1 Water Deliveries

Both the timing and quantity of runoff are expected to continue to be impacted by the changing climate. Together with changes in the magnitude and timing of the demands for water and energy, this will impact the ability of existing water infrastructure to satisfy public interests in diverting, storing, and delivering water when and where it is needed. Shifts in water availability will impact water uses and increase reliance on deliveries of water from reservoir storage or groundwater. The likelihood of increased year-to-year variability in surface water supplies also presents challenges. Figure 1–4 summarizes key considerations and anticipated impacts to water deliveries.

Additional examples are provided below, as illustrations of the impacts described:[5]

- In the **Colorado River Basin**, future projected development of water supplies and increased consumptive use in the Upper Basin, combined with potential reductions in future supply, are expected to result in reduced volumes of water stored in system reservoirs and a vulnerability to water delivery shortages.
- In the **Missouri River Basin**, irrigation shortages are generally expected to increase, and earlier calls on reservoir releases for irrigation water are expected to lead to a stronger reliance on stored water during the late summer months.

[5] Only select examples are provided for each category, as illustrations of the impacts described. Typically, additional examples are identified and described in one or more of the river basin chapters 3–10.

Changes in Water Supply and Demand

Climate assessments project that the manageable water supply, in general, will decline in much of the West. A decrease of up to 8 percent in average annual stream flow is projected in several river basins, including the Colorado, the Rio Grande, and the San Joaquin river basins.

Changes in Timing of Runoff and Water Availability

West-wide, runoff is expected to shift to earlier times of the year (less in summer, more in winter and spring), making it more difficult to manage water deliveries as they have been managed in the past. Reservoirs are anticipated to fill earlier in the year, with a corresponding reduction in the water supply available through the summer season.

Change in Snowpack versus Rainfall

Across the West, snowpack generally is projected to decrease as more precipitation falls as rain and warming temperatures cause earlier snowmelt. Water deficits are expected to worsen throughout the Columbia River Basin due to more precipitation falling as rain, shifts in runoff timing, lengthening of the growing season, and greater reliance on stored water.

More Extreme Weather Events

A likelihood for more frequent extreme weather events is projected in many areas of the West. In the Rio Grande Basin, an increased potential for strengthening of the summer monsoons is projected, with corresponding increases in the portion of the basin's precipitation falling downstream of current water storage infrastructure.

Figure 1–4. Anticipated impacts to water deliveries.

- For the **Central Valley Project** in California, projected earlier seasonal runoff will cause reservoirs to fill earlier, thereby reducing overall storage capability, as current flood control constraints limit early season storage in these reservoirs. End-of-September reservoir storage is projected to decrease by 3 percent over the course of the 21st century.
- In the **Klamath Basin**, the seasonal shift in runoff, more precipitation falling as rain, and the expected increased reservoir evaporation are projected to result in more years with water shortages.
- In the **Rio Grande Basin**, decreases in winter snowpack are projected to result in a decreased water supply (e.g., by about one-fourth to one-third in the upper basin over the course of the 21st century), limiting storage available for use during the summer irrigation season.

3.2 Hydropower

Hydropower production at Reclamation facilities provides a large, renewable supply of power to the West with a relatively small carbon footprint, and helps keep consumer power costs low. Reclamation is the largest producer of hydroelectric power in the Western U.S. Reclamation's 53 powerplants provide more than 40 billion kilowatt-hours annually, generating nearly a billion dollars in power revenues and producing enough electricity to serve 3.5 million homes. Hydroelectric generation to satisfy power demands is sensitive to climate change impacts on basin precipitation, the amount and timing of river flows, and reservoir levels. Figure 1–5 summarizes the anticipated impacts to western hydropower.

Changes in Supply and Runoff Timing

West-wide, runoff is anticipated to shift to earlier periods of the year (less in summer, more in the winter and spring). Where peak demand for hydropower occurs during the hottest weeks of summer, shift in runoff timing is expected to impact summer hydropower revenues due to a reduction in peak-season hydropower generation.

Changes in Hydropower Demand

The warming projected across the West is generally expected to decrease energy demand during winter (for heating) and increase demand during summer (for cooling). These changes might necessitate adjustments in reservoir operations to better align with demand, although the reduced summer inflow may present its own challenges.

Figure 1–5. Anticipated impacts to hydropower.

Select examples are provided below, as illustrations of the impacts described:

- In some western river basins, including the **Colorado River and Upper Rio Grande basins**, reduced flows and lower reservoir levels together with increased consumptive water demands associated with climate change are anticipated to result in reduced hydropower production.
- In the Pacific Northwest, power customers currently use more electricity in the winter than in the summer, so projected increases in winter and spring flows in the **Columbia River Basin** should not negatively affect generation to meet power demands during those periods. Nevertheless, decreased summer flows could present challenges to meet increasing summer season power demands, partly associated with increasing summer temperatures.

3.3 Recreation

The recreation areas developed as a result of Reclamation water projects are among the Nation's most popular for water-based outdoor recreation. Reclamation projects include approximately 6.5 million acres of land and water that is, for the most part, available for public outdoor recreation. Reclamation and its partners manage 289 recreation sites that have 90 million visits annually. Recreational uses are diverse, and include seasonal activities such as swimming, fishing, and boating on reservoirs and rivers. Figure 1–6 summarizes anticipated impacts on recreation including impacts to flatwater and river recreation.

Flatwater Recreation

Increased summer and winter temperatures may increase visitation at reservoirs for camping, boating, swimming, fishing, and other activities. Lower reservoir levels will mean a decrease in the area available for those activities. In some cases, reduced reservoir storage could make it more difficult for water-dependent recreational opportunities.

River Recreation

Increased summer and winter temperatures may increase the popularity of recreational opportunities in and along Western rivers, while decreased snowpack resulting in reduced flows in key river tributaries has negative implications for flow-dependent recreation such as boating and fishing.

Figure 1–6. Anticipated impacts to recreation.

Select examples are provided below, as illustrations of the impacts described:

- The **Colorado River Basin Study** indicated that without future action, the projected development of water supplies and increased consumptive use in the Upper Basin could reduce the access to shoreline recreational facilities in both the Upper and Lower Basins.
- The **Upper Rio Grande Impact Assessment** concluded that river recreation, including fishing, kayaking, and rafting, will be negatively impacted by projected decreases in flows.

3.4 Flood Management

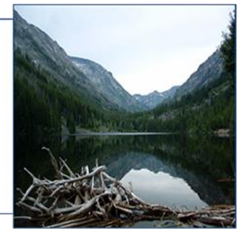
Flood control is an important function of many Reclamation reservoirs. From 1950 through 2014, for example, accumulated benefits from annual flood control in the Missouri River Basin are estimated to total over $2.9 billion. A trend toward earlier annual peak flows associated with warming temperatures and an increased frequency of rain-on-snow events is expected, especially in "transitional" basins – those that already straddle zones of rain- vs. snow-dominated hydrology – such as the Missouri River Basin. Figure 1–7 summarizes anticipated impacts to flood management.

At Reservoirs with Multiple Year Storage

Where reservoirs are designed to store several years of runoff, the additional flood risks associated with climate change are generally considered minimal, due to the considerable capacity of those facilities to deal with shorter-duration high flow events.

At Reservoirs Managed for Annual Refill

Where reservoirs require year-round balancing of flood control functions with other purposes, changes in the magnitude, intensity, and severity of extreme runoff events may prompt reconsideration of operating rules to better manage flood risks while maximizing storage opportunities.



Reservoir Sedimentation

At many reservoirs, the increased frequency of intense storms and flood events coupled with frequent, higher-intensity wildfires will lead to accelerated reservoir sedimentation due to increased sediment runoff during storm events.

Figure 1–7. Anticipated impacts to flood management.

Select examples are provided below, as illustrations of the impacts described:

- In the **Missouri River Basin**, warming is expected to lead to more rainfall runoff in higher-elevation watersheds such as Lake Sherburne and Fresno Reservoir, both in Montana, which provide flood-control benefits by storing water during the peak runoff period.
- In the **Rio Grande Basin**, runoff from forested areas subject to climate stress and impacted by an increased occurrence of catastrophic wildfires is projected to result in accelerated debris and sediment accumulation in reservoirs, which would lead to less reservoir storage and flood protection. In the **Upper Rio Grande Basin**, the frequency and intensity of floods is projected to increase at the main flood control reservoirs.
- Similarly, in the **Truckee River Basin**, an increase in the magnitude of peak flows is expected.
- Lake Powell and Lake Mead have the capacity to store several years of average Colorado River runoff. The **Colorado River Basin Study** indicated that flood control vulnerabilities were few over the next 50 years.

3.5 Fish, Wildlife, and Ecological Resources

The potential impacts of climate change on fish and wildlife habitats, federally listed species, and ecological systems in the West are complex and diverse. Current stresses on species habitats in many areas of the West are expected to be impacted by climate change. Changes in temperature and hydrology will shift the location and distribution of species and their preferred habitats, while improving conditions for certain species. Reclamation has many river restoration and enhancement efforts ongoing across the West that result in a broad array of benefits to fish and wildlife resources and their habitats. Climate change could adversely affect these programs, possibly impacting species populations and their resiliency to unpredictable shocks (e.g., disease, floods, fire, drought). The impacts could be positive, negative, or neutral, depending on the exact species, hydrology, and ecosystem affected. Figure 1–8 summarizes the anticipated impacts.

Water and Air Temperature Impacts

Fisheries sensitive to a warming aquatic habitat will be more frequently stressed, and suitable habitat for cold-water dependent species such as trout will be reduced. Shifts in the geographic range of various species are anticipated. The incidence of pathogens in warming waters also may increase.

Aquatic Migration

Changes in the timing of species migration will become more likely with increased water and air temperatures. In the Columbia River Basin, elevated temperatures would increase the number and severity of thermal barriers to migration for certain fish, including several federally listed species.

Invasive Species

Warmer water temperatures and other climate-related stresses on native species can confer competitive advantages to various non-native and invasive species. Studies indicate that quagga mussels could expand their range under projected climate scenarios, further complicating facility maintenance.

Sea Level Rise

Sea level rise increases the salinity of vulnerable coastal waterways. Sea level rise is a significant concern in the Sacramento-San Joaquin Delta, affecting not only its suitability as a water source for agricultural, municipal, and environmental uses, but also the ability to move freshwater through the estuary to water users.

Riverine Habitat

In Western river basins, it is anticipated that changes to hydrology and climate may make it more difficult to achieve environmental flows to support endangered species. In the Columbia River Basin, projected increases in winter flooding and decreases in summer flows will affect Coho and Chinook salmon as well as steelhead. .

Figure 1–8. Anticipated impacts to fish, wildlife, and ecological resources.

3.6 Water Quality

The quality of water in western river basins is vital to human and environmental health. Whether water quality improves or deteriorates under a changing climate depends on multiple variables including water temperature; the rate, volume, and timing of runoff; and the physical characteristics of the watershed. Figure 1–9 summarizes anticipated impacts.

Water temperature

As water warms, less oxygen dissolves in the water column, affecting that water body's ability to support fisheries and other aquatic life. In addition, higher water temperatures can increase the incidence of toxic algal blooms occurring at reservoirs and other water bodies.

Pollutants

Where runoff decreases without a corresponding reduction in pollutants, maintenance of acceptable water quality will become more difficult, especially during periods of low flow. Increases in the frequency and intensity of high-precipitation events will also increase the runoff of pollutants into water bodies.

Turbidity and Sediment

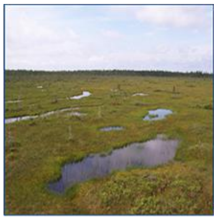
Where storm intensity and severity increases, there is a corresponding increase in land surface erosion, sediment transport, and occurrences of elevated surface water turbidity. Moreover, an increase in the frequency, extent, and intensity of forest fires associated with temperature- or drought-stressed forests will increase sediment production and surface water turbidity.

Figure 1–9. Anticipated impacts to water quality.

As one example of the anticipated impacts, in the **Rio Grande Basin** above the confluence of the Rio Grande with the Rio Puerco, concentrations of pollutants are expected to increase with increased surface water evaporation rates and more intense precipitation events.

3.7 Groundwater Management

Over the long term, groundwater supplies are sustainable only to the extent that aquifer recharge remains in approximate long-term balance with groundwater extraction. Climate change has the potential to affect this balance by altering the rate and/or the pathways of groundwater recharge associated with shifts in precipitation patterns, increased temperature, and other drivers of vegetative evapotranspiration and changes in streamflow. Figure 1–10 summarizes key groundwater considerations.



Changes in Groundwater Recharge

Studies project that warmer climate conditions could reduce groundwater recharge. In the Missouri River Basin (northern Great Plains) and in the Santa Ana watershed of southern California, groundwater recharge could be reduced as rising temperatures increase water demands and as decreased precipitation reduces recharge.

Changes in Groundwater Demands

With increased variability and uncertainty of precipitation and surface water supplies, many Western communities are expected to increase reliance on groundwater as a source for both agricultural and municipal purposes. In California's Central Valley, increased groundwater dependency may result in additional land subsidence and a reduction in aquifer storage capacity.

Coastal Saltwater Intrusion

In coastal communities, sea level rise and an increased reliance on aquifer withdrawals has the potential to increase the risk of saltwater intrusion into freshwater coastal aquifers.

Figure 1–10. Anticipated impacts to groundwater.

3.8 Watershed Integrity

To protect and sustain both surface-water and groundwater supplies, prudent management of contributing watersheds is essential. Forested lands, in particular, serve as crucial water supply zones in the West: high-elevation, forested landscapes are source areas for 65 percent of western water supplies. The health and integrity of these landscapes are fundamental to the maintenance of reliable quantities, timing, and quality of water supplies, including water to meet various Reclamation project purposes. Figure 1–11 summarizes the ways that climate change is expected to impact the landscape-scale factors that influence watershed hydrology.

Changes in Land Cover and Vegetation Mix and Density

Changes in precipitation, temperature, humidity, CO_2, and other climate conditions are expected to affect the composition, distribution, and productivity of vegetative communities, in turn affecting watershed hydrology. For example, in southern California, warmer temperatures are expected to cause forested landscapes to migrate over time northward and to higher elevations.

Forest Insects and Disease

Increased tree mortality from insects already has been observed throughout the West, raising concerns about the future distribution of forest vegetation. In the forests of some parts of New Mexico, moisture stress has led to bark beetle infestations, in turn leading to a potential transition of the affected forests to a new mix of species, forest structure, and ecological processes.

Forest Fires

In the Missouri River Basin, an increased risk of wildfires is projected due to the expectation that more intense droughts, higher temperatures, and disease will stress forest vegetation.

Figure 1–11. Anticipated impacts to watershed integrity.

4 Adaptation Strategies to Address Vulnerabilities

Reclamation, in consultation with customers and stakeholders, has already begun to identify and develop a variety of adaptation strategies to address vulnerabilities related to drought and climate change in western river basins. WaterSMART Basin Studies provide an important mechanism for identifying adaptation options appropriate for the area being studied. As collaborative studies that are cost-shared with non-Federal partners, Basin Studies evaluate the impacts of climate change and identify a broad range of potential options to address water supply and demand imbalances, both current and future. To date, Reclamation and its partners have initiated 24 Basin Studies in 15 of the 17 Western States, and 12 of those have now been released, meaning that a broad range of climate adaptation strategies have been developed.

Basin Studies evaluate *portfolios of multiple possible adaptation actions.* Rarely will one single action be sufficient to address all of the potential impacts of concern. While Basin Studies are not intended to be decision documents, they do provide a solid foundation for further exploring actions that will support sustainable water supplies and achieve other water management goals. The general categories of possible actions to adapt to climate change and other stresses on western water supplies are listed in Figure 1–12. Each type of adaptation strategy is discussed in the following section, with a brief description of Reclamation actions supporting implementation of these strategies.

Specifically, this section draws upon the extensive information and analysis provided by the WaterSMART Basin Study Program products (mapped in Figure 1–13). As Reclamation continues implementation of its Climate Change Adaptation Strategy, many adaptation strategies are already underway. In this section, examples of adaptation strategies are highlighted, along with the activities being undertaken by Reclamation and its partners to implement strategies and accomplishments to date.

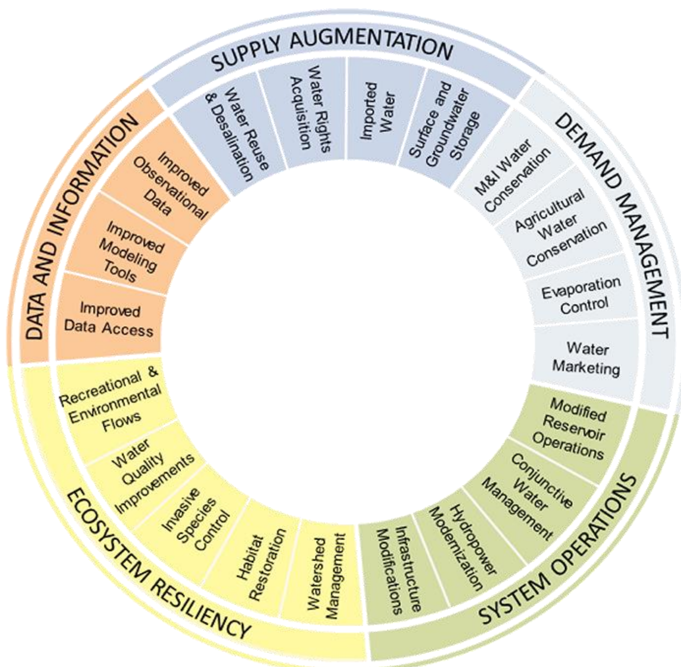


Figure 1–12. General categories of possible actions used in a water management portfolio to adapt to climate change.

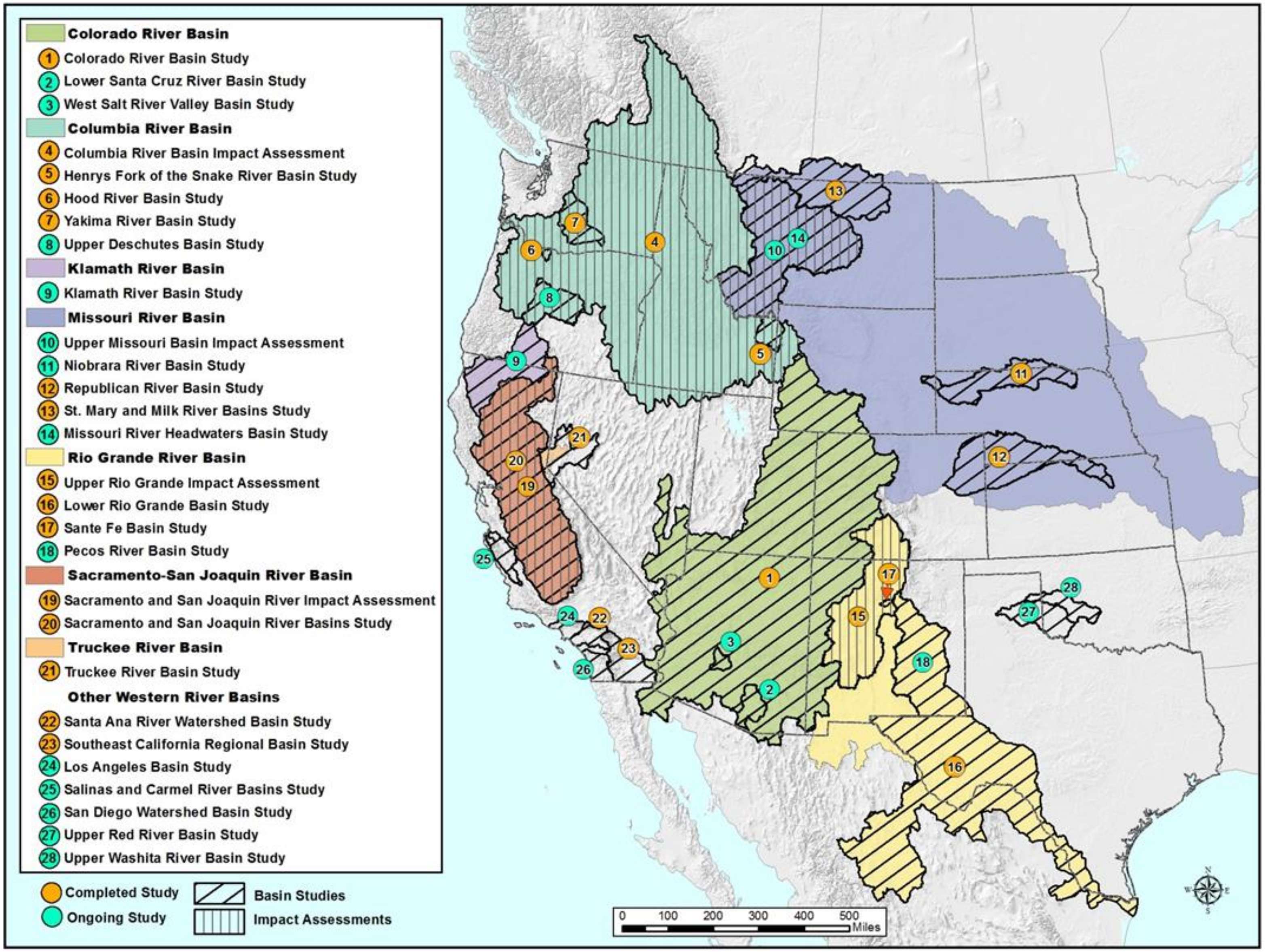


Figure 1–13. WaterSMART basin studies and climate impact assessments.

4.1 Supply Augmentation

The total supply of water available to meet user needs often can be augmented through one or more possible actions, including water reuse, desalination, stormwater capture, water rights acquisition, water importation, and new or expanded water storage. Augmented supplies can serve a variety of possible purposes, including municipal and industrial use, agricultural use, power generation, groundwater recharge, environmental restoration, fish and wildlife maintenance, and recreation. Select examples of potential adaptation strategies considered by Reclamation-sponsored Basin Studies and related efforts are identified in Figure 1–14.

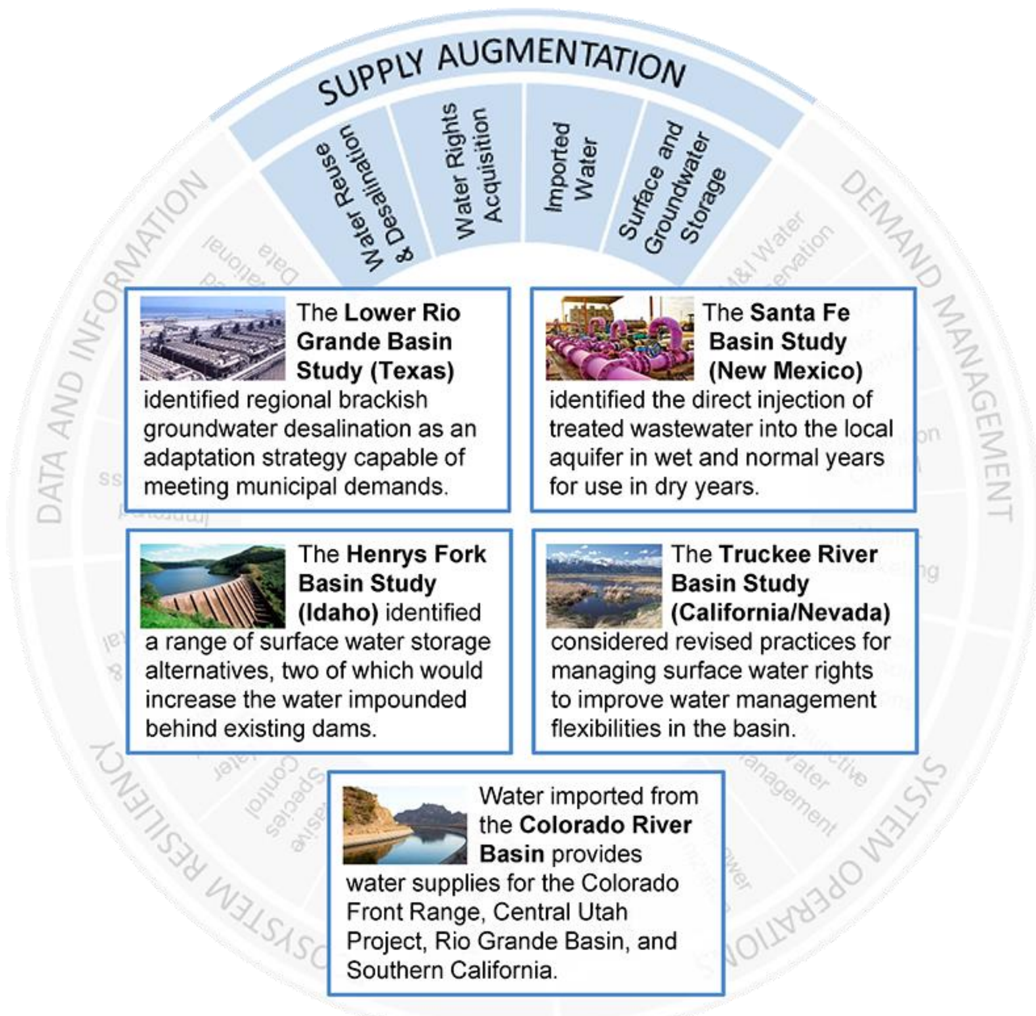


Figure 1–14. Potential water supply augmentation strategies.[6]

[6] Select examples are provided in this figure, as illustrations of the options considered. Additional examples are described in Chapters 3–10 or in individual Basin Studies.

Taking Action to Augment Supply

Reclamation has made significant progress in assessing the impacts of climate change to water resources and implementing on-the-ground actions to mitigate impacts of climate change. Reclamation's Climate Change Adaptation Strategy identifies increasing water management flexibility and enhanced adaptation planning as key goals to implementation the strategy.

To augment traditional surface and groundwater supplies, the **Title XVI Water Reclamation and Reuse Program** provides cost-shared funding for research, planning, design, and construction of water reuse projects. Water reuse and recycling can turn currently unusable water sources into a new source of supply that is less vulnerable to drought and climate change, increasing flexibility and reducing the pressure to transfer water from agricultural to urban uses. The State of California estimates that 900,000 to 1.4 million acre-feet of "new water" could be added to its supply by reusing municipal wastewater that currently flows to the ocean.

Purple pipe prior to installation by the Napa Sanitation District in California. The pipeline was constructed as part of Reclamation's Title XVI Program.

Since 1992, approximately $639 million in Federal cost-share funds have been leveraged with more than $2.4 billion in non-Federal funding to design and construct water recycling projects. In 2015, Reclamation announced grants totaling $25 million for continued construction of seven water reclamation and reuse projects in California and seven water reclamation and reuse feasibility studies in California and Texas.

As a next step to the Santa Fe Basin Study, the City of Santa Fe and Santa Fe County, New Mexico, are collaborating to develop greater resiliency and diversity in their water portfolios by exploring alternatives for reclaimed wastewater. In 2014, the City of Santa Fe received Title XVI funding for a feasibility study to evaluate alternatives for both potable and non-potable applications of reclaimed water to augment water supplies. The current water supply is vulnerable to uncontrolled factors, which include drought, fire, environmental regulations, and water quality limits.

Reclamation's Brackish Groundwater National Desalination Research Facility in Alamogordo, NM.

Reclamation's **Desalination and Water Purification Research (DWPR) Program** funds research projects to develop and test new advanced water treatment technologies that can make degraded water supplies available for consumptive use. In 2015, Reclamation announced grants totaling $1.4 million to nine laboratory and pilot-scale research studies in the field of water desalination and purification. The DWPR Program also supports operation and maintenance of Reclamation's Brackish Groundwater National Desalination Research Facility (BGNDRF) in Alamogordo, New Mexico, which provides a field environment to test and develop advanced water treatment technologies. The facility brings together researchers from Federal government agencies, universities, the private sector, research organizations, and State and local agencies to work collaboratively and in partnership. BGNDRF hosted the final round of the 2015 Desal Prize,[7] in partnership with U.S. Agency for International Development, focused on innovative brackish groundwater treatment technologies powered by renewable energy.

Reclamation's Water Quality Improvement Center at the Yuma Area Office, AZ.

Reclamation also has a state-of-the-art advanced water treatment research center, the Water Quality Improvement Center[8], located at the Yuma, Arizona, Area Office. These centers represent two of six National Centers for Water Treatment Technologies.

[7] See http://www.securingwaterforfood.org/the-desal-prize/

[8] See http://www.usbr.gov/lc/yuma/facilities/wqic/yao_facilities_wqic.html

4.2 Demand Management

Activities that reduce the demand for water, particularly during periods of water scarcity, provide valuable flexibilities for helping to bring those demands into better balance with supply. With water deliveries in the West facing increasing vulnerabilities from population growth and climate change, various strategies to ease demands are being implemented by communities across the West. These strategies include improved water conservation and efficiencies in water and energy use. Examples of the relevant adaptation options and actions considered by Reclamation-sponsored basin studies are identified in Figure 1–15.

Figure 1–15. Potential demand management strategies.[9]

[9] Select examples are provided in this figure, as illustrations of the options considered. Additional examples are described in Chapters 3–10 or in individual Basin Studies.

Taking Action to Implement Demand Management Strategies

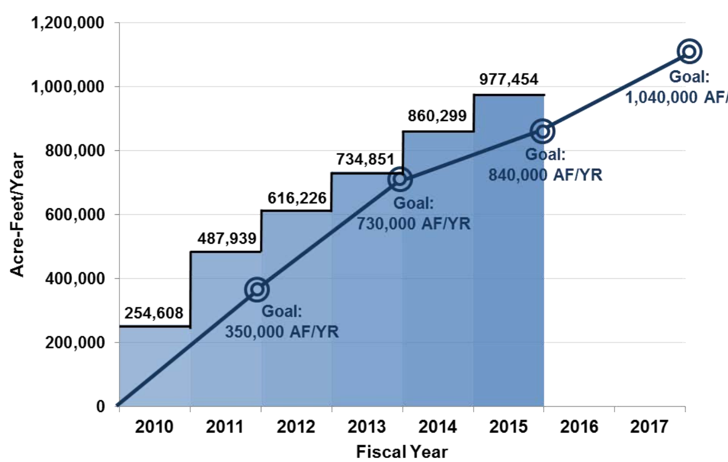
Reclamation continues to work with its partners to complete agricultural and municipal and industrial water conservation improvements that implement demand-management strategies identified through Basin Studies. Consistent with Reclamation's Climate Change Adaptation Strategy, which recognized a role for Reclamation in helping to increase water management flexibility, **WaterSMART Grants** make cost-shared funding available to non-Federal partners to carry out water conservation and efficiency projects collaboratively, and they prioritize projects that implement adaptation strategies identified through Basin Studies.

Hidalgo County Irrigation District #2 Water and Energy Efficiency Grant

Since 2009, about $149 million in Federal funding has been leveraged with non-Federal funding to implement 257 WaterSMART Grant projects that together represent more than $560 million in water management improvements across the West.

As Basin Studies are completed, water managers look to WaterSMART Grants to help them implement adaptation strategies. In southern Texas, for example, the Hidalgo County Irrigation District #2 is using $1 million in WaterSMART Grant funding, along with more than $4 million in non-Federal funding, to implement one of the demand management adaptation strategies identified in the Lower Rio Grande Basin Study, which the District participated in as a cost-share partner. The District's work to line 5.3 miles of an unlined canal and install advanced check gate structures is expected to result in annual water savings of more than 2,000 acre-feet currently lost to spills and seepage.

In 2010, DOI and other Federal agencies established a series of outcome-based performance goals, including a **Priority Goal for Water Conservation**. Activities funded through WaterSMART Grants, the Title XVI Program, and other water conservation programs through 2015 are expected to result in more than 970,000 acre-feet of water savings once completed — roughly the

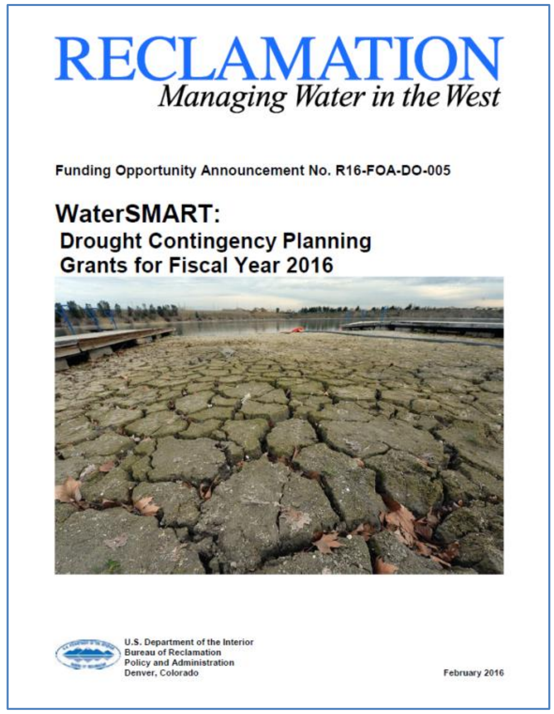


Priority Goal for Water Conservation

amount of water needed for household use in Phoenix and the surrounding area each year – and the Department of Interior is on track to meet its goal of 1,040,000 acre-feet of water savings by the end of 2017.

Climate change is expected to increase the frequency, intensity, and duration of drought conditions in the West. Drought contingency planning provides an important tool to proactively manage drought risks. In 2015, Reclamation reformulated its drought program to incorporate climate information and build resiliency against future droughts.

The new **Drought Response Program**[10] helps Reclamation and its partners avoid drought-related crises in the short term while laying a foundation for climate resiliency in the long term. In 2015, under this program, Reclamation announced grants for western communities totaling $5.1 million to implement 23 proactive projects to build long-term drought resiliency in nine western States. The program helps to implement Reclamation's Climate Change Adaptation Strategy and also directly supports the National Drought Resilience Partnership, identified in the President's Climate Action Plan, helping communities develop long-term resilience strategies by providing key climate change and drought information.


RECLAMATION
Managing Water in the West

Funding Opportunity Announcement No. R16-FOA-DO-005

WaterSMART:
Drought Contingency Planning
Grants for Fiscal Year 2016

U.S. Department of the Interior
Bureau of Reclamation
Policy and Administration
Denver, Colorado

February 2016

In northern Nevada, for example, the Truckee Meadows Water Authority is using Drought Response Program funding and its own cost-share contribution to update its current Drought Contingency Plan. The updated plan will incorporate climate projections developed through the Truckee River Basin Study and will specify mitigation actions that will help adapt to short-term changes in hydrologic conditions caused by drought. The Truckee Meadows Water Authority will update its plan by engaging stakeholders through established and successful stakeholder groups representing Federal, State, and local governmental organizations, tribes, agricultural producers, industries, and environmental and recreational interests.

[10] See http://www.usbr.gov/drought.

4.3 System Operations

With or without a change in future water supplies and demands, building additional flexibility and reliability into the systems used to manage those supplies helps to ensure that adequate water is available. The potential for increased frequency and intensity of floods and droughts brings additional challenges to operations and infrastructure conditions. Climate change, coupled with the fact that much of the water resources infrastructure in the Western U.S. is beyond its originally envisioned service life, highlights the importance of enhancing infrastructure resiliency to meet Reclamation's mission requirements in the future. Examples of the adaptation options and actions to improve system operations and resiliency are identified in Figure 1–16.

Figure 1–16. Potential system operations adaptation strategies.[11]

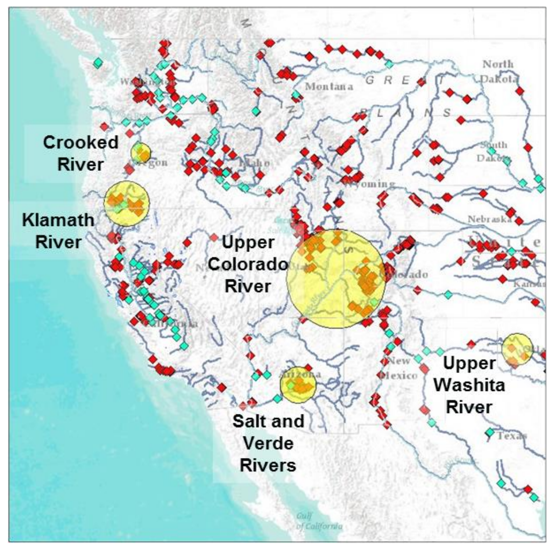
[11] Select examples are provided in this figure, as illustrations of the options considered. Additional examples are described in Chapters 3–10 or in individual Basin Studies.

Taking Action to Improve System Operations

To prepare for new extremes, Reclamation's Climate Change Adaptation Strategy identifies opportunities to incorporate climate change information into decisions regarding reservoir operations, infrastructure investments, and safety upgrades. The President's Plan provides support for this goal, prioritizing the need to build safer communities and infrastructure, manage drought, and prepare for future floods.

In 2014, Reclamation launched the **Reservoir Operations Pilot Initiative**[12] to determine how reservoir operations are impacted by climate change and how reservoir operations can be made more flexible to adapt to impacts. Reclamation's reservoirs are operated using criteria to meet a number of different water management priorities, including reliable water deliveries, power generation, environmental requirements, and needs for flood control management. Historically, uncertainties in weather prediction and assumptions of an unchanging climate have resulted in general rules for reservoir management, often seasonal to annual that will shift with future climate conditions.

In 2015, Reclamation initiated five pilot studies to evaluate how weather, hydrology, and climate-change information could better inform reservoir operations. Reservoir operation pilots are critical to understanding where flexibilities in reservoir operations may be increased through identifying trends in historic and current climate and hydrology, and through improved use of weather forecasting. Reclamation will use these pilot studies to develop guidance on considering climate change within reservoir operations.



Reservoir Operations Pilot Studies Initiated in 2015

WaterSMART also includes the **Resilient Infrastructure Program**, through which Reclamation proactively maintains and improves existing infrastructure for system reliability, safety, and efficiency to prepare for extremes and to support healthy and resilient watersheds. Prioritization of infrastructure investments is influenced by climatic conditions as well as by watershed management opportunities. In 2016, Reclamation is developing an enhanced decision-making framework to select a project to serve as a model for refining design considerations and decision-making criteria.

[12] The Reservoir Operations Pilot Initiative is funded through Reclamation's WaterSMART Basin Study Program: www.usbr.gov/watersmart/wcra/index.html

Hydropower production is vulnerable to altered water availability resulting from climate change; consequently, **optimizing hydropower production** is a key part of Reclamation's overall strategy to respond to the impacts of climate change. Reclamation is building on successful efforts already underway to continue generating clean energy, and it is providing Federal leadership in renewable energy development, both of which are priorities in the President's Climate Action Plan to slow the pace of climate change.

Aerial View of Hoover Dam and Lake Mead

Reclamation has a long, successful history of working with customers to upgrade turbines and rewind generators at powerplants to achieve water and energy conservation benefits. Such investments improve hydropower generation resilience as climate change impacts occur and increase the generation of clean renewable energy. Initial assessments have also identified an opportunity to improve efficiency and flexibility at some Reclamation-owned pumping plants, reducing the amount of Reclamation hydropower energy required for water deliveries.

Reclamation has identified equipment upgrades at hydropower and pumping plants to increase hydropower efficiency. For example, in cooperation with the Hoover power contractors, Reclamation has begun replacing 5 of the 17 existing generating turbines with wide-head turbines at Hoover Dam. These wide-head turbines can operate at a much wider range of reservoir levels that will allow the Hoover Powerplant to generate electricity more efficiently at lower Lake Mead levels. Since 1947, an average of about 4.4 billion kilowatt-hours of energy has been generated at the dam annually, or enough to supply about 400,000 U.S. households with all of their electricity needs for one full year.

The use of climate-change information to inform decisions about infrastructure investments is complex and on the cutting edge of climate science development. Warming is contributing to trends of heavier downpours over much of the U.S., which may lead to increases in local flood potential for some areas. However, at the local scale, substantial uncertainty remains about how global climate change will impact wet weather extremes.

Reclamation has a pilot initiative underway to incorporate climate change information into the Dam Safety risk assessment process. Reclamation's **Dam Safety Program** is developing a methodology for incorporating climate change information into hydrologic hazard analyses. An initial pilot completed at Friant Dam in California indicated that climate change is an important factor to consider in the hydrologic hazard analysis. A follow-on study is currently underway at Taylor Park Dam, Colorado. Additional work is also ongoing to integrate projections of future hydrology into existing methodologies for Reclamation dam safety comprehensive review studies, which are performed at all Reclamation dams on an 8-year cycle to identify and address risks to life and property.

4.4 Ecosystem Resiliency

Ecological resiliency refers the capacity of an ecological system to absorb change without major disruption to the system's structures and processes. Maintaining ecosystems and habitat affected by Reclamation projects is more challenging in changing climate and hydrology conditions. Anticipated changes in climate, the quantity and timing of river flows, and associated habitat conditions threaten ecological resiliency in many areas of the West. Examples of potential adaptation options and actions to enhance ecosystem resiliency are identified in Figure 1–17.

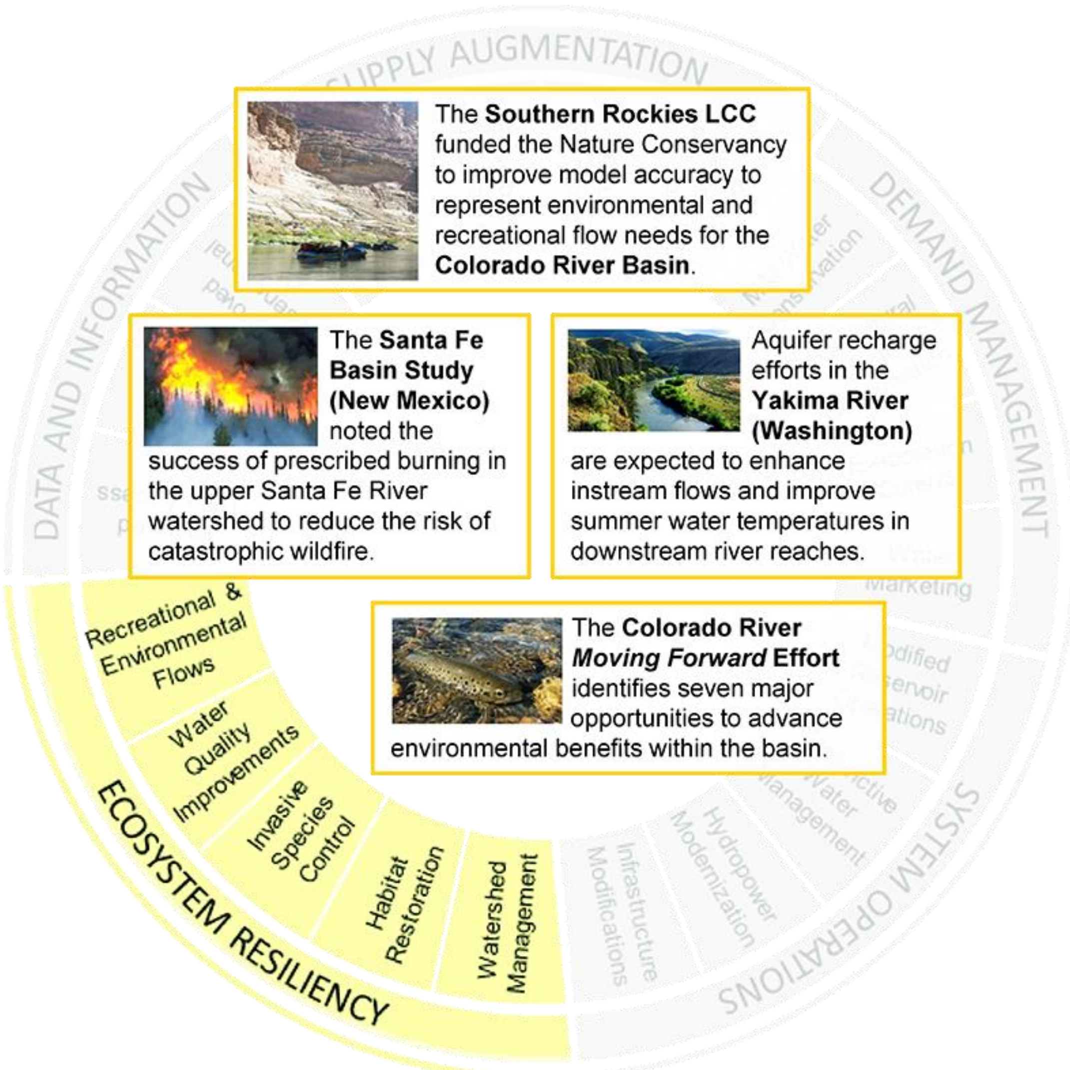


Figure 1–17. Potential ecosystem resiliency adaptation strategies.[13]

[13] Select examples are provided in this figure, as illustrations of the options considered. Additional examples are described in Chapters 3–10 or in individual Basin Studies.

Taking Action to Build Ecosystem Resiliency

Though meaningful and significant steps have been taken to protect or improve ecological and recreational resources, opportunities exist to expand environmental and recreational flow activities. Reclamation's Climate Change Adaptation Strategy identifies existing programs, including the WaterSMART Program, to address climate change impacts to ecosystems.

Under WaterSMART, the **Cooperative Watershed Management Program** provides financial assistance grants to improve water quality and ecological resilience and to reduce conflicts over water through collaborative conservation efforts in the management of local watersheds. To date, Phase 1 of the program has been initiated funding the formation or expansion of 19 watershed groups. Phase 2 of the program is under development and is expected to begin in 2017, to carry out projects in accordance with the goals of watershed groups to improve water quality and ecological resilience.

With the signing of Secretarial Order No. 3289, DOI launched the **Landscape Conservation Cooperatives (LCC)** to better integrate science and management to address climate change and other landscape-scale issues. By building a network that is holistic, collaborative, adaptive, and grounded in science, LCCs are working to ensure the sustainability of our economy, land, water, wildlife, and cultural resources. Reclamation and the U.S. Fish and Wildlife Service co-lead the Desert and Southern Rockies LCCs. Key highlights of ecological resource studies funded through the LCCs include:

1) *Building Decadal Prediction of Extreme Climate for Managing Water in the Intermountain West:* By reconstructing the history of streamflow and precipitation for watersheds in the Uinta Mountains and the Wasatch Range using tree-growth rings, a team of researchers at Utah State University improved water managers' understanding of streamflow variability and impact from climate extremes. Data from this research are being used directly by the Weber Basin Water Conservancy District to compare recent droughts and historic reconstructed records, in order to plan changes in operations management.
2) *Managing Water and Riparian Habitats on the Bill Williams River with Scientific Benefit for Other Desert River Systems:* The Corps Hydrologic Engineering Center, U.S. Fish and Wildlife Service, and USGS developed new operational rules for water managers to guide reservoir releases in the Bill Williams River that promote the establishment of native cottonwood and willow stands downstream of reservoirs while balancing other water management needs. By codifying water flow-ecology relationships for riparian species as operational rules for water managers and testing those rules under different climate scenarios, project benefits can be transferable to other managed river systems in the arid southwest.

3) *Predicting Snow Water Equivalence and Soil Moisture Response to Restoration Treatments in Headwater Ponderosa Pine Forests of the Desert LCC:* Northern Arizona University built upon the U.S. Forest Service's Four Forest Restoration Initiative to investigate how restoration efforts affect the water volume available in the snowpack and soil moisture. Models of snow water equivalence and soil moisture response to ponderosa pine forest restoration treatments are helping identify optimal treatments for sustaining water availability for plants as well as downstream water users in Verde Valley and the Phoenix metropolitan area.

4) *A Study of Climate Change Impacts on Water Quality and Internal Nutrient Recycling in Lake Mead, Arizona-Nevada:* Southern Nevada Water Authority modeled impacts of climate change on water quality and sediment transport in Lake Mead. This information enables organizations with water supply responsibilities to evaluate the likely quality of raw water in the future and plan for infrastructure or treatment changes. Additionally, organizations that discharge into Lake Mead or the Lower Colorado River can use the results to assess whether target nutrient loads for the point-source discharges may have to be reduced to offset the increased internal nutrient loading driven by climate change.

High-elevation forested zones are crucial for maintaining the quantities, timing, and quality of water supplies that serve Reclamation projects and western water users. Through the **Western Watershed Enhancement Partnership,** the U.S Forest Service and Reclamation seek to proactively improve the health and resiliency of National Forest System watersheds to reduce the potential for severe wildfire. Improving watershed functions and reducing the risk of uncharacteristically severe wildfire benefits Reclamation's water supply, irrigation, and hydroelectric customers.

Horsetooth Reservoir. The 2012 High Park Fire was the impetus for the Colorado-Big Thompson Headwaters Watershed Enhancement Partnership.

In 2015, projects in several areas of the West were competitively awarded a total of $770,000 in cost-shared funding to advance on-the-ground activities. This program supports site-specific treatments to mitigate risks by protecting upland ecosystem and watershed functions on Reclamation or U.S. Forest Service lands with a direct connection to facilities in order to avoid adverse impacts to water supplies.

4.5 Data and Information

Access to quality data on past and projected future hydrology, water use, land cover, and climate is essential if meaningful adaptation strategies are to be effectively evaluated and implemented. In many cases, quality data already exist, and considerable value can be added by merely making the data more accessible, understandable, and useful. In other cases, the development of tools that can analyze available data and use the data to model alternative scenarios can be useful. Where quality observational data are scarce or nonexistent, the collection of additional data to address key informational gaps may be invaluable. Examples of the relevant actions and data strategies identified within Reclamation-sponsored basin studies are provided in Figure 1–18.

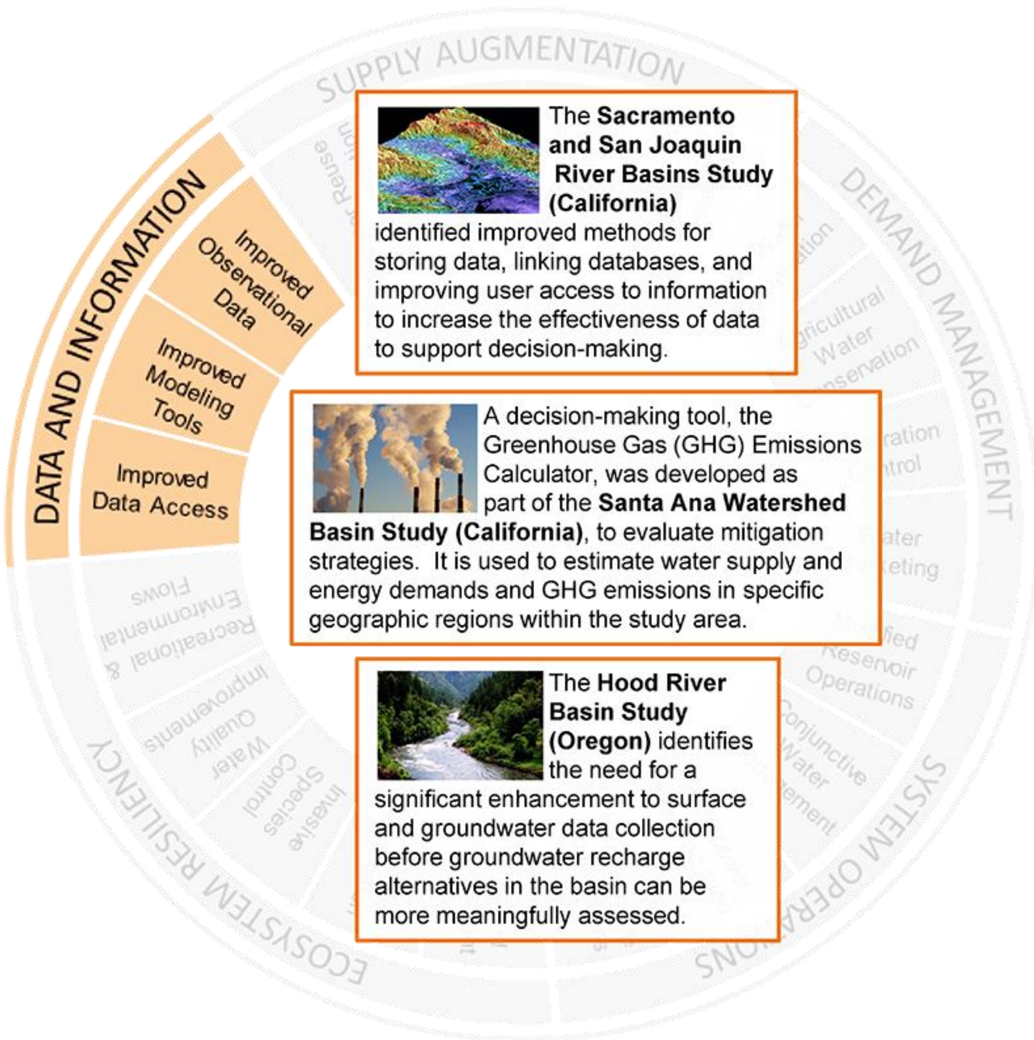


Figure 1–18. Potential data and information development strategies.[14]

[14] Select examples are provided in this figure, as illustrations of the options considered. Additional examples are described in Chapters 3–10 or in individual Basin Studies.

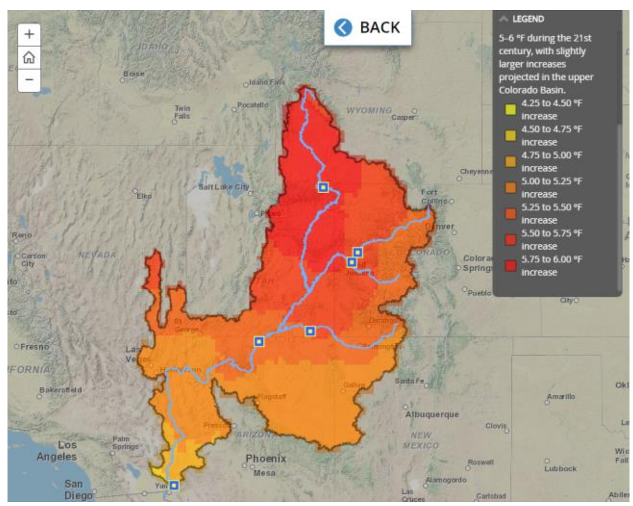
Taking Action to Access Data and Information

Reclamation's Climate Change Adaptation Strategy acknowledges that Reclamation and its stakeholders will benefit from increased access to climate change and water resources data. In order to successfully implement any supply augmentation strategy or demand management program, one must have a way to gauge needs and success, which requires an assessment of conditions before, during, and after exploration. Fundamental to developing new information for adapting to climate change is assessing the current state of knowledge, identifying where gaps exist, and finding opportunities to address those gaps.

Reclamation's Science and Technology Program is taking a leading role to develop the data and tools necessary to support climate change adaptation within Reclamation and by customers and stakeholders. During the course of these efforts, the research team has remained engaged with Reclamation-wide programs to enhance the relevance and utility of the climate adaptation strategies.

Downscaled Climate and Hydrology Projections Web Service:[15] Since 2007, Reclamation has led a partnership of nine Federal, academic, and nongovernmental organizations to provide future projections of temperature, precipitation, hydrology, and streamflow throughout the continental U.S. to support locally relevant decision making. These information resources are served though a website that provides users access to the monthly gridded precipitation, temperature, and hydrologic projection data, as well as additional climate projection information that covers the contiguous U.S.

Through the WaterSMART Basin Study Program, a data visualization site has been produced to accompany the release of this 2016 SECURE Water Act Report to Congress.[16] This tool allows users to view changes in temperature, precipitation, and snowpack in major river basins and to download supporting projection data sets as they walk through the SECURE Water Act Report.



SECURE Water Act Data Visualization Tool — Projected temperature change in the 2070s for the Colorado River Basin

[15] Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections Web Service site : http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

[16] SECURE Water Act Report website: http://www.usbr.gov/climate/SECURE

Climate Training: Since 2012, Reclamation and USACE have been collaborating with CCAWWG and the University Center for Atmospheric Research COMET® program to develop and pilot climate change training tools for Federal and non-Federal water agency staff and to explore sustained delivery approaches.

- *Technical Series:* Initial efforts focused on developing a new COMET® Professional Development Series, "Assessing Natural Systems Impacts under Climate Change." The series is designed to provide technical training to water resources professionals on how to incorporate climate change science and uncertainties into a variety of natural resource impacts assessments, including those related to surface water hydrology, crop irrigation requirements, water temperature, river and reservoir sedimentation, water quality, and land cover.
- *General Audience Series:* While the initial effort to develop technical training series has successfully engaged technical practitioners, there is also a need to provide training for senior leaders, program managers, project managers, resource specialists, public affairs specialists, and others who play critical roles in mainstreaming climate change into mission activities. In response, training partners have recently begun to scope and develop a parallel professional development series aimed at these communities.

Open Water Data Initiative: Reclamation is addressing the requirements of the President's Open Data Policy and DOI's Open Water Data Initiative by making Reclamation's water and related data more comparable across locations, easier to find, more shareable with other agencies, stakeholders, and the public, leading to an overall outcome of better managed data.

Colorado Drought Visualization Web Tool — Lake Mead in 2001 and 2015.

One example of an open data product is the specialized web tool developed by the USGS and Reclamation: "Drought in the Colorado River Basin – Insights Using Open Data."[17] This visualization is an effort to showcase the usefulness of open data by exploring the current 16-year drought and its effects on the Colorado River Basin. The dramatic data interactions show the interconnected results of a reduced water supply as reservoir levels have declined from nearly full to about 50 percent of capacity.

[17] See https://www.doi.gov/water/owdi.cr.drought/en/index.html

5 Collaboration

Given the important partner equities in water resource management, Reclamation has a responsibility to demonstrate leadership and to leverage resources by sharing information and capabilities with partners interested in climate adaptation. Reclamation recognizes that for Federal investments in climate resiliency to be successful, strong partnerships with State, tribal, and local governments and with water users, stakeholders, the public, and other Federal agencies are crucial. The President's Climate Action Plan emphasizes the importance of providing open government data that "can fuel entrepreneurship, innovation, scientific discovery, and public benefits."

5.1 Collaboration and Coordination with Federal Agencies

Reclamation is actively engaged in multiple collaborative efforts with Federal and non-Federal partners to monitor, develop, and share information for a common understanding of climate change impacts to water resources in the West. This section highlights activities that implement Section 9503(b)(1) of the SECURE Water Act, which directs the Secretary of the Interior, through Reclamation, to "coordinate with the USGS, National Oceanic and Atmospheric Survey (NOAA), the program, and each appropriate State water resource agency, to ensure that the Secretary has access to the best available scientific information with respect to presently observed and projected future impacts of global climate change on water resources."

Reclamation coordinates with the USGS, NOAA, and the Natural Resources Conservation Service on climate monitoring activities through the **WWCRA Implementation Team**. Climate monitoring objectives for the Implementation Team include:

- Sustain active communication between agencies on monitoring activities, climate and water resources data, and science tools for water management decisions,
- Understand data availability, accessibility, and applicability for direct use and implementation in Reclamation's climate change impact and planning studies, and
- Identify opportunities to improve climate monitoring data available for water management decisions.

Reclamation is using climate monitoring data networks in a broad set of studies to determine impacts and risks to water resources due to climate change. Inter-agency coordination to acquire and maintain water resources data aids in strengthening the understanding of water supply trends and assists in the assessments and analyses conducted by Reclamation. Information generated through WWCRA provides a foundation of climate change data, information, and tools that partners can build from to develop adaptation strategies.

Reclamation is coordinating with other Federal and non-Federal agencies to implement Section 9503 of the SECURE Water Act through multiple collaborative approaches. Together, these activities will allow Reclamation to better assess the risks and impacts of climate change on the hydrological cycle and to implement collaborative adaptation strategies. In addition to the climate-monitoring activities listed under Section 9503(b)(1), Reclamation also coordinates closely with the following other Federal agencies authorized under the SECURE Water Act.

As directed by Congress in **Section 9505 of the SECURE Water Act**, the U.S. Department of Energy (DOE), in consultation with the Federal Power Marketing Administrations and other Federal agencies, examines the potential effects of climate change on water available for hydropower generation at Federal facilities and on the marketing of that power. Through the WWCRAs, Reclamation coordinates with DOE to compare climate modeling analyses that project climate conditions and impacts to hydropower into the future and compare basin-specific climate impacts to hydropower.

The **SECURE Water Act Sections 9507 and 9508** authorized the “Water Data Enhancement by the United States Geological Survey” and the “National Water Availability and Use Assessment Program,” respectfully. As previously mentioned, through WaterSMART, the USGS has implemented a National Water Census. The SECURE Water Act authorized $20 million for each of fiscal years 2009 through 2023 for the USGS through the National Water Census; appropriations for this effort as of 2015 totaled $28 million. With this funding, the USGS continues to engage stakeholders in a discussion of priorities.

Reclamation coordinates closely with the USGS to leverage information produced by a number of activities, including groundwater assessments and surface water focus area studies in Reclamation’s Basin Studies. In 2016, the USGS began three additional Geographic Focus Area Studies of water availability and use in the Coastal Basins of the Carolinas and two which overlap with ongoing or completed assessments in the Basin Study Program: the Red River Basin and the Upper Rio Grande Basin. In addition, five topical areas are producing information on water budget components that are national in scope. The topical studies include:

- Estimating streamflow at ungaged locations and characterization of long-term trends in streamflow;
- Assessing regional groundwater availability of principal aquifers;
- Using remote sensing to quantify evapotranspiration;
- Improving information on human water withdrawals, consumptive uses, and return flows; and
- Developing tools and web-available resources to understand the effects of streamflow alteration on aquatic ecosystems.

Additionally, in 2015, the USGS received $1.5 million for grants to States to improve water use collection, estimation, and delivery. The USGS also received $2.4 million for grants to States to implement the National Groundwater Monitoring Network. These two efforts greatly enhance the ability of the Water Availability and Use Science Program to produce the information and tools necessary to improve water budget component information for water management decisions and are critical to Reclamation's climate resilience and adaptation planning efforts.

Reclamation's Research and Development Office focuses on researching innovative, workable solutions to our challenging issues with managing water and power in the Western U.S. CCAWWG is a partnership with the USACE, the USGS, NOAA, and others to identify mutual science needs for long-term planning and short-term operations. The development of these groups has included strong stakeholder interaction and involvement through the Western States Water Council, the American Water Works Association, Family Farm Alliance, Western Area Power Administration, and Seattle City and Light Department. Reclamation's Science and Technology Program has invested in a range of solutions to meet needs identified collaboratively by CCAWWG, including climate change training programs for Reclamation staff.

Reclamation is also collaborating with Federal entities on the National Fish, Wildlife and Plants Climate Adaptation Strategy. This strategy provides a framework for actions needed now to help safeguard our valuable natural resources and the communities and economies that depend on them in a changing climate. Implementing the strategy will also fill critical gaps in the science, monitoring, modeling and training to sustain fish, wildlife, and plants in a changing climate. Its implementation is being overseen by a Joint Implementation Working Group made up of representatives from the same Federal, State, and Tribal agencies that led the successful completion of the strategy, including Reclamation. The group's purpose is to help facilitate and promote implementation across multiple agencies, as well as to share information among participants.

5.2 Collaboration and Coordination with States and Stakeholders

Western water management and operations at Reclamation facilities are closely intertwined with the activities and interests of various western stakeholders. This includes other Federal agencies, States, Indian tribes, local water and irrigation districts, and other nongovernmental organizations. Although Reclamation builds, owns, and continues to operate much of its infrastructure, local partners also play a huge role in system operations and maintenance. The SECURE Water Act has catalyzed collaboration between Reclamation and multiple stakeholders, and has promoted the exchange of valuable technical assistance that otherwise may be difficult to acquire.

As Reclamation has taken steps to implement the SECURE Water Act, it also has engaged with State interests via participation in the **Western Federal Agency Support Team (WestFAST)** meetings and discussions. WestFAST is a collaboration of 12 Federal agencies with water management responsibilities in the West, established to support the Western States Water Council and the Western Governors' Association in coordinating Federal water resources efforts. WestFAST is engaged in a variety of activities related to water resources and climate change.

The **Western States Water Council (WSWC)** is a collaborative body created by western governors in 1965 and comprised of member States – from Texas to North Dakota and westward – which allows the governors to effectively address and work toward solutions that are larger than single states and across a regional scale. Over the past decade, a barrier to regional cooperation was identified: a lack of or difficulty accessing available water data that would assist with regional water resource management issues. To address this, the WSWC initiated the Water Data Exchange (WaDE) Program. Begun in 2012, the WaDE program is a cooperative effort between the WSWC, the Western Governors' Association, DOE, WestFAST, and the National Environmental Information Exchange Network.

The WaDE Program seeks to (1) better enable the States to share important water planning and administrative datasets with each other and the public, and (2) encourage Federal agencies to begin to share their datasets using "open data" formats and publication methods. WSWC support of Federal data-sharing stems from the difficulty of assembling and preparing myriad data produced by Federal agencies for incorporation into models and tools. It would greatly improve and ease the development of hydrologic and groundwater models, etc., for State agency water planners if they could access these datasets in a more interoperable and possibly centralized location. WSWC has engaged with Federal agencies that have water management responsibilities in the West through WestFAST, and asked that they consider what standards and formats exist for the types of data they wish to share and whether they could publish them using "open data" formats. WSWC has also offered to help agencies to develop standardized formats for specific data types if needed, and to provide feedback on any pilots or preliminary work done to make datasets publically accessible in interoperable and machine-readable formats. Specific examples include:

- **Reclamation's Lower Colorado River Data Sharing Pilot:** In 2014, Reclamation's Lower Colorado Region Office staff members asked WSWC for assistance with the development and review of a possible data-sharing portal for Colorado River data maintained by their offices. WSWC and the regional office team discussed and refined the potential products and interfaces that might be used in the future for publishing Reclamation datasets.

- **Open Water Data Initiative Coordination:** In late 2014, DOI began to pursue an Open Water Data Initiative — an effort to improve the availability of water datasets generated not only by Federal agencies, but by a wide range of authoritative public and private water data providers. The goals of Open Water Data Initiative are to integrate fragmented water information into a connected national framework and leverage existing shared resources, while encouraging more partners to share their information using interoperable and machine-readable formats.

WSWC and Reclamation are collaborating on the Open Water Data Initiative framework and on finding ways that Reclamation and State-managed data can be leveraged and integrated into useful tools for decision-making. The intent of these efforts is to demonstrate the value of "open data" when used to support key visualizations and policy tools in an automated and timely fashion.

The **Basin Study Program** is a key avenue of collaboration and coordination between Reclamation and various local, State, and tribal interests. With 24 Basin Studies now initiated (and 18 completed as of the release of this document), Reclamation has forged collaborative relationships in 15 of the 17 Western States with a diverse assortment of non-Federal partners, including State water resource agencies, regional water authorities, local planning agencies, water districts, agricultural associations, environmental interests, cities and counties, and tribal governments (see Table 1–1).

A number of these non-Federal partners point to the usefulness of efforts through Basin Studies to incorporate the best available science into planning activities. As part of the Los Angeles Basin Study, for example, Reclamation worked with partners to down-scale future precipitation projections to time intervals that could be used as part of existing planning efforts. Lee Alexanderson of the Los Angeles County Department of Public Works notes that those efforts allowed the county to incorporate more robust climate science into future water demand and supply analysis so that planning efforts can be adjusted accordingly: "In the end, that effort reaffirmed our confidence that the Los Angeles Basin is well-positioned to cope with anticipated climate changes and water demands for the remainder of this century, provided that we continue to implement appropriate planning and policies."

Similarly, Larry Dolan, Hydrologist at the Montana Department of Natural Resources, points to the usefulness of work carried out through the Upper Missouri River Impact Assessment and Missouri River Headwaters Basin Study: "Basin modeling enabled us to understand how water supplies in the future, although they might be similar to what we have today, will not be sufficient to meet future needs in the region for irrigation and other uses. Warming trends will mean higher shortages in the future due to a longer growing season and higher crops irrigations demands for the water that we have available to us."

Table 1–1. Basin Studies Initiated, Study Locations and Cost Share Partners

	Basin Study	Study Location	Cost Share Partners
Chapter 3	Colorado River Basin Study	Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming	Arizona Department of Water Resources, (California) Six Agency Committee, Colorado Water Conservation Board, New Mexico Interstate Stream Commission, Southern Nevada Water Authority, Utah Division of Water Resources, Wyoming State Engineer's Office
Chapter 3	Lower Santa Cruz River Basin Study	Arizona	Southern Arizona Water Users Association
Chapter 3	West Salt River Valley Basin Study	Central Arizona	West Valley Central Arizona Project Subcontractors
Chapter 4	Henrys Fork of the Snake River Basin Study	Central Idaho	Idaho Water Resource Board
Chapter 4	Hood River Basin Study	North-central Oregon	Hood River County Water Planning Group
Chapter 4	Upper Deschutes Basin Study	Oregon	Deschutes Basin Board of Control
Chapter 4	Yakima River Basin Study	South-central Washington	State of Washington Department of Ecology
Chapter 5	Klamath River Basin Study	California and Oregon	Oregon Water Resources Department, California Department of Water Resources
Chapter 6	Missouri River Headwaters Basin Study	Montana	Montana Department of Natural Resources and Conservation
Chapter 6	Niobrara River Basin Study	Northern Nebraska	Nebraska Department of Natural Resources
Chapter 6	Republican River Basin Study	Colorado, Kansas and Nebraska	Colorado Division of Water Resources, Kansas Department of Agriculture, Kansas Division of Water Resources, Kansas Water Office, Nebraska Department of Natural Resources
Chapter 6	St. Mary and Milk River Basins Study	Montana, southern Alberta and Saskatchewan Canada, Blackfeet and Ft. Belknap Indian Reservations	Montana Department of Natural Resources and Conservation

	Basin Study	Study Location	Cost Share Partners
Chapter 7	Santa Fe Basin Study	Northern New Mexico and southern Colorado	City of Santa Fe and County of Santa Fe
	Lower Rio Grande Basin Study	United States/Mexico border from Fort Quitman, Texas to the Gulf of Mexico	Rio Grande Regional Water Authority
	Pecos River Basin Study	New Mexico	New Mexico Interstate Stream Commission
Chapter 8	Sacramento and San Joaquin Rivers Basin Study	California	California Dept. of Water Resources, Stockton East Water District, California Partnership for the San Joaquin Valley, El Dorado County Water Agency, Madera County Flood Control and Water Conservation Agency
	Salinas and Carmel River Basins	California	Monterey Peninsula Water Management District, Monterey County Water Resources Agency, Monterey Regional Water pollution Control Agency, San Luis Obispo County
Chapter 9	Truckee River Basin Study	California and Nevada	Truckee River Flood Management Project, Placer County Water Agency, Truckee Meadows Water Authority and the Tahoe Regional Planning Agency
Chapter 10	Santa Ana River Watershed Basin Study	California	Santa Ana Watershed Project Authority
	Southeast California Regional Basin Study	California	Borrego Water District
	San Diego Watershed Basin Study	California	City of San Diego Public Utilities Department
	Los Angeles Basin Study	California	Los Angeles County Flood Control District
	Upper Washita River Basin Study	Oklahoma	Oklahoma Water Resources Board, Fort Cobb Reservoir Master Conservancy District, Foss Reservoir Master Conservancy District
	Upper Red River Basin Study	Oklahoma	Oklahoma Water Resources Board

Other non-Federal partners highlight the ways that collaborative efforts through Basin Studies are continuing, even after work on a particular study has been completed. For example, Hood River County Commissioner Les Perkins notes that the hydrological model developed as part of the Hood River Basin Study helped the community focus on strategies for long-term sustainability of water supplies, and that those efforts are continuing: "The study launched follow-up efforts to evaluate new storage options in Hood River County, and it spurred us to enhance groundwater monitoring in order to better understand local surface and groundwater interactions."

Others note that sharing of data developed through the Basin Study Program is helping with local planning efforts. Aaron Sussman, formerly with the Mid-Region Council of Governments in Albuquerque, New Mexico, points out that information on the projected effects of climate, developed as part of the Upper Rio Grande Climate Impact Assessment, is being used outside of water resources planning: "Together with our water demand analyses, that information jump-started community discussions on how we want to see our area grow—in particular, looking at our transportation needs in the broader and more comprehensive context of future land use and water resource needs."

Relationships established through the Basin Studies lead to additional collaborative efforts, such as the Colorado River Basin *Moving Forward* Effort, a collaborative partnership among Reclamation, the seven Colorado River Basin States, the Ten Tribes Partnership, and conservation organizations designed to pursue several areas of the "next steps" identified in the *Colorado River Basin Water Supply and Demand Study*. Collaboration with stakeholders is critical to the successful implementation of climate adaptation strategies through WaterSMART Grants, the Title XVI Program, Drought Response Program, Cooperative Watershed Management Program, and the Water Conservation Field Services Program. Additional information on coordination activities specific to each western river basin, including the strategies developed to address potential water shortages, is included in Chapters 3 through 10.

RECLAMATION

Managing Water in the West

Chapter 2: Hydrology and Climate Assessment

U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011[1], which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

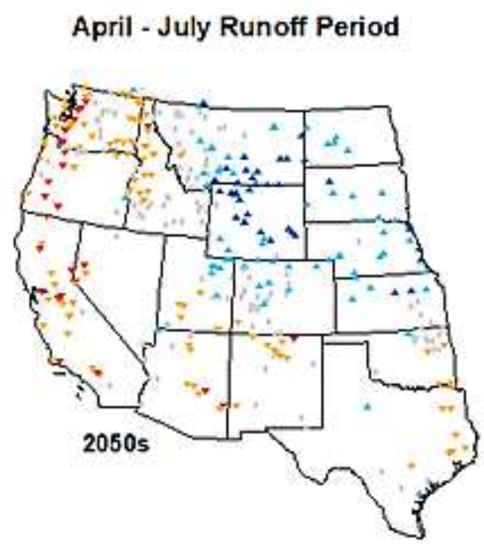
This chapter provides an updated summary of west-wide climate and hydrology projections and is organized as follows:

Section 1: Introduction to Reclamation's hydrology and climate assessments,

Section 2: Assessment of the effects and risks resulting from global climate change on water supply,

Section 3: Assessment of increases in water demand as a result of increasing temperatures and the rate of reservoir evaporation,

Section 4: Brief overview of coordination with the U.S. Geological Survey (USGS) to analyze groundwater supply and climate change impacts, and



Projected change in April-July runoff for the 2050s relative to the 1990s (See Figure 2-5)

Section 5: Coordination activities to strengthen the understanding of water supply trends through research activities.

The key studies referenced in this chapter include west-wide assessments of water supply and demand projections. Additional information specific to each western river basin, including the strategies developed to address potential water shortages, is included in Chapters 3 through 10.

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website here: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf

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1 Introduction

In meeting its mission, Reclamation's planning and operations rely upon assumptions of present and future water supplies based on climate. Water supply and water management are critical areas projected to be impacted by future climate conditions. Climate change adds to historic water challenges in the western United States (U.S.), not necessarily introducing new challenges, but adding additional stress to water supplies and resources already stretch to, or beyond, natural limits (Dettinger et al., 2015).

To assess the risk and impacts to water management and its operations, Reclamation is conducting West-Wide Climate Risk Assessments (WWCRA) to develop important baseline information about climate changes risks for western U.S. water supplies, water demands, and related conditions that influence water management. Reclamation's assessments are consistent with the key findings from the Third National Climate Assessment (Melillo et al., 2014) with respect to water supply that include:

- **Changing Rain, Snow, and Runoff:** Annual precipitation and river-flow increases are observed now in the Midwest and the Northeast regions. Very heavy precipitation events have increased nationally and are projected to increase in all regions. The length of dry spells is projected to increase in most areas, especially the southern and northwestern portions of the contiguous U.S.
- **Droughts Intensify:** Short-term (seasonal or shorter) droughts are expected to intensify in most U.S. regions. Longer-term droughts are expected to intensify in large areas of the Southwest, southern Great Plains, and Southeast.
- **Increased Risk of Flooding in Many Parts of the U.S.:** Flooding may intensify in many U.S. regions, even in areas where total precipitation is projected to decline. Increasing flooding risk affects human safety and health, property, infrastructure, economies, and ecology in many basins across the U.S.
- **Groundwater Availability:** Climate change is expected to affect water demand, groundwater withdrawals, and aquifer recharge—reducing groundwater availability in some areas.
- **Risks to Coastal Aquifers and Wetlands:** Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands.
- **Water Quality Risks to Lakes and Rivers:** Increasing air and water temperatures, more intense precipitation and runoff, and intensifying

droughts can decrease river and lake water quality in many ways, including increases in sediment, nitrogen, and other pollutant loads.

- **Changes to Water Demand and Use:** Climate change affects water demand and the ways water is used within and across regions and economic sectors. The Southwest, Great Plains, and Southeast are particularly vulnerable to changes in water supply and demand.
- **Water Supply Availability:** Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses.
- **Water Resources Management:** In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed within existing practices. In many places, competing demands for water create stress in local and regional watersheds.

This chapter describes Reclamation's climate and hydrology assessments that were conducted to collectively summarize the effect of global climate change on water resources in each major Reclamation river basin.

2 West-Wide Water Supply Assessment

Within water management planning, climate informs estimations of future water supplies, future water demands, and boundaries of system operation. In meeting its mission, Reclamation relies upon assumptions of present and future water supplies based on climate. The following section provides an overview of projected future climate and hydrology conditions. This information serves as an update to the climate projections presented in the 2011 SECURE Water Act Report to Congress using the most recent climate and hydrology projections available.

2.1 West-wide Climate and Hydrology

Climate information influences the evaluation of resource management strategies through assumptions or characterization of future potential temperature, precipitation, and runoff conditions among other weather information. Water supply estimates are developed by making determinations of what wet, dry, and normal periods may be like in the future and include the potential for hydrologic extremes that can create flood risks and droughts. Risks to future water supplies presented in this section are based on the West-Wide Climate Risk Assessments: Hydroclimate Projections Technical Memorandum (Reclamation, 2016 [Projections]).

The assessment involved developing hydrologic projections associated with a large collection of the global climate projections featured in the IPCC Fifth Assessment (IPCC, 2013) and developed as part of the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project (CMIP5) phase 5.[2] CMIP5 projections are regarded as the most recent project data available for describing future global climate possibilities. Additional information specific to the eight major western U.S. river basins listed in Section 9503 of the SECURE Water Act, including detailed plots, data, and routed hydrology locations, is included in Reclamation, 2016 (Projections).

Temperature

U.S. average temperature has increased by 1.3 degrees Fahrenheit (°F) to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970 (Melillo et al., 2014). The Western U.S. has warmed roughly 2 °F in the basins considered here and is projected to warm further during the 21st century. In many river basins, a warming trend has been noted since at least the 1970s (e.g., lower Colorado River basin) if not since the beginning of the 20th century (e.g., Columbia River Basin, Sacramento and San Joaquin River basins, the Rio Grande basin, and most of the Missouri River basin). This rise in

[2] The 2011 SECURE Water Act Report to Congress developed a similar assessment using hydrologic projections featured in the IPCC Fourth Assessment (IPCC, 2007) and developed as part of the WCRP Project phase 3: http://www.usbr.gov/watersmart/docs/west-wide-climate-risk-assessments.pdf. The assessment described in this chapter updates that 2011 assessment.

temperature will continue trends already observed. Central estimates of this continued warming vary from roughly 5 to 7 °F depending on location. A summary of the projected temperature trends by Reclamation river basin are presented in Figure 1–1.

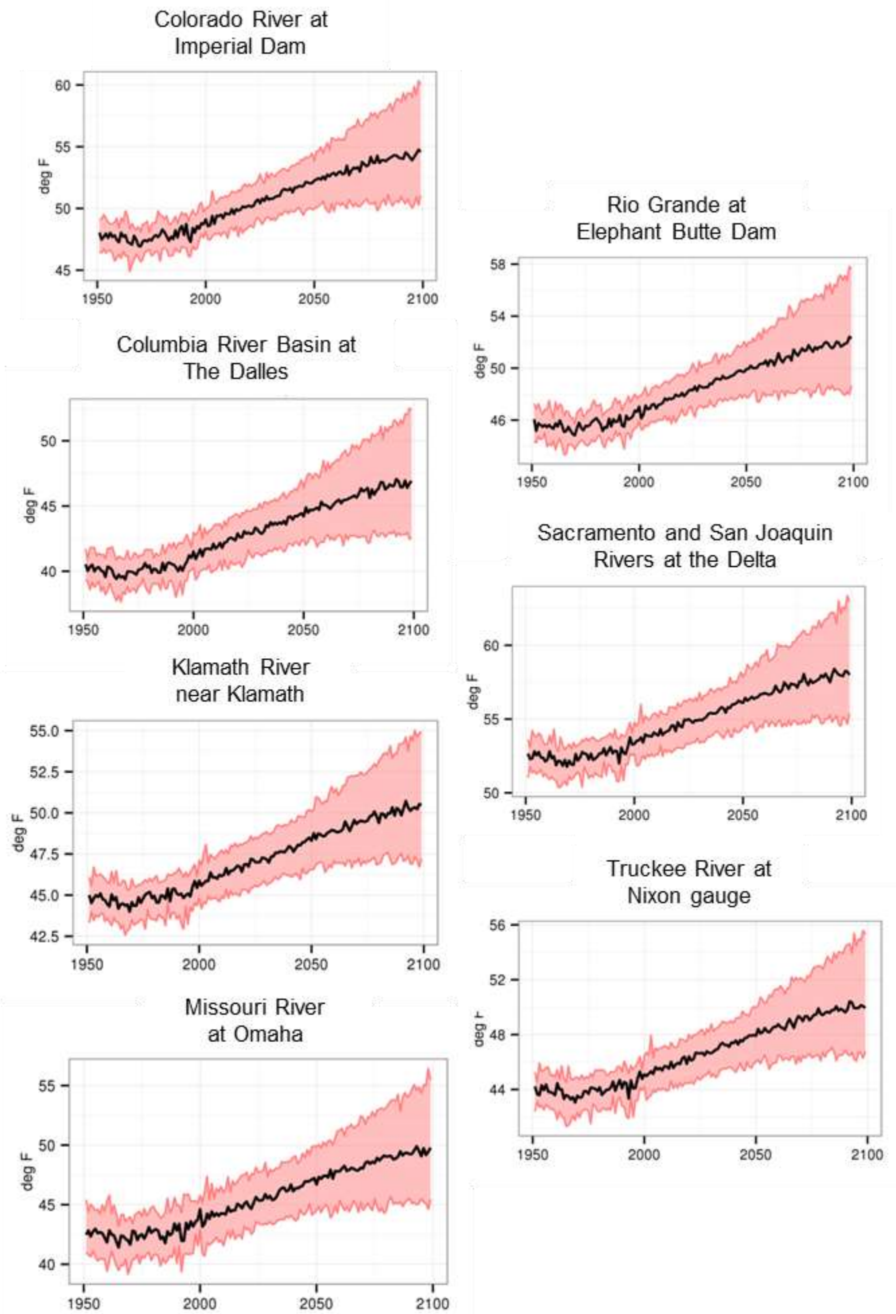

Figure 2–1. Projections of annual mean temperature in the major western river basins. Source: Reclamation, 2016 (Projections).

Annual mean temperature is plotted in degrees Fahrenheit. The heavy black line is the annual time series median value (i.e., ensemble-median). The shaded area is the annual time series of 10th to 90th percentiles. Note the plot scales vary by basin, but temperatures are expected to increase in all basins by approximately 5–7 °F by the end of the century.

Precipitation

Compared to projected changes in temperature, projected changes in precipitation are much less consistent among various climate models and are characterized by greater uncertainty. While projected changes in average total annual precipitation are generally small in many areas, both wet and dry extremes (heavy precipitation events and length of dry spells) are expected to increase substantially throughout the West (Georgakakos et al., 2014). Projected annual precipitation trends by river basin are presented in Figure 2–2.

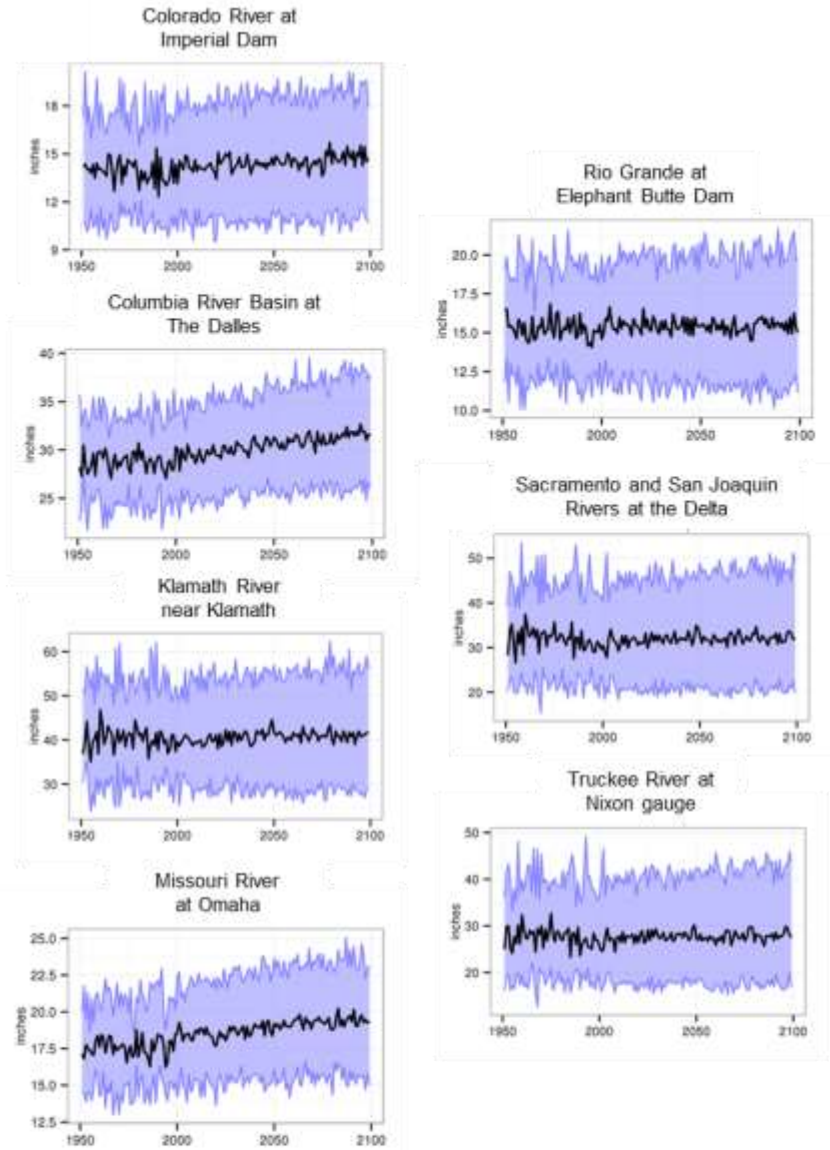

Figure 2–2. Projections of annual total precipitation in the major western river basins. Source: Reclamation, 2016 (Projections).

Total annual precipitation is plotted in inches. The heavy black line is the annual time series median value (i.e., ensemble-median). The shaded area is the annual time series of 10th to 90th percentiles. Note the plot scales vary by basin. Overall precipitation is projected to remain variable with no discernable trends in most basins.

Snowpack

Across most of the West, a trend toward more precipitation falling as rain and less as snow is already apparent. This is being observed both topographically (lower elevations receiving less precipitation in the form of snow) and seasonally (a shortening of the snow accumulation period). In most areas, projections of future hydrology suggest that warming and associated loss of snowpack will persist over much of the Western U.S. A summary of the projected annual snowpack trends are presented in Figure 2–3.

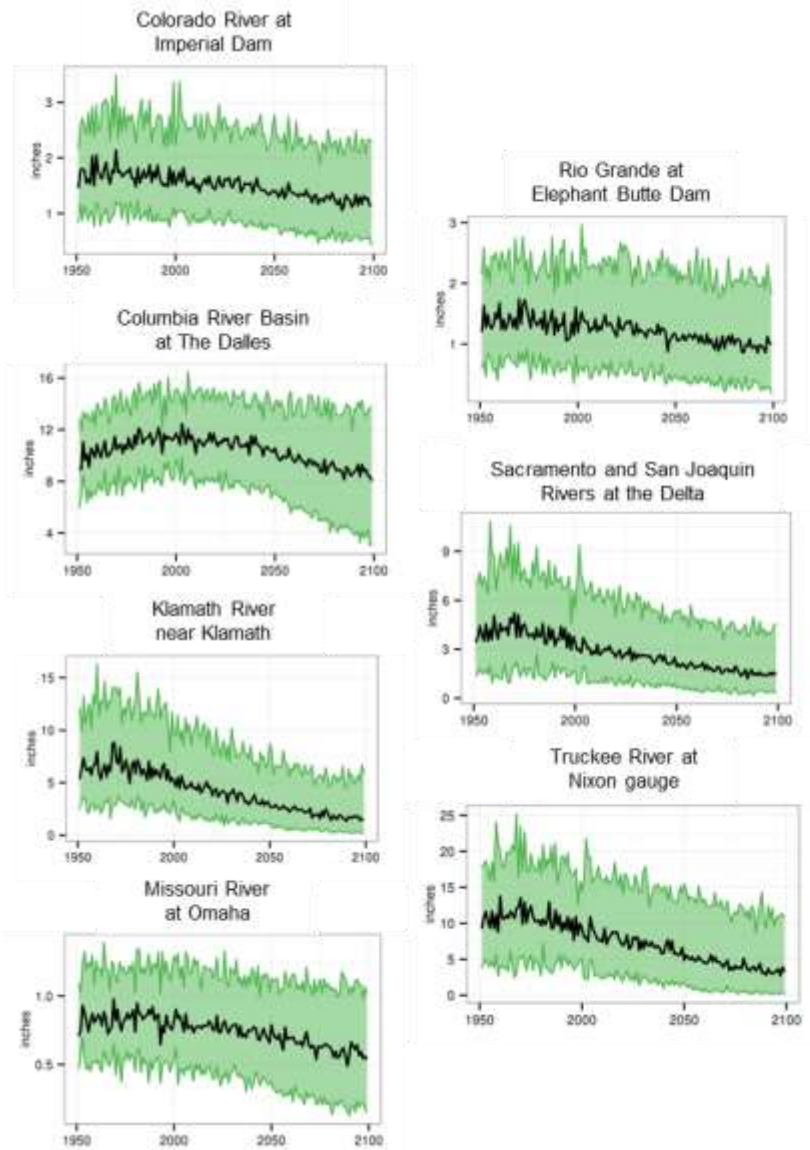

Figure 2–3. Projections of April 1st Snow Water Equivalent in the major western river basins. Source: Reclamation, 2016 (Projections).

Snow water equivalent is plotted in inches. The heavy black line is the annual time series median value (i.e., ensemble-median). The shaded area is the annual time series of 10th to 90th percentiles. Note the plot scales vary by basin. Trends toward decreasing snowpack are projected to continue across most of the West through the 21st century.

Runoff

Projected changes in temperature, precipitation, and snowpack are expected to change the magnitude and seasonality of runoff. Warming is expected to result in more rainfall-runoff during the cool season rather than snowpack accumulation, leading to increases in December–March runoff and decreases in April–July runoff. The southwest to the Southern Rockies is expected to experience gradual runoff declines during the 21st century. The Northwest to north-central U.S. is expected to experience little change through mid-21st century, with increases projected for the late-21st century. Projected annual runoff trends are presented in Figures 2–4 and 2–5, and are also summarized by river basin below.

- **Colorado River Basin:** Warmer conditions are projected to transition snowfall to rainfall, producing more December–March runoff and less April–July runoff. The median shift in the date of peak runoff is expected to be 12 days earlier by the end of the century.
- **Columbia River Basin:** Mean annual runoff is projected to increase by 2.9% by the 2050s. Moisture falling as rain instead of snow at lower elevations will increase the wintertime runoff with decreased runoff during the summer.
- **Klamath River Basin:** By the 2050s, projected warming is expected to change runoff timing, with a 23% increase in rainfall-runoff during the winter (December through March) and a 33% decrease in runoff during the spring and summer (April through July).
- **Missouri River Basin:** Mean annual basin runoff is projected to increase as much as 15%, with higher variability in sub-basin runoff by mid-century. Moisture falling as rain instead of snow at lower elevations is expected to result in an increase of the wintertime runoff and a decrease in summer runoff.
- **Rio Grande Basin:** Mean annual runoff is projected to decrease by 3% by the 2050s, with higher variability in sub-basins. By mid-century, warmer conditions are projected to transition snowfall to rainfall, shifting the timing of runoff by up to 11 days in the upper basin tributaries.
- **Sacramento and San Joaquin River Basins:** Mean annual runoff is projected to increase as much as 5.4% in the Sacramento and San Joaquin Rivers Delta by the 2050s. Moisture falling as rain instead of snow at lower elevations will increase wintertime runoff by 22% (December through March) and decrease springtime runoff by 27% (April through July).
- **Truckee River Basin:** Mean annual runoff is projected to increase by from 5.7% by the 2050s. Warmer conditions are projected to transition wintertime snow into rain, increasing December–March runoff and decreasing April–July runoff. The median date of peak runoff is expected to be 19 days earlier by the end of the century.

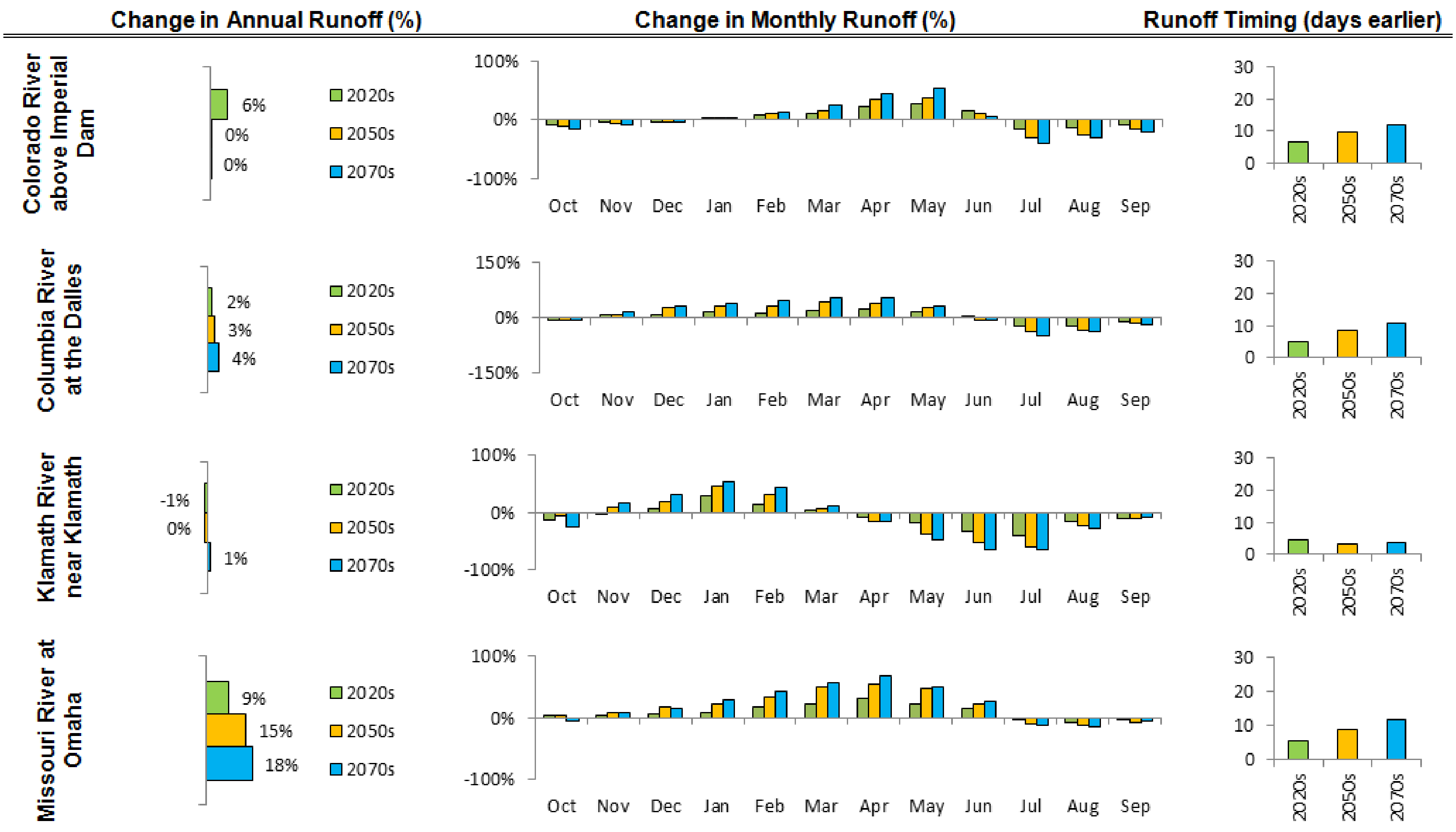

Figure 2–4. Projected shift in annual runoff, monthly runoff, and peak runoff date relative to the 1990s for the 2020s, 2050s, and 2070s in the major Reclamation river basins.

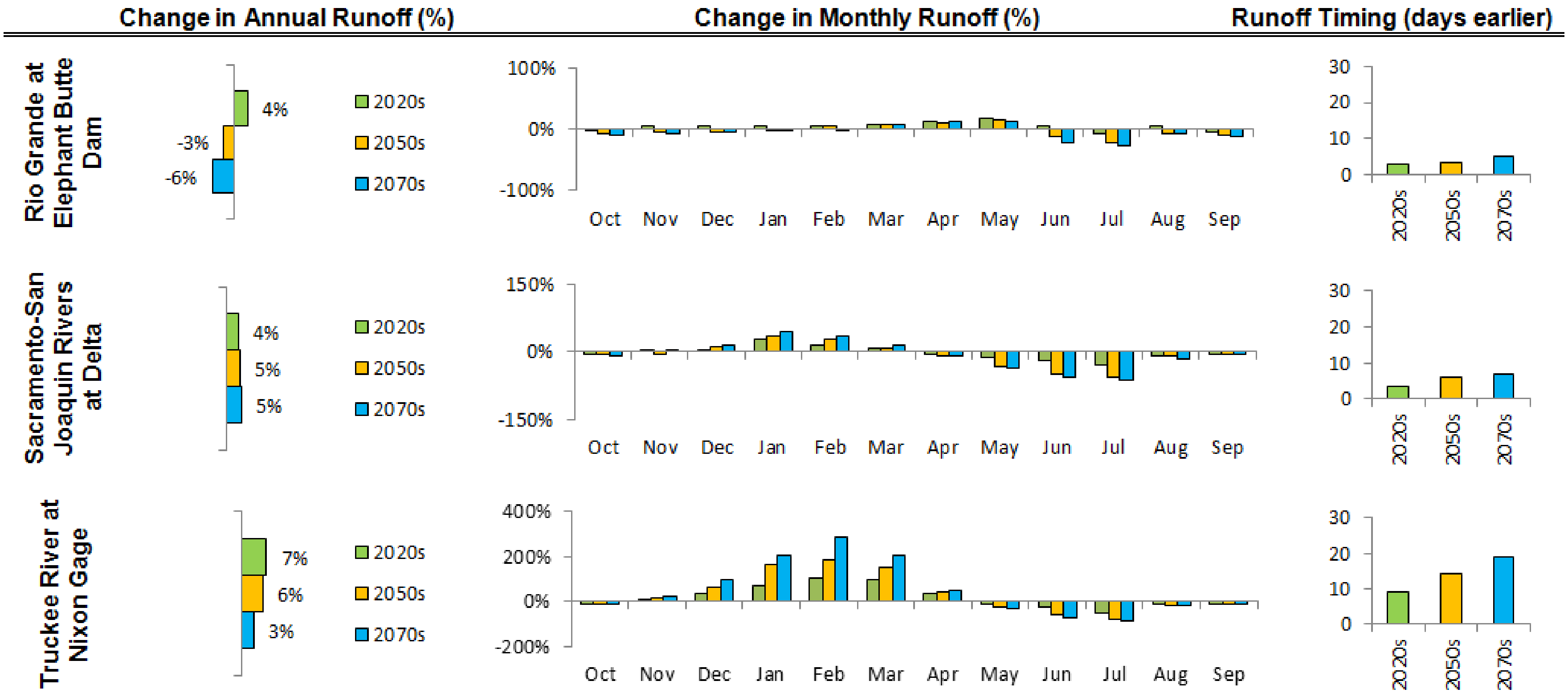

Figure 2–4 (continued). Projected shift in annual runoff, monthly runoff, and peak runoff date relative to the 1990s for the 2020s, 2050s, and 2070s in the major Reclamation river basins.

In almost all cases, projections indicate an increase in cool-season runoff (November through April), and a decrease in warm-season runoff (May through September) as well as a shift to earlier peak runoff timing in every basin.

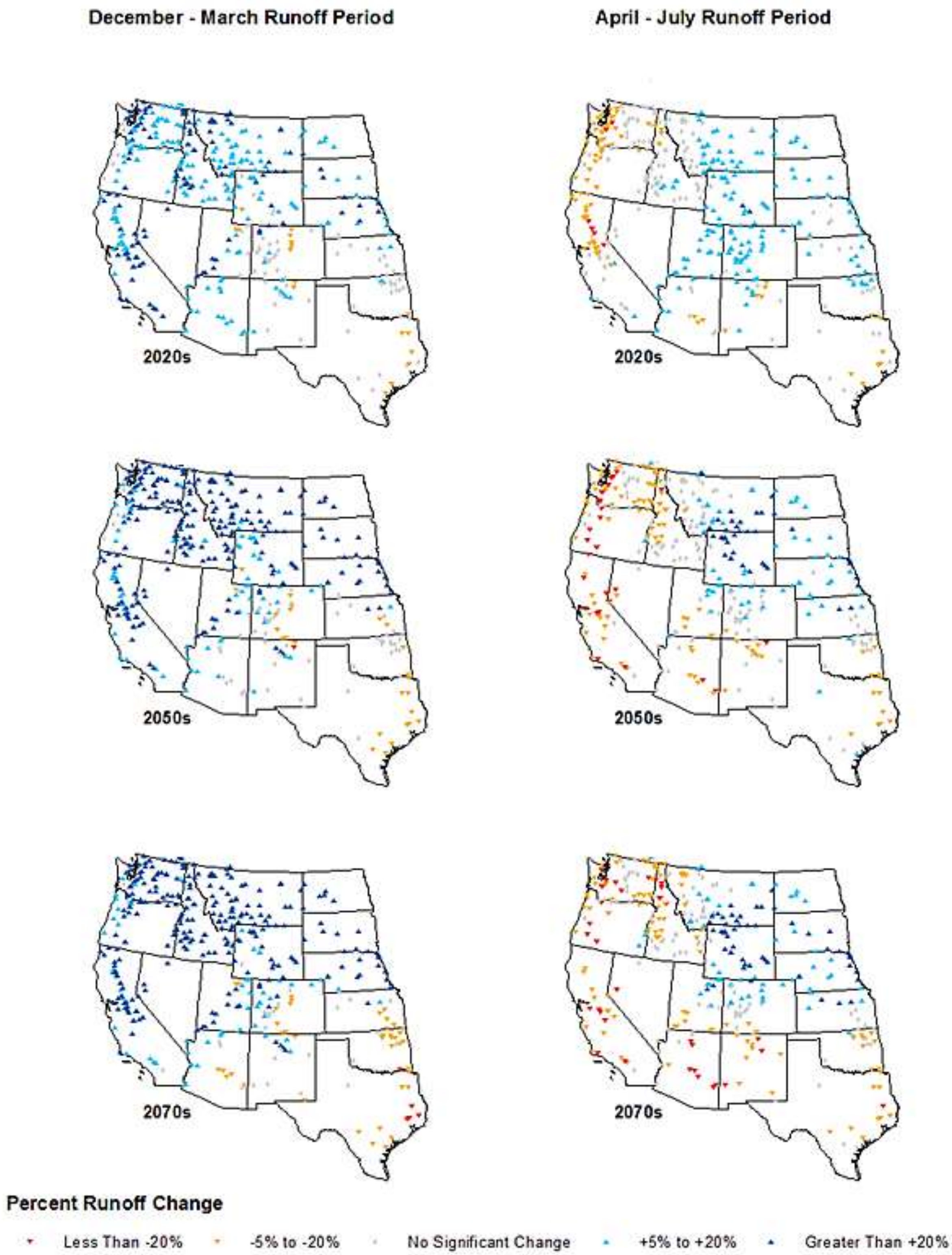

Figure 2–5. Projected change in December-March and April-July runoff relative to the 1990s for the 2020s, 2050s, and 2070s distributed over the West.

Moisture falling as rain instead of snow at lower elevations is projected to increase wintertime runoff and decrease runoff during the summer.

Inspection of the underlying ensemble of projection information shows that there is significant variability and uncertainty, particularly with respect to precipitation. Changes in the frequency and intensity of extreme events have significant implications for the management of floods, other high flows, and storable water. As already noted, studies indicate a strong potential for the occurrence of more intense precipitation events in most areas of the West. This in turn is expected to increase the frequency and/or magnitude of extreme runoff events. Evidence also suggests that we can anticipate more year-to-year variability of surface water supplies in at least some areas: for example, the future of the Southwest may include longer, more extreme dry (and wet) periods than previously observed (Georgakakos et al., 2014).

Where runoff is projected to increase relative to historical conditions, supplies available to meet delivery needs may increase (especially where adequate storage or other mechanisms exist for aligning the timing of water demands with runoff). Where runoff is projected to decrease, additional challenges for meeting water delivery needs can be anticipated. Impacts on water deliveries will vary from basin to basin and from year to year, depending on the timing and magnitude of water inflows and demands, available storage, and water delivery options.

Summary

In summary, temperature increases are projected to continue, resulting in decreased snowpack, differences in the timing and volume of spring runoff, and an increase in peak flows for some Western U.S. basins. The impacts to snowpack and runoff affect the timing and availability of water supplies. Precipitation changes are also expected to occur, interacting with warming to cause longer term and more frequent droughts and larger and more numerous floods, varying by basin. Note that these summary statements draw attention to mean projected changes in temperature and precipitation, characterized generally across the Western U.S.

- Temperature increases have resulted in decreased snowpack, differences in the timing and volume of spring runoff, and an increase in peak flows for some Western U.S. basins. The impacts to snowpack and runoff affect the timing and availability of water supplies.
- Warming is expected to continue, causing further impacts on supplies, increasing agricultural water demands, and affecting the seasonal demand for hydropower electricity.
- Precipitation changes are also expected to occur, interacting with warming to cause longer term and more frequent droughts and larger and more numerous floods, varying by basin.
- Cool season runoff is projected to increase over the west coast basins from California to Washington and over the north-central U.S., but little change to slight decreases are projected over the Southwestern U.S. to Southern Rockies.

- Warm season runoff is projected to decrease substantially over a region spanning southern Oregon, the Southwestern U.S., and Southern Rockies. However, north of this region warm season runoff is projected to change little or to slightly increase.
- Projected increasing precipitation in the northern tier of the Western U.S. could counteract warming-related decreases in warm season runoff, whereas projected decreases in precipitation in the southern tier of the Western U.S. could amplify warming-related decreases in warm season runoff

Collectively, the impacts of climate change to water resources give rise to difficult questions about how best to operate Reclamation facilities to address growing demands for water and hydropower now and how to upgrade and maintain infrastructure to optimize operations in the future. More extreme variations in climate will make it difficult for Reclamation to meet competing demands for water. Warming is expected to continue, causing further impacts on supplies, increasing agricultural water demands, and affecting the seasonal demand for hydropower electricity. Increased intensity of droughts and floods also raises concerns about infrastructure safety, the resiliency of species and ecosystems to these changes, and the ability to maintain adequate levels of hydropower production. Chapters 3 through 10 translate the simulated hydrologic effects under projected climate change into geographic impacts on water resources including water deliveries, flood management, hydropower generation, recreation, ecosystem resiliency, and water quality.

2.2 Uncertainty

The WWCRA hydroclimate projections were designed to take advantage of best available datasets and modeling tools; follow methodologies documented in peer reviewed literature, and update the consistent west-wide data developed for the 2011 SECURE Water Act Report to Congress. It should be noted that there are a number of analytical uncertainties, including uncertainties associated with climate projection information and assessing hydrologic impacts. Uncertainty in both climate projection information and assessing hydrologic impacts is discussed in detail in the WWCRA: Hydro-Climate Projections Technical Memorandum.[3]

The 2011 SECURE Water Act Report to Congress developed a similar assessment using bias corrected and spatially downscaled (BCSD) hydrologic projections using CMIP3 projections. This chapter's assessment updates the 2011 assessment using CMIP5 projections. A comparison of projected temperature and precipitation for both the BCSD-CMIP3 and BCSD-CMIP 5 projections is provided in Figure 2–6.

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[3] The West-Wide Climate Risk Assessments: Hydroclimate Projections Technical Memorandum referenced in this section is available on the Reclamation website here: http://www.usbr.gov/watersmart/docs/west-wide-climate-risk-assessments.pdf

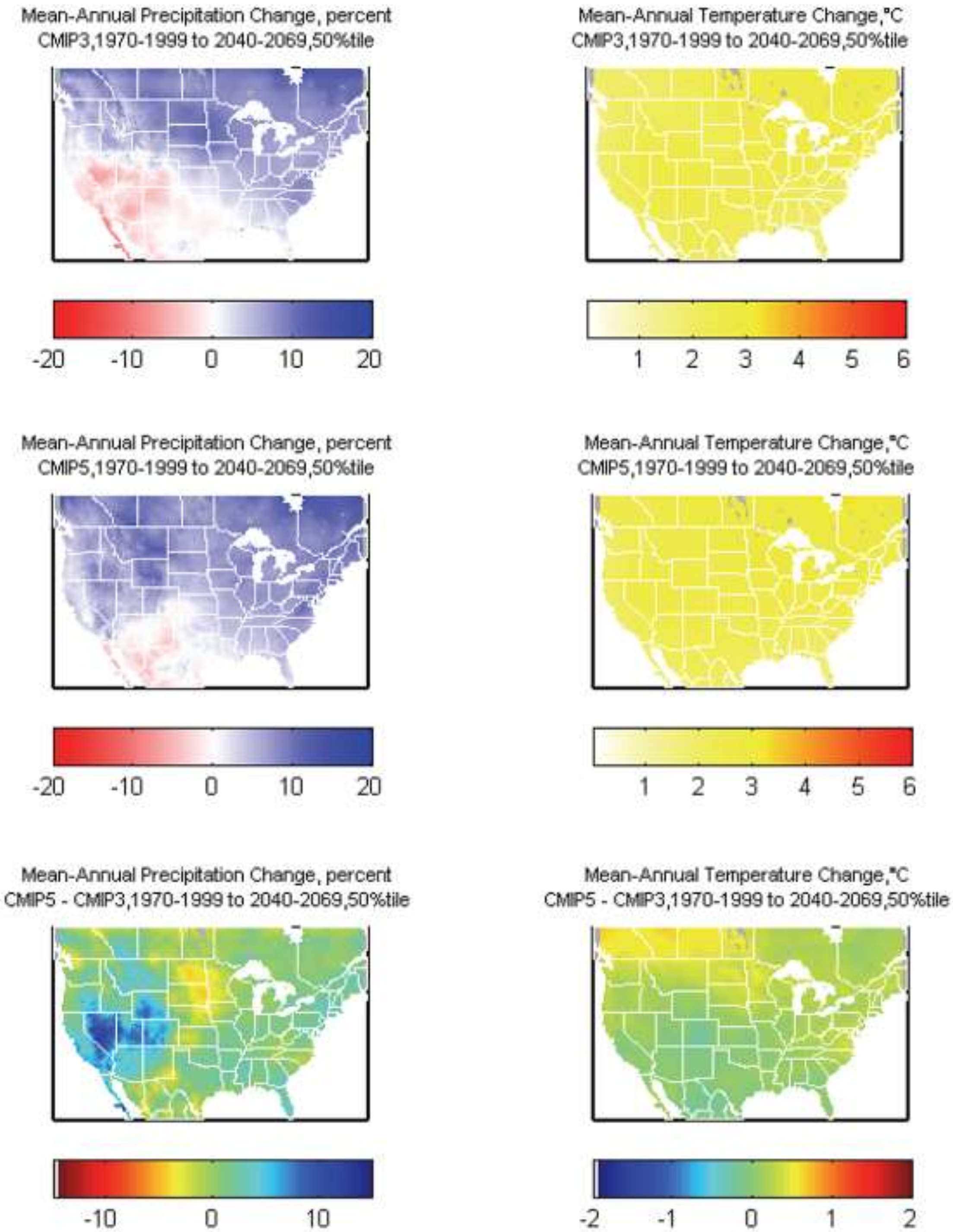

Figure 2–6. Central tendency changes in mean annual precipitation and temperature over the contiguous U.S. from 1970-1999 to 2040-2069 for BCSD-CMIP3 (top row), BCSD-CMIP5 (middle row), and the difference (bottom row). Source: Reclamation, 2013.

The CMIP5 projections indicate a similar pattern for temperature and precipitation with CMIP5 projections indicating greater warming in the north and a slight shift of increasing precipitation into the Upper Colorado River Basin and Northern California.

The BCSD-CMIP5 hydrology shows hydroclimate changes (i.e., temperature, precipitation, and runoff) that are generally similar to BCSD-CMIP3 across the contiguous U.S. However in the BCSD-CMIP5 hydrology, there are some region-specific differences including greater warming to the North, regions of more increased precipitation change in the West and Great Plains (although varying by season), and differences in runoff change that more closely follow those found for precipitation than for temperature (Reclamation, 2013 [CMIP]).

3 West-wide Water Demands Assessment

Climate change will alter not only water supply, but also demands for water. Below is a summary of projected changes in demands for water for municipal and industrial use, for irrigation, and due to reservoir evaporation.

3.1 Municipal & Industrial (M&I) Use

In recent decades, many of the Nation's fastest-growing municipal areas have been in the arid and semi-arid West (e.g., Las Vegas, southern California, Colorado's Front Range, Utah's Wasatch Front, southern Arizona). Substantial population growth in these and other urban areas of the West is anticipated to continue into the foreseeable future (e.g., Pincetl et al., 2013).

Outdoor use of water for maintaining vegetation at private lots, public parks, and other urban landscapes is generally expected to experience a gradual increase in evaporative demand along with rising temperatures during the 21st century, similar to irrigated agricultural vegetation. Except where these increased evaporative demands are offset by a corresponding increase in precipitation, or by measures to reduce outdoor use, M&I consumptive water demands also are expected to increase.

Notably, outdoor water use represents more than half of residential water use in many urbanized areas of the arid West (Mayer et al., 1999), and as much as 90% of household consumptive use. Thus, outdoor watering practices, and potential changes in those practices, represent (along with changes in urban population) factors with the greatest potential to influence M&I consumptive demands.

3.2 Irrigation Demands

As previously mentioned, the WWCRAs provide important baseline projections of risks to water supplies, changes in water demand, and potential operational impacts. Risks to future water demands were quantified in a west-wide assessment entitled West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections Technical Memorandum (Reclamation, 2015 [Irrigation])[4]. This assessment identified potential changes in crop irrigation demand in the eight major western river basins listed in the SECURE Water Act. Agricultural demand for water is highly susceptible to climate change.

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[4] The West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections Technical Memorandum referenced in this section is available on the Reclamation website here: http://www.usbr.gov/watersmart/wcra/docs/irrigationdemand/WWCRAdemands.pdf

Impacts across the evaluated basins vary, but according to the 2015 analysis, evapotranspiration (ET)—evaporation and plant transpiration—is projected to increase in all Western basins due to increasing temperatures, including an increase in the annual ET for perennial agricultural crops and many annual crops. Various assumptions are incorporated into any agricultural demand projection, in addition to the uncertainties inherent in the underlying climate and hydrological outlooks. As summarized in Table 2–1, some factors are projected to increase agricultural demands, while others would reduce demands. Other factors, such as agricultural management practices, have effects that are difficult to forecast.

Table 2–1. Factors, Including Changes in Climate and Atmospheric Conditions, Potentially Affecting Future Agricultural Water Demands

Factors Increasing Demand	Factors Reducing Demand	Factors With Unknown Effects
Increased evaporation and evapotranspiration due to temperature increase.	Reduced losses of agricultural water through improvements to delivery practices and facilities.	Changes in the types and characteristics of crops grown.
Increased evapotranspiration due to extended growing seasons.	Less per-unit crop water use associated with increased atmospheric CO_2 and ozone.	Changes in agricultural management practices (e.g., more dry-year fallowing or deficit-irrigation cropping).
Increase in lands requiring supplemental irrigation to remain viable.	Increased crop failure due to increased pests, diseases, etc.	Transfers of water between different uses.
Increase in irrigated lands due to northward warming.	Conversion of irrigated cropland to other less water-intensive uses.	Effects on the surface energy balance from factors other than temperature.
Increased livestock water demands.		
Increased total crop yield associated with increased atmospheric CO_2.		

3.3 Reservoir Evaporation

The WWCRA demands assessment also includes projections of evaporation for 12 reservoirs within the eight major Reclamation river basins (see Figure 2–7). The reservoirs at which evaporation was estimated include: Lake Powell (Colorado River), Lake Mead (Colorado River), American Falls (Columbia, Snake River tributary), Grand Coulee (Columbia), Upper Klamath Lake (Klamath River), Canyon Ferry Lake (Missouri River), Boysen Reservoir (Missouri River), Elephant Butte Reservoir (Rio Grande) , Lake Shasta (Sacramento River), Millerton Lake (San Joaquin River), Lake Tahoe (Truckee River), and Lahontan Reservoir (Carson River).

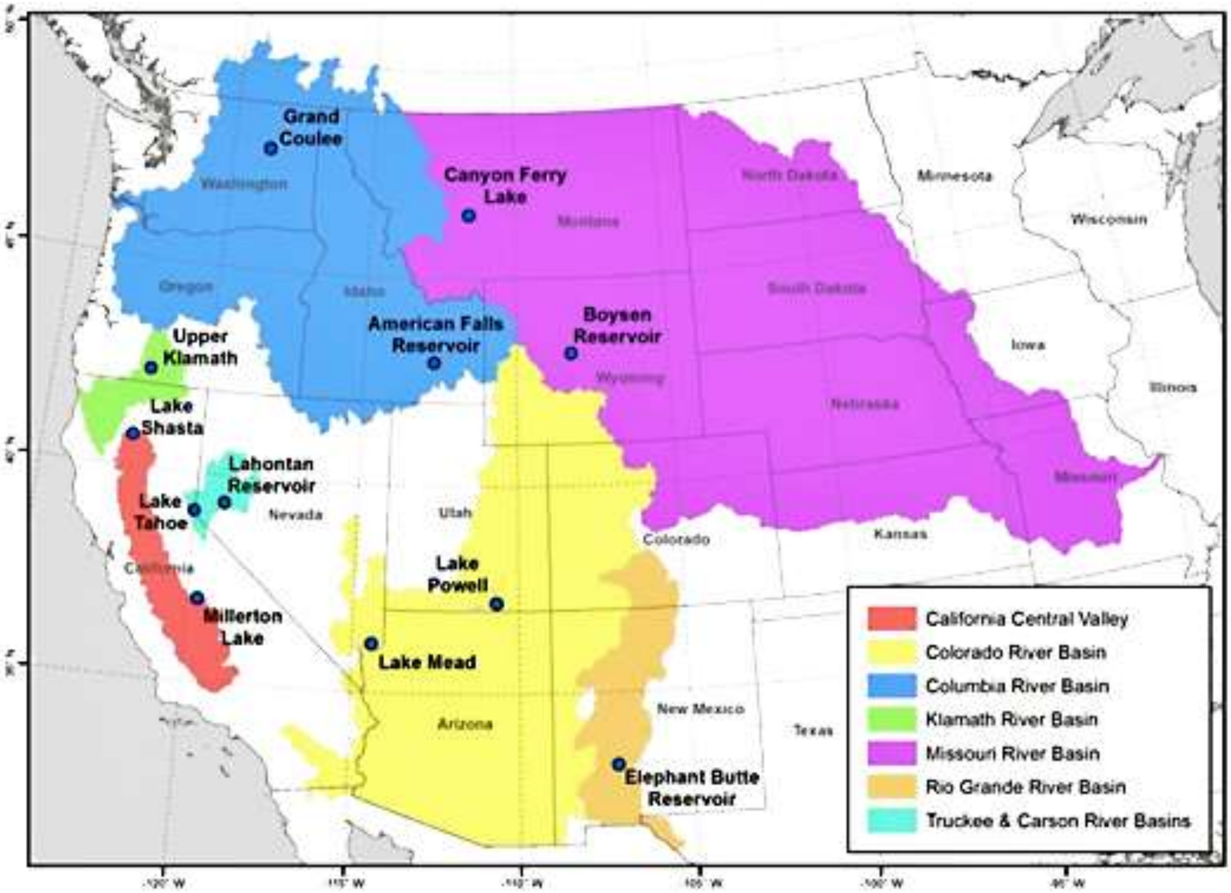

Figure 2–7. Reservoirs and lakes where an evaporation projection model was applied. West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections (Reclamation 2015b).

Open water evaporation from lakes and reservoirs is an important water budget component to consider for water planning, modeling of hydrologic systems, and projections of future water demands and supply. Evaporation pans are typically used to estimate lake and reservoir evaporation; however, the timing and magnitude of pan evaporation is not necessarily representative of actual evaporation from a lake or reservoir for numerous reasons, including significant time lags between peak pan evaporation and peak reservoir evaporation during a year, and has been shown to be highly uncertain (Hounam, 1973 and Morton, 1979). Open water evaporation in this study was estimated using an energy balance model, which has been widely applied for estimating operational reservoir and lake evaporation with limited climatic and heat storage information. Key results for this study include:

- The ensemble median of annual reservoir evaporation and net evaporation (evaporation minus precipitation) is projected to increase in all basins. As an example, projections for the Colorado River Basin (Lake Powell) are provided in Figure 2–8.

- Projected annual evaporation increases are typically around 2 to 6 inches by 2080 at most reservoirs modeled.
- However, the increase in annual net evaporation is relatively small at some reservoirs due to increased precipitation and nearly equal to or slightly greater than historical evaporation at others due to decreased precipitation.

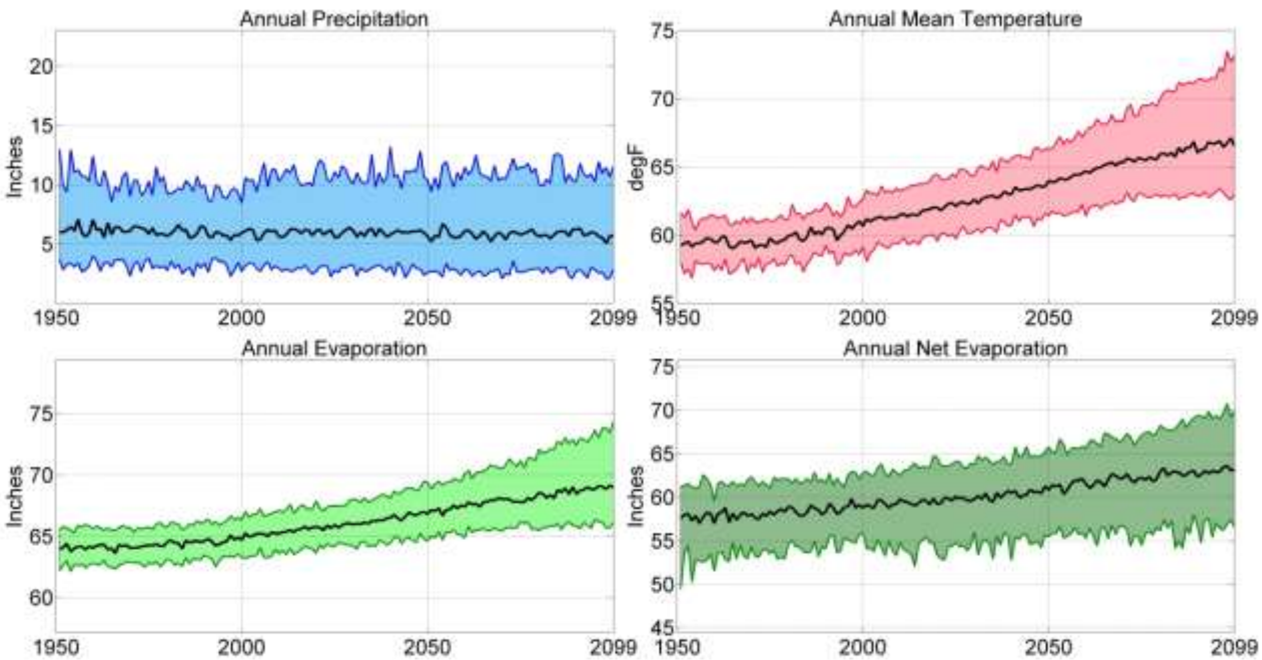

Figure 2–8. Example of projections for the Colorado River Basin – Lake Powell ensemble median and 5th and 95th percentile annual precipitation, temperature, reservoir evaporation, and net evaporation.

The heavy black line is the annual time series of 50 percentile values (i.e., ensemble-median). The shaded area is the annual time series of 5th to 95th percentiles. Plots for each major river basin exhibiting varying degrees of increasing evapotranspiration and reservoir evaporation due to warming are included in the Technical Memorandum (Reclamation, 2015 [Irrigation]).

3.4 Uncertainty

The West-Wide Climate Risk Assessment: Irrigation Demand and Reservoir Evaporation Projections Technical Memorandum (Reclamation, 2016 [Projections]) summarizes potential future climate impacts on irrigation demand and reservoir evaporation across the Western U.S. using best available datasets and methodologies. Uncertainties in projections of water demands are associated with the climate projections and the methods used for assessing irrigation demand and reservoir evaporation. It is important to note that these projections do not represent a comprehensive demand assessment, but are part of a focused examination of primary climate impacts on plant water needs and reservoir evaporation. Beyond climate related considerations, a number of additional factors may influence irrigation demands in the future, such as changing cropping patterns driven by market prices, changes in irrigation practices and soil-evaporation components, changes in crop varieties and phenologies, and total acres kept in production. A comprehensive future irrigation demand assessment would require consideration of all factors and strong stakeholder involvement. Uncertainty is discussed in more detail in Reclamation 2015 (Irrigation).

4 Groundwater Recharge and Discharge

Changes in temperature and precipitation will affect Western hydrology in multiple ways, including impacts to snow hydrology, surface water, and groundwater. Among the most significant of these anticipated effects are changes in snowpack accumulation and melt, changes in runoff timing and quantity, and additional risks associated with extreme runoff events. Groundwater and surface water are closely linked. Impacts to one will affect the other, directly or indirectly, over a shorter or longer timeframe, and through a variety of possible pathways.

When evaluating the potential effects of climate change on Western water resources, groundwater is an important consideration, as it comprises an estimated 33% of total freshwater diversions and withdrawals used for human purposes in the 17 western states (Maupin et al., 2014). The decreased snowpack could result in decreased groundwater infiltration, runoff and ultimately lower base flows in the rivers during the summer. Typically, groundwater is interconnected with surface water and withdrawals of groundwater will affect downstream flow in much the same way as withdrawals from the river itself. At the other extreme, geologic conditions and distances may result in weak, non-existent, or highly lagged interactions between groundwater and surface water, and recharge to associated aquifers may take millennia.

Thus, the pathways and rates of recharge versus withdrawal are fundamental considerations for sustaining groundwater resources. The rate of groundwater withdrawal, often exacerbated by drought, currently outstrips recharge in some areas of the West, including much of California's Central Valley (Harter and Dahlke, 2014) and certain areas of the Great Plains dependent on the Ogallala Aquifer (Konikow, 2013). Long-term sustainability of groundwater supplies is possible only where withdrawals are offset with —a balance that can be particularly challenging during severe or prolonged droughts.

With increases in the variability and uncertainty of precipitation and surface water supplies, it is anticipated that many Western communities will become more reliant on groundwater as a supplemental or primary water supply source for agricultural and municipal purposes. Recharge to groundwater also is expected to be affected by shifts in precipitation patterns, increased temperature, and other factors affecting plant uptake and evapotranspiration, just as these shifts will impact surface water.

4.1 U.S. Geological Survey Coordination

Through the WWCRAs, Reclamation coordinates with the USGS in several ways to assess groundwater availability and to assess the impact of climate change on groundwater recharge and discharge. As part of WaterSMART, the USGS has implemented a National Water Census (NWC). In response to the SECURE Water Act, the USGS has implemented a new program: the Water Availability and Use Science Program (WAUSP).

Regional Groundwater Assessments: Through the WAUSP, the USGS is undertaking a series of regional groundwater availability studies in the West to improve our understanding of groundwater availability in major aquifers across the Nation. These studies provide valuable data and tools that are leveraged in Reclamation's Basin Studies to assess climate impacts and adaptation strategies. A map of the locations is provided in Figure 2–9.

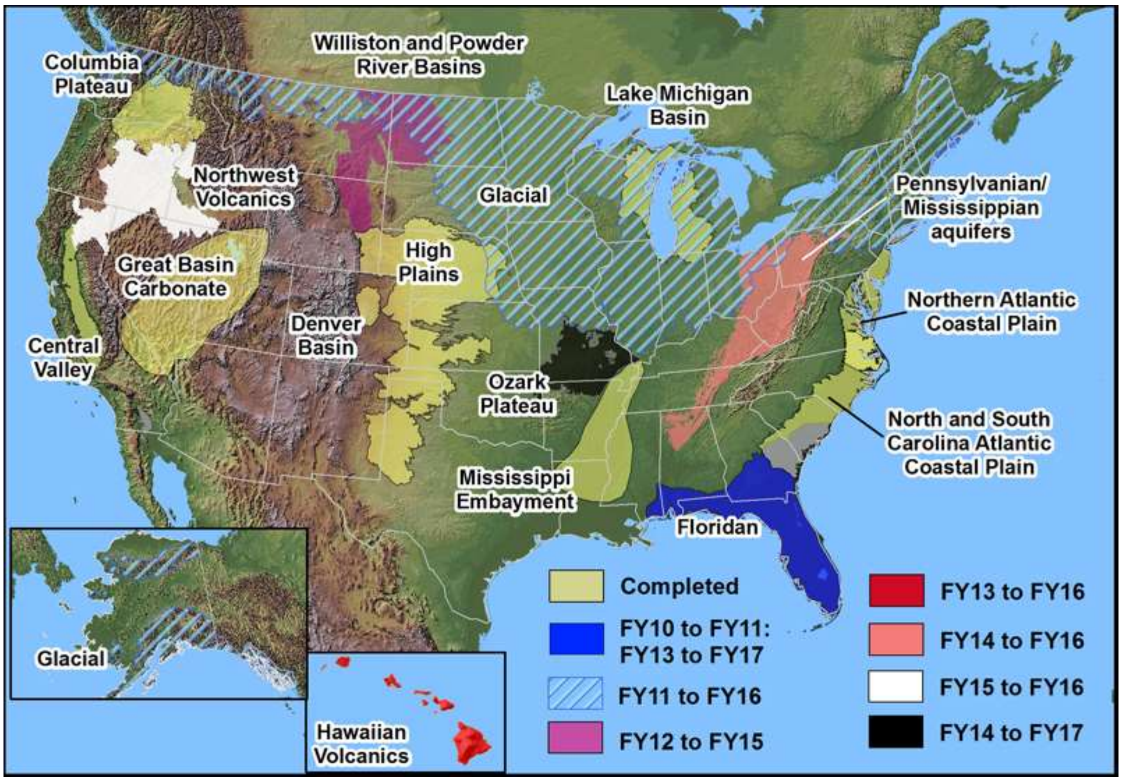

Figure 2–9. Map of USGS Groundwater Resources Program regional scale groundwater study areas, with the schedule for the studies indicated. (Courtesy of USGS. Updated April 2015).

Highlights from the regional groundwater studies relevant to western river basins are provided below:

- The **Pacific Northwest Volcanic Aquifer Study** will quantify groundwater resources and geothermal energy potential in much of eastern Oregon, northeastern California, southwestern Idaho, and northernmost Nevada. Groundwater is the major source of year-round dependable water supply in the study area, and water is a necessary component of geothermal energy development.

- The **Williston and Powder River Basins Study** will (1) quantify current groundwater resources in this aquifer system, (2) evaluate how these resources have changed over time, and (3) provide tools to better understand system response to future anthropogenic demands and environmental stress. The development of two nationally important energy-producing areas, the Williston structural basin (containing the Bakken Formation) and Powder River structural basin provide an important opportunity to study the water-energy nexus within a groundwater context. Large amounts of water are needed for energy development in these basins.
- The **High Plains Aquifer Study** quantified current groundwater resources, evaluated changes in those resources over time, and provided tools to forecast how those resources respond to stresses from future human and environmental uses. The improved quantitative understanding of the basin's water balance provided by this USGS study not only provides key information about water quantity but also is a fundamental basis for many analyses of water quality and ecosystem health.
- The **Columbia Plateau Regional Aquifer System Study** covers over 50,000 square miles of eastern Oregon and Washington and western Idaho. The USGS conducted a study of the Columbia Plateau Regional Aquifer System to characterize the hydrologic status of the system, identify trends in groundwater storage and use, and quantify groundwater availability.
- The **Great Basin Carbonate and Alluvial Aquifer Study** quantified current groundwater resources, evaluated how those resources have changed over time, and developed tools to assess system responses to stresses from future human uses and climate variability.
- The **Central Valley Aquifer Study** includes an assessment of groundwater availability and quantification of groundwater resources using a variety of tools. The ultimate benefit of this assessment will be a better understanding of how the system responds to current and future human and environmental stresses that will prove useful to water managers in their decision making process related to this valuable resource.
- The **Denver Basin Aquifer Study** addressed an important and non-renewable source of water for municipal, industrial, and domestic uses in the Denver and Colorado Springs metropolitan areas. The USGS conducted a groundwater availability of the Denver Groundwater Basin to enhance our understanding of regional groundwater flow and aquifer storage, to evaluate current conditions, and to predict future conditions.
- The **Middle Rio Grande Basin Study** was a 6-year effort (1995-2001) to improve the understanding of the hydrology, geology, and land-surface characteristics of the Middle Rio Grande Basin in order to provide the scientific information needed for water-resources management. This initial proof of concept study was conducted prior to the development of the strategy outlined in Circular 1323 and served as a precursor to current

Groundwater Resources Program (GWRP) regional groundwater availability studies.

National Brackish Groundwater Assessment: The use of brackish groundwater to supplement or, in some places, replace the use of freshwater sources has been analyzed as a potential climate resilient adaptation strategy in a number of WaterSMART Basin Studies. The WWCRA Implementation Team is coordinating with the USGS to gain a better understanding of the location and character of brackish groundwater in the Western U.S. An assessment is needed to expand development of the resource and provide a scientific basis for making policy decisions. To address this need, the USGS is conducting an assessment of brackish aquifers, using a consistent national approach, to compile existing information that can be used to:

- Characterize brackish aquifers
- Describe dissolved-solids concentrations, including other chemical characteristics, using existing data
- Describe the horizontal and vertical extents of aquifers containing brackish groundwater
- Describe ability of aquifers to yield water
- Identify current brackish groundwater use
- Generate national maps of dissolved-solid concentrations
- Identify data gaps that limit full characterization of brackish aquifers

5 Climate Coordination and Research

Reclamation is actively engaged in multiple collaborative efforts with Federal and non-Federal partners to develop and share information for a common understanding of climate change impacts to water resources in the West. This section highlights west-wide collaboration to develop climate and hydrology information for use by Reclamation. Additional information on coordination activities specific to each western river basin, including the strategies developed to address potential water shortages, is included in Chapters 3 through 10.

5.1 Reclamation's Science and Technology Program Research and Development

Fundamental to developing new information for adapting to climate change is assessing the current state of knowledge, identifying where gaps exist, and finding opportunities to address those gaps. Reclamation's Science and Technology Program is taking a leading role to develop the data and tools necessary to support climate change adaptation within Reclamation and by stakeholders.[5] Key highlights for the Science and Technology Program include the following:

- **Downscaled Climate and Hydrology Projections Web Service:**[6] Since 2007, Reclamation has led a partnership of nine Federal, academic, and non-governmental organizations to provide future projections of temperature, precipitation, hydrology, and streamflow throughout the continental U.S. to support locally relevant decision making. These information resources are served through a website that provides users access to the monthly gridded precipitation, temperature and hydrologic projection data, as well as additional climate projection information that covers the contiguous U.S. Reclamation and collaborators have also partnered with other information hosts to provide mirror access at other website, including the U.S. General Services Administration's Data.gov, [7] USGS's Geo Data Portal,[8] and the Federal Geospatial Data Committee's GeoPlatform.gov.[9] Reclamation also leveraged this web service in 2010-2011 to produce a Streamflow Projections Website that accompanied the release of the 2011 SECURE Water Act Report focusing on the streamflow reporting locations of that report.[10]

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[5] Downscaled Climate and Hydrology Projections Web Service: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html

[6] For detailed information on Reclamation's Science and Technology Program's Climate Change Research visit the Reclamation website: http://www.usbr.gov/research/climate

[7] U.S. General Services Administration's Data.gov: http://www.data.gov/climate

[8] U.S. Geological Survey's Geo Data Portal: http://cida.usgs.gov/gdp

[9] Federal Geospatial Data Committee's GeoPlatform.gov: https://www.geoplatform.gov

[10] Streamflow Projections Website: http://www.usbr.gov/WaterSMART/wcra/flowdata/index.html

- **Third Edition of the Literature Synthesis on Climate Change Implications for Water and Environmental Resources:** This report supports long-term water resources planning with region-specific climate change information, summarizing recent literature on the current and projected effects of climate change on hydrology and water resources. This report, which contains information surveyed through 2012, was assembled by Reclamation and was subjected to external review by staff from each of the five National Oceanic and Atmospheric Administration Regional Integrated Sciences and Assessments centers in the Western U.S.
- **Climate and Hydrology Impacts Assessment Tools:** Since 2011, Reclamation's Science and Technology Program has partnered with the U.S. Army Corps of Engineers (USACE) and National Center for Atmospheric Research (NCAR) to improve tools and methods for assessing climate change impacts on water resources. An initial project has involved identifying strengths and weaknesses of current methods that inform Reclamation's vulnerability assessments and adaptation planning. The project focused on methods to downscale climate projections and simulate hydrologic impacts, including those that the WWCRA team has relied upon to assess vulnerabilities and support adaptation planning. This initial effort revealed opportunities for research to develop improved techniques, and has led to a subsequent effort to develop and apply such techniques.
- **Climate Extremes Assessment Tools:** Since 2011, Reclamation's Science and Technology Program has partnered with the University of Colorado's Cooperative Institute for Research in Environmental Studies (CIRES) and NOAA's Earth System Research Laboratory (ESRL) to improve tools and methods for assessing climate change impacts on extreme events. Initial projects occurring in 2012-2013 focused on more physically-based methods for estimating climate change impacts on storm-scale events happening during the warm season along the Colorado Front Range, and also on tools to better diagnose moisture origins and storm setup for heavy precipitation events across the Intermountain West. These efforts have led to successor projects where the focus is on developing tools that can be applied by Reclamation's Technical Service Center as they estimate wet weather extremes and associated hydrologic hazards to support Dam Safety Office risk investigations in a changing climate.

5.2 Technical Assessments and Guidance

Reclamation's Climate Change Adaptation Strategy recognizes that the presence of critical Federal facilities throughout the West and the national interest in addressing climate change necessitates a heightened role for Reclamation to continue to address water resource challenges by providing expert technical assistance and the best available science through collaborative planning efforts. The planning process relies upon access to information to make statements about future climate possibilities. This section highlights activities using the existing information on climate change impacts, identifying gaps in knowledge, and taking a step forward to use this information in decision processes through a science based approach.

Technical Guidance for Incorporating Climate Change Information into Water Resources Planning Studies: In 2014, Reclamation released Technical Guidance for Incorporating Climate Change Information into Water Resources Planning Studies (Reclamation, 2014 [Guidance]).[11] The objective of this guidance is to assist Reclamation study teams in navigating the range of technical methods available to account for climate change impacts in planning studies. This document is designed to be used in the existing decision-making processes to understand climate change impacts on water supply, demand, and criteria that govern or guide water management.

Selecting Climate Projection Information for Water Resources Studies, Environmental Analyses, and Planning Applications: This document provides clear and concise information regarding the available climate projection information resources and methods to select a subset of climate projections for detailed analysis in support of a specific study.[12] When considering and analyzing the potential impacts of climate change, planners and analysts must choose an appropriate source of climate projection information within the context of their specific study or analysis. The scientific community has developed a vast amount of information regarding projected future climate conditions. Selecting an appropriate source of climate projection information for use in a given study or analysis is a critical first step in considering and analyzing potential climate change impacts in support of water resources and environmental planning.

Reclamation has made significant progress in assessing the impacts of climate change to water resources and implementing on-the-ground actions to mitigate impacts. However, Reclamation's Climate Change and Adaptation Strategy recognizes that more needs to be done to use information about future climate change in order to make decisions now about how best to operate Reclamation reservoirs, prioritize investments in new or improved facilities, and protect species and habitat in a changing climate. Additional information specific to each western river basin, including the strategies developed to address potential water shortages, is included in Chapters 3 through 10.

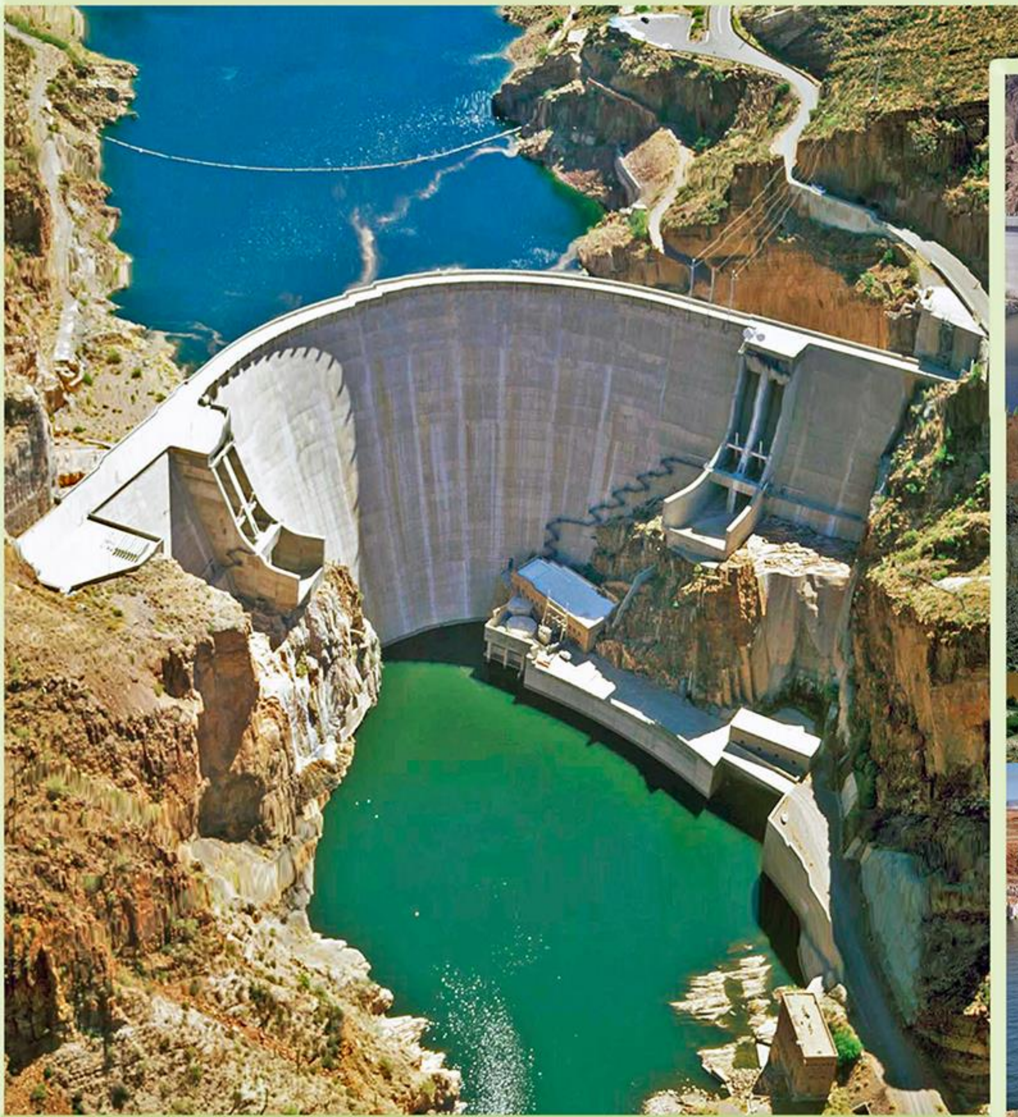
[11] The guidance is available on the WaterSMART website: http://www.usbr.gov/watersmart/wcra/docs/WWCRATechnicalGuidance.pdf.

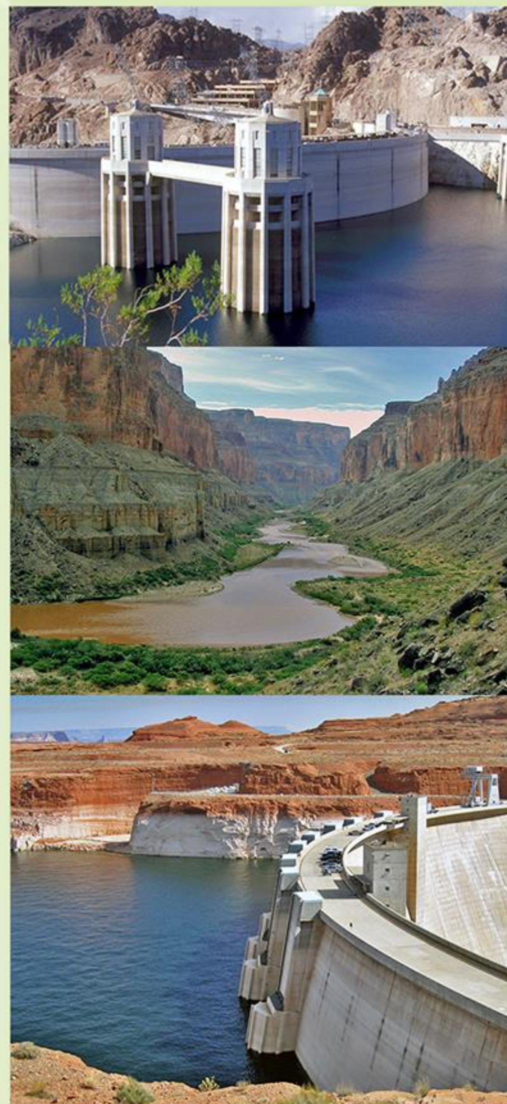
[12] The guidance is available on the WaterSMART website: http://www.usbr.gov/watersmart/wcra

RECLAMATION

Managing Water in the West

Chapter 3: Colorado River Basin





U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with section (§) 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011[1] , which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Colorado River Basin. This chapter is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Colorado River Basin Water Supply and Demand Study (Reclamation, 2012 [CO Basin Study) and the Colorado River Basin *Moving Forward* Phase 1 Report (2015 [Moving Forward]). Additional information relevant to the Colorado River Basin, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

Colorado River Basin Setting

States: Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming

Major U.S. Cities Supplied: Albuquerque, Denver, Las Vegas, Los Angeles, Phoenix, Salt Lake City, and San Diego

Areas Outside the Basin Receiving Colorado River Water: Albuquerque/ Santa Fe (San Juan Chama Project); Cheyenne, Wyoming; Colorado Front Range; Southern California (Colorado River Aqueduct Service Area/Imperial and Coachella Valley); and Wasatch Front Range (Central Utah Project/Strawberry Valley Project)

International: Mexico

River Length: 1,450 miles

River Basin Area: 246,000 square miles

Major River Uses: Municipal Supply (35 to 40 million people), Agricultural Irrigation (4.5 million acres), Hydropower (4,200 megawatts), Recreation, and Fish and Wildlife

Notable Reclamation Facilities: Hoover Dam, Glen Canyon Dam, Flaming Gorge Dam, Aspinall Unit, Navajo Dam, and Davis Dam, Parker Dam

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[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

Today, nearly 40 million people[2] in the seven Colorado River Basin states[3] rely on the Colorado River and its tributaries for some, if not all, of their municipal water needs. These same sources irrigate nearly 4.5 million acres of land (Reclamation, 2015 [Moving Forward]) in the basin and the adjacent areas that receive Colorado River water, generating many billions of dollars a year in agricultural and economic benefits. Within the basin, 22 federally recognized tribes consider the Colorado River and its tributaries an essential physical, economic, and cultural resource.

The Colorado River and its tributaries provide habitat for a wide range of species, including several that are federally endangered. These rivers flow through seven National Wildlife Refuges and 11 National Park Service (NPS) units[4] that provide a range of recreational opportunities and add significant benefits to the regional economy. Hydropower facilities in the basin can supply more than 4,200 megawatts of vitally important electrical capacity to assist in meeting the power needs of western states, reducing the use of fossil fuels. In addition, the Colorado River is vital to the United Mexican States (Mexico). The Colorado River Basin is depicted in Figure 3–1.

Total consumptive use and losses in the U.S. portion of the basin, including the 1944 Treaty delivery to Mexico, have averaged approximately 15.0 million acre-feet (MAF)[5] annually over the past decade (Reclamation, 2015 [Moving Forward]). Federally recognized tribes hold approximately 2.9 MAF of annual diversion rights from the Colorado River and its tributaries (Reclamation, 2012 [CRB Study TR-C]). In many cases, these rights are senior in priority to those held by other users. Agriculture is the dominant use of Colorado River water, accounting for approximately 70 percent of total Colorado River water used in the U.S. Of the total consumptive use, 40 percent is exported outside the basin's hydrologic boundaries for use in adjacent areas.

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[2] About 40 million people are estimated to live in the area encompassed by the hydrologic boundaries of the Colorado River Basin in the United States plus the adjacent areas of the Colorado River Basin states that receive Colorado River water (Reclamation 2012, CRB Study TR-C).

[3] Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

[4] Although there are 11 NPS Colorado River Basin Parks Program, nine are considered to be directly linked to the Colorado River and its major tributaries. (http://www.nature.nps.gov/water/Homepage/Colorado_River.cfm).

[5] Basin-wide consumptive use and losses estimated over the period 2002 to 2012, including the 1944 Treaty delivery to Mexico, reservoir evaporation, and other losses due to native vegetation and operational inefficiencies.

As shown on Figure 3–1, several major metropolitan areas that receive Colorado River water—including Albuquerque, Denver, Los Angeles, Salt Lake City, and San Diego—are located outside the basin's hydrologic boundaries.

The Colorado River system is operated in accordance with the Law of the River.[6] Apportioned water in the U.S. portion of the basin exceeds the average long-term (1906 through 2012) historical natural flow[7] of about 16.2 MAF (Reclamation, 2015 [Moving Forward]). To date, the imbalance has been managed and demands are largely met as a result of the considerable amount of reservoir storage capacity in the system (approximately 60 MAF, or nearly 4 years of average natural flow of the river); the fact that the upper-basin states of Colorado, New Mexico, Utah, and Wyoming are still developing their apportionment; and the continuing efforts the Basin States are making to reduce their need for Colorado River water.

1.1 Colorado River Basin Study Overview

It was against this challenging and complex management setting that the Colorado River Basin Water Supply and Demand Study was conducted. The Basin Study was funded through the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program and was conducted by Reclamation and agencies representing the Basin States. The purpose of the Basin Study was to define current and future imbalances in water supply and demand in the U.S. portion of the basin and the adjacent areas that receive Colorado River water through 2060, and to develop and analyze adaptation and mitigation strategies to resolve those imbalances.

The Basin Study did not result in a decision as to how future imbalances should or will be addressed. Rather, it provides a common technical foundation that frames the range of potential imbalances that may be faced in the future and the range of solutions that may be considered to resolve those imbalances. The Basin Study was conducted in collaboration with stakeholders throughout the basin. Interest in the study was broad, and participating stakeholders included tribes, agricultural users, purveyors of municipal and industrial (M&I) water, power users, and conservation and recreation groups.

There is great uncertainty in the precise trajectories of future water supply and demand, as well as how those trajectories may affect the reliability of the Colorado River system to meet the needs of basin resources. To address this

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[6] The treaties, compacts, decrees, statutes, regulations, contracts, and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often collectively referred to as the Law of the River. There is no single, universally agreed upon definition of Law of the River, but it is useful as a shorthand reference to describe this longstanding and complex body of legal agreements governing the Colorado River.

[7] Natural flow represents the flow that would have occurred at the location had depletions and reservoir regulation not been present upstream of that location.

Figure 3–1. Colorado River Basin.

Note: The scope of the Colorado River Basin Study was limited to the portion of the basin and adjacent areas that receive Colorado River water within the United States.

uncertainty, this Basin Study adopted a scenario planning process to capture a broad range of plausible water demand and supply futures, and then assessed the impacts to basin resources if such futures were to unfold. This approach confirmed that, absent future action, the basin faces a wide range of plausible future long-term imbalances between supply and demand. This imbalance, computed as a 10-year running average, ranges from 0 to 6.8 MAF, with a median of 3.2 MAF in 2060,[8] as shown in Figure 3–2. The assessment of impacts to basin resources found that any long-term imbalance will impair the ability of the Colorado River system to meet the needs of basin resources resulting in negative impacts (for example, reduced reliability of water deliveries for municipal and agricultural purposes, decreased hydropower generation, reduced recreational opportunities) to those resources.

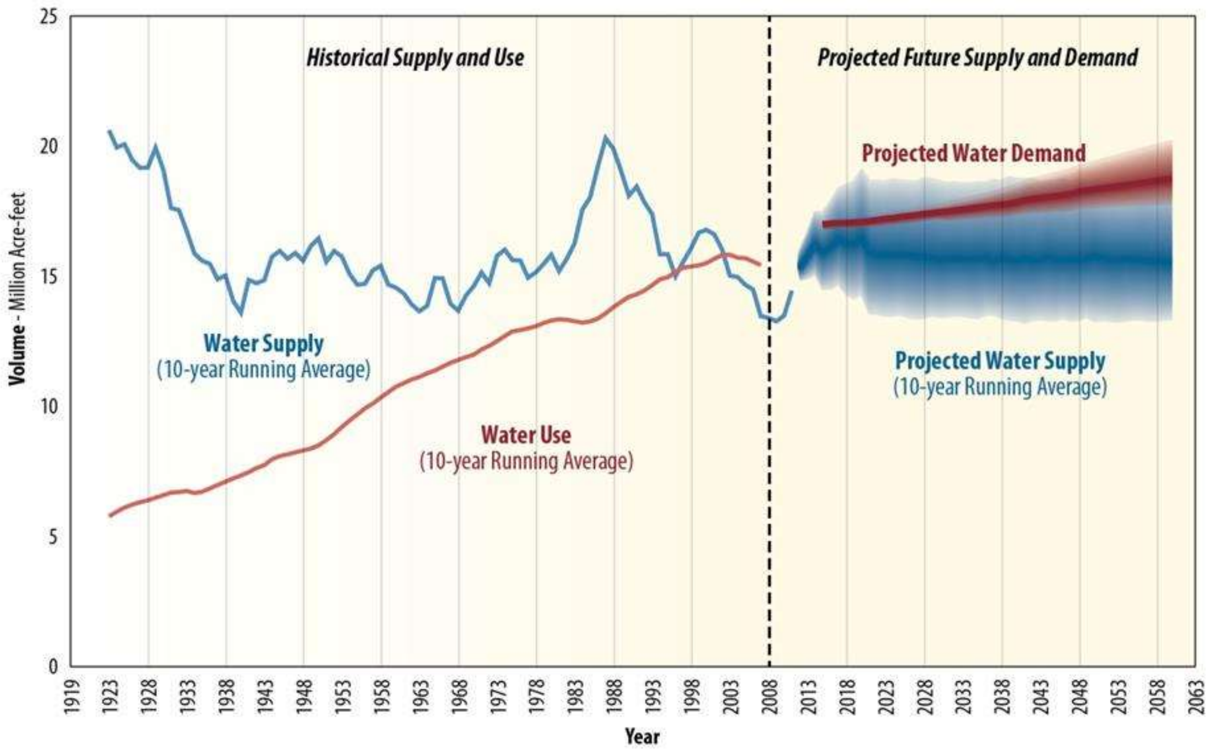

Figure 3–2. Historical water supply and use plus projected future water supply and demand in the Colorado River Basin.[9]

Source: Reclamation, 2012 (CO Basin Study Executive Summary), Figure 2.
Note: A range of future water supply and demand projections are presented (dashed blue and red lines) as well as the average future supply and demand projections (solid lines).

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[8] Comparing the 90th percentile supply to the 10th percentile demand results in no imbalance. Comparing the 10th percentile supply to the 90th percentile demand results in a 6.8-MAF imbalance. Comparing the 50th percentile of both supply and demand results in a 3.2-MAF imbalance.

[9] Water use and demand include Mexico's allotment and losses such as those due to reservoir evaporation, native vegetation, and operational inefficiencies.

No single sector can provide the solution for addressing future uncertain conditions or ensuring long-term sustainability. To respond to the challenges of the future, diligent planning is required to find adaptable solutions that build resiliency and apply a wide variety of ideas at local, state, regional, and basin-wide levels. With this in mind, Reclamation continues to investigate uncertainties related to water use, water-use efficiencies, reuse, and environmental and recreational flows by conducting a deeper analysis of issues and potential solutions identified in the Basin Study. Examples of these efforts include the following:

- **The Colorado River Basin Study *Moving Forward* Effort –** This effort was designed to pursue several areas of the next steps identified in the Basin Study. The *Moving Forward* effort (Reclamation, 2015 [Moving Forward]) builds upon and enhances the broad, inclusive stakeholder process demonstrated in the Basin Study with an ultimate goal of identifying actionable steps to address projected water supply and demand imbalances that have broad-based support and provide a wide range of benefits.
- **West Salt River Valley Basin Study –** The West Salt River Valley, located in central Arizona in the western portion of the Phoenix metropolitan area, is one of the fastest growing areas in Phoenix. Developing renewable water supplies, such as surface water and wastewater, will be important in slowing the existing groundwater overdraft. Funded by Reclamation in 2013, this study is examining and updating water supplies and demands projections, modelling groundwater and potential recharge, developing alternatives to deliver surface water, and identifying climate change adaptation strategies. This study is underway expected to be completed in 2016.
- **Colorado River Basin Ten Tribes Partnership Tribal Water Study –** Begun in late 2013, this study is a collaboration with the Ten Tribes Partnership,[10] whose members hold a significant amount of quantified and unquantified Federal reserved water rights to the Colorado River and its tributaries. The study builds on the technical foundation of the Basin Study by further assessing water supplies and demands for these tribes and identifies tribal opportunities and challenges associated with the development of tribal water. This study is scheduled to be completed in 2016.

1.2 Current Drought Conditions

In addition to the long-term challenges identified in the Basin Study, current extended drought conditions in the basin have further heightened a sense of

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[10] The tribes involved are: Chemehuevi Indian Tribe, Cocopah Indian Tribe, Colorado River Indian Tribes, Fort Mojave Indian Tribe, Jicarilla Apache Nation, Navajo Nation, Quechan Indian Tribe, Southern Ute Indian Tribe, Ute Indian Tribe of the Uintah and Ouray Reservation, and Ute Mountain Ute Indian Tribe.

urgency for ensuring Colorado River sustainability. The period from 2000 to 2015 was the lowest 16-year period for natural flow in the last century. Paleorecords indicate that this period was also one of the lowest 16-year periods for natural flow in the past 1,200 years (Meko et al., 2007).

During the drought, storage in Colorado River system reservoirs (system storage) has declined from nearly full to about half of capacity. Lake Mead has experienced its lowest elevations since May 1937 during the reservoir's initial filling (Figure 3–3). Despite these dry conditions, Reclamation has been able to meet contracted delivery commitments and scheduled reservoir releases throughout the drought. In the Upper Basin, junior priority water users in subbasins above major Reclamation reservoirs have experienced local shortages throughout the drought. Every resource in the basin is experiencing the impact of these current drought conditions, proving that no one sector solely bears the burden of these challenging conditions.

Figure 3–3. Lake Mead from Hoover Dam in March 2014.

1.3 Ongoing Efforts to Enhance System Reliability

The challenges and complexities of ensuring a sustainable water supply and meeting future resource[11] needs in an over-allocated and highly variable system such as the Colorado River have been recognized and documented by Reclamation, the Basin States, and many stakeholders. Consequently, significant investments have been made in constructing infrastructure, developing other water resources, and implementing innovative conservation programs and policies to sustain current and future supplies. Notable examples include Hoover and Glen Canyon Dams, the Central Arizona and Central Utah projects, Colorado's many headwaters trans-basin diversions, California's Colorado River Aqueduct, the All-American Canal, and a wide range of other local and regional water infrastructure projects. In the latter part of the 20th century and in the early portion of the 21st century, focus has shifted from developing available water resources to an emphasis on improving the efficiency of the operation of Colorado River reservoirs and better planning and managing of available water supplies. Two notable examples from this period are the Operation of Glen Canyon Dam Final Environmental Impact Statement (Reclamation, 1996) and the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead Final Environmental Impact Statement (Interim Guidelines [Reclamation, 2007]). Both of these resulted in the adoption of new reservoir operating policies. These efforts have resulted in solutions to past water management challenges and will continue to provide benefits in meeting the challenges that lie ahead.

Future challenges arise from the likelihood of continued population growth and the significant uncertainty regarding an adequate future water supply. Nevada, Arizona, and Utah rank first, second, and third, respectively, for the greatest population growth rates in the United States from 2000 to 2010. During that same decade, California experienced the second-greatest population increase in the United States (U.S. Census Bureau, 2011). Along the Colorado Front Range, emphasis on water conservation education programs has contributed to reductions in residential per capita use. The historical population, total M&I water use, and gross per capita water use for the Front Range metropolitan area are shown in Figure 3–4.

All of the major metropolitan areas dependent on Colorado River water are taking action to help ensure sustainable supplies. The communities and economies of major cities such as Albuquerque, Denver, Los Angeles, Phoenix, Salt Lake City, and San Diego are in part dependent, and Las Vegas is almost entirely dependent, on the Colorado River for water supply. As water demand for municipal and

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[11] Resources include water allocations and deliveries for municipal, industrial, and agricultural use; hydroelectric power generation; recreation; fish, wildlife, and their habitats (including candidate, threatened, and endangered species); water quality including salinity; flow- and water-dependent ecological systems; and flood control.

agricultural purposes increases to serve the needs of growing populations, ensuring the availability of water for non-consumptive uses such as the environment, recreation, and hydropower becomes increasingly challenging, especially since water supply uncertainty is further compounded by the potential impacts from climate change.

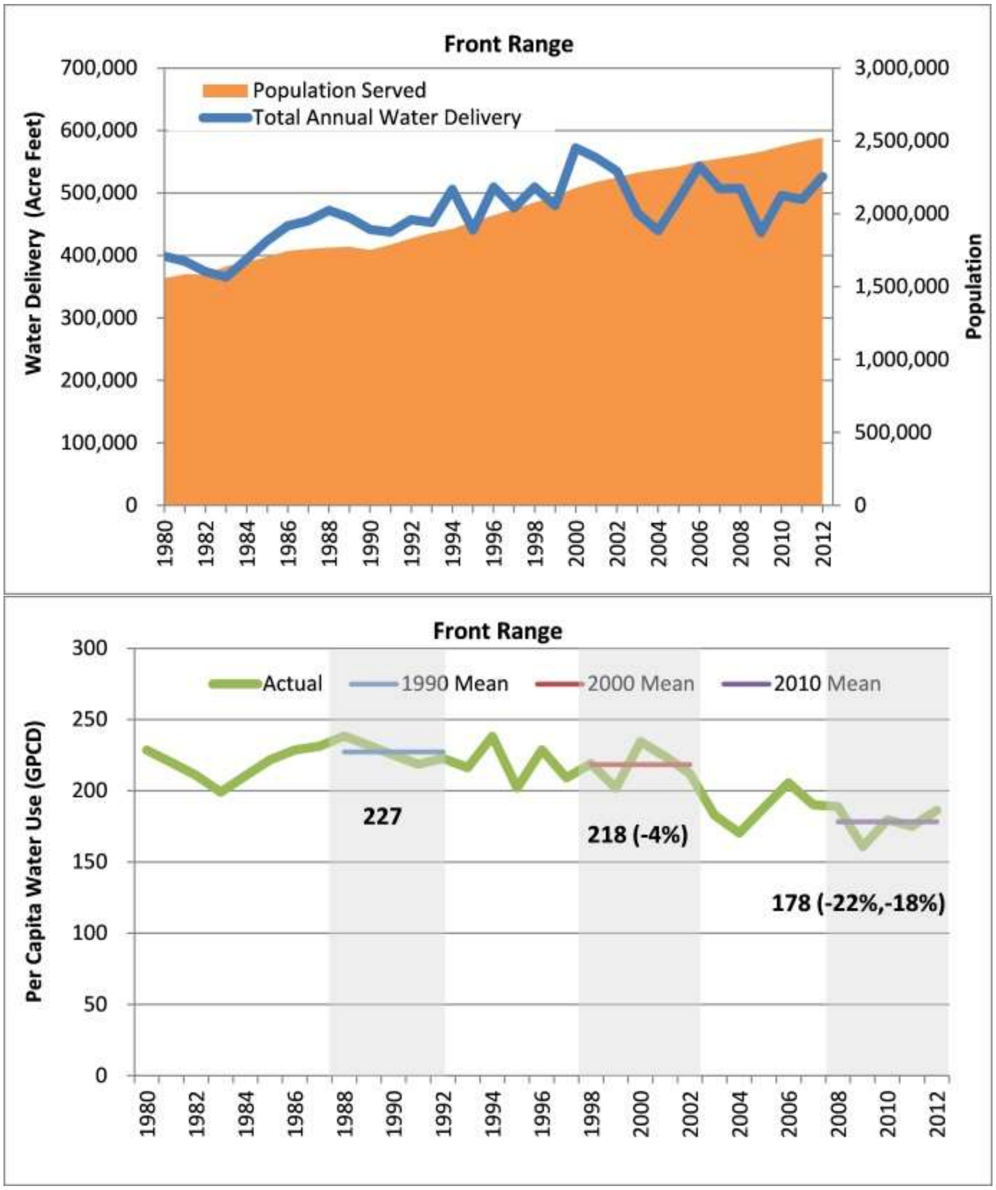

Figure 3–4. The rising population in the Colorado Front Range metropolitan area has resulted in increased water deliveries over the last three decades, even though per capita use has declined during this period.

From: Reclamation, 2015 (Moving Forward), Figure 3-4.
Note: As shown on the top graph, the Colorado Front Range metropolitan area has added nearly 1 million people to the municipal water service population since 1980, an increase of approximately 60 percent, while over the same period, the total annual water delivered increased by only about 26 percent.

2 Analysis of Impacts to Water Resources

The Basin Study evaluated the reliability of the Colorado River system to meet basin resource needs under all future supply and demand scenarios (termed baseline system reliability) and defined vulnerable conditions—those stressing to basin resources. Two important vulnerabilities that provide an overall indication of system reliability were:

1. **Lake Mead elevation** dropping below 1,000 feet above mean sea level (msl) in any month and
2. **Lee Ferry deficit,**[12] when the 10-year running total flow at Lee Ferry, Arizona, is less than 75 MAF.

Vulnerability or resource risks in the basin were related to both projected impacts to basin water supply and water demand. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff through 2060 are presented below.[13]

- **Temperature** is projected to increase across the basin, with the largest changes in spring and summer and with larger changes in the Upper Basin than in the Lower Basin.
- **Precipitation** patterns continue to be spatially and temporally complex, but projected seasonal trends toward drying are significant in certain regions. A general trend basin-wide is toward drying, although increases in precipitation are projected for some higher elevation and hydrologically productive regions. Consistent and expansive drying conditions are projected for the spring throughout the basin. For much of the basin, drying conditions are also projected in the summer, although slight increases in precipitation are projected for some areas of the Lower Basin, which may be attributed to the monsoonal influence in this region. Fall and winter precipitation is projected to increase in the Upper Basin but to decrease in the Lower Basin.

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[12] Article III(d) of the Colorado River Compact states that the Upper Division States will not cause the flow of the river at the Lee Ferry Compact Point to be depleted below an aggregate of 75 maf for any period of 10 consecutive years. For the purpose of the Basin Study, a Lee Ferry deficit is defined as the difference between 75 MAF and the 10-year total flow arriving at Lee Ferry.

[13] These findings are based on the assessment described in the Colorado River Basin Water Supply and Demand Study, Technical Report B – Water Supply Assessment (Reclamation, 2012 (CO Basin Study TR-B). Additionally, Chapter 2: West-wide Climate Assessment Summary Report of the SECURE Report to Congress provides the latest Reclamation climate projections for the Colorado River Basin.

- **Snowpack** is projected to decrease as more precipitation falls as rain rather than snow, and warmer temperatures cause an earlier melt. Even in areas where precipitation increases or does not change, decreased snowpack is projected in the fall and early winter as warming temperatures result in more rain and less snow. Substantial decreases in spring snowpack are projected to be widespread, due to earlier melt or sublimation of snowpack.
- **Runoff** (both direct and baseflow) is spatially diverse, but is generally projected to decrease, except in the northern Rockies. As with precipitation, runoff is projected to increase significantly in the higher elevation Upper Basin during winter, but is projected to decrease during spring and summer.
- **Droughts**[14] lasting 5 or more years are projected to occur 50 percent of the time over the next 50 years.

The Basin Study also considered a range of projections based on data and information provided by the Basin States, tribes, Federal agencies, and other water entitlement holders. Key findings related to projected changes in demand are summarized below.

- Under the scenarios considered by the Colorado River Basin Study, the demand for consumptive uses was projected to range between about 18.1 MAF to 20.4 MAF by 2060. The largest increase in demand is projected to be in the M&I category, owing to population growth.
- Future water demands may be affected by a changing climate, primarily due to changes in ambient temperature and the amount and distribution of precipitation. The mean projected change in evapotranspirative demand was approximately 4 percent by 2060, compared to demands without changes in climate. A total demand increase of more than 500 TAF per year by 2060 was estimated, considering potential effects of climate change (Reclamation, 2012 [CO Basin Study TR-C]).

In the Basin Study, impacts to water resources or system reliability were modeled considering all combinations of the projected supply and demand scenarios. Additionally, two operational assumptions were considered regarding Lake Powell and Lake Mead operations beyond 2026 (the end of effective period of the Interim Guidelines (Reclamation, 2007). Additionally, despite findings that the Lower Division States have demand for Colorado River water beyond their 7.5 MAF basic apportionment, the baseline system reliability assumed deliveries to the Lower Division States remain consistent with their basic apportionment. Since each supply scenario had more than 100 individual sequences, the baseline system reliability comprised more than 20,000 simulations. The Baseline system reliability revealed that many combinations of future water supply and demand result in management challenges (Figure 3–5).

[14] For the purpose of the Basin Study, a drought period occurs whenever the running 2-year average flow at Lees Ferry falls below 15.0 M, the observed historical long-term mean.

	Time Period	Baseline
Upper Basin Shortage (exceeds 25% of requested depletion in any one year)	2012-2026	4%
	2027-2040	5%
	2041-2060	7%
Lee Ferry Deficit (exceeds zero in any one year)	2012-2026	0%
	2027-2040	3%
	2041-2060	6%
Lake Mead Pool Elevation < 1000 feet (below 1000 feet in any one month)	2012-2026	4%
	2027-2040	13%
	2041-2060	19%
Lower Basin Shortage (exceeds 1 maf over any two year window)	2012-2026	7%
	2027-2040	37%
	2041-2060	51%
Lower Basin Shortage (exceeds 1.5 maf over any five year window)	2012-2026	10%
	2027-2040	43%
	2041-2060	59%
Remaining Demand Above Lower Division States' Basic Apportionment (exceeds moving threshold in any one year)	2012-2026	0%
	2027-2040	40%
	2041-2060	93%
		0% 50% 100% Percent Years Vulnerable

Figure 3–5. Percent of vulnerable years for each water delivery indicator metric across three time periods for the baseline.

Modified from: Reclamation, 2012 (CO Basin Study), Figure 22.
Note: green depicts vulnerabilities less than 25 percent; yellow depicts vulnerabilities between 25 to 50 percent; orange depicts vulnerabilities between 50 to 75 percent; red depicts vulnerabilities between 75 to 100 percent.
Note: The percentage of vulnerable years for water deliveries increases in intensity through the downstream storage reservoirs and over future projected time periods.

In the near-term (2012 through 2026), water demands are similar across scenarios, and the largest factor affecting the system reliability is water supply. In the mid-term (2027 through 2040), the demand for water is an increasingly important element in the reliability of the system, as are assumptions regarding the operations of Lakes Powell and Mead. In the long-term (2041 through 2060), the futures that consider the Downscaled GCM Projected water supply scenario, which incorporates projections of future climate, show a high inability to meet resource needs, regardless of the demand scenario and the operation of Lakes Powell and Mead.

In summary, the baseline analysis indicated that without action, it would become increasingly difficult for the system to meet basin resource needs over the next 50 years. For instance:

- Future projected development of water supplies and increased consumptive use in the Upper Basin combined with potential reductions in future supply results in reduced volumes of water stored in system reservoirs.
- With lower water elevations in reservoirs, the needs for resources such as hydropower and shoreline recreation were less frequently satisfied, while water delivery shortages increased.
- Decreases in flows in key river tributaries have negative implications for flow-dependent resources such as recreation and river ecology.
- Flood-control vulnerabilities were few and actually decreased over time under the baseline condition due to the increase in availability of storage associated with growing demand.

These findings fully support the need to develop and evaluate options and strategies to help resolve the water supply and demand imbalance.

3 Potential Adaptation Strategies to Address Vulnerabilities

In the Colorado River Basin Study and the *Moving Forward* Effort, the Federal government, Basin States, and basin stakeholders recognize that no single option will be sufficient to resolve future projected supply and demand imbalances. In the Colorado River Basin Study groups of options, or portfolios, were developed for analysis purposes. The objective of the portfolio analyses in this Basin Study was to demonstrate the effectiveness of different strategies in resolving future supply and demand imbalances.

3.1 Colorado River Basin Study Potential Future Climate Adaptation Actions

To identify a broad range of additional potential options to resolve water supply and demand imbalances, input was sought from Basin Study participants, interested stakeholders, and the public; more than 150 suggestions were received. Although several of the ideas may ultimately be considered too costly or technically infeasible, the Basin Study explored the wide range of options with the goal of ensuring that all viable options were considered. Each submitted option was assigned to a category based on its primary function. Recognizing that time and resource constraints would not allow for full evaluation of every option, about 30 representative options that spanned the range of the option categories were developed. A summary of the representative options, yield, and timing, where applicable, is provided in Table 3–1.

Although the portfolios explored in the Basin Study addressed water supply and demand imbalances differently, there were commonalities across the options implemented for each portfolio. All of the portfolios incorporate significant agricultural water conservation, M&I water conservation, energy water-use efficiency, and some levels of weather modification. However, some options were implemented more frequently in response to challenging water supply conditions. For example, ocean and brackish water desalination, wastewater reuse, and importation options were implemented for the most challenging water supply conditions in portfolios in which they were included. Future planning requires careful consideration of the timing, location, and magnitude of anticipated future Basin resource needs.

Table 3–1. Summary of Options and Potential Yields by 2035 and 2060

Modified from: Colorado River Basin Water Supply and Demand Study, Executive Summary, Table 2

Option Category	Representative Option	Years Before Available	Potential Yield by 2035 (AFY)	Potential Yield by 2060 (AFY)
Desalination	Gulf of California	20–30	200,000	1,200,000
	Pacific Ocean in California	20–25	200,000	600,000
	Pacific Ocean in Mexico	15	56,000	56,000
	Salton Sea Drainwater	15–25	200,000	500,000
	Groundwater in Southern California	10	20,000	20,000
	Groundwater in the Area near Yuma, Arizona	10	100,000	100,000
	Subtotal		776,000	**2,476,000**
Reuse	Municipal Wastewater	10–35	200,000	932,000
	Grey Water	10	178,000	178,000
	Industrial Wastewater	10	40,000	40,000
	Subtotal		418,000	**1,150,000**
Local Supply	Treatment of Coal Bed Methane-Produced Water	10	100,000	100,000
	Rainwater Harvesting	5	75,000	75,000
	Subtotal		175,000	**175,000**
Watershed Management	Brush Control	15	50,000	50,000
	Dust Control	15–25	280,000	400,000
	Forest Management	20–30	200,000	300,000
	Tamarisk Control	15	30,000	30,000
	Weather Modification	5–45	700,000	1,700,000
	Subtotal		**1,260,000**	**2,480,000**
Importation	Imports to the Colorado Front Range from the Missouri or Mississippi Rivers	30	0	600,000
	Imports to the Green River from the Bear, Snake[1], or Yellowstone Rivers	15	158,000	158,000
	Imports to Southern California via Icebergs, Waterbags, Tankers, or from the Columbia River[1]	15	600,000	600,000
	Subtotal		**758,000**	**1,358,000**

Option Category	Representative Option	Years Before Available	Potential Yield by 2035 (AFY)	Potential Yield by 2060 (AFY)
M&I Water Conservation	M&I Water Conservation	5–40	600,000	1,000,000
	Subtotal		**600,000**	**1,000,000**
Agricultural Water Conservation	Agricultural Water Conservation	10–15	1,000,000	1,000,000
	Agricultural Water Conservation with Transfers	5–15	1,000,000	1,000,000
	Subtotal		**1,000,000** [2]	**1,000,000** [2]
Energy Water Use Efficiency	Power Plant Conversion to Air Cooling	10	160,000	160,000
	Subtotal		**160,000**	**160,000**
System Operations	Evaporation Control via Canal Covers	10	18,000	18,000
	Evaporation Control via Reservoir Covers	18	200,000	200,000
	Evaporation Control via Chemical Covers on Canals and Reservoirs	15–25	200,000	850,000
	Modified Reservoir Operations	15	0 – 300,000	0 – 300,000
	Construction of New Storage	15	20,000	20,000
	Subtotal		**588,000** [3]	**1,238,000** [3]
	Total of All Options		**5,735,000** [4]	**11,037,000** [4]

AFY = acre-feet per year

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

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

[3] Subtotal assumes 150,000 AFY for the Modified Reservoir Operations representative option.

Note that the potential adaptation strategies listed in the table are organized by category. Total does not account for several options that may be mutually exclusive due to regional integration limitations or are dependent on the same supply.

3.2 Current and Planned Adaptation Actions

The Federal government, Basin States, and basin stakeholders have made significant investments in developing infrastructure, identifying water resources and implementing programs and policies to balance current and future supplies with existing and future demands. Many of these efforts have resulted in solutions to past water management challenges and will continue to provide benefit to the system in meeting the challenges that lie ahead. Actions to improve the sustainability of the Colorado River are occurring at a variety of scales and locations, ranging from basin-wide initiatives to specific infrastructure improvements. Examples of some of the activities occurring throughout the basin in which Reclamation is involved are described below.

Planning Activities and Pilot Programs

Colorado River Basin Ten Tribes Partnership Tribal Water Study – The tribes of the Ten Tribes Partnership hold a significant amount of quantified Federal reserved water rights to the Colorado River and its tributaries, and in addition, some tribes have unresolved reserved rights claims. In recognition of the importance in bringing the tribal perspective to bear in furthering the understanding and management of Colorado River water, Reclamation and the members of the Ten Tribes Partnership began this Study in 2014. The purpose of the Study is to, for the tribes of the Partnership,[15] assess tribal water supplies, document current tribal water use, project future water demand, document use of tribal water by others, and identify tribal opportunities and challenges associated with the development of tribal water considering the future projected water supply and demand imbalances documented in the Basin Study.

Drought Contingency Planning: Reclamation and the Colorado River Basin states are concerned with the potential that critically low elevations in Lake Powell and Lake Mead would be reached if the ongoing drought continues. Work is ongoing in both basins to develop and pursue strategies to avoid reaching such elevations, should this drought continue.

Strategies currently being considered in the Upper Basin include:

- Steps to manage demand by upper basin stakeholders to allow more water to reach Lake Powell;
- Extended and coordinated operations of Colorado River Storage Project reservoirs to better maintain the power pool at Glen Canyon Dam; and
- The potential for increased weather modification, including support from Reclamation, in the Upper Basin.

In the Lower Basin, Reclamation is working with Arizona, California, and Nevada to identify proactive steps to lower the risk of reaching critical elevations at Lake Mead. A step forward was a Memorandum of Understanding (MOU) for Pilot Drought Response Actions, signed by Reclamation and several water agencies in the lower Basin States in December 2014. The MOU outlines a commitment by the parties to use best efforts to generate between 1.5 and 3.0 MAF of additional water in Lake Mead through 2019.

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[15] For purposes of the Study, “tribal” refers collectively to the tribes and only those tribes of the Ten Tribes Partnership.

System Conservation Pilot Program – In July 2014, an $11 million funding agreement for system conservation was executed among Reclamation, the Central Arizona Water Conservation District, the Metropolitan Water District of Southern California, Denver Water, and the Southern Nevada Water Authority. The Pilot System Conservation Program (PSCP) allows water users to participate in pilot projects that establish temporary, voluntary, compensated programs to conserve or reduce the use of Colorado River water, increasing storage levels in Lake Powell and Lake Mead for the benefit of the Colorado River system. Requests for proposals under the PSCP have been received by potential program participants in both the upper and Lower Basins, and implementation agreements were executed in 2015.

Reservoir Operations Pilots – In the Upper Colorado Region, Reservoir Operations Pilot efforts have primarily focused on evaluating past flow trends (e.g., earlier runoff, lower overall inflow, etc.) and how those have or could affect reservoir operations and whether reservoir operations have already adapted to changing climate or will need to adapt in the future.

Operational Flexibility - 2007 Interim Guidelines

In response to 7 years of unprecedented drought in the basin, the Colorado River 2007 Interim Guidelines (Reclamation, 2007) were adopted by the Secretary of the Interior in December 2007 in consultation with the seven Basin States and stakeholders. The Interim Guidelines, in effect for an interim period through 2026, provide a prescriptive methodology for determining the annual releases from Lake Powell and Lake Mead throughout the full range of reservoir operations, including periods of low reservoir levels.

The Interim Guidelines also provide criteria for determining and implementing shortage reductions in the Lower Basin and a mechanism for Lower Basin water contractors to conserve and store water in Lake Mead as Intentionally Created Surplus (ICS). At the end of calendar year 2014, there was approximately 837 TAF of ICS in storage, equivalent to about 10 feet in Lake Mead at current elevations. The Interim Guidelines do not include provisions for Mexico.

Municipal and Industrial Water Conservation

Through the WaterSMART program, Reclamation provides leadership and technical assistance focusing on water conservation and helping water and resource managers make wise decisions about water use. In the basin, Reclamation funds metering programs, residential indoor and outdoor conservation, commercial, industrial and institutional conservation, and water reuse.

For example, in 2010, Reclamation collaborated with the Weber Basin Water Conservancy District to install 1,100 water meters on untreated irrigation systems in central Utah. These meters are estimated to save an average of 0.25 acre-feet of water per year and overall are proving to be an effective way in helping consumers understand how much water they are using and how to appropriately adjust usage. In southern California, WaterSMART Grants have been used by municipal water agencies to provide rebates for turf replacement, installation of advanced meters for residential and commercial customers, and construction of recharge basins to develop groundwater storage, among other types of projects.

Agricultural Water Conservation

Reclamation supports a variety of programs that offer conservation and efficiency project funding. Projects funded through WaterSMART Grants in the Colorado River Basin include conversion of unlined irrigation canals to buried pipe and installation of advanced flow meters, automated valves, and gates to increase efficiency. Through the Colorado River Basin Salinity Control Program, Reclamation has collaborated with the National Resources Conservation Service (NRCS) and the Basin States to provide cost-share assistance to landowners who install salinity control measures. These projects typically involve off-farm conveyance work and on-farm efficiency measures to reduce deep percolation, which mobilize and transport salts back to the river system (Figure 3–6).

Figure 3–6. Low-pressure sprinkler irrigation.

In June 2014, the Basin was named a Critical Conservation Area under the NRCS Regional Conservation Partnership Program (RCPP), allowing project proponents to compete for an additional pool of RCPP funds. NRCS has collaborated with Reclamation and the Colorado River Water Conservation District to implement a large agricultural water efficiency project on the Gunnison River. The grant will help irrigators use water more efficiently and reduce the amount of salts and selenium carried in the Colorado River and its tributaries. These efforts include boosting water efficiency by coordinating canals, ditches and pipes that deliver water to farms with improvements in the way water is delivered to crops, frequently by eliminating flood irrigation in favor of sprinkler and other irrigation systems.

Environmental and Recreational Flows

Reclamation participates as a partner in many new and existing programs established for protecting or improving ecological and recreational opportunities on the Colorado River and its tributaries. Reclamation activities include providing project funding, cost share funding with managing partners, coordinating reservoir operations, collaborating on species recovery and habitat conservation programs, and participating in stakeholder and interagency workgroups. Some examples of these activities follow.

Signed in November 2012, Minute 319 is a historic binational agreement that promotes sharing, conserving, and storing Colorado River water. Minute 319 provides, in part, water for environmental flows for the Colorado River Delta, and an opportunity to gain important scientific information on the effectiveness of these flows. From March through May 2014, a one-time pulse flow event of approximately 105,000 acre-feet was released to the riparian corridor of the Colorado River Delta from Morelos Dam at the U.S.-Mexico border. The water flowed down the river's channel, infiltrated to groundwater and helped to regenerate native cottonwood and willow habitat. A portion of the water eventually flowed to the Gulf of California. The experimental flow provided the scientific community the opportunity to gather valuable data from collaborative monitoring activities; these data will inform both countries in developing future management actions regarding water flows in the delta.

The construction and operation of dams on the Colorado River have fundamentally altered the Colorado River ecosystem. Because of the importance of the Colorado River to the desert Southwest, there is considerable debate over how to share and manage this natural resource. An important part of that debate is the need to address the impacts to the downstream ecosystem resulting from the ongoing operation of Reclamation dams in the Colorado River. To address this challenge at Glen Canyon Dam, Reclamation is a partner in the Glen Canyon Dam Adaptive Management Program, established in 1997, to provide for long-term research and monitoring of downstream resources. The scientific information obtained under the Adaptive Management Program is used as the basis for recommendations for dam operations and management actions. Through the adaptive management approach, scientific experimentation is integrated into resource management actions.

For example, Reclamation and the National Park Service are preparing an environmental impact statement (EIS) for the adoption of a long-term experimental and management plan for the operation of Glen Canyon Dam. The EIS will fully evaluate dam operations and will provide the basis for decision that identify management action and experimental options that will provide a framework for adaptively managing Glen Canyon Dam over the next 15 to 20 years.

Other examples of environmental and recreational flow activities in the Colorado Basin include the Upper Colorado River Endangered Fish Recovery Program, San Juan River Basin Recovery Implementation Program, and the Lower Colorado River Multi-Species Conservation Program.

Hoover Dam Infrastructure

In cooperation with the Hoover power contractors, Reclamation has begun replacing five of the 17 existing power generating turbines with wide-head turbines at Hoover Dam (Figure 3–7). As the elevation of Lake Mead has dropped in recent years, the ability for water in the reservoir to drive the existing turbines has decreased, and their effectiveness at producing hydroelectric power has been reduced. At current Lake Mead elevations, the water level is at or below the level designed for the existing turbines. The new wide-head turbines can operate at a much wider range of reservoir levels and will allow the Hoover Powerplant to generate electricity more efficiently at lower Lake Mead levels. Four of the new turbines have already been installed and the remaining turbine is scheduled to be installed in Fiscal Year 2017.

Data and Tool Development

Reclamation continually works to enhance its suite of modeling tools, including the basin's long-term planning model and data to support such tools. Recently, The Nature Conservancy completed a project, funded by the Southern Rockies Landscape Conservation Cooperative (LCC) that explored modeling improvements to represent environmental and recreational flow needs in the planning model more accurately (Alexander et al., 2013). The University of Arizona, funded by the Desert LCC, is completing a geospatial database of environmental flow needs and responses (environmental water demands) to provide water and land managers easy access to the best techniques available for determining how much water ecosystems need. In addition, we are currently analyzing information from the CMIP 5 suite of climate model projections across the Colorado River Basin. This information will be used to conduct additional analysis to update our risk assessments and explore how the new climate projections compare to those used in the Basin Study.

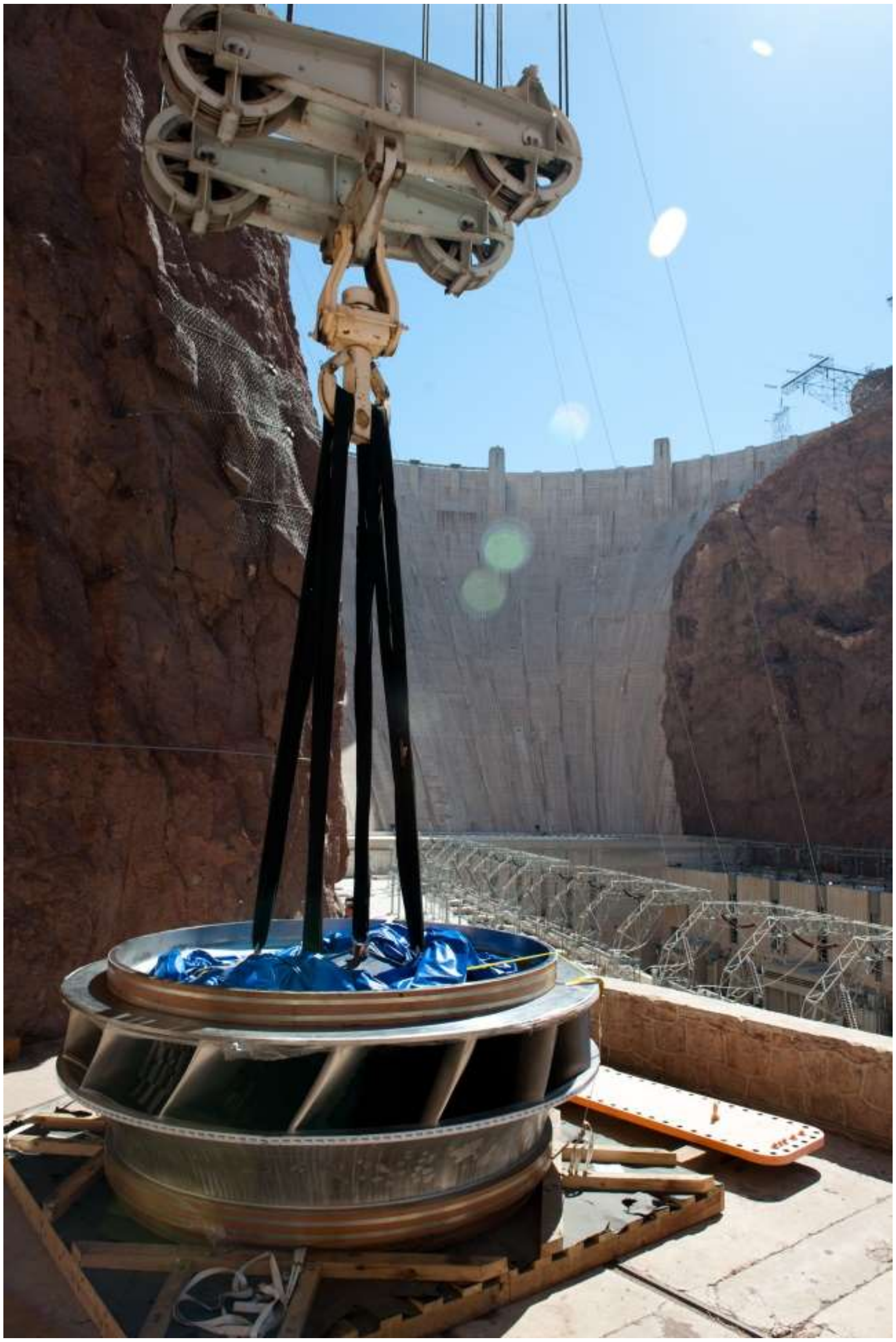

Figure 3–7. Delivery of a widehead turbine runner for Hoover Dam.
The turbine was delivered on a flatbed truck wrapped in a protective tarp. The turbine was flown in using the overhead crane.
Date Taken: June 17, 2015.

4 Coordination Activities

Interest in ensuring the sustainability of the Colorado River is broad and includes federal, state, and local governments, tribes, agricultural users, M&I water suppliers, power users, and conservation and recreation groups. No one sector solely bears the burden of future challenging conditions and no one sector can provide the solution for ensuring long-term sustainability. Water management in the basin is complex, as are the challenges associated with balancing competing needs such as water delivery, hydropower generation, and environmental protection. To meet such challenges, various stakeholders have implemented programs and initiatives, each with their own set of goals, objectives, approaches, and processes, in various parts of the basin. These stakeholders recognize that facilitating cross-program coordination and information exchange are important strategies that can allow such programs to work together and focus resources to address basin-wide challenges.

Reclamation and its stakeholders are actively partnering in activities and programs to help mitigate the impact of the on-going drought and to address future water management challenges. These programs include the Pilot System Conservation Program, Drought Contingency Planning efforts, and the Water Conservation Field Services Program. Other examples of precedent-setting partnerships occurring throughout the basin include the Colorado River Basin Ten Tribes Partnership Tribal Water Study and commitments by Reclamation, the Basin States, and Mexico to share and conserve water during both high and low reservoir conditions while also respecting the operational constraints and ecological health of the Colorado River Basin. These activities and programs are described in more detail in section 3.2.

4.1 *Moving Forward* Effort

The Basin Study demonstrated that implementing a broad range of options could reduce basin resource vulnerability and improve the basin's resiliency to dry and variable hydrologic conditions. Implementing such options requires diligent planning and collaboration that applies a wide variety of water management ideas throughout the basin.

Colorado River Basin Study – Moving Forward Effort: In May 2013, Reclamation and Basin stakeholders initiated the *Moving Forward* effort to build on future considerations and next steps identified in the Colorado River Basin Study. The *Moving Forward* effort enhances the broad, inclusive stakeholder process demonstrated in the Basin Study, with an ultimate goal of identifying actionable steps to address projected water supply and demand imbalances that have broad-based support and provide a wide range of benefits.

The *Moving Forward* effort is being conducted in a phased approach. Phase 1 began with the formation of a coordination team and three multi-stakeholder workgroups that focus on water conservation, reuse, and environmental and recreational flows. The Phase 1 Report was published in May 2015 (Reclamation, 2015 [Moving Forward]). The report documents the activities and outcomes of the workgroups during this phase and includes opportunities for potential future action. Phase 2, which began in 2015, signals the transition from study to action. In this phase, building from the workgroup's identified opportunities for future action; several pilot projects will be identified and pursued.

4.2 Additional Coordination

Climate change challenges highlight the need for increased coordination to exchange information, compare findings, and collaborate on data collection and other efforts to establish and address basin-wide priorities. Federal-agency integration within and across Departments is strong throughout the basin. For example, under the WaterSMART program, Reclamation and the U.S. Geological Survey coordinate on a variety of research activities in the basin, including the collection and evaluation of consumptive uses and loss data.

The Southern Rockies and Desert LCCs encompass the basin and are partnerships of governmental (Federal, state, tribal, and local) and non-governmental entities. The primary goal of the LCCs is to bring together science and resource management to inform climate adaptation strategies to address climate change and other stressors within an ecological region, or landscape. There are many examples in the basin of where stakeholder involvement and coordination is a critical element in the success of the program or project such as:

- The Bill Williams River Corridor Steering Committee (BWRCSC) is a stakeholder group that includes regulatory agencies, federal agencies such as Reclamation, non-governmental organizations, local jurisdictions, and scientists with management concerns and responsibilities related to the Bill Williams River (BWRCSC, 2014). This group works cooperatively to help fund and coordinate research and adaptive management of the river's resources.
- On the Upper Colorado River, salinity issues are being addressed by the NRCS, Reclamation, and state agencies through the basin-wide Salinity Control Program, which has implemented irrigation improvements throughout the basin aimed at reducing salt load. Examples of program activities include reducing high salinity agricultural drain water return flows and preventing highly saline waters from reaching the Colorado River.

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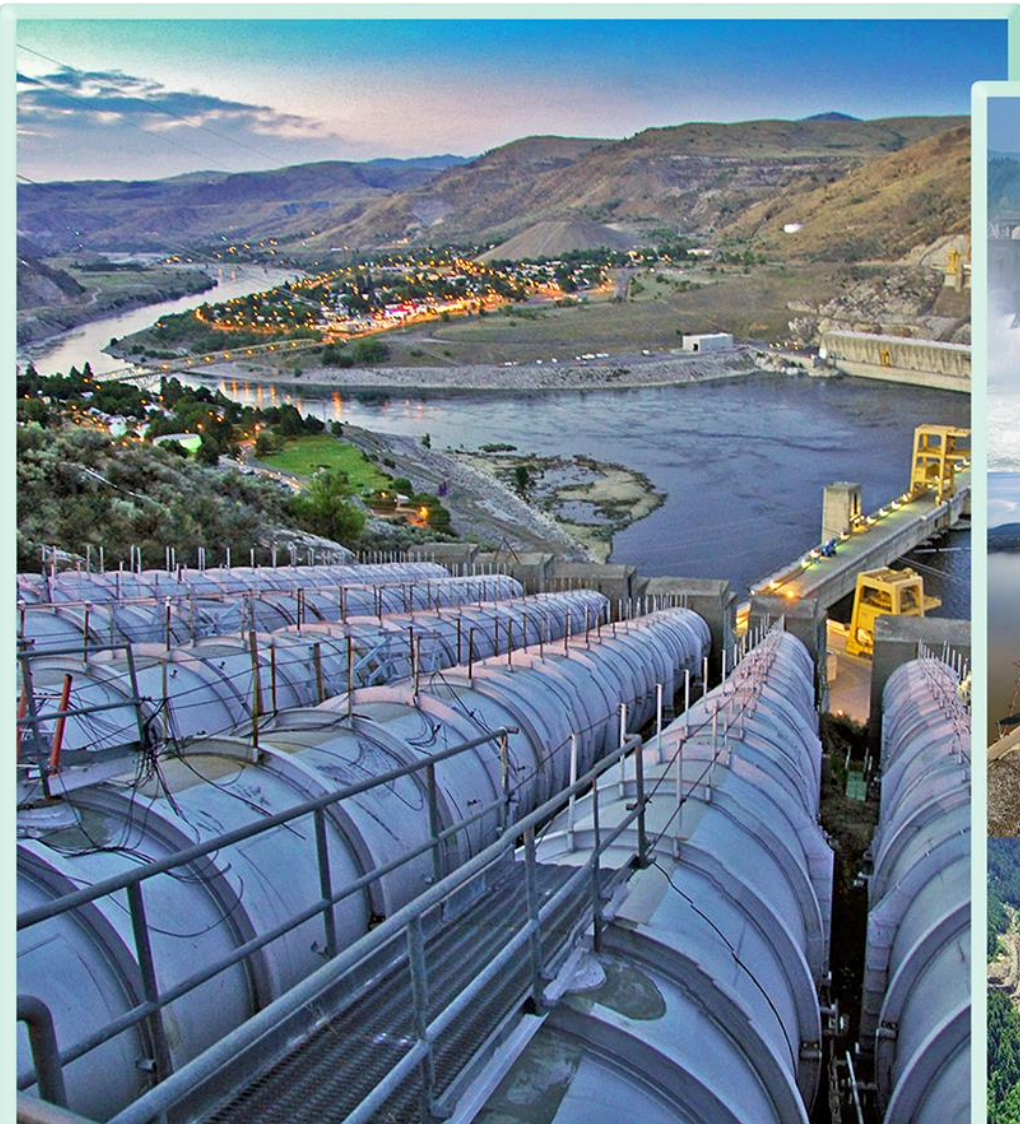
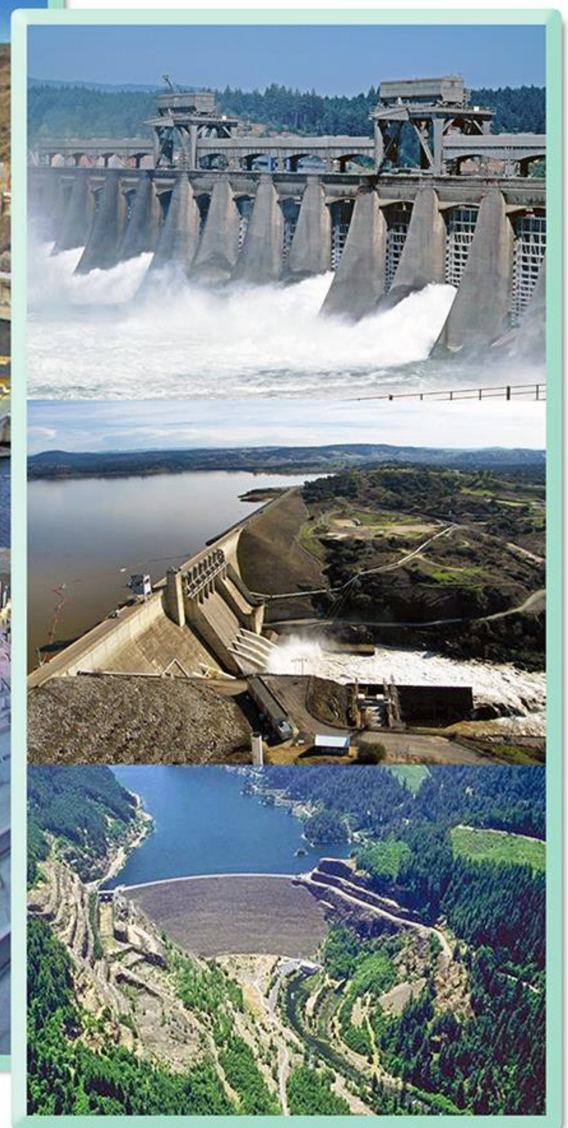
Managing Water in the West

Chapter 4: Columbia River Basin





U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with section (§) 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011,[1] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Columbia River Basin and is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Yakima River Basin Study Integrated Water Resource Management Plan, Henrys Fork of the Snake River Basin Study (Henrys Fork Basin Study), Hood River Basin Study, Upper Deschutes Basin Study, and Columbia River Basin Impact Assessment. Additional information, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

Columbia River Basin Setting

States: Idaho, Montana, Nevada, Oregon, Utah, Washington, Wyoming

Major U.S. Cities: Boise, Missoula, Yakima, Portland, Spokane

International: Canada

River Length: 1,243 miles

River Basin Area: 258,000 square miles

Major River Uses: Municipal (8 million people), Agricultural (7.8 million acres of land), Hydropower (400 dams provide 60 to 70% of the electrical needs in the northwest, with 31 major federal dams comprising the Federal Power System), Recreation, Flood Control (39.7 million acre-feet of flood storage), Navigation, and Fish and Wildlife including anadromous salmon and steelhead

Notable Reclamation Facilities: Hungry Horse and Grand Coulee

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[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

Contents

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1 Basin Setting

The Columbia River Basin is located in the Pacific Northwest region of the United States, extending over seven U.S. states and parts of southern British Columbia, Canada (Figure 4–1). The Columbia River is the largest river in the Pacific Northwest, traveling more than 1,240 miles and draining roughly 260,000 square miles. Beginning at its headwaters in the Rocky Mountains of British Columbia, the river first flows northwest before heading south into the State of Washington. It then continues west along the boundary between Oregon and Washington until it drains into the Pacific Ocean. Where the river meets the coast, saltwater intrusion from the Pacific Ocean extends approximately 23 river miles upstream from the mouth; tidal effects can be experienced up to Bonneville Dam, located 146 river miles inland.

The Columbia River has an annual average runoff of approximately 200 million acre-feet per year (AF/year), with roughly 25 percent of that volume originating in the Canadian portion of the basin (Bonneville Power Administration [BPA], 2011). Major tributaries (shown in Figure 4–1) to the Columbia River include:

- The Snake River, which originates in Wyoming and flows primarily through Idaho;
- The Yakima, Spokane, and Methow Rivers in Washington;
- The Kootenai River, which originates in British Columbia, Canada and flows through Montana and Idaho, and joins the Columbia River in British Columbia;
- The Pend Oreille River, which includes the Clark Fork and Flathead Rivers as tributaries, originates in Montana and Canada and flows through Idaho and Washington before joining the Columbia River in British Columbia; and
- The Willamette, Deschutes, and John Day Rivers in Oregon.

Reclamation manages more than 50 dams and reservoirs in the Pacific Northwest Region, with a combined active capacity of more than 18 million acre-feet (AF). Federal and non-Federal entities work together to coordinate reservoir operations for multiple objectives, including flood risk management, irrigation water supply, hydropower production, and ecosystem requirements. Sixty to 70 percent of Pacific Northwest energy supplies come from hydropower in the Columbia River Basin, including both Federal and non-Federal hydropower facilities. The Federal portion alone, referred to as the Federal Columbia River Power System (FCRPS), generates approximately 40 percent of the electricity used in the Northwest (approximately 75,700 gigawatts annually).

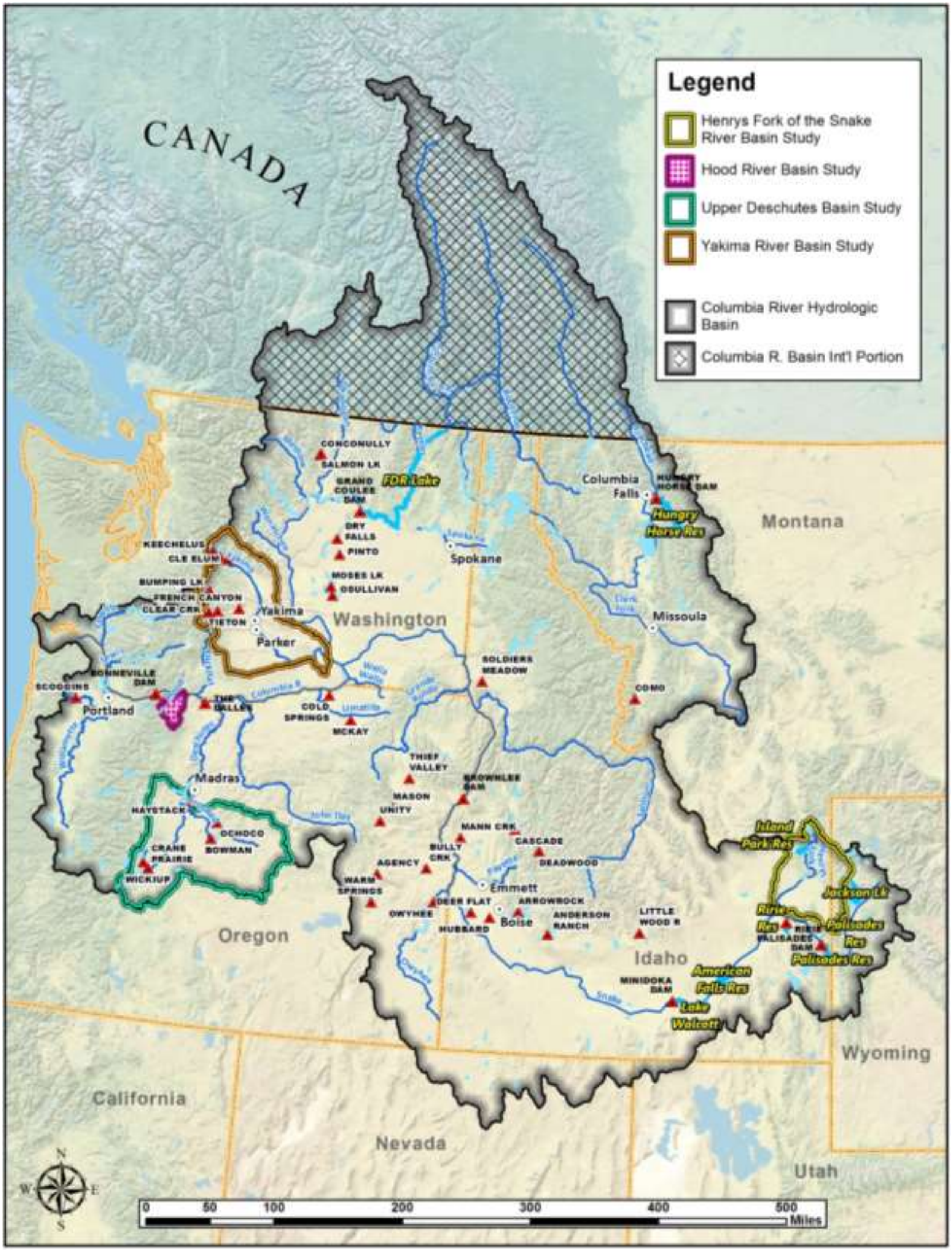

Figure 4–1. Columbia River Basin map.

Within the Columbia River Basin, Reclamation works with other Federal agencies, state government departments (e.g., departments of water resources, fish and wildlife/game, and ecology in Montana, Oregon, Idaho, and Washington), Native American tribes, local entities, and water users on a variety of water resource planning activities. Such activities include water supply analysis, water quality assessments, renewable energy production, and water conservation activities.

Reclamation and the basin states have documented the challenge of ensuring a sustainable water supply and meeting future demands in a complex and highly variable system such as the Columbia River in several studies over the past several decades. Looking ahead, there is growing concern over the ability of the Columbia River system to continue to meet water resource needs[2] due to the likelihood of increasing demands for water throughout the basin and the projected changes in water supply due to climate change.

1.1 Columbia River Basin Studies

Impact Assessments and Basin Studies are funded through the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. Reclamation conducts these assessments/studies in coordination with stakeholders in a specific basin or sub-basin for the purpose of defining current and long-term imbalances in water supply and demand in a basin or sub-basins, and developing adaptation and mitigation strategies to resolve those imbalances. Since 2009, five impact assessment and basin studies have been completed or are ongoing in the Columbia River Basin. These include the following:

Columbia River Basin Impact Assessment: Reclamation conducted the Columbia River Basin Impact Assessment to evaluate the potential effects of future climate change on river flows at 158 locations across the basin.

Yakima River Basin Study: Reclamation collaborated with the Washington Department of Ecology – Office of the Columbia River (OCR) to complete the Yakima River Basin Study in south-central Washington. This study was completed in 2011.

Henrys Fork of the Snake River Basin Study: Reclamation collaborated with the Idaho Water Resource Board to complete the Henrys Fork of the Snake River Basin Study (also referred to as the Henrys Fork Basin Study). This study, completed in 2015, included an evaluation of the surface water and groundwater

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[2] Water resource needs include water allocations and deliveries for municipal, industrial, and agricultural use; hydroelectric power generation; recreation; fish, wildlife, and their habitats (including candidate, threatened, and endangered species); water quality, including temperature and dissolved gas; flow- and water-dependent ecological systems; and flood control.

resources in an area upstream of the confluence of the Henrys Fork and the Snake River in central Idaho.

Hood River Basin Study: Reclamation collaborated with the Hood River County Water Planning Group to complete a study of climate change impacts to surface water and groundwater in the basin. The study area encompasses a 339-square-mile region in Hood River County in north-central Oregon. This study was completed in 2015.

Upper Deschutes Basin Study: Reclamation is currently collaborating with the Deschutes Basin Board of Control (DBBC)[3] and Basin Study Work Group to complete the Upper Deschutes Basin Study. The study includes an investigation of surface water and groundwater resources upstream of the confluence of the Deschutes, Crooked, and Metolius River systems in Oregon's Deschutes River Basin.

Reclamation is also involved in ongoing climate change studies that the River Management Joint Operating Committee (RMJOC) is conducting. This committee includes representatives from the Bonneville Power Administration (BPA), U.S. Army Corps of Engineers (USACE), and Reclamation and functions as a forum for the coordination of FCRPS dam operations and other river management activities within the Columbia River Basin. With respect to addressing climate change impacts in the Columbia River Basin, Reclamation is working with the RMJOC on the continued development of up-to-date climate change projections in support of long-range planning activities performed by Federal agencies, states, tribes, local governments, and nonprofits. The latest iteration of this effort is referred to as the RMJOC-II Climate Change Study.

[3] DBBC is acting as the fiscal agent for the Basin Study Work Group, with non-Federal contributions coming from State of Oregon funds.

2 Analysis of Impacts to Water Resources

Climate varies considerably in the Columbia River Basin, both temporally (year-to-year, month-to-month, etc.) and spatially (geographically). The El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) have a strong influence on winter weather patterns in the Columbia River Basin and drive much of the year-to-year variability. The warm-phase ENSO (referred to as El Niño) is generally associated with warmer and drier conditions in the basin, while cooler and wetter conditions are typically associated with the cool-phase ENSO (referred to as La Niña). Similarly, warm-phase PDO winters tend to be warmer and drier than average, while cool-phase PDO winters tend to be cooler and wetter than average. When these two events occur at the same time (El Niño and warm-phase PDO, or La Niña and cool-phase PDO), the potential for temperature and precipitation extremes increases. Such conditions often translate into significant shifts in the distribution of January-through-July runoff at The Dalles Dam (Barton and Ramirez, 2004).

Geographically, the north-south Cascade Mountain Range, the Blue-Wallowa Mountains of northeast Oregon, and the Rocky Mountains at the eastern and northern boundaries of the basin strongly influence climate in the Columbia River Basin. These geographic features play an important role in creating the cooler and wetter climate that is characteristic of the western, or windward, side of these mountain ranges, and the warmer and drier climate that is more characteristic of the eastern, or leeward, side (Oregon Climate Change Research Institute, 2010). The variation in precipitation and temperature patterns from one year to the next, combined with the geographic complexity of the basin, result in highly variable Columbia River flows from year to year (Figure 4–2).

Recent studies by Reclamation (including the Henrys Fork Basin Study, Hood River Basin Study, Yakima River Basin Study, Columbia River Basin Impact Assessment, and River Management Joint Operating Committee (RMJOC) Climate Change Study [RMJOC-Phase I][4]) provide more detailed insight into the range of impacts that are expected across the region. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below.

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[4] RMJOC-Phase I refers to the 2011 studies (primarily Brekke et al., 2010) conducted for RMJOC using CMIP3 climate models to develop hydrologic projections and run river system models (the entire set of reports is at: http://www.usbr.gov/pn/climate/planning/reports). The 2011 RMJOC-I study is being updated with CMIP5 climate models as RMJOC-Phase II.

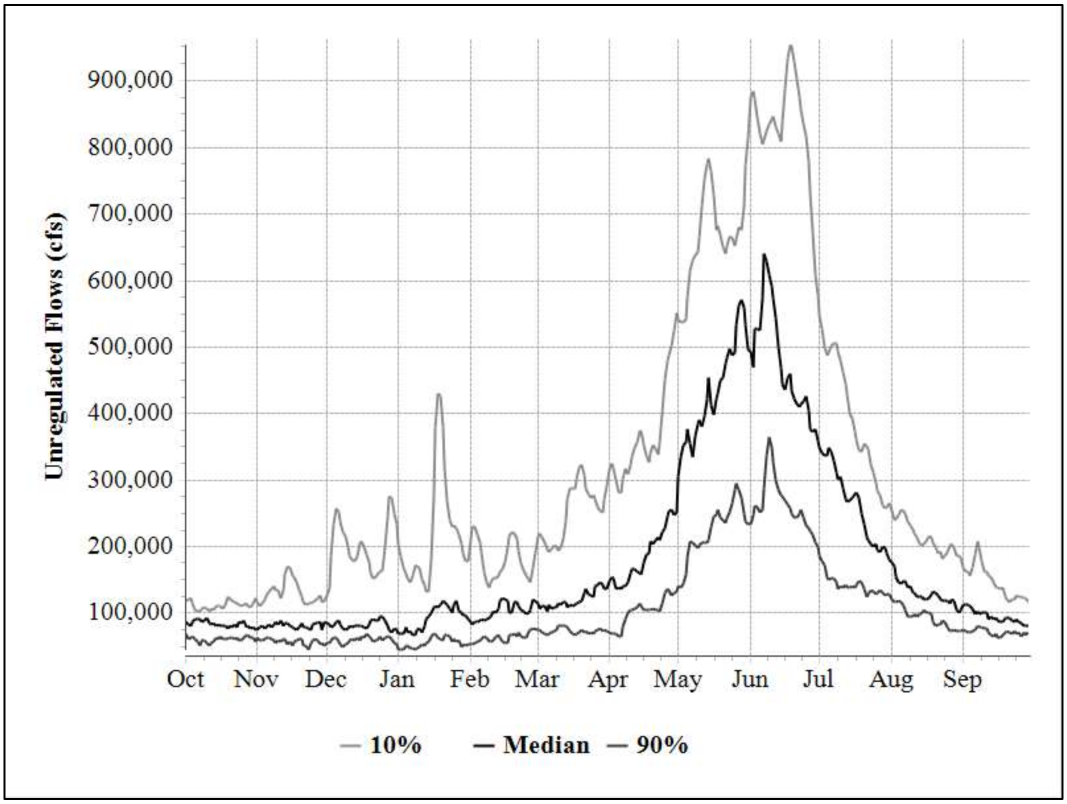

Figure 4–2. Daily summary of historical unregulated inflows for the Columbia River at The Dalles for water years 1967–2015.

Shown here are the 10 percent, median, and 90 percent exceedance values (or the flow rates that are exceeded 10 percent, 50 percent, and 90 percent of the time). Source: Pacific Northwest Region Hydromet, 2015.

- **Temperature** is projected to increase steadily over the next century in the Pacific Northwest, with the greatest changes occuring during the summer months.
- **Precipitation** projections are less certain, but models generally agree in the potential for drier summers and wetter autumns and winters.
- **Snowpack** accumulation is projected to decline as a result of increasing temperatures. Rising temperatures will also cause earlier snowmelt in many subbasins. In areas where water resource systems have been designed around historical hydrologic patterns, this shift toward earlier snowmelt and runoff has the potential to stress flood control and irrigation supply as more water runs off in the late winter and early spring and less water runs off during the irrigation season.
- Decreased snowpack could also result in decreased **groundwater** infiltration, potentially reducing river base flows during the summer season.
- Precipitation falling as rain instead of snow at lower elevations will result in increased winter **runoff** and decreased summer runoff, potentially reducing the overall water availability during the irrigation season.

The multitude of processes (e.g., economic, behavioral, and biological) that play into agricultural, municipal, industrial, and in-stream water demands makes it difficult to quantify the impacts of climate change on water demands from these sectors. However, changes are expected to occur due to increased air temperatures and atmospheric carbon dioxide levels, as well as changes in precipitation, winds, humidity, and atmospheric aerosol and ozone levels. Key findings related to projected changes in demand are summarized below.

- Agricultural demands associated with plant water consumption and surface water evaporation are projected to increase in a warming climate. Additionally, longer growing seasons are expected to result in increased irrigation demands.
- In-stream water demands, including those associated with ecosystem requirements, hydropower and thermoelectric power production, industrial cooling, navigation, and recreation, may increase due to rising temperatures.
- Diversions of water for thermoelectric power production and industrial cooling are predicted to increase as warmer air and water temperatures cause these processes to function less efficiently.
- Demand for hydropower during the warm season is expected to increase over the next century, due in part to increased use of air conditioners and increased cooling degree-days (number of days with temperatures over 65° F) as people adapt to a warming climate.
- In addition to these natural system changes, socioeconomic changes (including those related to infrastructure, land use, technology, and human behavior) will also affect future water demands.

Reservoir systems in the Columbia River Basin were designed under the assumption that snowpack would act as an additional reservoir, holding water (in the form of snow) during the cool season and gradually releasing it in the summer months. Similarly, ecosystems have evolved to depend on specific hydrologic regimes to support important life-cycle events. Climate change impacts to water supplies and demands will stress these systems and may require more tradeoffs among reservoir management objectives (e.g., irrigation, municipal and industrial use, hydropower production, flood control, recreation, flow augmentation for ESA-listed fish, and preservation of habitat for aquatic species).

2.1 Water Delivery

Recent Reclamation water resource studies have examined the projected changes to hydrologic regimes, reservoir operational constraints, and ecological requirements. Although projected impacts vary across the basin, studies suggest the potential for marked decreases in runoff during the irrigation season, causing increased reliance on water storage (where available) and other supplies, such as groundwater. Shifts in runoff timing, lengthening growing seasons, and greater reliance on limited water storage will increase the potential for water supply shortages throughout the agricultural portions of the basin. Specific examples of impacts to water delivery in the Columbia River Basin include the following:

- The Henrys Fork Basin Study points out the potential for climate change to worsen current supply-and-demand imbalances throughout the area due to changes in the phase of precipitation, shifts in runoff timing, a lengthening of the growing season, and greater reliance on storage water (as declining summer flows become less sufficient for the fulfillment of natural flow water rights).
- The Yakima River Basin Study suggests that shifts in runoff quantity and timing are expected to cause significant impacts to water supply. Reservoir operations models indicate that such shifts will correspond to increased cool-season storage, decreased warm-season storage, and decreased end-of-season storage.
- For the Snake River basin above Milner Dam, results from the recent Columbia River Basin Impact Assessment (CRBIA) indicate increases in water delivery shortages across all periods and scenarios (with the exception of the 2020s Less Warming/Wet scenario), with the largest shortages occur during July and August, when demands are at their peak (Figure 4–3).
- The Hood River Basin Study revealed the potential for greater shortages for potable water districts and major irrigation districts within the basin. The study also points out that most irrigation districts in the basin are already operating at very high efficiencies, meaning there are limited opportunities for conservation in terms of water delivery.
- The RMJOC-Phase I Climate Change Study results suggest that under extremely dry conditions, increased withdrawals from reservoirs during the summer and fall may be so significant that refill the following year may not be possible.

2.2 Hydropower

Hydropower provides a significant portion (60 to 70 percent) of the electricity consumed in the northwest (BPA, 2001); however, the impacts of climate change may reduce hydropower generation capacity and flexibility. Climate modeling indicates that a shift to earlier runoff could result in increased generation capability during the winter and early spring months, but reduced generation capability during the late-summer periods. Currently, customers in the Northwest use more electricity during the winter than in the summer, so projected changes to increased winter and spring flows may not negatively affect generation to meet demand during those periods. Decreases in summer flows may be problematic, however, as warming over the next century results in increased energy requirements for cooling.

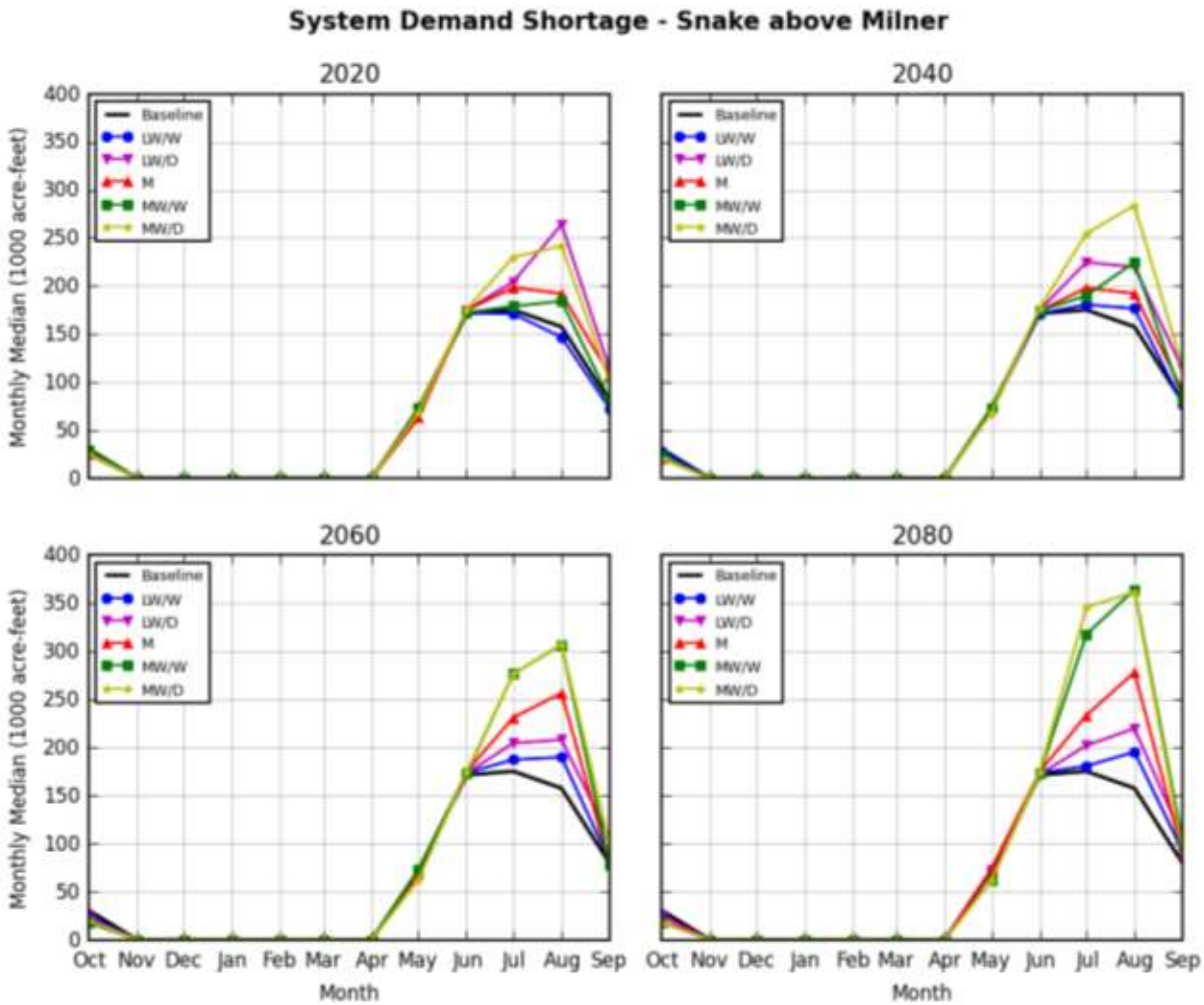

Figure 4–3. Water delivery shortages (i.e., inadequate water supply relative to water demands) in the Upper Snake River Basin above Milner Dam for the 2020s, 2040s, 2060s, and 2080s.

The solid black line represents the historical baseline (1990s), while colored lines represent each of the modeled scenarios (LW/W - LessWarming/Wet, LW/D - LessWarming/Dry, M - Median, MW/W - MoreWarming/Wet, and MW/D - MoreWarming/Dry) considered in the Columbia River Basin Impacts Assessment.

To a certain extent, reservoir systems can be operated to help correct for the discrepancy between the timing of supply and demand by storing water when it is not needed for hydropower production and releasing it when it is. The extent to which this is possible is already limited by a number of (often competing) operational objectives. In the Columbia River Basin, BPA, USACE, and Reclamation collaborate on the operations of the Federal Columbia River Power

System (FCRPS),[5] balancing operations for hydropower, fish and wildlife, irrigation, navigation, cultural resources, and flood-risk management.

Historically, requirements under the Columbia River Treaty with Canada, which recognizes only flood control and power production, served as the primary influence on system operations; however, starting in the 1990s, several species of fish were listed as threatened or endangered under the Endangered Species Act (ESA), adding further constraint to power operations. Biological Opinions, formalized through a series of consultations by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA Fisheries) and U.S. Fish and Wildlife Service (USFWS), now serve to guide BPA, Reclamation, and USACE to perform operations in ways that protect endangered and threatened species. Based on these guidelines, the current strategy calls for increased storage in the fall and winter with increased flows and spill during the spring and summer (BPA, 2001). However, this strategy can conflict with hydropower demand.

The impact of climate change on individual FCRPS hydropower facilities and their ability to adapt and meet future hydropower demands will vary between facilities, depending upon their unique set of operational limitations. At Hungry Horse, flood-control obligations, transmission limitations, and downstream flow requirements for several ESA-listed fish species limit hydropower operational flexibility more significantly than hydrologic conditions do; however, other facilities have more flexibility to respond to hydrologic conditions.

At Grand Coulee Dam, increased inflows from November to May resulting from climate change may be sufficient to operate the facility at or near maximum turbine capacity. However, under existing operating criteria, satisfaction of flood-risk management objectives, which take priority over hydropower production, may result in decreased storage for hydropower production during the summer period. This, combined with the projected decrease in summer and fall flows, may have important consequences for summer hydropower production.

2.3 Flood Management

Reclamation reservoirs in the Pacific Northwest Region range from coastal (fed primarily from rainfall) to alpine (fed primarily from snowmelt); however, most of Reclamation's reservoirs are located in the transitional zone (receiving a mixture of rain and snow as their primary water source and with average winter temperatures near the freezing threshold). Projects in these mixed rain-and-snow

[5] The FCRPS as defined here is consistent with the National Marine Fisheries Service's FCRPS Biological Opinion and only refers to 14 Federal projects: Bonneville, The Dalles, John Day, McNary, Ice Harbor, Little Goose, Lower Monumental, Lower Granite, Dworshak, Chief Joseph, Grand Coulee, Albeni Falls, Hungry Horse, and Libby.

basins are projected to exhibit the largest increase in flood risk due to a combination of warming and increased winter precipitation. For example:

- Studies in the Upper Snake River basin indicate that flows will increase during the cool season and decrease during the summer, with peak flow timing shifting to earlier in the spring. Given these projected changes and current flood-risk management requirements, the probability of passing floodwaters downstream is projected to increase in this basin.

- Similarly, in the Yakima River basin, studies note that higher air temperatures are projected to result in earlier snowmelt and a shift in peak runoff timing to earlier in the season.

Flood-risk management requirements are unique to each project or reservoir system and were developed using individual historical datasets, risk assumptions, flood-protection criteria, and rule-curve development techniques. While many of the reservoirs' operating criteria were developed to account for a wide range of natural variability, operating rules will need to be examined and potentially modified to ensure their adequacy for any changes brought by climate change.

2.4 Recreation at Reclamation Facilities

The Columbia River Basin offers a number of water-dependent recreational activities (Figure 4–4) that are expected to be influenced by climatic changes that affect hydrologic conditions. The reservoirs and rivers in the Columbia River Basin provide recreational opportunities such as camping, boating, swimming, fishing, nature study, and hunting. Potential impacts to recreation due to climate change in the Columbia River Basin include the following:

- Increased summer and winter temperatures may increase the popularity of these water-based recreation activities.
- Changes in the hydrologic regime and project operations may alter the timing of boat ramp availability and flows associated with floating rivers.
- Climate change may cause fluctuations in water depth and surface acreage, which may affect recreation use and economic value in a variety of ways. For instance, extended periods of low reservoir levels may decrease overall visitor numbers.
- Water-based recreation is susceptible to events such as debris flows caused by rainstorms over fire scars. Such impacts may become more common as the climate becomes hotter and drier and rainstorms become more intense.

These examples are in addition to the climate change impacts on fish and wildlife, which will affect associated recreational hunting, fishing, and wildlife viewing. Overall, reduced supplies, altered timing of flows, and increased variability will change the availability and nature of recreational opportunities.

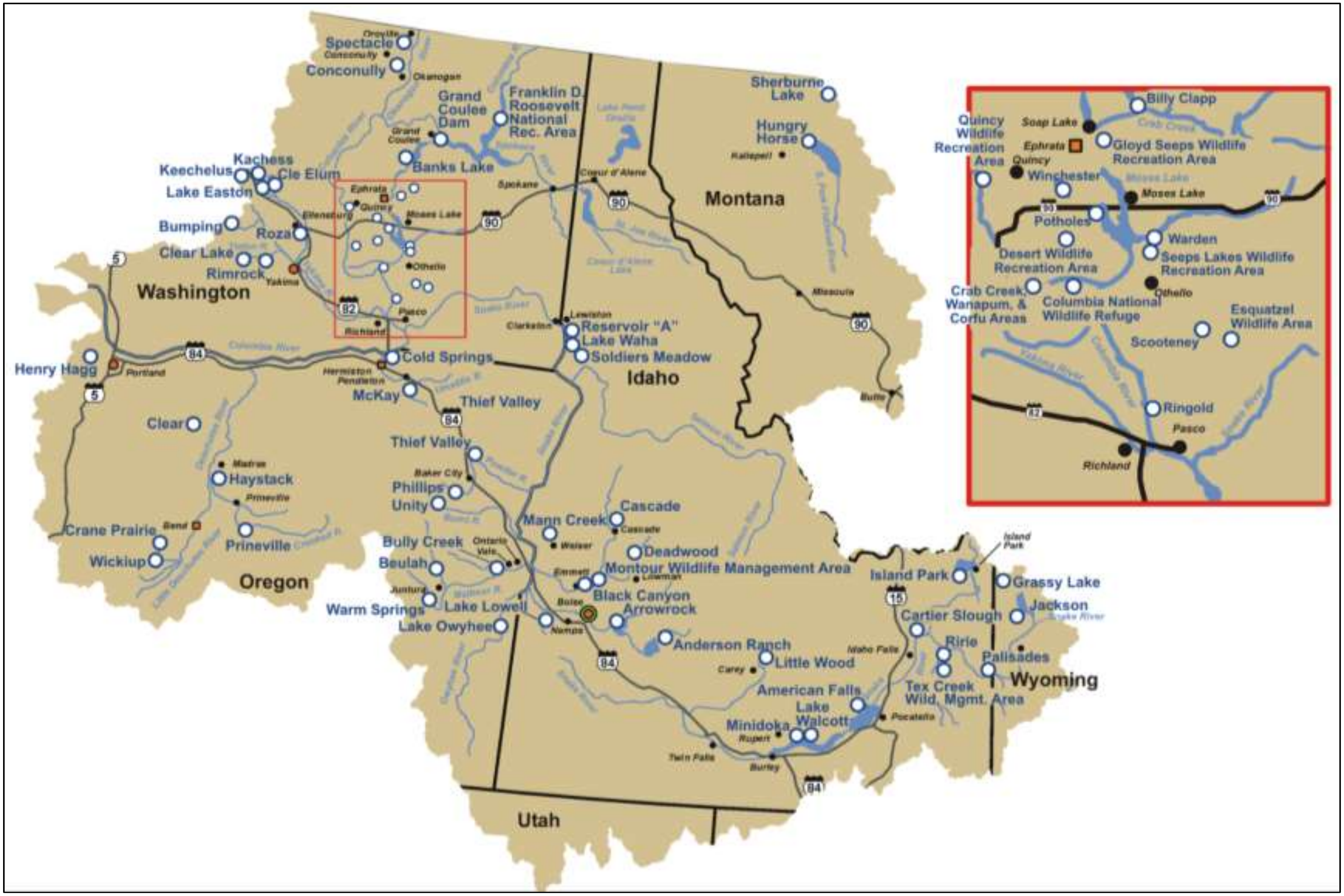

Figure 4–4. Maps of recreation locations in the Columbia River Basin.
Source: Reclamation, 2008.

2.5 Fish and Wildlife Habitat

The Columbia River Basin provides important habitat to a variety of fish and wildlife. The basin is home to small mammals such as beavers, mice, muskrats and otters, and large mammals such as deer, elk, moose, wolves, sheep and bears. The basin also serves as a migration corridor for small birds, raptors, and waterfowl. The lower Columbia River and estuary provide habitats for green sturgeon, eulachon, and leatherback turtles. The Columbia River and tributaries[6] comprise a wide range of fish habitat for resident fish such as bull trout, cutthroat trout, and white sturgeon and are home to six species of anadromous Pacific salmonids: Chinook, Coho, sockeye, chum, pink salmon, and steelhead.[7] In addition to anadromous fish, the Columbia River and its tributaries are home to sturgeon, lamprey, whitefish, and rainbow, cutthroat, and bull trout (char), among other species. Many animals, including bald eagles, osprey, and bears, rely on fish from the Columbia River and its tributaries to survive and feed their young.

Climate change is projected to have an array of interrelated and cascading ecosystem impacts, many of which are primarily associated with increases in air and water temperatures. These include:

- increased stress on fisheries that are sensitive to a warming aquatic habitat,
- increased risk of watershed vegetation disturbances due to increased fire potential,
- shifts in the geographic range of various species (Isaak et al., 2012)
- impacts on migration timing, and
- effects on the distribution and abundance of pests and pathogens in ecosystems.

Instances of high stream temperatures causing hundreds or thousands of adult salmon to die when their thermal tolerances are exceeded have been documented (Isaak et al., 2012) and are projected occur more frequently. The Washington Climate Change Impacts Assessment (WACCIA) (Mantua et al., 2009) reports that rising stream temperatures will likely reduce the quality and extent of freshwater salmon habitat and suggests that the duration of periods that cause thermal stress and migration barriers to salmon is projected to at least double by the 2080s. These findings are consistent with the results of other studies in the region (e.g., Battin et al., 2007).

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[6] Major tributaries include the Kootenai, Flathead/Clark Fork/Pend Oreille, Kettle, Okanogan, Methow, Spokane, Wenatchee, Yakima, Snake/Clearwater/Salmon, Owyhee, Grande Ronde, Walla Walla, Umatilla, John Day, Deschutes, Hood, Willamette, Klickitat, Lewis, and Cowlitz Rivers.

[7] Pink salmon are not listed and are not part of the FCRPS Biological Opinion.

Aquatic ecosystems are also expected to be impacted by the potential for increased winter flood frequency and intensity and decreased summer flows. Increased winter flooding would affect incubating eggs and juvenile Coho, Chinook, and steelhead survival (Hatten et al., 2014), while decreased summer flows will result in shallower and less suitable aquatic habitat, specifically reducing the availability of sections of river that are important for rearing. Climate change also has the potential to trigger synergistic effects (such as temperature influences on metabolism, growth rate, and population impacts) and exacerbate invasive species problems. Allan et al. (2005) suggest that although freshwater ecosystems will adapt to climate change, native biodiversity in these ecosystems could diminish.

2.6 Endangered, Threatened, or Candidate Species

There are 13 Evolutionarily Significant Units (ESU) of salmonids and one char (bull trout) listed as threatened or endangered under the ESA in the Columbia River Basin. The Columbia River Basin salmonids were first listed in the 1990s and include Chinook, chum, Coho, sockeye, and steelhead. Table 4–1 provides more complete list of ESA-listed species with habitat in the Columbia River Basin. As these species are already at risk, climate change has the potential to have detrimental impacts to their survival.

The ESA requires agencies to ensure that their actions are not likely to jeopardize the continued existence of a listed species and that they do not result in the destruction or adverse modification of habitat designated as critical to its conservation. Reclamation currently operates according to several biological opinions (including those on the FCRPS, the Upper Snake, Deschutes, Tualatin, and Umatilla Rivers, and the Lewiston Orchards Project) to protect the continued existence of anadromous species (NOAA Fisheries, 2008) and bull trout (USFWS, 2005).

The FCRPS biological assessment (BA) and associated BiOp take into account the mainstem effects from Reclamation projects in the Deschutes, Umatilla, Okanogan, and Yakima basins, as well as the effects of diversions directly from the Columbia River. The FCRPS BiOp guides the agencies in operating the FCRPS and requires a series of Reasonable and Prudent Alternative (RPA) actions to reduce or offset impacts to salmon and steelhead. The FCRPS RPAs include an aggressive program of actions to improve tributary habitat and survival through system operations.

Tributary habitat actions typically aim to improve spawning and rearing habitat, provide habitat access, and enhance in-stream flows. Since 1992, consultations between Reclamation and NOAA Fisheries under Section 7(a)(2) of the ESA have included the consideration of flow augmentation from Reclamation's Upper Snake Projects to increase flows in the Lower Snake and Columbia Rivers.

Table 4–1. ESA-Listed Species with Habitat in the Columbia River Basin
Source: Columbia River Basin Impact Assessment

Amphibians • Oregon spotted frog **Birds** • Marbled murrelet (CH) • Northern spotted owl (CH) • Red knot • Streaked horned lark (CH) • Western snowy plover • Yellow-billed cuckoo **Fish** • Bull trout (CH) • Chinook salmon (CH; 5 populations) • Chum salmon (CH) • Coho salmon (CH) • Eulachon • Green sturgeon (CH) • Lahontan cutthroat trout • Sockeye salmon (CH) • Steelhead (CH; 5 populations) • White sturgeon (CH) **Mammals** • Canada lynx • Columbian white-tailed deer • Gray wolf • Grizzly bear • Northern Idaho ground squirrel • Orca • Pygmy rabbit • Woodland caribou (CH)	**Plants** • Applegate's milk-vetch • Bradshaw's desert parsley • Golden paintbrush • Howell's spectacular thelypody • Kincaid's lupine (CH) • Macfarlane's four-o'clock • Nelson's checkermallow • Showy stickseed • Spalding's catchfly • Umtanum desert buckwheat (CH) • Ute ladies'-tresses • Water howellia • Wenatchee Mountains checkermallow (CH) • White bluffs bladderpod (CH) • Willamette daisy (CH) **Insects** • Fender's blue butterfly (CH) • Taylor's checkerspot (CH) **Snails** • Banbury springs limpet • **Bliss Rapids snail** • **Bruneau hot springsnail** • **Snake River physa sn**ail **Reptiles** • Leatherback turtle

CH = Critical Habitat has been designated for the species.

Population = A population of individuals that are more or less alike, and that are able to breed and produce fertile offspring under natural conditions (USFWS 2015).

Flow augmentation is important to improving anadromous fish migration in the Lower Snake and Columbia Rivers and relies on adequate storage supplies in the spring and summer months. In the reservoirs that require minimum pools or flows, it may be more difficult to meet these augmentation objectives in the driest conditions.

2.7 Water Quality

Climate change is also expected to have important consequences for water quality conditions across the Columbia River Basin. In addition to causing increased temperatures and altered flow regimes, climate change also has the potential to alter stream networks and erosion regimes (Lettenmaier et al., 2008 and USFS, 2010). Changing weather patterns and the projected increase in fire potential are expected to affect forested watersheds adversely, which generally act to reduce storm runoff, stabilize streambanks, shade surface water, cycle nutrients, and filter pollutants. In many locations, reservoir spill (over spillways or through outlet tubes) generates total dissolved gas (TDG) at levels that are potentially lethal to downstream fish populations. Projections for larger and/or earlier peak flows may require increased spill, having the potential to affect downstream fisheries adversely.

Grand Coulee operational configurations have been studied as a potential mechanism to moderate high temperatures downstream during the summer (projected to become more extreme in the future). However, these investigations have found that Grand Coulee has little flexibility to influence downstream temperatures due to the short residence time water has in the reservoir and the lack of stratification in the reservoir pool.

2.8 Flow- and Water-Dependent Ecological Resiliency

The impacts to fish populations (Section 2.5), and on endangered and threatened species (Section 2.6), will largely depend on the resiliency of the aquatic ecosystems and the specific species. The effects of a changing climate on salmon populations will depend upon the species, local conditions, habitat characteristics, and the ability of specific populations to adapt (Schindler and Rogers, 2009). In addition to increasing mortality rates and creating thermal barriers, warming stream temperatures are also expected to affect the growth and development of juveniles, although this impact will vary substantially with latitude (Schindler and Rogers, 2009).

Restoring floodplain connectivity, restoring stream flow regimes, and re-aggrading incised channels are most likely to ameliorate stream flow and temperature changes and increase habitat diversity and population resilience (Beechie, et al., 2013). Reclamation currently works extensively with partners to improve salmonid spawning and rearing habitat, improve habitat access, and enhance in-stream flows in tributaries across the Columbia River Basin. In addition to being important in helping to reduce the impacts of climate change on ecosystems, the success of these efforts is also directly vulnerable to climate change impacts. For this reason, it is important that climate change impacts must be considered in the identification and planning process for habitat restoration and improvement efforts.

3 Potential Adaptation Strategies to Address Vulnerabilities

The Department of the Interior's (DOI) Climate Change Adaptation Policy requires Reclamation to effectively and efficiently adapt to the challenges posed by climate change using Best Available Science to increase understanding of climate change impacts, inform decision-making, and coordinate an appropriate response to impacts on land, water, wildlife, cultural and tribal resources, and other assets. The Basin Studies conducted in the Columbia River Basin identify potential adaptation strategies that could help reduce the supply and demand imbalances that are projected to result from climate change. Following is a summary of the adaptation strategies considered.

3.1 Reservoir Operations and Modifications

Increased water management flexibility is a core strategy in the Bureau of Reclamation's Climate Change Adaptation Strategy. As climate change alters the hydrologic regime, reservoir operations (e.g., refill schedules, flood risk management rule curves, and flood operating criteria) may need to be adjusted in order to maintain reliable water deliveries, power generation, support for environmental needs, and flood risk management. In response, Reclamation has convened a team of regional reservoir operations experts, planners, climate scientists, and hydrologists to develop a process for evaluating reservoir-operating criteria to determine whether adjustments are needed in response to climate change. As part of this effort, the Pacific Northwest Region of Reclamation will initiate a pilot operations study examining a specific river basin in 2016-2018.

The State of Idaho is also addressing the need to adapt to potential water shortages in the Upper Snake River Basin by conducting an ongoing investigation on the potential for a pool raise (increased reservoir storage capacity) at Island Park Reservoir. Among the list of alternatives presented in the Henrys Fork Basin Study to increase water-delivery reliability under a changing climate, the Island Park pool-raise alternative had low or beneficial environmental impacts, and the lowest cost for additional water. Upon completion of the Henrys Fork Basin Study, the Idaho Water Resource Board secured state funding to move forward on a more detailed study of this alternative.

3.2 Hydropower Modernization

As discussed in Section 2, the impacts of climate change on hydropower will reduce hydropower generation capacity in the region during summer months. Although not identified specifically to address the anticipated impacts of climate change, the Pacific Northwest Region is undergoing modernization efforts on aging infrastructure to provide increased reliability and efficiency that may provide improved resilience to some impacts from climate change.

As the largest hydroelectric facility in the U.S., the 6,809-megawatt (MW) Grand Coulee Dam on the Columbia River is integral to power generation in the Pacific Northwest. If implemented, rehabilitation and potential uprating of generating units at Grand Coulee (currently a proposed action that is undergoing the National Environmental Policy Act [NEPA] process) will ensure continued reliable operation of this valuable asset and provide an additional 510 MW in generating capacity.

The turbines at Palisades Dam and Reservoir on the Upper Snake River have been in service since 1957 and have experienced a 1.6 percent decrease in efficiency. Due to the winter minimum flow requirements and the rough-zone characteristics of the original turbines, two units are required to operate at low efficiency from October through March, which decreases power generation. Reclamation will replace the two units with new turbines that will have a 4.5 to 6.0 percent efficiency improvement and a 30 percent efficiency improvement during winter operations, translating to approximately 44 gigawatt hours (GWh) per year in additional generation. After all work is completed, the four hydroelectric generating units will operate with optimized efficiencies and increased generation capacity and will have a life expectancy of at least 50 years.

Similarly, at Hungry Horse Dam on the Flathead River in Montana, proposed modernization efforts (currently undergoing the NEPA process) will improve the reliability and efficiency for power generation at this facility. The proposal includes the replacement and/or overhaul of the entire powertrain (all four generating units) during the 10-year modernization program. The capstone of the modernization effort will be the replacement of the turbines with a new design that improves efficiency and reduces cavitation. Because of this effort, there will be improved reliability and less need for maintenance.

On the Payette River, a tributary of the Snake River, Reclamation is planning the construction of a third hydroelectric generating unit at Black Canyon Dam. The proposed 12.5 MW hydroelectric unit will expand the capacity of the two existing 5 MW units to generate 105 million kilowatt-hours (kWh)—enough to power 9,359 homes a year. The additional generating unit will take advantage of water that is currently being bypassed and use it for the generation of hydroelectric power.

3.3 Aquatic Ecosystem Restoration

In addition to these modernization efforts, the Pacific Northwest Region is a leader in aquatic ecosystem restoration, specifically targeting critical habitat improvements for anadromous salmon and steelhead and benefitting other resident species as well. Tributary habitat rehabilitation efforts typically aim to improve spawning and rearing habitat, provide habitat access, and enhance in-stream flows. These rehabilitation efforts, which provide increased fish passage, thermal refugia, and refuge from predators, can help reduce the impacts of climate change on ecosystems; however, projected changes in climate and hydrologic regime will likely influence their success. Careful planning and consideration of climate change impacts is important in ensuring the success of these efforts.

Ongoing habitat rehabilitation efforts are taking place in the Methow Basin in Washington and the Salmon River drainage in Idaho. On the Methow River, Reclamation has worked with partners to reconnect a side channel and provide vegetative cover, creating thermal refuge and rearing habitat for salmon and steelhead. The Yankee Fork, a tributary of the Salmon River in Idaho, is also undergoing an extensive rehabilitation, including flood plain reconnection, side-channel development, and large-wood placement, all of which will contribute to improved spawning and rearing habitat for salmonids.

The Appraisal Investigation of the Lewiston Clearwater Exchange Project is a Rural Water Supply Program study of options for removing the Lewiston Orchards Project in Idaho from the watershed and developing alternative water supplies, namely groundwater, while maintaining minimum stream flows necessary for the Nez Perce Tribe to manage steelhead recovery efforts. The Lewiston Orchards Project diverts water from streams on the Nez Perce Indian Reservation that are occupied by ESA-listed steelhead. Warming climate trends have shifted the water supply from a snowpack-driven system to a system dependent primarily on rainfall. Earlier runoff, higher flows in winter, lower summer flows and warmer stream temperatures are expected in the future. Minimum stream flow requirements (established in a Biological Opinion for the Lewiston Orchards Project to limit impacts to steelhead and avoid impacts to critical habitat) should mitigate some impacts due to climate change.

4 Coordination Activities

Since 2010, Reclamation has led multiple collaborative efforts to address climate change impacts in the Columbia River Basin. These include the studies and coordination discussed below.

- Operations of the FCRPS are reviewed by the RMJOC, which comprises representatives from BPA, USACE, and Reclamation and functions as a forum for the coordination of FCRPS dam operations and other river management activities within the Columbia River Basin. With respect to addressing climate change impacts in the Columbia River Basin, Reclamation is working with the RMJOC on the continued development of up-to-date climate change projections in support of long-range planning activities performed by Federal agencies, States, tribes, local governments, and nonprofits. Information from the RMJOC-I climate change study (Brekke et al., 2010) was used in the three completed Basin Studies in the Pacific Northwest Region to assist local entities in addressing water imbalances and the potential impacts of climate change. RMJOC Phase II will assist further coordination and study of the FCRPS.
- Operation of the Columbia River is also coordinated through the Pacific Northwest Coordination Agreement (PNCA), an agreement for coordination of reservoir operations among power systems of the Pacific Northwest. USACE, BPA, Reclamation, and the major generating utilities in the Pacific Northwest signed the PNCA in 1964 to optimize the amount of usable power from the system.
- The wide variations of flows and the need to coordinate for flood risk management and hydropower benefits led to the development of the Columbia River Treaty, an agreement between Canada and the United States. Because of this agreement, several dams[8] were constructed in the Upper Columbia River Basin for the purposes of power generation and flood control.
- Reclamation is an active member of the Columbia River Technical Management Team (TMT). The TMT is an interagency group responsible for making in-season recommendations on dam and reservoir operations to optimize passage conditions for juvenile and adult anadromous fish. In addition to Reclamation, the TMT comprises representatives from BPA, USACE, NOAA Fisheries, USFWS, and various other State and Tribal entities. The TMT was established to implement the reasonable and prudent alternatives (RPA) under the NOAA Fisheries FCRPS BiOp for anadromous salmonids, starting with the 1995 BiOp. The FCRPS is currently operating under the 2014 NOAA Fisheries FCRPS BiOp.

[8] Four dams were constructed under the Treaty: Duncan, Mica, and Keenleyside Dams in Canada and Libby Dam in Montana.

The Basin Studies and the Columbia River Basin Impact Assessment, mentioned in Section 1, are good examples of past and ongoing efforts that involve multiple stakeholder groups. One of the purposes of the basin studies is to engage stakeholders in a collaborative investigation of potential mitigation actions by providing relevant climate and hydrologic analysis. For example:

- The Henrys Fork Basin Study identified alternative actions to help mitigate for a changing climate, including a pool raise at Island Park Reservoir. While the Idaho Water Resource Board will lead the effort to complete the pool raise, Reclamation will continue coordination, as Island Park is a Reclamation facility.
- The Hood River Basin Study found that the occurrence of flows below the established minimum flow requirements would increase under the simulated climate change conditions. These minimum flow shortages are most severe in the summer months and are a direct impact of changes in the basin's hydrologic regime, where spring runoff is projected to peak earlier in the season. Reclamation has made Basin Study results and water recourse models available to study partners to assist better-informed decision-making.
- In the Yakima River basin, Reclamation is coordinating with partners to evaluate better water management options and provide flows for endangered fish. In 2009, Washington Department of Ecology and Reclamation gathered representatives from the Yakama Nation, irrigation districts, environmental organizations, and other Federal, state, and local stakeholders to develop a consensus-based solution to current and future water issues, referred to as the Integrated Water Resources Management Plan. Some of the strategies outlined in the plan were directly related to the Reclamation Yakima River Basin Study, which identified that snowpack (often referred to as the sixth reservoir) is in jeopardy due to current and projected temperature increases and changes in precipitation timing and form.
- Reclamation has also been working collaboratively with a diverse group of stakeholders to initiate the Upper Deschutes River Basin Study in central Oregon. Reclamation and its non-Federal cost-share study partners finalized a Plan of Study in May 2015, and a comprehensive analysis of water supply and demand that addresses the impacts of climate change is now underway. The study will use integrated surface water and groundwater models to apply climate change scenarios to future water-resource-management alternatives. Outcomes will include a tradeoff analysis of the options identified in terms of their ability to address agricultural, environmental, and municipal water supply interests.
- Reclamation has generated reconnaissance-level hydrologic data and analysis on the potential effects of climate change on water supply and demand as part of the Columbia River Basin Impact Assessment. Results from the CRBIA provide important information to the water management community and establish a foundation for stakeholders to develop more

in-depth analyses and adaptation strategies through basin studies, operations planning, feasibility-level analyses, or any other activity that can benefit from the results.

Reclamation also coordinates with, and provides technical review and information to, the Columbia Basin Development League. This group is a 501(C)(6) nonprofit organization incorporated in 1964 with the mission to provide support for the Columbia Basin Irrigation Project and its future development, protect its water rights, and educate the public on the renewable resource and multi-purpose benefits of the project. Reclamation is also a member of the Columbia River Water Resources Program Policy Advisory Group, formed in 2006 to provide a forum for communication among stakeholders and the State of Washington's Department of Ecology with respect to key water-resource management issues in the Columbia River Basin. Reclamation and the Columbia River Water Resources Program Policy Advisory Group work with the State of Washington to identify policy issues associated with implementing water-resource management programs for the Columbia River and assist in setting criteria for funding of storage and conservation projects.

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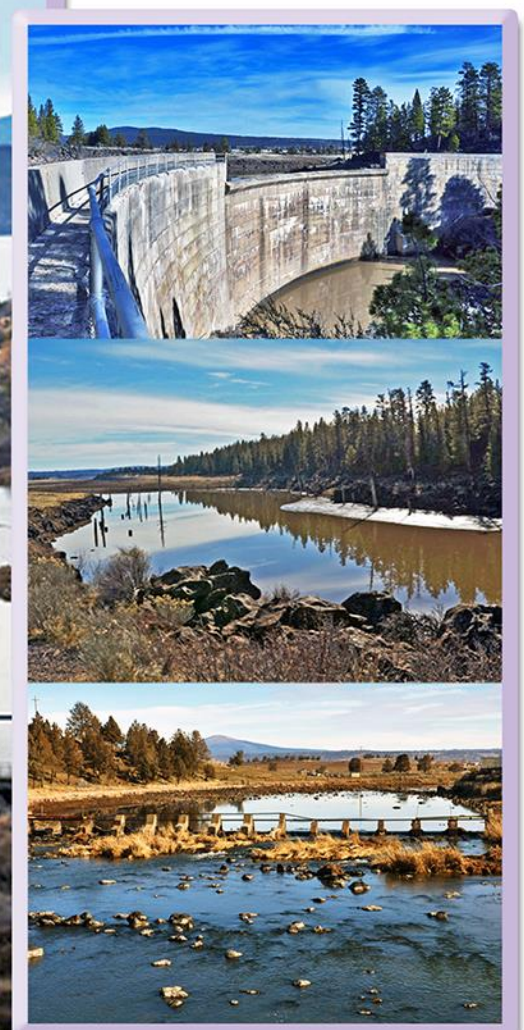
Managing Water in the West

Chapter 5: Klamath River Basin



U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011,[1] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Klamath River Basin. This chapter is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Historical background on the Klamath River Basin,
- **Section 3**: Description of the on-going Klamath River Basin Study,
- **Section 4**: Brief description of resources management efforts related to the Basin Study, and
- **Section 5**: Coordination activities within the basin to build climate resilience.

Klamath River Basin Setting

States: California and Oregon

Major U.S. Cities: Klamath Falls, OR (nearby Medford, OR and Redding, CA)

River Length: 254 miles

River Basin Area: 12,100 square miles

Major River Uses: Municipal, Agricultural, Hydropower, Recreation, Flood Control, and Fish and Wildlife

Notable Reclamation Facilities: Trinity Dam, Lewiston Dam, Clear Lake Dam, Gerber Dam, and Link River Dam

The key study referred to in this chapter is the Klamath River Basin Study, which is being conducted through a partnership between Reclamation, Oregon's Water Resources Department, and California's Department of Water Resources to identify strategies to address current and future water demands in the basin. The Klamath River Basin Study is anticipated to be available in 2016. Because the Klamath River Basin Study is not yet complete, portions of this chapter are limited to a description of ongoing activities rather than final results. Additional information relevant to the Klamath River Basin, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

The Klamath River Basin covers approximately 5,700 square miles in California and Oregon. The Klamath River starts downstream of Upper Klamath Lake and carries these waters approximately 254 miles to its outflow at the Pacific Ocean in Requa, California (Figure 5–1). The Klamath River Basin includes all or parts of Klamath and Lake Counties, Oregon, and Modoc, Siskiyou, Del Norte, Trinity, and Humboldt Counties, California. Five National Forests intersect the Klamath River Basin. From a water management perspective, it is divided into two regions, the dividing line being approximately at the location of Iron Gate Dam (Figure 5–1): (1) the upper portion (Upper Klamath Basin), and (2) the lower portion (Lower Klamath Basin). The Upper Klamath and Lower Klamath Basins generally have different climates and different management challenges.

The Klamath River begins in Lake Ewauna, south of Upper Klamath Lake in the city of Klamath Falls, Oregon. The river reach between Upper Klamath Lake and Lake Ewauna is called the Link River. Contributing flows to Upper Klamath Lake originate from the slopes of the Cascade Range. The primary tributaries to Upper Klamath Lake include Wood River to the north, Williamson River to the north, Sprague River to the east, and inflows from the eastern flank of the Cascades. The Klamath River flows southwesterly into California and then west to the Pacific Ocean. The major tributaries entering the mainstem river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers all join the Klamath River downstream of Iron Gate Dam and provide 44 percent of the mean annual flow, which heavily influences the hydrology of the Klamath River Basin. The mean annual flow of the Klamath River is about 17,900 cubic feet per second.

Enactment of the Reclamation Act in 1902, in addition to legislation passed by Oregon and California to transfer ownership of land to the Federal Government, led to the development of the Klamath Project. The initial project was completed in 1907. By 1924, portions of Lower Klamath and Tule Lakes were drained to uncover additional desirable farmland. In addition, dams were built to facilitate diversions and produce hydropower for the region.

Six dams currently stand along the mainstem of the Klamath River (Figure 5–1 and Table 5–1). Link River Dam (Figure 5–2), at river mile 254 in Oregon, maintains Upper Klamath Lake levels and largely replaced a natural reef that historically formed the lake.

Figure 5–1. Klamath River Basin map.

Table 5–1. Summary of Klamath Basin Dams

Dam Name	Location	Klamath River Mile	Year Completed	Reservoir Capacity (acre-feet)	Primary Purpose
Upper Klamath Basin					
Clear Lake	Lost River	NA	1910	527,000	Irrigation
COPCO No. 1	Klamath River	197	1918	6,235	Hydropower
Link River	Klamath/Link River	253	1921	873,000	Control UKL level
COPCO No. 2	Klamath River	198	1925	73	Hydropower
Gerber	Miller Creek	NA	1925	94,300	Irrigation
J.C. Boyle	Klamath River	227	1958	3,377	Peaking power
Iron Gate	Klamath River	190	1962	58,000	Hydropower
Keno	Klamath River	232	1966	18,500	Hydropower, recreation
Lower Klamath Basin					
Dwinnell Dam	Shasta River	NA	1928	50,000	Water supply
Lewiston	Trinity River	NA	1967	14,660	CVP water supply
Trinity	Trinity River	NA	1962	2,400,000	CVP water supply

Notes: NA= Not Available; UKL = Upper Klamath Lake; CVP = Central Valley Project

Figure 5–2. Link River Dam, at the outlet of Upper Klamath Lake.

Keno Dam, at river mile 233 in Oregon, replaced a natural reef which historically regulated water surface elevations of Lower Klamath Lake (Reclamation, 2005). The remaining mainstem dams were constructed where the Klamath River enters sections of the canyon through the coastal mountain range. These dams were primarily constructed for hydropower production and include California Oregon Power Company (COPCO) No. 1 dam at river mile 198 (California); COPCO No. 2 dam at river mile 199 (California), which was constructed to reregulate flows out of COPCO No. 1; JC Boyle Dam at river mile 225 (Oregon), which was constructed primarily for producing peaking power upstream of the COPCO dams; and Iron Gate Dam at river mile 190 (California). PacifiCorp owns and operates the hydropower producing facilities on the Klamath River as the Klamath Hydroelectric Project (KHP) No. 2082. Since the 2006 expiration of its license from the Federal Energy Regulatory Commission, PacifiCorp has been operating the KHP under annual licenses.

The Klamath River Basin is unusual in that the largest agricultural development in the basin occurs in the Upper Basin, which receives disproportionately low precipitation compared with the rest of the basin. Implementation and enforcement of state and Federal water allocation policies has been a challenge. The Klamath River Compact (ORS 542.620; CA Water Code § 5900 et seq.; P.L. 85-222) between California and Oregon was ratified by the states and consented to by the United States in 1957, giving domestic and irrigation users in the Klamath River Basin preference for use of water supplies over recreation, industrial, hydropower, and other uses.

In March 2013, the Final Order of Determination for the general stream adjudication of the Upper Klamath Basin was delivered to the Klamath County Circuit Court, demarking a significant milestone in determining the water rights of the Upper Klamath Basin by confirming the senior water rights of the Klamath Tribes. The adjudication appeals process is ongoing. Water rights for the mainstem Klamath River have not been adjudicated in California, even though adjudication was completed there for the Shasta River Basin in 1932 and for the Scott River Basin in 1980.

The United States must provide sufficient water to sustain and protect Indian Trust Assets, which include sufficient water to meet treaty rights such as hunting, gathering, and fishery purposes. The Klamath Tribes were terminated in 1954 (Klamath Termination Act, P. L. 587) and then regained Federal recognition in 1986. As a result, the Klamath Tribes lost designated reservation land. As part of the Oregon adjudication process, a court has held that the rights protecting Trust Assets of the Klamath Tribes have a priority date of the Klamath Treaty of 1864, which may significantly affect water management in the Upper Klamath Basin.

Figure 5–3. Irrigated croplands along both sides of the Klamath River south of Klamath Falls.

Because three Klamath River Basin fish species have been listed under the Federal Endangered Species Act, Reclamation coordinates its Klamath Project operations plans with the U.S. Fish and Wildlife Service (USFWS; responsible for Lost River and shortnose suckers) and with the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA Fisheries; responsible for the Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unity Coho Salmon). Accommodations for these species are described in the 2012 Biological Assessment for Proposed Klamath Project Operations (Reclamation, 2012 [Klamath BA]) and the associated 2013 non-jeopardy Joint Biological Opinion for Klamath Project Operations (NOAA Fisheries and USFWS, 2013). The Joint Biological Opinion, for instance, recommends Upper Klamath Lake levels needed to protect endangered Lost River and shortnose suckers, and also sets Klamath River flow rates required for the well-being of threatened coho salmon.

The Klamath Basin National Wildlife Refuges (NWR) are a complex of six refuges, all of which are adjacent to or within Reclamation's Klamath Project, with the exception of the Bear Valley NWR. They were established by various executive orders starting in 1908, and they support many fish and wildlife species and provide suitable habitat and resources for migratory birds of the Pacific Flyway. The Lower Klamath and Tule Lake NWRs, in the upper Klamath Basin, rely on Klamath Project water. The refuges have Federally reserved water rights claims for the water necessary to satisfy their primary purposes, subject to more senior water rights in the basin, including the Klamath Tribes and the Klamath Project. The Joint Biological Opinion (NOAA Fisheries and USFWS, 2013) outlines the availability of water to the Lower Klamath and Tule Lake NWRs.

2 Analysis of Impacts to Water Resources

The Klamath River Basin, like the western United States overall, has experienced a general decline in spring snowpack, reduction in the amount of precipitation falling as snow in the winter, and earlier snowmelt runoff between the middle and late 20th century (Reclamation, 2011 [SWA]). Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below:

- **Temperatures** increased across the region from 1895 to 2011, with a regionally averaged warming of about 1.3° F (Melillo et al., 2014). Climate change models indicate temperatures throughout the Klamath River Basin may increase by approximately 5 to 6 °F over the 21st century.
- Mean annual **precipitation** in the basin ranges from as little as 10 inches at lower elevations to more than 70 inches in the mountains of the Cascade Range (Reclamation, 2011 [SWA]). Precipitation is projected to increase by approximately 3 percent by 2050.
- The annual long-term average **snowfall** in Klamath Falls (1981–2010 average) is about 32 inches per year. Crater Lake (62 miles northwest of Klamath Falls) averages about 483 inches of snow annually. About two-thirds of the precipitation falls as snow between October and March. Historical trends basin wide indicate about a 41 percent decrease in April 1 snow water equivalent, with a range of about 22 to 45 in various parts of the basin.
- Historical **runoff** in the Klamath River Basin is highly variable from year to year. Although precipitation is concentrated in the winter months, water percolates slowly through the volcanic soil such that monthly discharge is almost constant in the Upper Basin (CDWR, 1960). Projected warming might also change runoff timing, with more rainfall runoff during the winter and less runoff during the late spring and summer.

Historical variability in groundwater levels in the Upper Klamath Basin is closely tied with changing groundwater management practices. Under natural conditions, the Upper Klamath Basin lakes had a significant regulatory effect on the river (CDWR, 1960). A review of historical information in the Klamath River Basin suggests that although there may be trends in historical runoff at some sites, they are relatively weak or insignificant (Reclamation, 2011 [SWA]). Natural climatic cycles like the El Nino/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) have influenced and will continue to influence these general trends (Thorsteinson et al., 2011).

The projected increase in wildfires also poses risks to water supply through increased sediment loads to lakes, reservoirs, and streams, potential damage to water supply infrastructure, and changes to landscape characteristics that affect water temperatures, infiltration dynamics, and runoff timing, among other things. Some of the causes of increased wildfire risk include projected decreases in late summer streamflows in some parts of the Klamath River Basin, changes in the timing and amount of recharge, increases in evapotranspiration, and declines in the groundwater table due in part to increases in pumping demand. A number of studies have documented increases in fire season duration and fire frequency, and they also project increases in the probability of large wildfires. Although wildfire is a natural process that has historically played a beneficial role in most Northwest forest ecosystems, warmer and drier conditions combined with the effects of fuel buildup resulting from a century of fire suppression have greatly increased the number, extent, and ferocity of wildfires in western U.S. forests since the 1970s (McKenzie et al., 2008).

3 Potential Adaptation Strategies to Address Vulnerabilities

The Klamath River Basin has a long history of water management challenges, and many studies have been conducted there. Reclamation is currently working with partners to conduct the Klamath River Basin Study to evaluate water supply and demand within the basin and identify and evaluate potential adaptation strategies which may reduce any identified imbalances in collaboration with stakeholders in the region. Non-Federal cost share partners and major stakeholders for the study include:

- California Department of Water Resources and the Oregon Water Resources Department
- Major stakeholders include six federally recognized Indian Tribes: the Yurok Tribe, Hoopa Valley Tribe, Karuk Tribe, the Klamath Tribes (consisting of Klamath, Modoc, and Yahooskin), Quartz Valley Indian Community, and Resighini Rancheria
- Other stakeholders including numerous Federal, state, and local entities as well as the general public.

3.1 Klamath River Basin Study Components

The Basin Study will seek to add value to previous and ongoing work in the watershed by evaluating water supply and demand together in a risk-based framework and by exploring a range of adaptation strategy portfolios. The Basin Study is anticipated to be available to the public in 2016. The main components of the Klamath River Basin Study are provided below.

- **Component 1:** An assessment of current and projected future water supplies through the evaluation of (past and projected future) changes in precipitation and temperature, as well as changes in snowpack, evapotranspiration, and groundwater.
- **Component 2:** An assessment of current and projected future water demands. As part of the West-Wide Climate Risk Assessment (WWCRA) (Reclamation, 2011 [BCSD]), this Basin Study will quantify historical and projected future agricultural demands and losses due to reservoir evaporation.
- **Component 3:** An evaluation of the watershed's ability to meet or withstand any identified future water supply/ demand imbalances. Risks and system reliability are determined by testing the system against various defined metrics. These metrics are being developed with input from the Klamath River Basin Study Technical Working Group and interested

organizations and individuals. This component relies heavily on projections from the assessment of current and projected future water supply and demand. The proposed approach includes evaluation of risk and reliability considering multiple scenarios of projected future climate/demand conditions.

- **Component 4:** An identification and quantification of potential adaptation strategies or opportunities to address potential supply/demand imbalances, considering a range of future scenarios. Identifying strategies involves an iterative modeling process whereby future system reliability is evaluated with certain adaptation strategies in place.

In general, the study will identify potential adaptation strategies that could help reduce the supply and demand imbalances that are likely to result from climate change. These adaptation strategies are being evaluated using a trade-off analysis, which involves weighing and comparing strategies. As a result, individual strategies will be compiled into a range of management portfolios that, together, could address imbalances more comprehensively than a single strategy. The Basin Study is intended to be a collaborative planning process, not a decision process, and does not recommend implementation of specific adaptation strategies.

4 Coordination Activities

In addition to the Klamath River Basin Study, Reclamation continues to work with partners on adaptation actions in response to climate stresses. These activities include extending water supplies, water conservation, hydropower production, planning for future operations, and supporting rural water development. Specific examples of coordination and adaptation in the Klamath River Basin include:

- Since the listing of three Klamath River Basin fish species under the Endangered Species Act, Reclamation has also coordinated with the USFWS and the NOAA Fisheries on Klamath Project operations plans that reduce regulated flow impacts to these species.
- The Trinity River Fishery Restoration Program is appraising alternatives that would improve the current cold-water transmission through Lewiston Reservoir, thereby increasing the adaptability for future climate change stressors that may impact cold-water yield to the reservoir from the drainage basin.
- The Klamath Basin NWRs are managed by USFWS under the Migratory Bird Treaty Act (codified as 16 U.S.C. §§ 703-712), National Wildlife Refuge System Administration Act of 1966 (16 U.S.C. §§ 668dd-668ee), National Wildlife Refuge System Improvement Act (Pub. L. 105-57, 111 Stat. 1252-1260), and other laws pertaining to the NWR System. Reclamation manages leases on refuge lands for agricultural purposes in compliance with the Kuchel Act (1964) through a cooperative agreement with the USFWS (Reclamation, 2012 [Klamath BA]).

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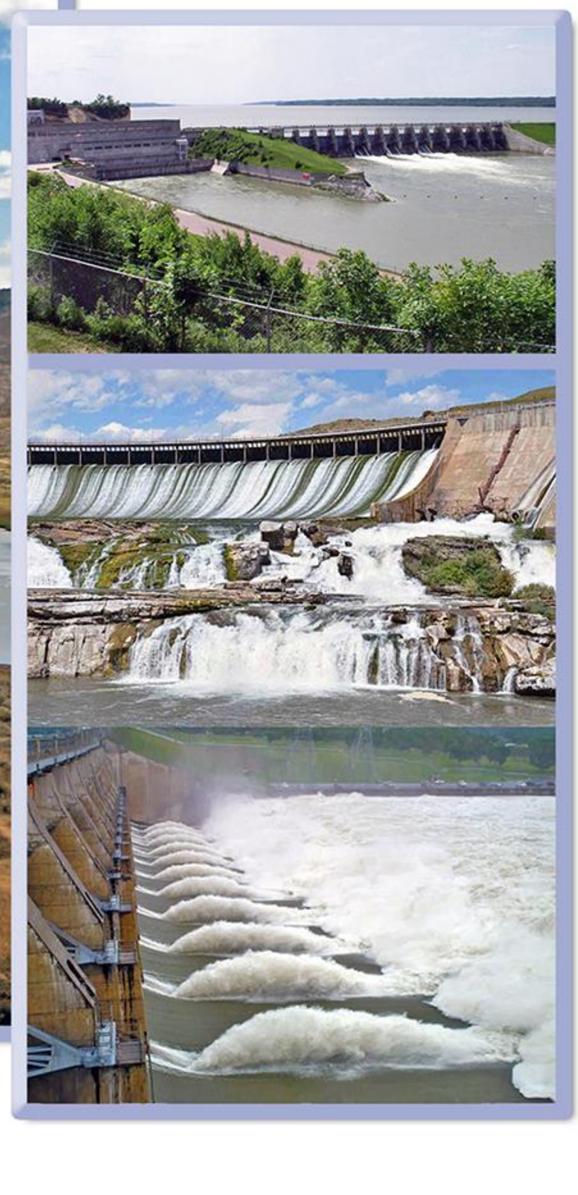
Managing Water in the West

Chapter 6: Missouri River Basin



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This chapter provides a basin-specific summary for the Missouri River Basin. This chapter is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Upper Missouri River Basin Impact Assessment, Missouri River Basin Headwaters Basin Study, St. Mary and Milk River Basins Study, Republican River Basin Study, and Niobrara River Basin Study. Additional information relevant to the Missouri River Basin, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

Missouri River Basin Setting

States: Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wyoming

Major U.S. Cities: Great Falls, Billings, Casper, Cheyenne, Denver, Rapid City, Lincoln, Omaha, Bismarck, Pierre, Sioux City, Kansas City, St. Louis, and Topeka

International: Canada

River Length: 2,500 miles

River Basin Area: 500,000 square miles

Major River Uses: Municipal, Agricultural, Hydropower, Recreation, Flood Control, Navigation, and Fish and Wildlife

Notable Reclamation Facilities: Reclamation has constructed more than 40 dams on Missouri River tributaries that have helped with agriculture development in the basin

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

At 2,565 miles in length, the Missouri River is the longest river in the United States and the third longest river in the world. Its watershed spans more than 500,000 square miles through portions of seven states and one Canadian province, making it the largest watershed within the United States (U.S.). The headwater tributaries of the Missouri River form along the Continental Divide in southwestern Montana. These tributaries convey snowmelt runoff to the Gallatin, Madison, and Jefferson Rivers, which converge near Three Forks, Montana, to create the Missouri River. From the headwaters in Three Forks, the Missouri River flows through Montana, North Dakota, South Dakota, Nebraska, Iowa, Kansas, and Missouri to its confluence with the Mississippi River near St. Louis, Missouri. Basin topography varies from glaciated mountain ranges to flat and rolling grasslands to wide floodplain valleys. Climate and vegetation are similarly varied, ranging from alpine tundra environments to subhumid grasslands and temperate forests. The majority of the basin consists of rolling plains, with agriculture the predominant use of the land.

Despite the river's length and the watershed's size, the Missouri River produces annual yields (40 million acre-feet [MAF]) that are significantly less than either the Columbia (199 MAF) or Ohio (181 MAF) Rivers, both of which are more than 1,000 miles shorter than the Missouri River. This low annual flow, in combination with a large watershed and socioeconomic factors, contributes to conflict in management and use of the river throughout the Missouri River Basin.

The Missouri River crosses the 98th meridian in northeastern South Dakota. This meridian roughly divides the U.S. between relatively arid and humid (i.e., 20 inches or more of annual precipitation) climates. The Missouri River Basin exhibits strong temperature and precipitation gradients consistent with larger continental gradients in North America. Mean annual temperatures decrease northward, and average annual precipitation increases from west to east. In the portions of the basin west of the 98th meridian, most precipitation falls as snow. Most of the precipitation in the eastern basin falls as rain.

1.1 Missouri River Basin Studies Overview

The Missouri River Basin presents unique management challenges due to the size and complexity of the basin. Particularly, Reclamation recognizes the difficulty in serving both international obligations and differing interstate needs across a large geographic area, all with relatively low yields.

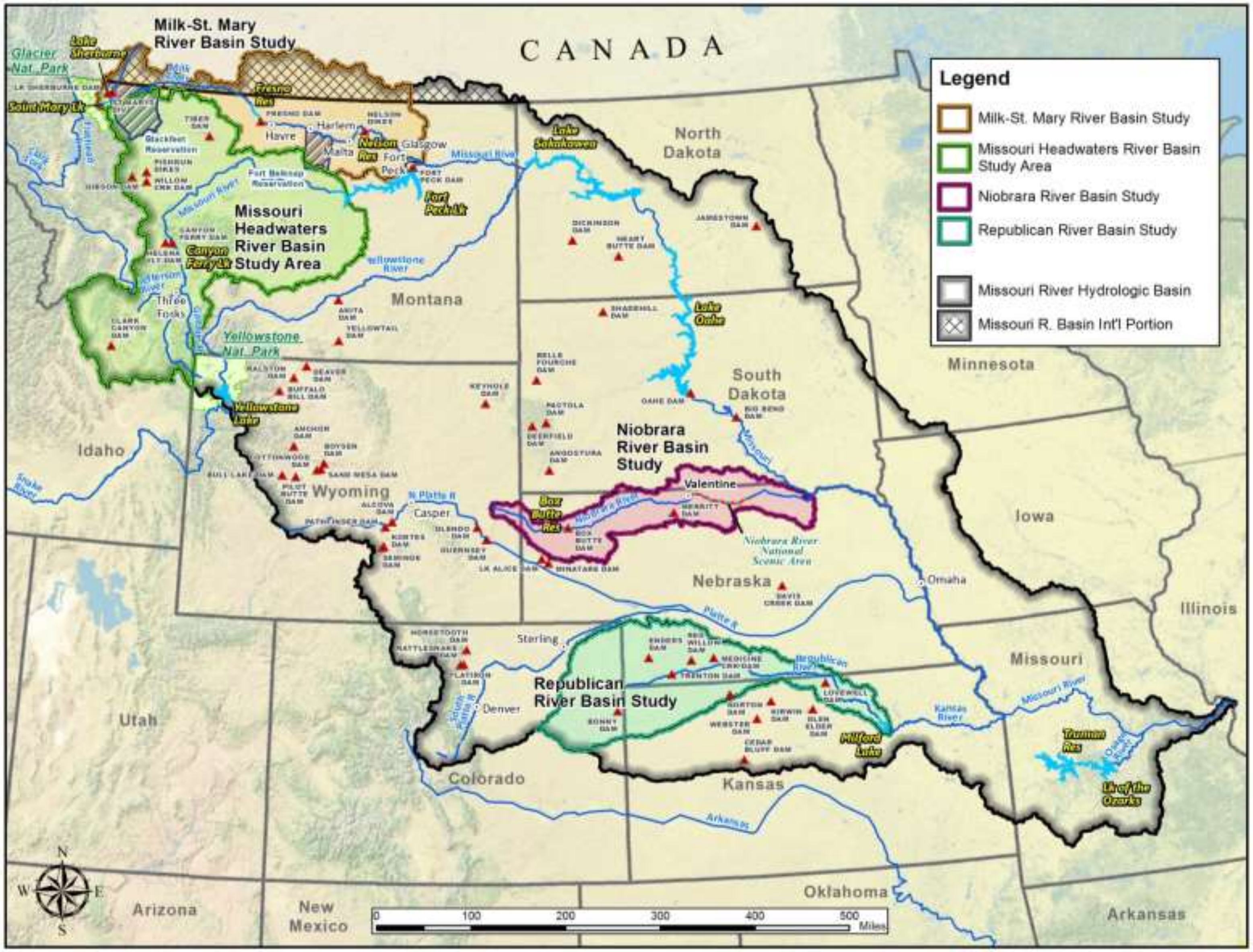


Figure 6–1. Missouri River Basin overview map.

Reclamation has undertaken several Climate Impacts Assessments and Basin Studies in order to evaluate the reliability of the Reclamation's irrigation and water systems to meet the current and future needs in the basin, with an emphasis on the impacts of future climate variability. Impacts Assessments and Basin Studies are funded and conducted by Reclamation through the Basin Study Program under the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. The Basin Studies are conducted in coordination with stakeholders in the Missouri River Basin. The purpose of the Basin Studies is to define current and future imbalances in water supply and demand in the basin and subbasins over a long-term planning horizon, and to develop and analyze adaptation and mitigation strategies to address those imbalances. Since 2009, the following five climate impacts assessments and basin studies have been undertaken in the Missouri River Basin:

- **Upper Missouri River Basin Climate Impacts Assessment**: Reclamation is conducting the Upper Missouri River Basin Climate Impacts Assessment to determine baseline risks to water supplies and demands in order to establish a foundation for more in-depth analyses and the development of adaptation strategies in the Missouri River Headwaters Basin Study. This study is expected to be complete in 2016.
- **Missouri River Headwaters Basin Study**: Reclamation is collaborating with the Montana Department of Natural Resources and Conservation to fund the basin study. The study area encompasses the Missouri River Basin headwaters in Montana from the Continental Divide to the Landusky and Mosby gauges, both upstream of Fort Peck Reservoir.
- **St. Mary and Milk River Basins Study:** Reclamation collaborated with the Montana Department of Natural Resources and Conservation to fund the study, which was completed in 2010. The study area encompasses north-central Montana, southern Alberta, and Saskatchewan in Canada, and includes the Blackfeet and Fort Belknap Indian Reservations.
- **Republican River Basin Study**: Reclamation collaborated with the state governments of Colorado, Nebraska, and Kansas to fund the study. The Republican River Basin Study area covers the entire Republican River Basin in eastern Colorado, southern Nebraska, and northern Kansas, down to the Clay Center gauging station in Kansas. This study was released in March 2016.
- **Niobrara River Basin Study**: Reclamation collaborated with the Nebraska Department of Natural Resources to fund the study. The study area is located along the Niobrara River in northern Nebraska. This study is expected to be complete in 2016.

To date, the St. Mary River, Milk River, Republican River, and Niobrara River Basin Studies have been completed. The following sections focus on water management, water resources impacts, and adaptation strategies within these three subbasins of the Missouri River.

1.2 Management

Since the U.S. Army Corps of Engineers (USACE) began debris-snagging and other river maintenance activities in 1838, issues along the Missouri River related to competing uses of water have been commonplace. USACE and Reclamation developed separate water management plans focused on flood control, navigation, and water scarcity and irrigation, respectively. Congress passed the Flood Control Act of 1944 that included both USACE and Reclamation management plans for the river that came to be known as the Pick-Sloan Missouri Basin Program (Pick-Sloan Program). The Flood Control Act of 1944 also included the O'Mahoney-Millikin Amendment, making navigation subordinate to beneficial consumptive uses of water west of the 98th meridian. Section 9 of the Flood Control Act of 1944, as amended, authorized the Pick-Sloan Program for flood control, navigation, irrigation, power, water supply, recreation, fish and wildlife, and water quality purposes. In response to the Pick-Sloan Program, USACE constructed six mainstem dams on the Missouri River (Figure 6–2), and Reclamation constructed more than 40 dams on basin tributaries (Figure 6–1). Reclamation's development in the basin focused on agricultural irrigation in the upper basin states west of the 98th meridian.

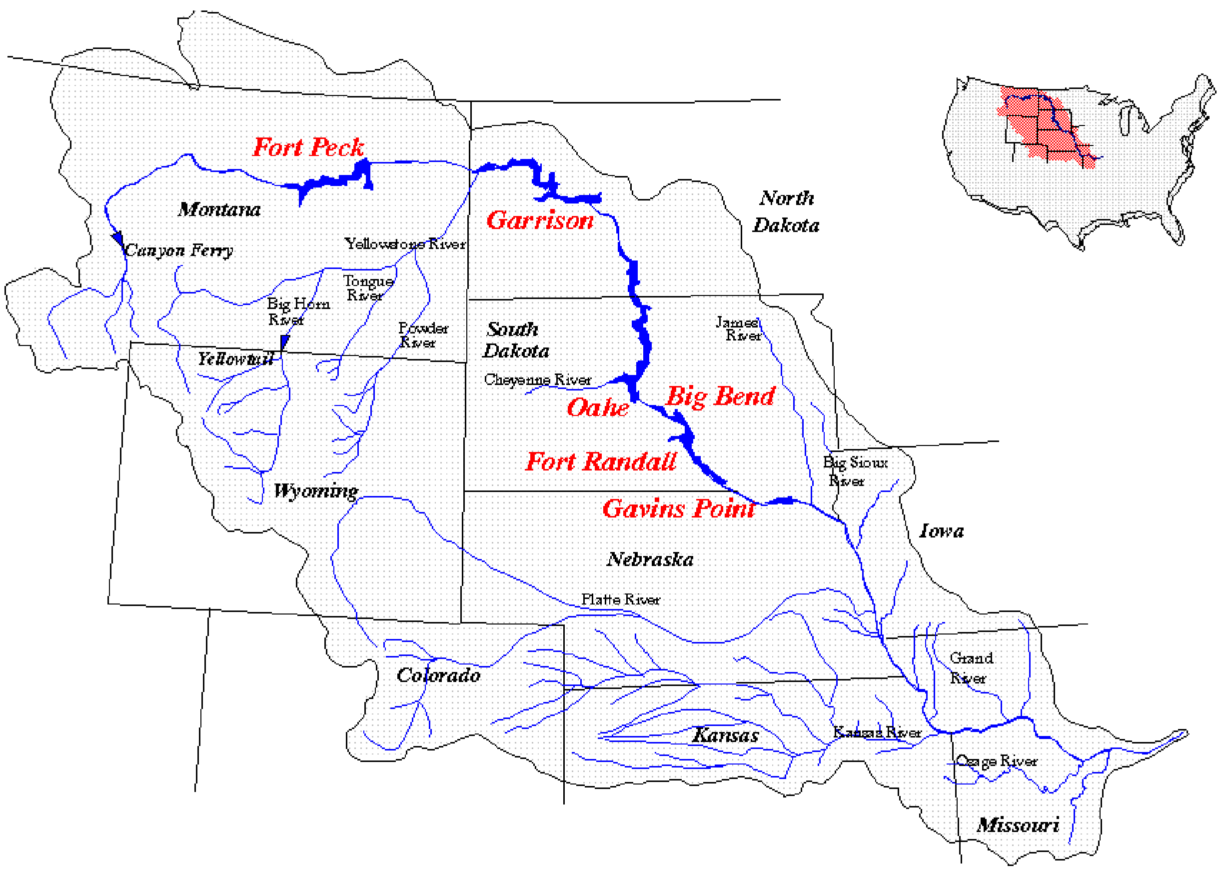


Figure 6–2. Major U.S. Army Corps of Engineers dams on the Missouri River.

St. Mary River and Milk River Setting and Management

The St. Mary River and Milk River subbasins run from the Rocky Mountains in the west to the Milk River confluence with the Missouri River below Fort Peck Dam in the east. The St. Mary River rises in Glacier National Park, in northern Montana, flowing northeast through the Blackfeet Reservation into Canada, to its confluence with Oldman River near Lethbridge, Alberta, below Fort Peck Reservoir. The Milk River originates in the foothills of the Rocky Mountains on the Blackfeet Reservation, flowing northeasterly into Alberta for about 200 river miles before crossing the border again into Hill County, Montana. Thereafter, the river flows in an easterly direction for 490 river miles until joining the Missouri River near Nashua, Montana. The Milk River system is augmented by a trans-basin diversion from the St. Mary River Basin.

Reclamation's Milk River Project includes the facilities in both the St. Mary River and Milk River Basins, and these facilities are operated as a synchronized system. The Milk River Project irrigates about 121,000 acres in the Milk River Basin. Principal crops are alfalfa, grass hay, oats, wheat, and barley. Approximately 50,000 people depend on the Milk River Project for municipal, rural, and industrial water supplies, including the communities of Havre, Chinook, and Harlem, and the Fort Belknap and Blackfeet Indian Reservations.

In the northernmost portion of the basin, the United States and Canada share the waters of the St. Mary and Milk Rivers in accordance with the Boundary Waters Treaty of 1909, the International Joint Commission (IJC) 1921 Order, and subsequent Letter of Intent. Current administration of the Treaty, combined with infrastructure limitations, has resulted in the United States receiving less than its share of St. Mary River flow and Canada receiving less than its share of Milk River flow.

A Water Rights Compact between the State of Montana and the Gros Ventre and Assiniboine Tribes of the Fort Belknap Indian Reservation was ratified by the Montana State Legislature and signed by the Governor in 2001. The compact entitles the Tribes to divert up to 645 cfs from the U.S. share of the natural flow of the Milk River. The compact negotiated between the Blackfeet Tribe and the State of Montana was approved by the Montana Legislature and recommended for further action by the Blackfeet Tribal Business Council in 2009. The Compacts are not yet in effect since they have not been approved by Congress; if approved by Congress, the Compact would give the Tribe the right to 50,000 acre-feet per year (AFY) from the St. Mary drainage, other than from Lee Creek and Willow Creek. For Lee Creek and Willow Creek, the Tribe has a right to all natural flow available to the United States under the Boundary Waters Treaty, and all groundwater in the St. Mary River drainage not subject to the Boundary Waters Treaty. After satisfaction of all water rights arising under state law and full development, the Tribe would have a right to the remaining portion of the United States' share of the St. Mary River under the Boundary Waters Treaty.

In 1973, the State of Montana began a state-wide adjudication of all water right claims that existed prior to July 1, 1973. This included reserved water rights associated with Indian and other federal reservations. Claims on the St. Mary and Milk Rivers are being examined by the Montana Department of Natural Resources and Conservation (DNRC) and are being adjudicated by the Montana Water Court. The Montana Water Court has issued temporary or preliminary decrees in the St. Mary River Basin and the Milk River Basin. The DNRC has completed all initial examinations in the St. Mary River Basin and the Milk River Basin by the June 30, 2015, deadline for final re-examinations. The parties involved in the adjudication proceedings are working toward resolution in 2023, along with a deadline in 2028 for completion of the claims prior to final decrees being issued by the Montana Water Court.

Republican River Setting and Management

The Republican River Basin, located in the southern portion of the Missouri River Basin, is an important region for the states of Nebraska, Colorado, and Kansas that includes highly productive agricultural lands, large reservoirs with recreational and wildlife habitat features, and established communities that rely on the agriculturally driven economy and the water supplies that sustain it. The Republican River originates in the high plains of northeastern Colorado, western Kansas, and southern Nebraska. Tributaries originating in northeastern Colorado and western Nebraska flow to the southeast to join the northern side of the mainstem. Tributaries originating primarily in northwestern Kansas flow in a northeastern direction to join the south side of the mainstem. In total, the Republican River flows east for 453 miles until it joins with the Smoky Hill River at Junction City, Kanas, to form the Kansas River.

The Republican River Basin covers approximately 16 million acres and partially overlies the Ogallala Aquifer, which is a component of the High Plains Aquifer[2], the largest groundwater system in North America that spans eight western states (Figure 6–3). Groundwater is the primary water supply for most of the irrigated agriculture in the basin, and is the sole supply for municipal, industrial, and domestic uses throughout most the basin. There are many demands on the limited water supply within the Republican River Basin, including irrigation, recreation, fish and wildlife, and municipalities. By far, the largest demands come from groundwater wells that pump water from the Ogallala Aquifer for agricultural irrigation in order to support cultivation of various crops (winter wheat, grain sorghum, soybeans, corn, and sugar beets).

[2] The High Plains aquifer underlies an area of about 174,000 square miles that extends through parts of eight states. The aquifer is the principal source of water in one of the major agricultural areas of the U.S.

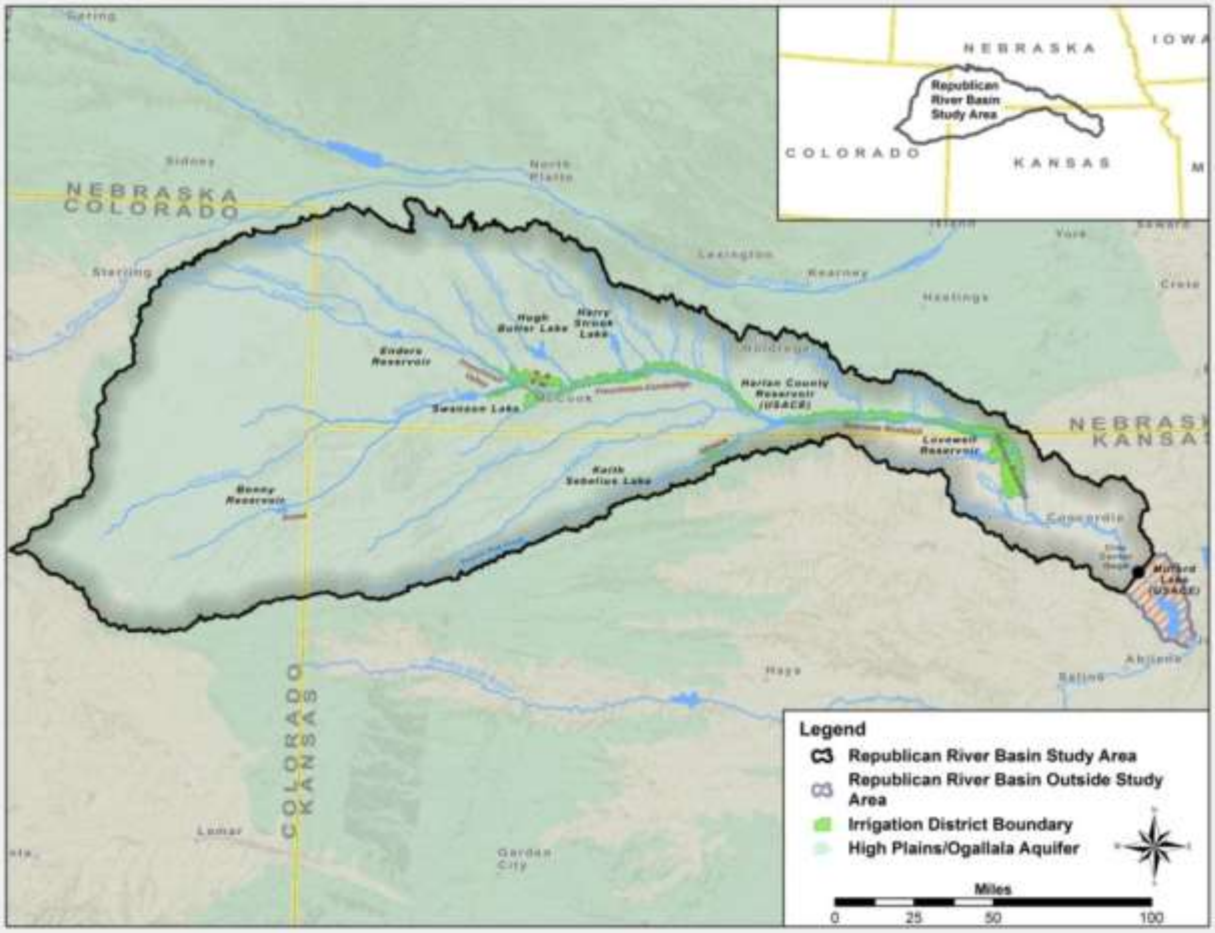


Figure 6–3. Republican River Basin study area. Source: Reclamation, 2016 (Republican).

Reclamation facilities within the Republican River Basin were constructed in the 1940s as part of Reclamation's Pick-Sloan Missouri River Program. The features in the study area include a system of seven Bureau of Reclamation reservoirs, one USACE reservoir, and six irrigation districts. The Reclamation reservoirs include Bonny Reservoir, Swanson Lake, Enders Reservoir, Hugh Butler Lake, Harry Strunk Lake, Keith Sebelius Lake, and Lovewell Reservoir; the USACE reservoir is Harlan County Lake.

The water management issues in the Republican River Basin are complex and involve a long history of stakeholder involvement and activities by Colorado, Nebraska, and Kansas. The Republican River is subject to an interstate compact among Colorado, Nebraska, and Kansas. The Republican River Compact, established in 1943, divides the basin's water supply across eastern Colorado, northwest Kansas, and southwest Nebraska. The high water demands within the basin and declines in adjacent streamflows have created intense competition for limited water supplies, which has ultimately resulted in litigation on compliance with the Republican River Compact. In 1998, the State of Kansas filed a lawsuit against the State of Nebraska, asserting that Nebraska had allowed diversions that exceeded their legal share. Following litigation in the U.S. Supreme Court, the States entered into a Final Settlement Stipulation, approved by the U.S. Supreme Court in 2003. Under the Final Settlement Stipulation, most streamflow depletions caused by surface water and groundwater diversions for beneficial consumptive use are included in the determination and allocation of the virgin water supply of the basin. As a result, interaction between groundwater and surface water is a key component of water management within the basin.

Niobrara River Setting and Management

The Niobrara River Basin originates on the high plains of eastern Wyoming and spans 535 miles east, to the point where the Niobrara River empties into the Missouri River near Niobrara, Nebraska. The Niobrara River Basin drains 12,600 square miles of northern Nebraska and adjacent parts of Wyoming and South Dakota. The basin currently supports about 600,000 irrigated acres and provides municipal water use for approximately 20,000 people, as well as water for hydropower, recreation, and wildlife. In 1991, a 76-mile stretch of the river was designated as the Niobrara National Scenic River, just downstream from the Fort Niobrara National Wildlife Refuge (Figure 6–4). The Niobrara River Basin and the underlying High Plains Aquifer are the primary water resources in the watershed. Temperature and precipitation vary greatly along the Niobrara, both spatially and temporally.

Figure 6–4. Aerial view of the Niobrara River.

Replenished by seepage from various formations, the Niobrara is a predominantly aquifer-supplied river. Szilagyi et al. (2002) found that in the river's upper reaches, 70 to 90 percent of its flow can be attributed to seepage from groundwater. Near its origin in southeastern Wyoming, the river cuts through the water-bearing Arikaree Formation. As it bends through Sioux, Dawes, and Sheridan Counties, Nebraska, it gradually begins to run over the more prolific Ogallala Formation. Water management in the Upper Niobrara River Basin is guided by the Niobrara River Compact between the States of Wyoming and Nebraska.

Within Nebraska, the basin has two Reclamation projects for irrigation: the Mirage Flats Project (11,662 acres) and the Ainsworth Unit (35,000 acres). The basin has one non-Federal hydropower facility, Spencer Hydropower. Reclamation facilities in the Niobrara River Basin include Box Butte Dam and Reservoir (Mirage Flats Project) and Merritt Dam and Reservoir (Sandhills Division, Ainsworth Unit of the Pick-Sloan Missouri Basin Program). Box Butte Dam and Reservoir lie in the arid western Niobrara River Valley, which is dominated by dense cottonwood and willow trees and is surrounded by rolling prairie. The Ainsworth Unit, including Merritt Dam and Reservoir, is located southeast of the Mirage Flats Project, within the northern portion of the Sandhills Region of Nebraska. The Sandhills Region is dominated by rough hills made of fine, wind-blown sands and the occasional broad, shallow valley. In the lower reaches, the valleys often become narrow and deeply entrenched. Merritt Dam and Reservoir are built on the Snake River, where the valley narrows and becomes entrenched.

2 Analysis of Impacts to Water Resources

In the Missouri River Basin the local climate and impacts to water resources varies considerably within the basin. For example, annual average temperatures are generally cooler in the high-elevation upper reaches located in the western portion of the upper basin. Warmer temperatures are observed over lower-lying plains to the east and south. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below.

- **Temperature** is expected to follow a similar general trend to current basin conditions with the upper reaches of the basin (e.g., Missouri River at Canyon Ferry) projected to see a smaller relative increase in mean annual temperature during the 21st century, than the middle and lower reaches of the basin (e.g., Missouri River at Omaha).
- **Precipitation** projections are geographically complex for the Missouri River Basin. Precipitation is generally greater in the western upper reaches along the mountains and over the southeastern reaches, and lesser in the High Plains region located in between these two areas. Projections indicate that the Great Plains region will continue to experience the kind of inter-annual to inter-decadal variations in precipitation that it has experienced historically (Reclamation, 2016 [Projections]).
- **Drought** and heat waves are expected to increase in frequency due to climatic changes. Climate change may also exacerbate hazards such as tornadoes, droughts, and floods and will increase economic losses in the future (University of Nebraska-Lincoln, 2014).
- **Snowpack** is expected to diminish during the cool season due to increasing temperature (late autumn through early spring) and the availability of snowmelt to sustain runoff during the warm season (late spring through early autumn). Decreases in snowpack are projected to be more substantial over the portions of the basin where baseline cool-season temperatures generally are closer to freezing thresholds and are more sensitive to projected warming. This is particularly the case for the eastern plains.
- **Seasonality and timing of runoff** also are projected to change. Historically, unimpaired streamflow in the basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Warming is expected to lead to more rainfall runoff, rather than snowpack accumulation, during the cool season. This is especially true for the higher-elevation watersheds.

Changes in water supply and reservoir operations due to climate change may have cascading effects to water allocations from year to year, which in turn could trigger changes in water use (e.g., crop types, cropping dates, environmental flow targets, transfers among different uses, hydropower production, and recreation). Key findings related to projected changes in demand are summarized below.

- Agricultural irrigation is the predominant water demand on Reclamation reservoir systems within the western reaches of the Missouri River Basin. Given that the atmosphere's moisture-holding capacity increases when air temperature increases, plant water consumption and surface water evaporation associated with agricultural demands should increase in a warming climate.
- Additionally, agricultural water demand could decrease due to crop failures caused by changes in pests and diseases in the future. Seasonal volumes of agricultural water demand could increase if growing seasons become longer, and if farming practices adapt to this opportunity by planting more crop cycles per growing season.
- Climate change could also result in changed demand for in-stream flow or reservoir release to satisfy other system objectives, including ecosystem support, hydropower generation, municipal and industrial water deliveries, river and reservoir navigation, and recreational uses.
- Water demands for endangered species and other fish and wildlife could increase with ecosystem impacts due to warmer air and water temperatures and resulting hydrologic impacts (i.e., runoff timing).
- Diversions and consumptive use by industrial cooling facilities are predicted to increase, since these processes will function less efficiently with warmer air and water temperatures. The timing of these diversions and those for hydropower production also could be a factor in ecosystem demands and navigation and recreational water uses.

The Missouri River Basin is highly complex and Reclamation must manage its facilities within the basin to meet a vast array of objectives and needs, such as making reliable water deliveries, producing hydropower, providing recreational opportunities and flood control, and managing fish and wildlife (including Federally listed species and their habitat). The impacts of climate change on Reclamation's ability to satisfy these key management objectives are described in the following sections.

2.1 Water Delivery

Changes in climate, particularly shifts in the timing of runoff, are expected to affect Reclamation's ability to meet contracted and scheduled water deliveries. Mean annual basin runoff is projected to increase as much as 9.7 percent, but higher variability is also expected in sub-basin runoff. Moisture falling as rain instead of snow at lower elevations may increase the wintertime runoff with decreased runoff during the summer. For example, in the St. Mary River/Milk River area, the irrigation season is projected to begin approximately 7 days earlier, and irrigation shortages are expected to increase. Earlier calls on reservoir releases for irrigation water will lead to a stronger reliance on stored water during the late summer months.

Figure 6–5. St. Mary Diversion Dam, Montana.

Additionally, aging infrastructure is expected to affect water deliveries. The actual conveyance capacity of the St. Mary Canal has been reduced from 850 cfs to about 650 cfs at the St. Mary siphon as a result of seepage, slides, and canal bank slumping. Reclamation and the irrigation districts perform replacement and extraordinary maintenance on St. Mary facilities dependent on funding availability.

2.2 Hydropower

Electricity demand from hydropower generation and other sources generally correlates with temperature (Scott and Huang, 2007). Hydroelectric generation to satisfy demands is sensitive to climatic changes that may affect basin precipitation, river discharge (amount and timing), and reservoir water levels. Hydropower operations also are affected indirectly when climate change affects air temperatures, humidity, or wind patterns (Bull et al., 2007). Climatic changes that result in decreased reservoir inflow or disrupt traditional timing of inflows could adversely affect hydropower generation. Alternatively, increases in average flows would increase hydropower production. Projected increases in water availability under climate change may benefit the production of hydropower in this basin.

Figure 6–6. Canyon Ferry Dam and Powerplant, Missouri River.

2.3 Recreation at Reclamation Facilities

Recreation impacts in the Missouri River are varied across the large expanse of recreation facilities within the basin (Figure 6–7). Under drier climate scenarios, a sizable reduction in water levels may be offset by increased visitation estimates due to increases in air temperatures. In these scenarios, warmer air temperatures could draw more visitors to certain reservoirs even if water levels are lower thereby improving the recreational benefits in the basin. Due to the size of this river basin and large number of recreation locations, the impacts of climate change, particularly warming temperatures, could actually result in a significant benefits for the basin through increased flatwater recreation.

Examples of recreation benefits from completed basin studies are included below. In the St. Mary River/Milk River subbasin, elevations are expected to be an average of 1 to 6 feet lower. With lower water elevations in reservoirs and a projected increase in demand for recreational uses at Fresno, Nelson, Sherburne, and Glacier National Park, the demands for flatwater recreation will be satisfied less frequently.

Meanwhile, impacts in the Republican River are varied, with reservoirs resulting in reduced recreation benefits under the warmer and drier climate scenarios and increases in water levels and temperatures leading to increases in recreation visitation. Overall, in the sub-basin, water levels across the April-to-September high-recreation-use season were estimated to decline while temperatures were estimated to increase. In calculating visitor days, the increases in temperature of 5 to 6 degrees Fahrenheit by 2070 outweighed the losses in water levels, resulting in an increase in visitor days, and thus, recreation benefits.

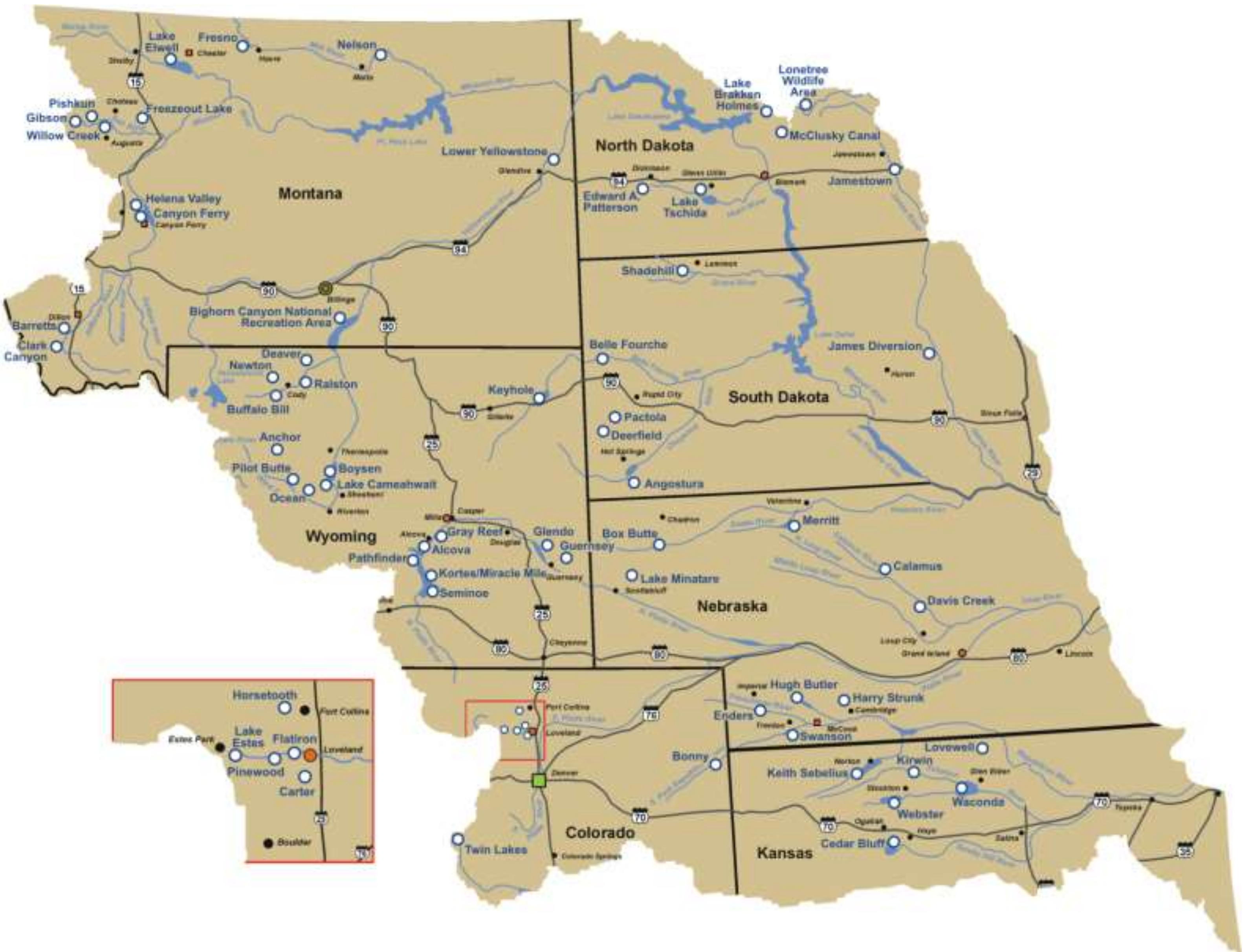


Figure 6– 7. Recreation locations in the Missouri River Basin.

Figure 6–8. Sailboats moored on Canyon Ferry Reservoir, a unit of the Pick-Sloan Missouri Basin Program.

2.4 Flood Management

Historically, unimpaired streamflow in the basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Warming is expected to lead to more rainfall runoff, rather than snowpack accumulation, during the cool season. This is especially true for the higher-elevation watersheds.

Presently, Lake Sherburne and Fresno Reservoir provide flood control benefits by storing water during the peak runoff period. Some of these benefits are derived by reducing local damages; for Fresno Reservoir, other benefits are derived by storing water that would have contributed to flooding downstream on the main stem of the Missouri River below Fort Peck Reservoir. Between 1950 and 2010, Lake Sherburne has prevented $7.9 million in flood damages, while Fresno Reservoir has prevented $14.2 million in flood damages, according to USACE estimates. A full list of the annual flood control benefits in the Missouri Basin by project are listed in Table 6–1.

Table 6–1. Annual Flood Control Benefits for the Missouri River Basin

Missouri River Basin Project	Accumulated Actual Benefits from 1950 through 2014 ($)
Pick-Sloan Missouri Basin Program Total	2,811,158,100
Sun River Project Total	3,085,600
Milk River Project Total	25,912,900
Shoshone Project Total	30,502,400
Kendrick Project Total	48,553,800
North Platte Project Total	17,741,700
Missouri River Total	**2,936,954,500**

2.5 Fish and Wildlife Habitat

Projected climate changes are expected to have an array of interrelated and cascading ecosystem impacts (Janetos et al., 2008). At present, most projected impacts are primarily associated with increases in air and water temperatures and decreases in reservoir level and include increased stress on fisheries that are sensitive to a warming aquatic habitat. For example, Fresno Reservoir is expected to frequently fall below the Montana Fish, Wildlife, and Parks' recommended reservoir level of 2,560 feet for fisheries habitat. Other impacts of a decrease in reservoir level include increased water temperature and reduced dissolved oxygen, which are detrimental to native aquatic organisms. Conversely, lower lake levels at the Bowdoin National Wildlife Refuge may increase habitat for shoreline nesting birds.

Warmer air and water temperatures could potentially improve habitat for quagga mussels and other invasive species, which, in turn, may additionally affect maintenance of hydraulic structures and increased risk of watershed vegetation disturbances due to increased fire potential. Other warming-related impacts include pole-ward shifts in the geographic range of various species and impacts on the arrival and departure of migratory species.

Climate changes could decrease the effectiveness of chemical or biological agents used to control invasive species (Hellman et al., 2008). Warmer water temperatures also could spur the growth of algae, declines in water quality (Lettenmaier et al., 2008), and changes in species composition. In addition, landscape fragmentation is increasing in the context of energy development activities, for example, in the northern Great Plains. A highly fragmented landscape will hinder adaptation of species when climate change alters habitat composition and timing of plant development cycles (Shafer et al., 2014). The magnitude of expected changes will exceed those experienced in the last century.

Dunnell and Travers (2011) report that some spring-flowering species have advanced their first flowering time, some fall species have delayed their first flowering, and some species have not changed. Given the importance of flowering timing for reproductive success, the changing climate in the Great Plains is expected to have long-term ecological and evolutionary consequences for native plant species.

A warming climate is projected to result in fewer wetlands in the Missouri River Basin. If temperature and precipitation trends of the 20th century continue, a steeper west-to-east gradient in wetness may further shrink wetland acreage in the most productive portion of the prairie pothole region (Millett et al., 2009). Prairie wetlands were found to be more sensitive to changes in temperature than to changes in precipitation, and increased temperature scenarios resulted in wetland drying and declining numbers of ponds and ducks (Sorenson et al., 1998). Large increases in precipitation are necessary to offset even small temperature increases. Wetland size, depth, and vegetation characteristics were found to be more sensitive to increases in temperature rather than changes in precipitation (Poiani and Johnson, 1991).

Primary productivity in temperate grasslands was found to be more responsive to precipitation than to temperature, and changes in primary productivity responding to changes in moisture continued up the food web (Hunt et al., 1991). Changes to primary productivity may affect migratory birds by upsetting migratory timing and habitat and food availability. Increased intensity of summer storms, especially those with large hail, is expected to increase avian mortality.

Simulations of 50 years of climate change show losses of soil organic carbon across the entire central Great Plains due to increased temperatures that led to increased decomposition rates (Burke et al., 1991). Some areas were expected to lose 3 percent of the total soil carbon pool. Areas with the highest precipitation (and high initial soil organic matter) suffered the largest loss of organic soil carbon.

Rising nighttime minimum temperatures and their potential effect on grassland productivity in northeastern Colorado were considered by Alward et al. (1999). Minimum temperatures increased 0.3° F per year over the previous 23 years. Averages of seasonal minimum temperatures also exhibited significant warming, with similar trends in winter, spring, and summer. Annual precipitation exhibited a significant linear increase from 9 inches to 19 inches during the same timeframe. The study indicates that for each 1.8° F increase in average spring minimum temperature, aboveground net primary productivity of dominant grasses decreases by nearly one-third. Increased growing season duration is expected primarily to benefit cool-season plants that grow most rapidly early and late in the growing season.

Increases in temperature and reduced precipitation have the potential to reactivate significant areas of now-stabilized or mostly stabilized sand dunes and sheets in the Great Plains (Muhs and Maat, 1993). Some of the areas with the greatest potential increase in dune activity are in central Wyoming, eastern Colorado, and western Kansas. At least one plant listed as endangered (blowout penstemon) under the Endangered Species Act is a species found only in sand dune habitats.

Many ecosystems of the Great Plains are not well suited for accommodating fish distributional shifts that will occur because of climate change, owing to the lack of nearby hydrologic connectivity with higher-latitude and -elevation habitats generally associated with climate change-induced range shifts. Despite uncertainty in precisely how Great Plains fish species distributions may be affected by a warming climate, this lack of hydrologic connection may lead to additional climate-related stress on fish communities in the Great Plains compared to other regions of North America (Pracheil et al., 2014).

2.6 Endangered, Threatened, or Candidate Species

A number of species listed under the Endangered Species Act (ESA) can be found in the St. Mary River and Milk River region (Table 6–2). Endangered species include the black-footed ferret, whooping crane, pallid sturgeon, and interior least tern. Threatened species include the grizzly bear, piping plover, bull trout, and Canada lynx.

Table 6–2. Where Endangered Species Can Be Found within the St. Mary River and Milk River Region

Species	Where Species Has Been Found
Bull trout (east of the Continental Divide)	St. Mary River Basin
Grizzly bear	Near Swiftcurrent Creek on the Blackfeet Reservation, as well as using the St. Mary Canal as a travel corridor
Black-footed ferret	On lands near the Milk River, residing in abandoned prairie dog towns
Whooping crane	Migratory birds that have been documented to migrate through the Milk River Basin in the spring and fall each year
Canada lynx	Use the St. Mary River Basin as a main traveling corridor, and this population of lynx is thought to be the strongest lynx population within the United States
Least tern	Nesting along the banks of the Milk River
Piping plover	In the Milk River Basin, nesting on the shore and islands in Nelson Reservoir, and at Bowdoin National Wildlife Refuge

The U.S. Fish and Wildlife Service (USFWS) listed bull trout as threatened under the ESA in 1999. USFWS identified three areas where Reclamation structures and operations may have adverse impacts on bull trout: lack of winter flows in Swiftcurrent Creek below Sherburne Dam, entrainment into the St. Mary Canal, and passage at the St. Mary Diversion Dam. Reclamation is required to comply with the ESA as it relates to bull trout in its operations of these facilities. In March 2011, Reclamation, in cooperation with the Blackfeet Tribe, National Park Service, USFWS, Milk River Joint Board of Control, St. Mary Rehabilitation Working Group, DNRC, and Bureau of Indian Affairs, completed a value planning study on fish passage and entrainment for the St. Mary Diversion Dam. Reclamation is also completing designs, specifications, and associated environmental documents for fish passage and entrainment for the St. Mary Diversion Dam.Whooping cranes, Eskimo curlews, peregrine falcons, interior least terns, piping plovers, and the American burying beetle occur within the Republican River Basin.

2.7 Water Quality

Typically, water quality problems become more pronounced during droughts when dissolved chemical concentrations and water temperatures are highest, although suspended sediments are higher during high-flow events such as spring runoff. Irrigation can contribute to water quality degradation. Problems typically occur when irrigation diversions result in low river flows and when return flows from fields contain higher concentrations of salts, nutrients, suspended solids, and pesticides.

Sedimentation

Fine-grained sediments are transported by the Milk River downstream to Fresno Reservoir, where they settle and reduce the storage capacity of the reservoir. Reclamation estimated that the reservoir has lost 36,200 acre-feet (AF) (as of May 1999) from its original 129,062 AF storage capacity from sedimentation since it was completed in 1939. Similar rates of sedimentation are expected to continue into the future. Sedimentation in reservoirs will cause a reduction in storage availability and increased evaporation due to shallower and warmer reservoir pools.

3 Potential Adaptation Strategies to Address Vulnerabilities

The Basin Studies conducted in the Missouri River Basin identify potential adaptation strategies that could help reduce the supply and demand imbalances that are projected to result from climate change. Adaptation strategies considered in the St. Mary River/Milk River and the Republican River Basin studies:

- **Canal efficiency:** Methods include lining canals and laterals, putting laterals into pipe, reusing spills and return flows, and adding and improving water measurement sites. Ditch efficiencies could be improved by reducing seepage losses and, in some cases, increasing capacities to meet peak demands.
- **Infrastructure Rehabilitation:** Replacement of aging infrastructure to increase capacity and reduce seepage losses would provide additional water storage. For example, at the St. Mary Canal, the original 850 cfs capacity is reduced to 650 cfs capacity.
- **On-farm efficiencies:** Methods include field leveling, more-efficient flood-irrigation water distribution, converting from flood irrigation to sprinklers, and shorter field runs.
- **Increase storage capacity:** Raise spillway crests, expand current reservoirs, and build new dams and reservoirs (in both Canada and the United States).
- **Expansion of Lovewell Reservoir, KS:** This adaptation strategy involves increase storage in Lovewell Reservoir located 8 miles south of Superior, Nebraska on White Rock Creek. This alternative is subdivided into three options of increasing storage by 16,000, 25,000, or 35,000 AF
- **Swanson Reservoir Augmentation via New Frenchman Creek Pipeline, NE:** These adaptation strategies involve augmentation of Swanson Reservoir by taking advantage of existing available storage and diverting water from either Frenchman Creek or the Republican River. In recent years, Swanson Reservoir has consistently had available storage capacity. This alternative would divert water directly from Frenchman Creek into Swanson Reservoir when storage space is available.
- **Swanson Reservoir Augmentation via New Republican River Pipeline, NE:** This is the same as the prior example, with the exception of water being diverted downstream of the confluence of Frenchman Creek and the Republican River, rather than diverted directly from Frenchman Creek.
- **New Thompson Creek Dam, NE:** This adaptation strategy involves construction of a new dam on Thompson Creek, a tributary to the Republican River, and conveying the water to the Franklin Canal for delivery to NBID in exchange for allowing water to be stored in Harlan County Lake.

4 Coordination Activities

Where opportunities exist, Reclamation participates in coordinated adaptation actions in response to climate stresses. These activities include discussing reservoir operating plans, extending water supplies, conserving water, increasing hydropower production, planning for future operations, and supporting rural water development.

Reclamation coordinates with many entities within the Missouri River Basin. Each spring, Reclamation Area Offices in Montana, Wyoming, and Colorado meet with state government representatives, water users, in-stream and flat-water interests, and others to present tentative reservoir operating plans for comment and discussion. Similar meetings are held for facilities in the Plains States (Dakotas, Nebraska, and Kansas). Reclamation takes into consideration all comments, concerns, and suggestions.

The National Drought Resilience Partnership is a partnership of several Federal agencies that conducts pilots to link drought information such as monitoring, forecasts, outlooks, and early warnings with longer-term drought resilience strategies in critical sectors such as agriculture, municipal water systems, energy, recreation, tourism, and manufacturing. A pilot study is currently ongoing in the Upper Missouri River Basin that leverages the Climate Impact Assessment and Basin Study in the Upper Missouri Headwaters and is the foundation of Federal and state partnerships. The pilot initiative is focused on how improved drought preparedness at the local, state, and tribal levels can be achieved through enhanced coordination of Federal agency resources.

The Federal Highway Administration provided funding through Reclamation to work with the Blackfeet Tribe on the Swiftcurrent/Boulder Creek Bank and Bed Stabilization Project. The project addresses tribal concerns about Reclamation facilities and operations affecting tribal resources by diverting water from Swiftcurrent Creek into Lower St. Mary Lake. Reclamation and the Blackfeet Tribe formed a working group in 2009 to investigate and evaluate alternatives to address these concerns.

Additional coordination activities include long-range planning efforts. Reclamation is also a participating agency in the Missouri River Recovery Implementation Committee (MRRIC). MRRIC was established in 2008 to serve as a basin-wide collaborative forum in which to develop a shared vision and comprehensive plan for Missouri River recovery.

Reclamation continues to support projects ranging from endangered species recovery to rural water supply projects. In the Missouri River Basin, three rural water projects are currently being constructed to serve tribal areas within the basin (Table 6–3).

Table 6–3. Rural Water Projects within the Missouri River Basin

Rural Water Project	Purpose
Garrison Diversion Unit (Pick-Sloan Missouri Basin Program) in North Dakota	Will serve the West Fort Totten area of the Spirit Lake Tribal Reservation
Fort Peck Reservation/Dry Prairie Rural Water System (Montana)	Will assist the Assiniboine Sioux Tribe with completion work to deliver water to Dry Prairie
Rocky Boy's/North Central Montana Rural Water System (Montana)	Assist the Chippewa Cree Tribe of the Rocky Boy's Indian Reservation to complete major portions of its new water system and three areas of the North Central Montana Rural Water System.

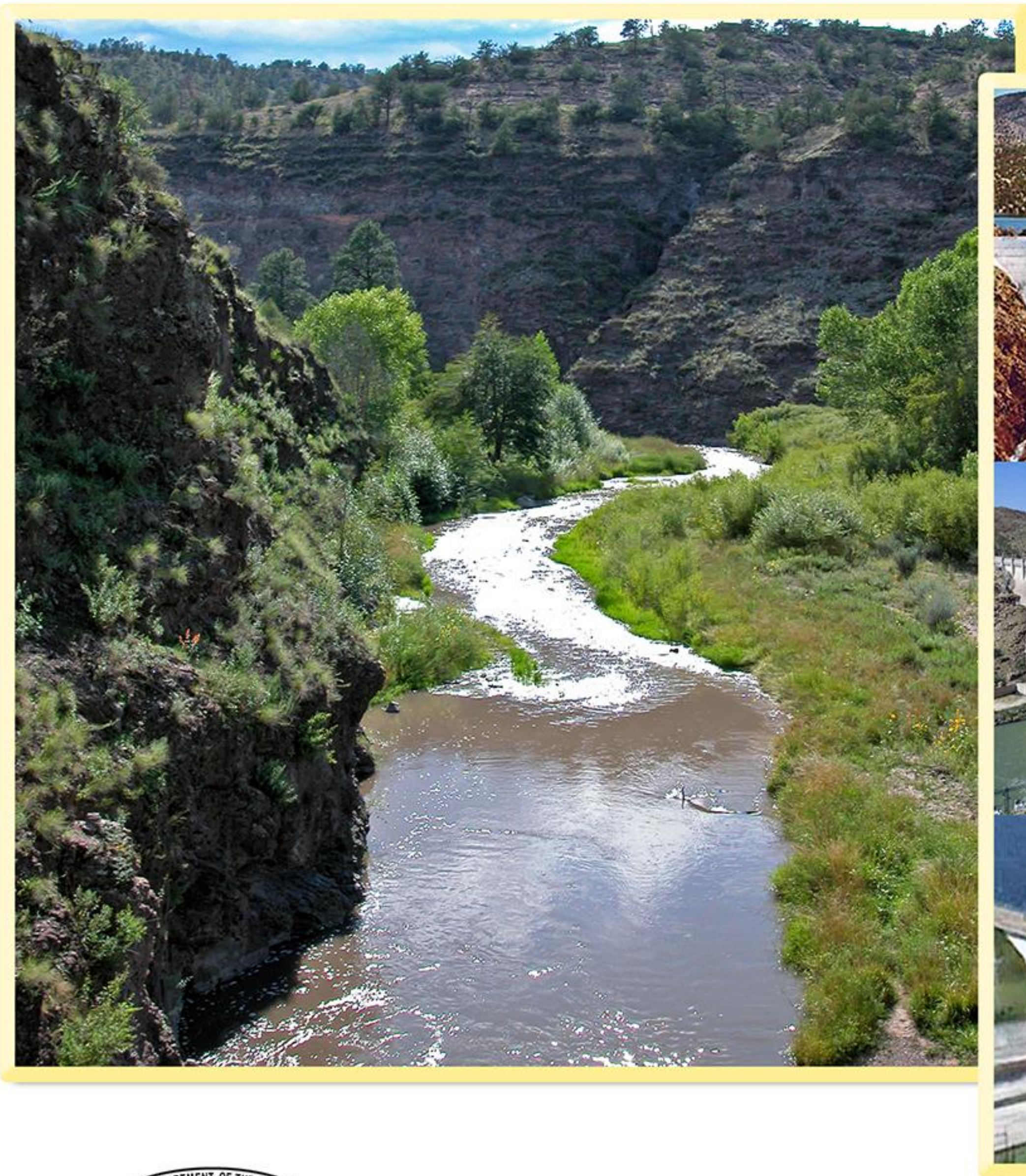
Finally, Reclamation also coordinates with the U.S. Geological Survey (USGS) Water Availability and Use Science Program to understand groundwater availability in the West. In the Missouri River Basin, there is one completed groundwater assessment and one planned:

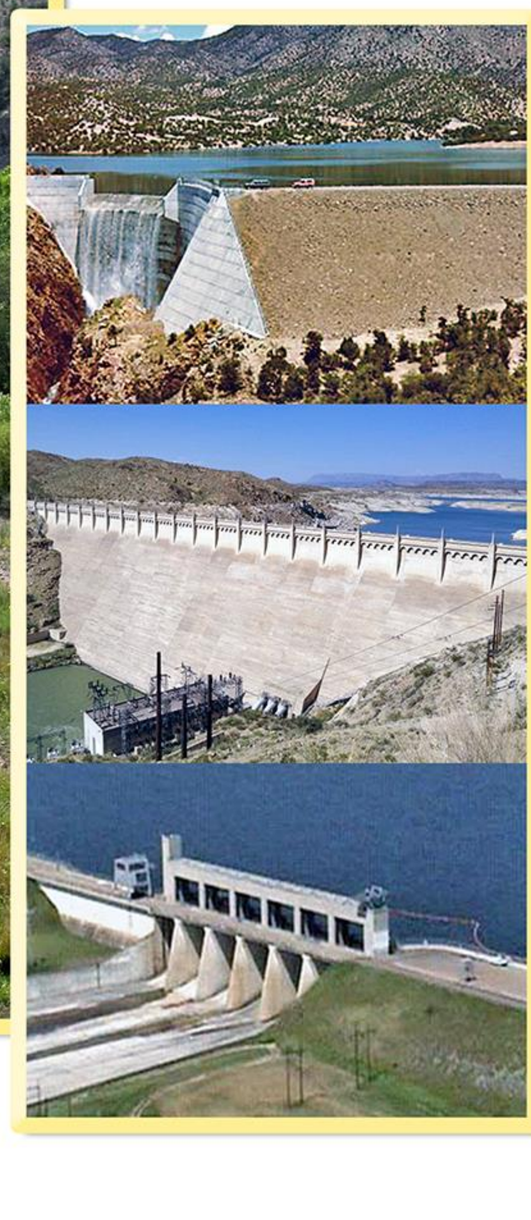
- The High Plains Aquifer study quantified current groundwater resources, evaluated changes in those resources over time, and provided tools to forecast how those resources respond to stresses from future human and environmental uses. The improved quantitative understanding of the basin's water balance provided by this USGS study not only provided key information about water quantity but also is a fundamental basis for many analyses of water quality and ecosystem health.
- In addition to the High Plains Aquifer study, the development of two nationally important energy-producing areas, the Williston Basin (containing the Bakken Formation) and Powder River Basin, provide a critical opportunity to study the water-energy nexus within a groundwater context. Large amounts of water are needed for energy development in the Williston and Powder River Basins and this area is the focus of a USGS groundwater availability study that will:
    - quantify current groundwater resources in this aquifer system,
    - evaluate how these resources have changed over time, and
    - provide tools to better understand system response to future anthropogenic demands and environmental stress.

The aquifers in the regional system are the shallowest, most accessible, and in some cases, the only potable aquifers within the Northern Great Plains.

RECLAMATION
Managing Water in the West

Chapter 7: Rio Grande Basin





U.S. Department of the Interior
Bureau of Reclamation

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About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with section (§) 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011,[1] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Rio Grande Basin. This chapter is organized as follows:

- **Section 1**: River basin setting,
- **Section 2**: Impacts to water and environmental resources,
- **Section 3**: Potential adaptation strategies to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities to build climate resilience.

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Upper Rio Grande Impact Assessment, Lower Rio Grande Basin Study, Santa Fe Basin Study, and the Pecos Basin Study. Additional information relevant to the Rio Grande Basin, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

Rio Grande Basin Setting

States: Colorado, New Mexico, and Texas in the US; four states in Mexico

Major Cities: Santa Fe, Albuquerque, and Las Cruces, New Mexico; El Paso, Del Rio, Laredo, and Brownsville, Texas, and Ciudad Juarez, Mexico.

International: Mexico

River Length: 1,900 miles

River Basin Area: 180,000 square miles

Major River Uses: Municipal, Agricultural (2,000,000 acres of land in U.S. and Mexico), Hydropower (15 megawatts), Recreation, Flood Control, Navigation, and Fish and Wildlife

Notable Reclamation Facilities: San Juan-Chama Project, Heron Dam , El Vado Dam, Nambe Falls Dam, Elephant Butte Dam and Powerplant, and Caballo Dam.

Other Notable Facilities: Amistad and Falcon Dams (International Boundary and Water Commission

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf .

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1 Basin Setting

Today, the Rio Grande supplies water for municipal and irrigation uses for more than 6 million people and 2 million acres of land in the United States (U.S.) and Mexico. The headwaters in the San Juan Mountains of southern Colorado drain approximately 182,200 square miles from both Texas and Mexico. The Rio Grande serves as a source of water for agricultural irrigation, municipal and industrial supplies, as well as domestic, environmental, and recreational uses in Colorado, New Mexico, Texas, and Mexico. Seventy-five percent of Rio Grande Basin water is currently allocated for agriculture. Significant agricultural production occurs in Colorado's San Luis Valley and New Mexico's acequias, Indian Pueblos, and irrigation districts upstream of the bi-national boundary between Mexico and the U.S. Surface water supplements groundwater pumping for the New Mexico cities of Albuquerque and Santa Fe; however, it is significantly less than the 50 percent reliance on surface water for municipal uses by the City of El Paso.

The river's flows are often insufficient to meet the basin's water demands. The magnitude and frequency of water supply shortages within the Rio Grande Basin are severe, even without the effects of climate change. In recent years, intermittent and low flows have occurred throughout the Rio Grande system, and in many years, river flows do not reach the Gulf of Mexico. The river also supports unique fisheries and riparian ecosystems along much of its length, and significant efforts are underway to protect migratory bird habitat in a number of wildlife refuges, as well as threatened and endangered riverine and riparian species in the basin. In addition, the low flows are often associated with elevated river temperatures and water quality concerns, especially along the United States-Mexico border region.

The Rio Grande Basin is located in the southwestern United States and northern Mexico (Figure 7–1). The river's headwaters are in the San Juan Mountains of southern Colorado. The river flows southward through Colorado's San Luis Valley, then through central New Mexico, where it picks up flows from the Rio Chama, and then southeastward as it forms the international boundary between Texas and four states in Mexico. The Rio Grande picks up flows from the Pecos River within Texas and from the Rio Conchos within Mexico, before ultimately flowing into the Gulf of Mexico. The total river length is 1,896 miles, and it flows through the cities of Alamosa, Colorado; Albuquerque and Las Cruces, New Mexico; El Paso, Laredo, and Brownsville, Texas; and through several large sister cities in Mexico along the United States/Mexico border. Basin topography varies, from the mountains and gorges of the headwaters to the Rio Grande Bosque (riverside forest) and high desert of central New Mexico, to deserts and subtropical terrain along the boundary between Texas and Mexico.

Figure 7–1. The Rio Grande Basin of Colorado, New Mexico, Texas, and Mexico.

The Reclamation projects in or serving the Upper Rio Grande Basin include the Closed Basin Project in Colorado, the San Juan-Chama trans-mountain diversion project between Colorado and New Mexico, the Middle Rio Grande Project in central New Mexico, and the Rio Grande Project in southern New Mexico and far-west Texas. These projects support approximately 200,000 acres of irrigated agriculture, which produces alfalfa, cotton, vegetables, pecans, and grain; they also provide water to municipalities, tribes, and industry. Reclamation's facilities provide critical water and power for industry and communities including Albuquerque and Las Cruces in New Mexico; El Paso, Texas; and Ciudad Juarez in Chihuahua, Mexico.

The waters of the Rio Grande are heavily utilized, and due to the highly variable and limited supply, as well as this heavy usage, the river is subject to regular intermittency, especially in the central to southern New Mexico and West Texas reaches. The Rio Grande Basin supports critical habitat for the Rio Grande silvery minnow and the southwestern willow flycatcher, both designated as endangered under the Endangered Species Act (ESA). To protect these critical resources, Reclamation must continually evaluate and report on compliance with the ESA, including the risks and impacts from a changing climate, and identify appropriate adaptation and mitigation strategies in conjunction with stakeholders, utilizing the best available science.

Along the Pecos River, Reclamation operates Sumner Dam, which serves the Fort Sumner Irrigation District, and Avalon and Brantley Dams, which serve about 25,000 acres of agricultural land in the Carlsbad Irrigation District. In the Lower Rio Grande Basin, Amistad and Falcon Reservoirs are operated by the International Boundary and Water Commission (IBWC) for flood control and water supply purposes, and have been designated as a special water resource by the Texas Water Development Board (TWDB). Seventy-eight percent of the watershed that feeds these international reservoirs is in Mexico. Historically, Mexico has not always been able to meet its obligations under the governing Treaty due to drought and its own competing needs for, and uses of, tributary waters.

This section along the United States/Mexico border is subject to additional water supply and water quality challenges. As Hurd stated (2012), decreasing runoff and streamflow in Mexico's arid north bordering the Rio Grande threaten not only Mexican irrigation and food production but also Treaty-obligated deliveries to the Rio Grande. The Good Neighbor Environmental Board (GNEB) identified numerous challenges of working in international watersheds. As noted by the GNEB, "an arid climate, the presence of poverty, rapid population growth, aging infrastructure, an international border, and laws in both countries that were put into place in earlier times under different circumstances are just a few of the potential roadblocks" to effective water management in the U.S.-Mexico border region (GNEB, 2005).

1.1 Rio Grande Basin Studies

Climate change is affecting water supply, infrastructure, and management practices of the Rio Grande Basin to meet basin resource needs[2] reliably. Since 2011, Reclamation has funded and conducted four studies in the Rio Grande Basin through the Department of the Interior's WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program. These studies were used to define current and future imbalances in water supply and demand in the basin and sub-basins over a long-term planning horizon (i.e., more than 50 years), and to develop and analyze adaptation and mitigation strategies to resolve those imbalances.

Upper Rio Grande Impact Assessment: Reclamation conducted the Upper Rio Grande Impact Assessment to determine baseline risks to water supplies and demands, establishing a foundation for more in-depth analyses and the development of adaptation strategies. The study was conducted by Reclamation in partnership with Sandia National Laboratories and the U.S. Army Corps of Engineers (USACE) and was completed in 2013.

Lower Rio Grande Basin Study: Reclamation collaborated with the Rio Grande Regional Water Authority (RGRWA), which includes 53 member entities, to fund the study. The study area encompasses 166,000 square miles along the United States-Mexico border from Fort Quitman, Texas, to the Gulf of Mexico. The study was completed in 2013.

Santa Fe Basin Study: Reclamation collaborated with the City of Santa Fe and Santa Fe County on a basin study focused on the Santa Fe River Basin in northern New Mexico. This study also evaluated water sources in New Mexico and southern Colorado that provide water supply to the City of Santa Fe and Santa Fe County, including the Upper Rio Grande, Reclamation's San Juan-Chama Project, and local groundwater supplies. The study was released in 2015.

Pecos River Basin Study: Reclamation is collaborating with the New Mexico Interstate Stream Commission to fund this study. The basin study will focus on the Fort Sumner Underground Water Basin (Fort Sumner Basin), within the Pecos River Basin, New Mexico, and includes a general assessment of climate change impacts and potential adaptation strategies in the entire Pecos River Basin of New Mexico. The study is scheduled to be completed in 2016.

These Basin Studies are conducted in coordination with stakeholders in the Rio Grande Basin. The purposes of the Basin Studies are to define current and future imbalances in water supply and demand in the basin and sub-basins over a long-term planning horizon, and to develop and analyze adaptation and mitigation strategies to address those imbalances.

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[2] Resource needs include water allocations and deliveries for municipal, industrial, and agricultural use; hydroelectric power generation; recreation; fish, wildlife, and their habitats (including candidate, threatened, and endangered species); water quality including salinity; flow- and water-dependent ecological systems; and flood control.

2 Analysis of Impacts to Water Resources

The Rio Grande passes through a number of climatic zones. The high-mountain headwater areas in the San Juan and Sangre de Cristo Mountains of Colorado and New Mexico receive an average of 40 inches of precipitation per year, mostly in the form of snow. Snowmelt from these headwater regions forms the majority of total annual flow in the Upper Rio Grande Basin, from the headwaters to Elephant Butte Reservoir. These flows peak in the late spring and early summer and diminish rapidly by mid-summer in the arid and semi-arid basin, but are supplemented by summer rains that are components of the North American Monsoon.

In the reach between Elephant Butte Dam and Fort Quitman, Texas, the supply comes primarily from storage reservoirs. Farther downstream, in the Lower Rio Grande Basin, flows are generated from local rainfall, inflows from Mexico, (especially the Rio Conchos, a major tributary for which Mexico has a delivery obligation to the United States), and reservoir releases. The climate of the Lower Rio Grande region in Texas ranges from arid subtropical where the river enters the state at El Paso to humid subtropical in the eastern portion of the region. Prevailing winds are southeasterly throughout the year, and the warm tropical air from the Gulf of Mexico produces hot, humid summers and mild, dry winters.

Key findings related to projected changes in temperature, precipitation, snowpack, and runoff in the Rio Grande Basin from the Chapter 2: Climate and Hydrology Assessment as well as completed Basin Studies and Impact Assessments are presented below.

- **Temperature** is projected to increase with the range of annual possibility widening through time. Climate projections suggest that temperatures throughout the Rio Grande are projected to increase by roughly 5 to 6 degrees Fahrenheit (°F) during the 21st century. Projected changes in climate and hydrology in the Rio Grande Basin have geographic and temporal variation, and the progression of change through time varies among the climate models used to develop the projections.
- **Precipitation** projections show that mean-annual precipitation is projected to decrease gradually during the 21st century. Climate projections suggest that annual precipitation in the Rio Grande Basin will remain quite variable over the next century, with a decrease of from 2.3 to 2.5 percent by 2050. Temperature and precipitation changes are expected to affect hydrology in various ways, including snowpack development.
- **Snowpack** is expected to diminish due to warming impacting the accumulation of snow during the cool season (late autumn through early spring) and the availability of snowmelt to sustain runoff to the Rio Grande during the warm season (late spring through early autumn). Snowpack

decreases are expected to be more substantial over the portions of the basin where baseline cool-season temperatures are generally closer to freezing thresholds and more sensitive to projected warming. This is particularly the case for the lower-lying areas of the basin.

- **Annual runoff**, at all locations, is projected to steadily decline through the 21st century, responding to slight decreases in precipitation in combination with warming across the region.
- **Seasonality of runoff** is also projected to change in the Upper Rio Grande. Warming would be expected to lead to more rainfall and runoff, rather than snowpack accumulation, during the winter. Projections show this seasonality change to be more pronounced in the portions of the basin currently with lower-elevation snowpack, and therefore to be larger in the Rio Chama than in the mainstem of the Rio Grande.
- **Changes in the magnitude of flood peaks** also are expected in the Upper Rio Grande, although there is less certainty in the analysis of these types of acute events than there is for changes in annual or seasonal runoff. These changes have implications for flood control and ecosystem management. However, there is a high degree of variability among model simulations, suggesting there is a high degree of uncertainty in this flood metric.
- **Low-flow periods** in the Rio Grande are projected to become more frequent due to climate change. Decreasing annual minimum runoff would be associated with reduced water availability to support diversions for agricultural, municipal, and industrial uses and adversely affects aquatic habitats through reduced wetted stream perimeters and availability of aquatic habitat and through increased water temperatures detrimental to temperature-sensitive aquatic organisms.
- **Availability of water supplies** will be impacted by changes in climate and precipitation within the Rio Grande Basin. Mean annual runoff is projected to decrease. Warmer conditions are expected to transition from snowfall to rainfall, producing more December-March runoff and less April-July runoff.

Changes in water supply and reservoir operations because of climate change may have subsequent effects to water allocations from year to year, which in turn could trigger changes in water use (e.g., crop types, cropping dates, or transfers among different uses). Key findings related to projected changes in demand are summarized below.

- The atmosphere's moisture-holding capacity increases when air temperature increases. Therefore, plant water consumption and surface water evaporation associated with agriculture, riparian consumption, and other outdoor water uses will increase in a warming climate. Net irrigation water demand is expected to increase by up to 19 percent in 2080 (Reclamation, 2015 [Irrigation]).

- Additionally, agricultural water demand could be locally affected by crop failures caused by changes in pests and diseases. Furthermore, these natural-system changes must be considered in combination with socioeconomic changes, including population growth, infrastructure, land use, technology changes, and human behavior.
- Agricultural irrigation is the predominant water use in the Rio Grande Basin and the western United States as a whole. The seasonal volume of agricultural water demand could increase if growing seasons become longer.
- In addition, reservoir evaporation at Elephant Butte Reservoir, the reservoir with the highest evaporative losses in the Upper Rio Grande Basin, is projected to increase by up to 10 percent (Reclamation, 2015 [Irrigation]) (Reclamation, 2015 [Santa Fe]). Changes in factors other than temperature, such as net radiation and wind speed, can also affect reservoir evaporation rates.
- Climate change also could result in increased demand for in-stream flow or reservoir releases to satisfy other system objectives, including ecosystem support, the needs of Threatened and Endangered species, hydropower generation, municipal and industrial water deliveries, river and reservoir navigation, and recreational uses.
- Diversions and consumptive use by industrial cooling facilities are predicted to increase, since these processes will function less efficiently with warmer air and water temperatures. The timing of these diversions and timing of diversions needed for the production of hydropower also could be a factor in ecosystem demands and navigation and recreational water uses. New or expanded industries, such as oil and gas development, are also expected to result in increased demands.
- In the Lower Rio Grande, the storage capacity of the system is expected to decrease gradually due to future sedimentation of the reservoirs. Prolonged drought and higher intensity rainfall events may result in increased sediment loading. The U.S. share of the firm annual yield of the Amistad-Falcon Reservoir System is expected to decrease from 1.01 million acre-feet per year (AFY) in the year 2010 to 979,200 AFY in the year 2060, a reduction of about 6 percent.

Climate projections indicate changing hydrology for the Rio Grande Basin, with potential effects on water management, human infrastructure, and ecosystems. Although there are uncertainties in the details, some general patterns are clear. The impacts of climate change on Reclamation's ability to satisfy these key management objectives are described in the following sections.

2.1 Water Delivery

The projected water supply imbalances will greatly reduce the reliability of deliveries to all users who depend on Rio Grande water. In the Upper Rio

Grande, supplies over the course of the 21st century are projected to decrease by about one-fourth in the Colorado portion of the basin, and by about one-third in the New Mexico portion. In the Lower Rio Grande, in addition to the projected supply imbalance of approximately 592,000 AFY due to population growth, there is projected be another approximately 86,000 AFY of supply imbalance due to climate change. The reliability of the Rio Grande to meet future needs in the study area is severely compromised by a growing gap between demand and availability and the potential for diminishing supplies due to climate change and competing uses in the Texas Rio Grande Regional Water Planning Area (also known as Region M).

The usable, manageable water supply is projected to decline. There will be a loss of winter snowpack, which will result in a decrease in water supply, as well as a decrease in the ability throughout the basin to store water for use during the summer irrigation season. There will also be an increase in all outside demands (including agricultural, riparian, and urban landscaping) due solely to the projected increases in temperature. The decrease in water supply will be exacerbated by the increase in demand; the gap between supply and demand will grow even if there are no decreases in average annual precipitation.

The growing imbalance between supply and demand is expected to lead to a greater reliance on non-renewable groundwater resources. Increased reliance on groundwater resources will lead to greater losses from the river into the groundwater system. Additionally, projections suggest a somewhat more reliable supply from the imported San Juan-Chama Project water than from native Rio Grande water. A greater reliability of the imported water supply than the native water supply, which has the most aboriginal and senior water rights holders and users, could have significant socio-economic implications. Finally, all of the changes in water supply that are projected to result from climate change would be compounded by the numerous other changes made to the landscape and to the water supply.

2.2 Hydropower

Climate changes that result in decreased reservoir inflow or disrupt traditional timing of inflows could adversely affect hydropower generation. Lower flows and lower reservoir levels associated with climate change are projected to lead to decreases in opportunities for hydropower generation. The projected decrease is substantial, from an initial generation within the Upper Rio Grande system of around 15 megawatts, the projected rate drops almost 50 percent to around 8 megawatts by the end of the 21st century, with most of the decrease coming during the months of May through September. Hydropower is generated in the Upper Rio Grande Basin at El Vado, Abiquiú, and Elephant Butte Dams. Hydropower generation at these facilities fluctuates both seasonally and annually. Because reservoirs in the Upper Rio Grande Basin typically generate power incidental to other reservoir releases, hydropower generation is vulnerable to both changes in annual runoff and seasonal runoff patterns.

2.3 Recreation at Reclamation and Other Federal Facilities

The Upper Rio Grande Impact Assessment identified a number of water-dependent recreational activities that are expected to be negatively affected by climatic changes that reduce water supply in the basin for recreational uses. These activities include:

- Fishing along the Conejos River and Rio Grande in Colorado, along the Rio Grande between Taos Junction Bridge and Embudo in New Mexico, and in Heron, El Vado, Abiquiú (USACE), Cochiti (USACE) Elephant Butte, and Caballo Reservoirs
- Camping along the Rio Grande in Colorado and New Mexico, including below Taos Junction Bridge, along the Rio Chama above Abiquiú Reservoir, and at Heron, El Vado, Abiquiú, Cochiti, and Elephant Butte Reservoirs
- White-water rafting along the Rio Grande above Embudo, and between El Vado and Abiquiú Reservoirs on the Rio Chama
- Flat-water boating in Heron, El Vado, Abiquiú, Cochiti, Elephant Butte and Caballo Reservoirs

Although decreases in available water many decrease the opportunities for water-related recreation at these facilities, demand for water-related recreation is anticipated to increase as the climate warms (Reclamation, 2013 [URGIA]).

The Texas Department of Tourism notes that in 2013, the total destination spending for tourism for Cameron, Hidalgo, Willacy, Webb, and Starr Counties was more than $28.8 billion (Texas Economic Development & Tourism, 2014). In addition, water-related recreational activities such as boating, sport fishing, birdwatching, and commercial fishing in the lower Laguna Madre and adjacent waters also influence the regional economy. Increased summer and winter temperatures may increase the popularity of these water-based activities. Moreover, reduced supplies, altered timing of flows, and increased variability will change the availability and nature of these recreational opportunities.

2.4 Flood Control Management

Floods are projected to grow in magnitude with climate change; thus, flood control operations are projected to be needed more often in the future, even as overall supplies decrease. In the Upper Rio Grande Impact Assessment, all climate simulations projected an increase in the month-to-month and inter-annual variability of flows over the course of the century. Abiquiú, Cochiti, and Jemez Reservoirs are the main flood control reservoirs on the system managed and operated by USACE. Table 7–1 indicates how often these primarily flood control reservoirs fill to within 99 percent of capacity, under both past and projected future conditions. The frequency, intensity, and duration of both droughts and floods are projected to increase.

Table 7–1. Instances of insufficient flood control capacity in the USACE Abiquiu, Cochiti, and Jemez reservoirs by major period—Upper Rio Grande Basin

Source: Reclamation 2013 (URGIA)

Reservoir	Simulation period (years)	Months with insufficient flood control capacity	Years with insufficient flood control capacity
Abiquiu	1950 – 1999 (49)	0 (0%)	0 (0%)
Cochiti		0 (0%)	0 (0%)
Jemez		0 (0%)	0 (0%)
Abiquiu	2000 – 2049 (50)	4 (0.7%)	4 (8 %)
Cochiti		172 (29%)	47 (94 %)
Jemez		6 (1%)	6 (12%)
Abiquiu	2050 – 2099 (50)	5 (0.8 %)	3 (6%)
Cochiti		110 (18%)	26 (52%)
Jemez		4 (0.7%)	4 (8 %)

2.5 Fish and Wildlife Habitat

Climate change is projected to reduce available water in the Upper Rio Grande system. This reduction in water is expected to make environmental flows in the river more difficult to maintain and reduce the shallow groundwater available to riparian vegetation. Both of these impacts have implications for the habitat of fish and wildlife in the Upper Rio Grande Basin riparian ecosystems.

Projected decreases in minimum runoff are projected to affect aquatic habitats adversely through reduced wetted stream perimeters and availability of aquatic habitat, and through increased water temperatures that are detrimental to temperature-sensitive aquatic organisms. However, there is a high degree of variability among model simulations, suggesting there is a high degree of uncertainty in this low-flow metric.

Figure 7–2. Along the Rio Grande, restoration of riverine habitat is commencing. Projects, such as the one shown here, near Santo Domingo Pueblo, NM, include removing invasive species like saltcedar and replanting native trees like cottonwood and willows.

In the Middle Rio Grande Valley Basin area, the U.S. Fish and Wildlife Service (USFWS) administers three national wildlife refuges, including the Valle de Oro National Wildlife Refuge, Sevilleta National Wildlife Refuse and Bosque del Apache National Wildlife Refuge. In addition, within the wildlife corridor of the Lower Rio Grande Valley Basin area, the U.S. Fish and Wildlife Service administers two individually unique national wildlife refuges, including Lower Rio Grande Valley National Wildlife Refuge and Santa Ana National Wildlife Refuge, and the Texas Parks and Wildlife Department administers multiple other wildlife management areas. The Lower Rio Grande Valley National Wildlife Refuge covers 91,000 acres in the region, with plans to expand to 132,000 acres. The Santa Ana National Wildlife Refuge covers 2,088 acres in the region. Two flyways for migratory birds and waterfowl converge in the Lower Rio Grande Basin in Texas, which is also home to the World Birding Center, a top worldwide destination for bird watching. According to a study by Texas A&M University, the economic contribution from wildlife watchers in the Rio Grande Valley is estimated to be approximately $463 million per year (Texas A&M University, 2012).

2.6 Endangered, Threatened, or Candidate Species

A delicate balance in water management in the basin is required to meet species and habitat needs, manage flows in the highly variable flow regime of the Rio Grande, and satisfy competing human water demands. In the mid-1990s, the Rio Grande silvery minnow and the southwestern willow flycatcher were designated as endangered under the ESA. Portions of the Rio Grande Basin are proposed to be designated as critical habitat for the western distinct population segment of the yellow-billed cuckoo (western yellow-billed cuckoo). Climate plays a key role in determining the distribution and biophysical characteristics of habitats and ecosystems that provide the ecological resources needed for life. In-stream flows and riparian systems that support endangered species and other fish and wildlife will be negatively affected by decreases in water supply and changes in the timing of flows. This will result in increases in demand due to open water evaporation and water use by plants (transpiration).

In the Lower Rio Grande Basin, imbalances have and will continue to have adverse impacts on the sensitive ecological communities that depend on the Rio Grande and associated riparian habitat. The Lower Rio Grande Valley National Wildlife Refuge and Wildlife Corridor support 69 rare, threatened, or endangered species. All of these sensitive resources will be subject to increased stressors in the future as water supplies become more constrained by increased demand and climate change.

2.7 Water Quality

More intense droughts and higher temperatures lead to a greater moisture deficit in the region's forests. Trees that are not getting enough water are more susceptible to beetle infestations, and infected weakened and dead trees are more susceptible to catastrophic wildfires. Thunderstorms tend to build over fire scars because heat builds up over the blackened ground, and intense thunderstorms on the fire scars lead to the washing of ash into rivers and reservoirs, and often to large debris and sediment flows. Ash in the rivers and reservoirs can lead to decreased oxygen in the water and cause fish kills. Fire-scar runoff can lead to debris and sediment accumulation in reservoirs and this accumulation can lead to less reservoir storage and flood protection for downstream human infrastructure, and so on.

A recent Environmental Protection Agency (EPA) study considered climate change impacts to water quality in the Rio Grande Basin above the confluence with the Rio Puerco (EPA, 2013). In the EPA analyses, absolute reductions in total nitrogen, phosphorous, and suspended solids loads reflect reductions in total flow volumes. However, projected reductions do not reflect how the concentration of these pollutants may change under future climate scenarios. Concentrations of these and other pollutants, and of salt, are expected to increase in the future under projected warming scenarios in response to increased evaporation rates for surface water and increased precipitation intensity that could wash a greater volume of pollutants from the land surface into the river (Reclamation, 2013 [URGIA]).

2.8 Flow- and Water-Dependent Ecological Resiliency

In the Upper Rio Grande Basin, the available water supply is low relative to the demand for water. Ecological and human systems within the basin already operate close to thresholds (points at which small changes could have larger-scale repercussions) related to available water supply. In the future, if projected water supplies decrease and demands increase, water availability thresholds may be crossed, and key systems may undergo regime shifts. It has been suggested (Williams et al., 2010) that forests in some parts of New Mexico, such as in the Jemez Mountains, may have crossed such a threshold. Moisture stress in the trees has led to bark beetle infestations and wildfire, and the forest may be undergoing a transition even now to a new ecosystem, with new structures, processes, and species (Benson et al., 2014).

Many parts of the Upper Rio Grande system are also near thresholds with respect to snowpack temperatures. In areas where the winter snowpack temperatures are already close to the freezing point, a small increase in temperature could lead quickly to a large decrease in the region's ability to store winter moisture in snow for use during the summer. It is possible that some systems in the basin have already crossed ecological thresholds.

3 Potential Adaptation Strategies to Address Vulnerabilities

Reclamation administers programs that include long-term planning focused on options to provide water management assistance to address complex water issues on local, regional, and statewide levels, as well as water conservation-related projects under WaterSMART (Sustain and Manage America's Resources for Tomorrow). Recent and on-going Reclamation studies with partners in the Rio Grande Basin include:

Santa Fe Basin Study: This small sub-watershed of the Upper Rio Grande completed a basin study focused on options to provide water management assistance to address complex water issues. Adaptation strategies identified for further development for the municipal supplies within this watershed include combinations of water conservation (decreases in the water used per person in the basin), direct reclaimed water reuse, aquifer storage and recovery through direct injection and indirect seepage through the bed of the Santa Fe River, and acquisition of additional water rights (Table 7–2).

Table 7–2. Adaptations to Projected Changes in Water Supply and Demand

Source: Reclamation, 2015 (Santa Fe)

Adaptation Strategy	Description	Infrastructure Components
Direct/Indirect Reclaimed Water Reuse	Use reclaimed water from the City of Santa Fe wastewater treatment plant to meet contract obligations; remaining reclaimed water for potable reuse or return flow credits for pumping	New conveyance for reclaimed water from wastewater treatment plant to existing Buckman Regional Water Treatment Facility and distribution system or new conveyance to the Rio Grande for return flow credits
Water Conservation	Reduce water use on a per person per day basis	None
Direct Injection for Aquifer Storage and Recovery	Inject treated water into the aquifer in wet and normal years for use in dry years	Construction and operation of injection well(s); withdrawal using existing wells and distribution system
Infiltration for Aquifer Storage and Recovery in the Santa Fe River	Maintain flow in the Santa Fe River to induce infiltration into the aquifer for use in dry years	Withdrawal using existing wells and distribution system.
Additional Surface Water Rights	Additional surface water would be diverted at the Buckman Direct Diversion and treated at the Buckman Regional Water Treatment Facility.	Existing diversion, conveyance, treatment, and distribution systems

The City and County of Santa Fe have received a Water SMART Title XVI Grant to begin development of their water reuse strategy. This project is currently scheduled for completion in May 2016. The water reuse feasibility study will evaluate alternatives for both potable and non-potable applications of reclaimed water to augment water supplies. The feasibility study will evaluate ways to use reclaimed wastewater in a more cost-effective and efficient manner and will consider both potable and non-potable alternatives to meet water demand while better balancing environmental conditions in the watershed.

The Santa Fe Basin Study also included a general assessment of adaptation strategies that could be pursued within the basin, or which are already underway within the basin, to provide adaptations related to energy, transportation, land use, watershed wildlife and ecology, food security, and quality of life (Reclamation, 2015 [Santa Fe]). Adaptation strategies reviewed in this process include:

- Incorporate urban agriculture in water and land-use planning
- Cultivate climate-appropriate crops
- Provide incentives and programs to reduce water use, especially during drought
- Increase solar panel installation to reflect heat and produce energy
- Encourage limited-term urban lease of agricultural water rights during drought
- Expand rainwater harvesting techniques
- Adjudicate Santa Fe Basin water rights
- Augment potable supplies with reclaimed wastewater
- Increase above- and below-ground water storage capacity
- Require pervious pavement where appropriate
- Improve soils and watershed resiliency
- Design or modify bridges and culverts to handle higher-intensity runoff events
- Manage and plan restoration holistically
- Improve ecosystem biodiversity
- Decentralize energy infrastructure
- Establish a climate change-targeted monitoring system to observe changes in key resources, such as snowpack or ecological indicators

Lower Rio Grande Basin Study: The Lower Rio Grande Basin Study evaluated four adaptation strategies to the projected gap between water supply and demand, which were analyzed at the 2060 levels of water supply/demand. The potential adaptation strategies identified in the study include:

- seawater desalination,
- brackish groundwater desalination,
- reuse, and
- fresh groundwater development.

Brackish groundwater desalination was identified as the strategy most suitable for preliminary engineering and affordability analysis. In the Lower Rio Grande Basin, brackish groundwater supplies are four times more plentiful than fresh groundwater supplies and have much fewer competing demands. To address expected shortages in the area, potential adaption strategies include the continued development of the range of strategies recommended by State of Texas Water Planning Region M (i.e., Lower Rio Grande Basin planning area) and adapted by the Texas State Water Plan. Figure 7–3 depicts the relative proportions of future water strategies contained in the current Region M Plan. Many of these strategies would increase the efficiency of the use of Rio Grande supplies when implemented by the water user groups and government entities at all levels.

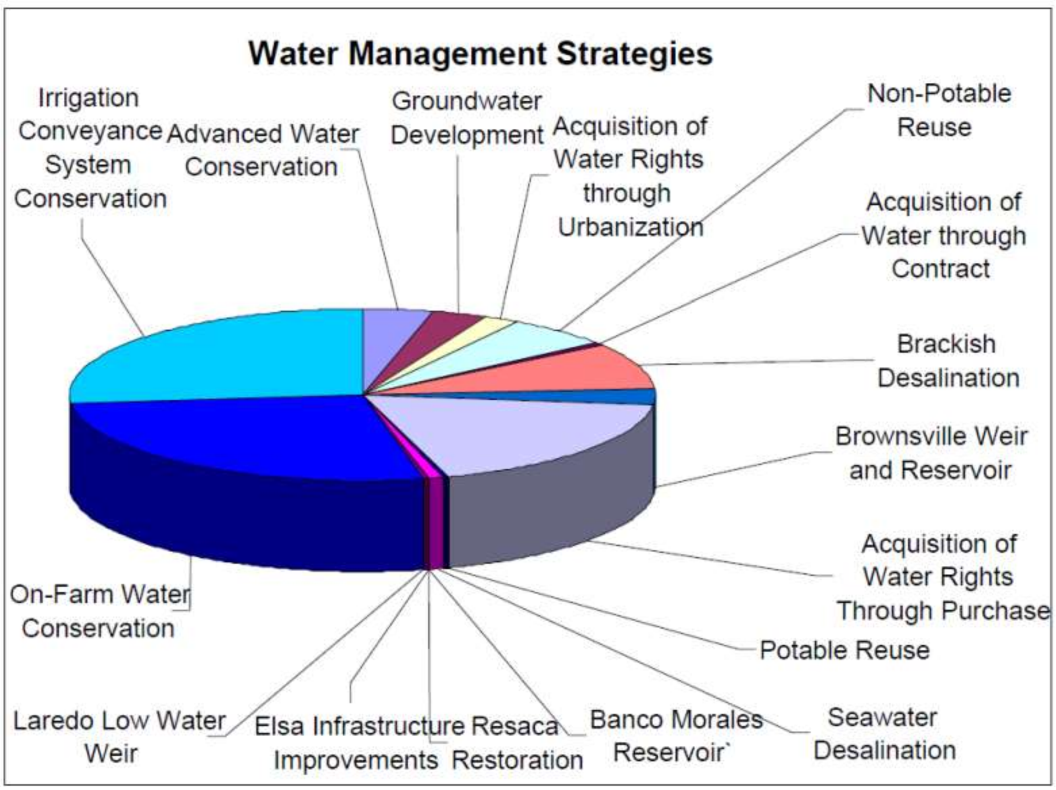

Figure 7–3. Relative portions of future water supply strategies for the Lower Rio Grande from the 2010 Region M Plan.
Source: Reclamation, 2013 (Lower Rio Grande)

4 Coordination Activities

Reclamation participates in coordinated adaptation activities that respond to climate stresses, as well as changes in land use, population growth, invasive species, and other stressors. These activities include managing limited water supplies for multi-purpose beneficial uses, implementing water conservation, optimizing hydropower production, planning for future operations and supporting rural water development. Specific examples of coordination in the Rio Grande Basin include:

- **United States Geological Survey (USGS) National Water Census: Upper Rio Grande Basin Focus Area Study** – Reclamation is participating in the USGS National Water Census Focus Area Study. This study seeks to improve estimates of selected water budget components to assess water availability and use in the Upper Rio Grande Basin of Colorado, New Mexico, and Texas. See below for additional details on this effort (Section 4.1).
- In the central New Mexico reach, Reclamation works closely with the **Middle Rio Grande Endangered Species Collaborative Program**, which includes 16 Federal, state, and local governmental entities, Indian tribes and Pueblos, and non-governmental organizations representing diverse interests, to support the water and habitat needs of Federally listed endangered species in the Middle Rio Grande.
- The **Lower Rio Grande Basin Study** was conducted in partnership with the Rio Grande Regional Water Authority (RGRWA), which includes 53 member entities comprising several irrigation districts and municipalities, along with the Texas Parks and Wildlife, Texas Water Development Board, and International Boundary and Water Commission. Reclamation also attended regularly scheduled stakeholder meetings sponsored by RGRWA and local planning groups. Local sponsors are currently exploring options to better understand aquifer characteristics that would enable them to make more-informed decisions about a specific location for one or more brackish desalination plants.

4.1 U.S. Geological Survey Upper Rio Grande Basin Focus Area Study

The USGS has initiated a series of studies, focused on selected large watersheds, where there is a desire on the part of watershed stakeholders to conduct a comprehensive technical assessment of water availability with the best available tools. These geographic Focus Area Studies contribute toward ongoing assessments of water availability in these watersheds and provide opportunities to test and improve approaches to water availability assessment.

In 2014, the Upper Rio Grande Basin of Colorado, New Mexico, Texas, and northern Mexico was chosen as one of three new focus area studies for the USGS National Water Census, with work to commence in Fiscal Year 2016. The conjunctive use of water in the Upper Rio Grande Basin takes place under a myriad of legal constraints, including the Rio Grande Compact (Compact) and several Federal water projects. The conveyance and use of surface water in the Upper Rio Grande Basin, which serves as the primary source of irrigation water for agriculture throughout the basin, as well as for municipal use by the major municipalities along the river corridor, and environmental and recreational uses, is achieved through an engineered system of reservoirs, diversions, and irrigation canals.

Changes in climate have reduced reservoir water supplies, leading to increased use of groundwater for irrigation, municipal and industrial uses, and for downstream delivery under the Compact. These new demands have significantly altered surface water/groundwater exchange along reaches of the Rio Grande. In particular, reaches that previously had groundwater discharge to the Rio Grande are now losing reaches. In addition, the operation of agricultural drains changes the distribution of surface-water/groundwater exchange, and has implications for river flows and river and riparian ecosystems. The Upper Rio Grande Basin Focus Area Study is being performed in collaboration with Reclamation, USACE, USFWS, and other resource management agencies in the study area to better understand and adapt to these changes. Products will include:

- basin-wide water-use data by category (such as municipal, agricultural, and domestic);
- field-verified evapotranspiration estimates;
- evaluation of streamflow trends and regional calibration of a national-scale watershed model;
- improved snowmelt modeling techniques;
- groundwater availability assessment, development of a basin-scale hydrogeological framework, and water-level surface and change maps; and
- estimates of surface water and groundwater exchange

In addition to work done as part of the National Water Census, and funded through WaterSMART, the USGS has undertaken a series of regional groundwater availability studies in the West to improve the understanding of groundwater availability in major aquifers across the country including work on the One-Water Hydrologic Flow Model to simulate a broad range of conjunctive-sufface and groundwater use issues. The Middle Rio Grande Basin Regional Groundwater Availability Study, a 6-year effort (1995-2001) was conducted to improve the understanding of the hydrology, geology, and land-surface characteristics of the Middle Rio Grande Basin in order to provide the scientific information needed for water resources management. This initial proof-of-concept study was conducted prior to the development of the groundwater availability assessment strategy outlined in Circular 1323 and served as a precursor to current regional groundwater availability studies.

4.2 U.S. Army Corps of Engineers Coordination

Within New Mexico, and in the Rio Grande Basin generally, climate change is anticipated to have profound effects on flood risk, water supply, ecosystem health, land cover, and other areas of national concern. The Upper Rio Grande facilities are operated by Reclamation and USACE, in cooperation with local water management agencies, including state agencies, municipalities, irrigation districts, and Native American tribes. Coordination among Federal partners around these regional issues is a significant need. In 2013, Reclamation released an Impact Assessment within the WaterSMART Basin Study Program West-wide Climate Risk Assessments to support the identification of impacts from climate change on the resources within the basin. This work has provided a basis for basin studies to evaluate potential adaptations to the projected changes in the Pecos and Santa Fe watersheds in New Mexico, and could provide a basis for a multi-stakeholder basin study to evaluate potential adaptation measures throughout the Upper Rio Grande. The USACE Albuquerque District has been working with Reclamation's Albuquerque Area Office on the Pecos Basin Study, currently scheduled for completion in 2016.

In addition, water operations staff from both agencies, as well as the Middle Rio Grande Conservancy District, USFWS, and other interested parties hold frequent, often daily, water-operations conference calls during the irrigation season to discuss what water is being called on, where it is being demanded, how it will move through the system, and how to maintain ESA target flows. On these calls, stakeholders discuss releases by Reclamation from Heron and El Vado Reservoirs in northern New Mexico and releases by USACE at Abiquiú and Cochiti Reservoirs to meet various flow needs in the Middle Rio Grande.

Finally, the USACE Albuquerque District has initiated the New Mexico Watershed Futures meeting series to improve regional coordination among Federal partners to better understand how New Mexico watersheds and water resources are likely to respond to climate change. This regular meeting among regional Federal staff is used to share information pertinent to climate change within New Mexico and adjacent regions, so that Federal agencies can better serve sponsors, stakeholders, and constituents. The meeting draws attendees from the regional offices of almost all Federal agencies to discuss climate modeling, impacts assessment and visualization, adaptation, resilience, and vulnerability. It is anticipated that these meetings will enable Federal agencies to better leverage their individual science and expertise to the benefit of all participants.

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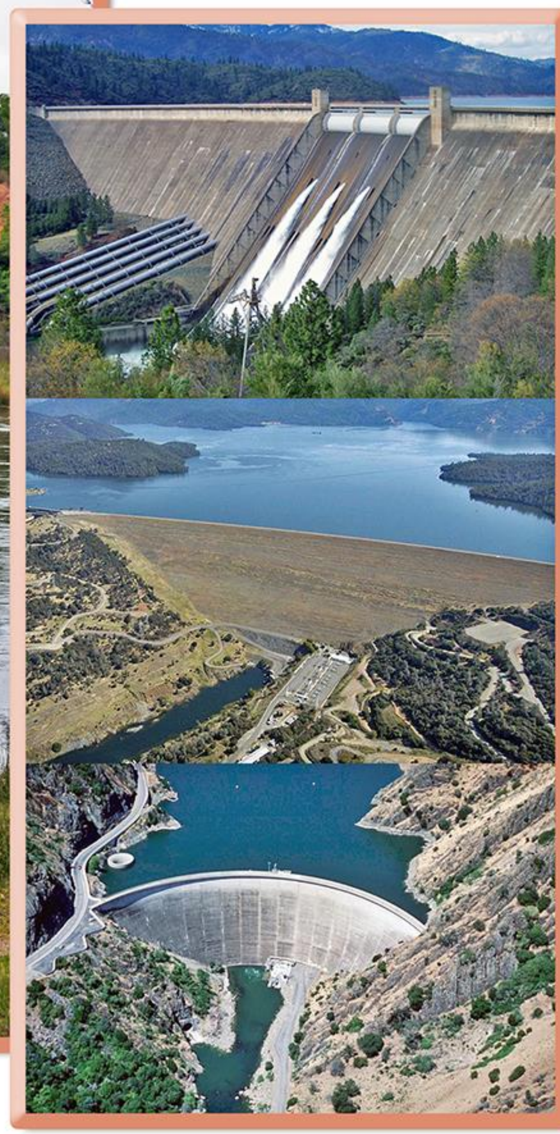
Managing Water in the West

Chapter 8: Sacramento and San Joaquin River Basins



U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011,[1] which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Sacramento, San Joaquin and Tulare Lake basins. This chapter is organized as follows:

- **Section 1:** Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

Sacramento and San Joaquin River Basins Setting

States: California

Major U.S. Cities: Redding, Sacramento, Stockton, San Jose, Fresno, Bakersfield

River Length: Sacramento 445 miles and San Joaquin 366 miles

River Basin Area: 60,000 square miles

Major River Uses: Municipal (310,000 acre-feet), Agricultural (5.4 million acre-feet), Hydropower (2.1 GW), Recreation, Flood Control, Navigation, and Fish and Wildlife

Notable Reclamation Facilities: Central Valley Project – 20 dams, 11 powerplants, and more than 500 miles of canals

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key studies referenced in this chapter include the Sacramento and San Joaquin Rivers Impact Assessment and Sacramento and San Joaquin River Basins Study. Additional information relevant to the Sacramento and San Joaquin River Basins, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

The Sacramento and San Joaquin Basins are located in the Central Valley of California. The Central Valley is divided into three hydrographic regions, the Sacramento, San Joaquin, and Tulare Lake Basins. The Sacramento River drains the northern portion of the Central Valley, and the San Joaquin River drains the central and southern portions. Both of these rivers flow into the Delta, which is the largest estuary on the West Coast of the United States. Typically, the Tulare Lake Basin is internally drained. However, in wetter years, flow from the Tulare Lake region reaches the San Joaquin River. This report discusses several other areas as well, because of their importance to Reclamation's water management in California. These areas include a part of the Trinity River watershed, from which water is exported to the Sacramento River, and a portion of the central California coast, where the San Felipe Division of Reclamation's Central Valley Project (CVP) is located. The entire area is shown in Figure 8–1.

The Sacramento River is the largest river in California, with a historical mean annual flow of about 18 million acre-feet (MAF). It drains an area of about 27,000 square miles. The San Joaquin River is the second largest river in California, with a mean annual flow of 6 MAF. The Tulare Lake basin in the southern Central Valley drains about 17,050 square miles and includes the Kings, Kaweah, Tule, and Kern Rivers, which have a combined mean annual runoff of approximately 2 MAF.

The CVP and California's State Water Project (SWP) are the two major water management projects in the Central Valley. Reclamation began construction of the CVP in 1933. Today it consists of 20 dams, 11 hydropower plants, and more than 500 miles of canals that serve many purposes. The CVP provides an average of 3.2 MAF of water per year to senior water rights holders under settlement/ stipulation agreements primarily for irrigation purposes, 2.2 MAF for CVP irrigation water contractors, and approximately 310 thousand acre-feet (TAF) for CVP urban water users. The agricultural water deliveries irrigate about 3 million acres of land in the Sacramento, San Joaquin, and Tulare Lake basins. The 1992 Central Valley Project Improvement Act (CVPIA) dedicated about 1.2 MAF of annual supplies for environmental purposes. The State of California built and operates the SWP, which provides up to about 3 MAF/year on average in water supplies from Lake Oroville on the Feather River to municipal and agricultural water users in the Central Valley, as well as in the central and southern coastal areas.

Figure 8–1. Map of the Sacramento and San Joaquin Basins study area.

Rapidly increasing populations, changes in land use, and environmental and other regulatory requirements have put pressures on the CVP that were not envisioned when the project was originally conceived and constructed. In addition, climatic changes that have already occurred in the 20th century are further affecting the ability of the CVP to deliver water and power reliably to its contractors, especially during periods of below-average precipitation. These problems have serious impacts on the people and economy of the Central Valley and California in general.

The Sacramento and San Joaquin Basins Study was performed to address multiple objectives including the assessment of potential impacts from changing climate and socioeconomic conditions on water supplies and demands, as well as effects on water temperature and quality, hydropower and greenhouse gas (GHG) emissions, urban and agricultural economics, and ecological resources in Central Valley basins throughout the 21st century. Employing a scenario-based approach, the partners and Reclamation, along with other stakeholders, worked collaboratively to evaluate risks and uncertainties to Central Valley water and related resources from potential changes in future climate, population, and land use. These vulnerabilities were used as a basis for identifying a variety of potential water management actions responding to these existing and future challenges. Through an objective screening process developed collaboratively with partners, stakeholders, and the public, adaptation strategies were characterized, evaluated, and combined to formulate a variety of robust portfolios addressing identified vulnerabilities posed by future climatic and socioeconomic uncertainties. Through this process, the Basins Study has developed new insights into 21st century vulnerabilities and relevant information useful to future efforts in formulating adaptive responses.

The Basins Study evaluated the effects of projected 21st century climate changes, along with assumptions about potential population increases and land use changes. In total, 18 socioeconomic-climate scenarios, including current socioeconomic conditions combined with historic climate, were employed to characterize future uncertainties. Temperatures and sea levels are projected to increase throughout the century, as described in more detail in subsequent sections. Variation in precipitation, both temporally and spatially, will likely occur, and snowpack will likely decline consistently over time, primarily due to warming. In addition, runoff and river flows will likely continue to exhibit temporal variability and earlier seasonal runoff, with little overall flow changes in the north and slight reductions in the south. In general, impacts to water-related resources include:

- increased river water temperatures and Sacramento-San Joaquin Delta salinity;
- decreased reservoir storage, CVP/SWP water exports and hydropower generation;
- decreased aquatic habitat quality and recreational opportunities; and
- increased opportunities for spring riparian flows and fall flood-control storage.

2 Analysis of Impacts to Water Resources

The analysis of impacts to water and related resources in California's Central Valley were quantified in the Basins Study using CalLite and other performance assessment models. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below.

- During the 20th century, periods of warming and cooling occurred in the Central Valley, as illustrated in Figure 8–2. Most important is the warming trend that has occurred since the late 1970s. This warming has also been observed in North American and global trends. Overall, basin average annual temperatures have increased by approximately 2 degrees Fahrenheit (°F) since the start of the last century.
- **Temperature** is projected to increase steadily during the century, with changes generally higher farther away from the coast, reflecting a continued ocean cooling influence.

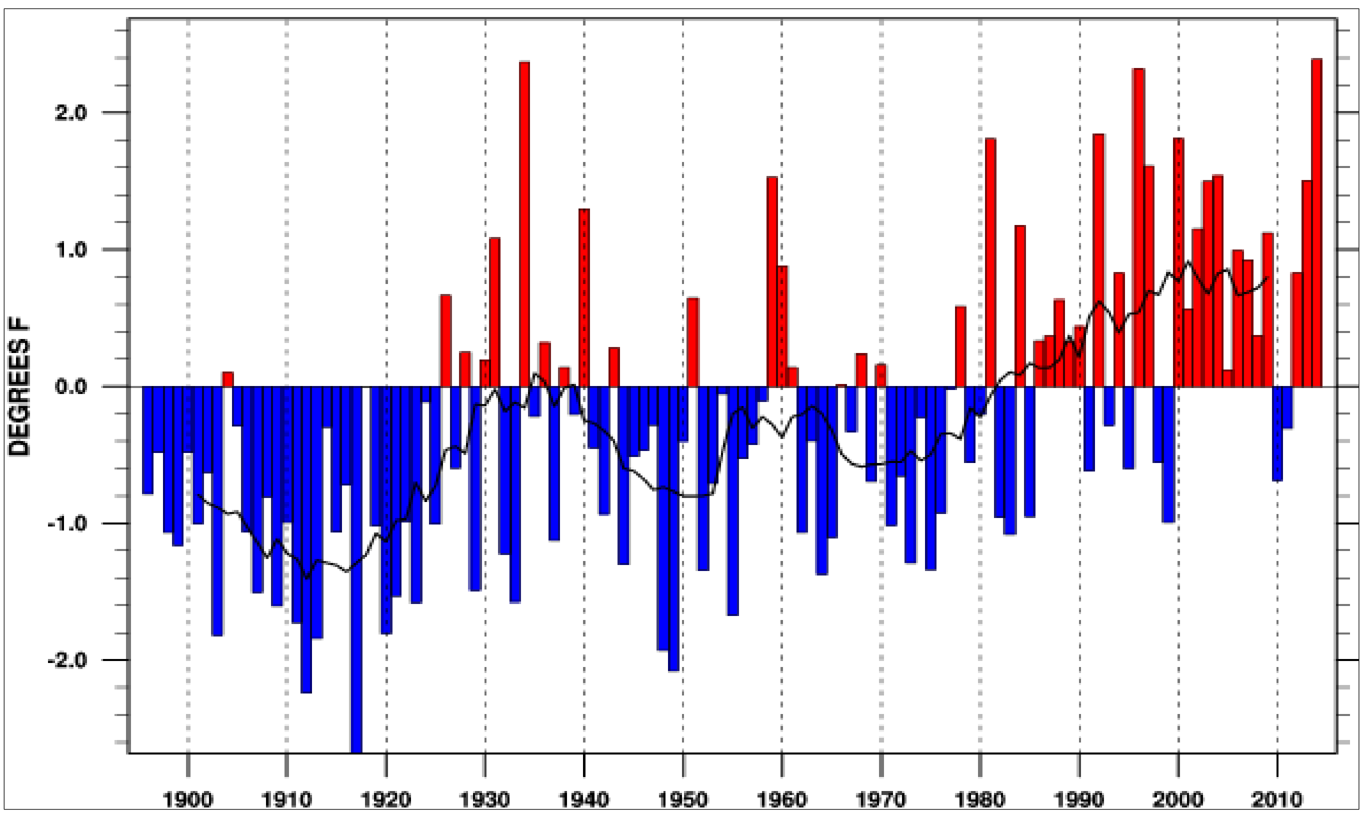

Figure 8–2. California statewide mean annual temperature departures (°F) from 1949–2005 base time period.

Solid line is 10-year moving average of departures. Source: Reclamation 2016 (SSJ Basins Study).

- Projections of future **precipitation** levels are much more uncertain than temperature projections. Trends in annual precipitation also are not as apparent as temperature trends. Regional difference indicate that it is more likely for the upper Sacramento Valley to experience the same or slightly greater precipitation, while the San Joaquin Valley is likely to experience little change. Drier conditions may be experienced in the Tulare Lake Basin.
- Mean annual **streamflow** follows a pattern similar to precipitation and is projected to remain relatively constant to decreasing slightly, especially in the south.
- Each basin is projected to exhibit a **shift in runoff** to more during late fall and winter and less during the spring. This projected shift occurs because higher temperatures during winter cause more precipitation to occur as rainfall, leading to increased runoff, less snowpack water storage, and earlier spring snowmelt runoff with reduced volume. This seasonal shift is greater in basins where the elevations of the historical snowpack areas are lower and therefore are more susceptible to warming-induced changes in precipitation from snow to rain.
- **Sea-level change** is also an important factor in assessing the effect of climate change on California's water resources, specifically on water quality in the Sacramento-San Joaquin Delta. Higher mean sea level (msl) is associated with increasing salinity in the Delta, which influences the suitability of its water for agricultural, urban, and environmental uses. Global and regional sea levels have been increasing steadily over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gauges along the California coast has risen at rate of about 6.7 to 7.9 inches (17 to 20 centimeters) per century (Cayan, et al., 2009). The National Research Council (NRC) recently completed a comprehensive assessment of sea-level-change projections for the Pacific Coast of North America (NRC, 2012). In the San Francisco Bay and Delta region, mean sea level rise is projected to accelerate during the century, reaching about 1 foot of sea level rise by mid-century and about 3 feet by the end of the century.

The Basins Study also considered a range of water demand projections. Key findings related to projected changes in demand are summarized below.

- Short-term variability and longer-term trends exist in agricultural water demands. The short-term demand variability is highly correlated with the variability in annual precipitation. In years of low precipitation, irrigated crop demands are higher, and in years of high precipitation, these demands decrease. Longer-term agricultural demands were projected to remain relatively constant in the early to mid-21st century and decline in the late-century period, due to multiple factors, including decreases in irrigated lands related to urban area expansion; effects of increasing atmospheric CO_2

concentrations of crop water use efficiency and increasing temperature effects on crop water stress responses.

- In contrast with agricultural demands, the urban demands do not show as large a degree of year-to-year variability because much of the urban demand is for indoor use, which is not sensitive to precipitation variability. Because the urban demands are driven largely by population, they tend to change steadily over time within each of the socioeconomic scenarios with the growth in population and expansion in commercial and industrial activities.
- Reservoir evaporation is an important component of the water budget in the management of water resources in the Central Valley.

Through the WaterSMART program, Reclamation recently completed a study of the potential impacts of climate change on reservoir evaporation (Reclamation, 2015). Results from this study indicate that peak evaporation occurs in August and September, while the minimum evaporation occurs between February and April. The change in annual evaporation and net evaporation from the baseline to the 2080 time period ranges from 7.6 to 14.7 percent (2.5 to 3.5 inches) for Lake Shasta, and 7.7 to 12.3 percent (4.3 to 5.0 inches) for Millerton Lake, respectively. Although other reservoirs were not included in the study, it is likely that these results represent a reasonable range of changes for other Central Valley terminal reservoirs.

The overall 21st century projected impacts were evaluated in the Basins Study assuming that current CVP/SWP operations, infrastructure, and regulatory requirements remain in effect throughout the 21st century without the implementation of any adaptation strategies. The results presented in this section were selected to correspond generally with resource categories identified in Section 9503 of the SECURE Water Act: delivery reliability, water quality, hydropower, flood control, recreational use, and ecological resources. Table 8–1 provides a generalized assessment of the category impacts. The impacts described in the table represent the overall 21st century averaged results for the entire Central Valley and Delta regions. However, considerable temporal and geographic variations exist. These important variations, as well as characteristics of selected performance metrics, are described in more detail in the Sacramento and San Joaquin Basins Study report (Reclamation, 2016 [SSJ Basins Study]).

Table 8–1. Summary of Projected Impacts by SECURE Water Act Resource Category
Source: Reclamation, 2016 (SSJ Basins Study).

SWA Resource Category	Change Metrics	Overall 21st Century Projected Impacts[1]	Contributing Factors
Water Deliveries	Unmet demands	Projected to increase by 2%	Projected earlier seasonal runoff would cause reservoirs to fill earlier, leading to the release of excess runoff and limiting overall storage capability and reducing water supply
	End-of-September reservoir storage	Projected to decrease by 9%	
	CVP/SWP Delta exports	Projected to decrease by 3%	Sea level rise and associated increased salinity would result in more water needed for Delta outflow standards with less water available to deliver to water contractors
Water Quality	Delta salinity	Projected to increase by 20%[2]	Projected sea level rise would contribute to increased salinity in the Delta
	End-of-May storage	Projected to decrease by 9%	Climate warming and reduced reservoir storage would contribute to increased river water temperatures
Fish and Wildlife Habitats	Pelagic species' habitats	Projected to decrease by 33%	Increasing Delta salinity would contribute to declining pelagic habitat quality
	Food web productivity	Projected to decrease by 9%	Reduced Delta flows in summer would contribute to declining food web productivity
ESA Species	Adult salmonid migration	Projected to increase by 7%	Reduced Delta OMR flows in fall would contribute to increasing salmonid migration
	Cold-water pool	Projected to decrease by 19%	Reduced reservoir storage would contribute to reduced cold-water pool
Flow-dependent Ecological Resiliency	Floodplain processes	Projected to decrease by 1%	Reduced reservoir storage and spring runoff due to decreasing snowpack would contribute reduced river flows
Hydropower	Net power generation[3]	Projected to increase by 1%	Projected decreased in CVP reservoir storage would contribute to reduced generation but projected decreased CVP water supply would result in reduced power use for pumping and conveyance
Recreation	Reservoir surface area	Projected to decrease by 17%[4]	Projected lower reservoir levels would impact the surface area available for recreation
Flood Control	Reservoir storage below flood-control pool	Projected to increase by 11%[4]	Increased early season runoff would contribute to releases earlier in the flood control period providing more flood storage.

[1]Unless otherwise noted, all changes represent differences between the projected central tendency climate with projected current trend changes in socioeconomic conditions and the Reference (historical) climate with projected current trend socioeconomics. See Reclamation 2016 for details of socioeconomic-climate scenarios.

[2]Representative change salinity in the western Delta region.

[3]Net generation is the difference between CVP hydropower production and use of CVP hydropower by Delta export pumps and water delivery infrastructure.

[4]Assumes Lake Shasta as representative of Central Valley changes

3 Potential Adaptation Strategies to Address Vulnerabilities

Based on the analysis of impacts, the Basins Study partners and stakeholders developed an array of water management actions targeted at addressing one or more categories of water and related resource risks. A public workshop was conducted to receive input on the types of actions that should be considered. In addition, recognizing the significant previous efforts to develop adaptation strategies, the Basins Study partners reviewed Reclamation's drought-project response list, the California Water Plan Update water management actions, and the California Water Action Plan. Preliminary screening of the large array of potential actions was performed to identify actions that could address impacts to multiple resource categories. The general approach for the development of the adaptation strategies from the Basins Study is summarized below:

- **Solicit input –** In order to examine a broad range of potential actions, the Study team participants, interested stakeholders, and the public were asked to submit actions.
- **Organize actions –** The responses were reviewed and organized into seven broad functional objectives: (1) increase water supply, (2) reduce water demand, (3) improve operational efficiency, (4) improve resource stewardship, (5) improve institutional flexibility, (6) improve data and management, and (7) other.
- **Water management actions** – From these functional groupings, individual water management actions were developed.
- **Characterize actions –** Each action was characterized using a set of both quantitative criteria including potential yield, timing of implementation, annualized cost per acre-foot, energy use, and qualitative criteria such as technical feasibility and implementation risk.
- **Develop portfolios –** No single action is likely to be adequate to meet all of the future demands of the Basin resources. Therefore, combinations of actions (portfolios) were developed to address identified risks to the reliability of Central Valley water management systems. As such, portfolios representing potential strategies to address future supply and demand imbalances were developed from the representative actions and action characterization results. Portfolios were developed by selecting certain action characteristics based on the particular strategy (e.g., remove actions that rated low for implementation risk or technical feasibility.)

Section 3.1 describes the characterized water management actions, the exploratory portfolios, and the performance of these portfolios in addressing the key resource categories mandated in the Secure Water Act Section 9503(c).

3.1 Sacramento and San Joaquin Basins Study Potential Future Actions

The Basins Study considered a wide range of water management actions grouped into six broad categories. Examples of each are listed below:

- **Reduce water demand:** Increase agricultural, municipal and industrial water use efficiency
- **Increase water supply:** Increase regional wastewater reuse, increase ocean desalination, develop local supplies (e.g., rainwater harvesting)
- **Improve operational efficiency:** Conjunctive groundwater management, enhance groundwater recharge, improve salinity and nutrient management, improve river temperature management, increase surface storage
- **Improve resource stewardship:** Improve forest health, particularly in the higher-elevation forested watersheds
- **Improve institutional flexibility:** Improve regulatory flexibility and adaptability to improve water system efficiency
- **Improve data and management:** Improve data management and the use of data to support near-term and long-term decision-making

Within these broad categories, 20 representative actions were evaluated for 11 different criteria related to economic, policy, technical, and environmental characteristics as shown on Figure 8–3. In addition, the actions were also sorted based on the cost, quantity of yield or water provided, and timing (Figure 8–4).

Based on the results of the characterization and development of adaptation actions, various actions were combined into portfolios representing different potential adaptation strategies. The Basins Study developed seven exploratory adaptation portfolios to reflect different strategies for selecting and combining actions to address Central Valley imbalances between water supply and water demand as well as other system vulnerabilities. Each portfolio consists of a unique combination of water management actions included to address potential vulnerabilities existing under future socioeconomic-climate conditions. The following seven portfolios were analyzed to assess the effects of each strategy on resolving vulnerabilities to Basin resources:

- **Least Cost:**[2] Least Cost includes water management actions that either improved system operations at minimal cost per acre-foot of yield or actions that provide additional yield efficiently. These actions include improvements in both urban and agricultural water use efficiency, increased surface and groundwater storage and Delta conveyance.

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[2] The Least Cost portfolio represents the least amount of cost per unit of increased supply or reduced demand.

Action Name	Cost	Quantity of Yield	Timing	Technical Feasibility	Permitting	Legal	Policy	Implementation Risk	Long-term Viability Risk	Operational Flexibility	Energy Needs
Agricultural Water Use Efficiency	A	A	B	B	B	B	A	B	C	E	A
M&I Water Use Efficiency	A	A	C	A	A	A	B	B	B	B	A
M&I Water Reuse	B	A	C	B	C	C	B	B	C	D	D
Ocean Desalination	D	B	C	C	C	C	C	B	C	D	D
Precipitation Enhancement	A	C	A	C	B	C	C	B	D	B	C
Rainwater Harvesting	E	D	A	A	A	A	B	A	B	A	A
Conjunctive Management	C	B	C	B	C	C	A	B	C	D	B
Enhance Groundwater Recharge	C	B	C	B	B	B	A	B	B	E	A
Improve Tributary and Delta Environmental Flows	A	E	B	A	C	B	D	B	B	B	C
Improve System Conveyance	E	C	C	B	D	C	C	C	C	D	D
Improve CVP/SWP Operations	A	D	B	A	D	C	C	B	B	B	C
Improve Regional/Local Conveyance	A	D	B	A	B	B	B	A	B	C	C
Increase Sacramento Valley Surface Storage	A	C	C	B	D	C	B	C	B	D	C
Increase San Joaquin Valley Surface Storage	C	D	C	B	D	C	B	C	B	D	C
Increase Export Area Surface Storage	B	C	C	B	D	C	B	C	B	D	C
Increase Upper Watershed Surface Storage	B	D	C	B	D	C	B	C	B	D	B
Improve Forest Health	A	B	C	D	C	C	E	D	D	E	C
Improve Regulatory Flexibility and Adaptability	A	D	B	A	D	D	B	C	B	A	A
Improve River Temperature Management	E	E	B	A	B	C	B	C	D	C	C
Improve Salinity and Nutrient Management	E	E	D	B	C	D	B	D	C	D	B

Figure 8–3. Water management actions and evaluation criteria ratings.

Actions with an A rating (dark green) are most favorable and actions with the E rating (dark red) are least favorable for each of the criteria. Source: Reclamation, 2016 [SSJ Basins Study]).

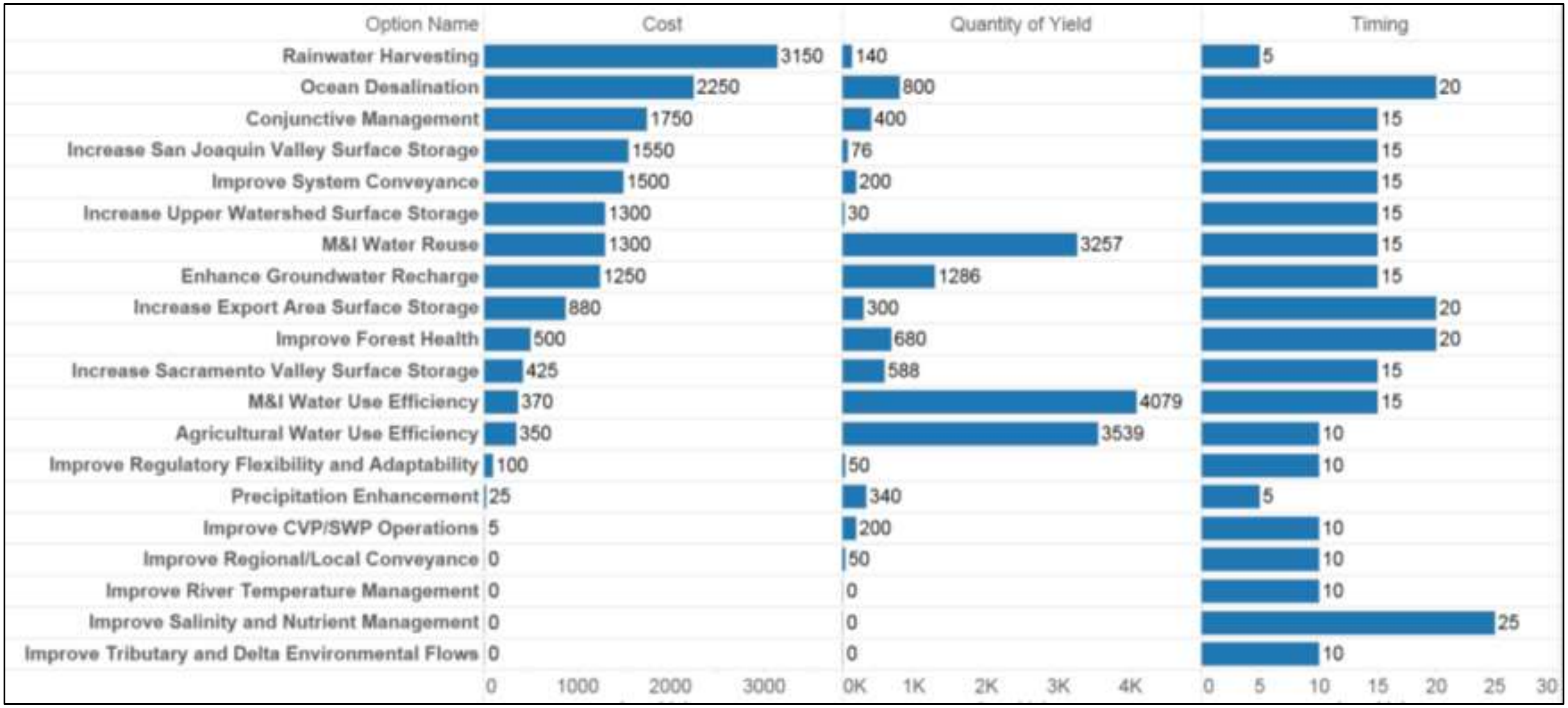


Figure 8–4. Estimated median cost, quantity, and timing for each of the actions.

Costs are in dollars per acre-foot per year ($/AFY) of supply improvement or demand reduction. Quantity of new supply or demand reduction yield is in thousand acre-feet per year (TAFY), and timing for implementation is in years. Source: Reclamation, 2016 [SSJ Basins Study]).

- **Regional Self-Reliance:** Regional Self-Reliance is intended to include regional actions that either reduce demand or increase supply at a regional level without affecting CVP and SWP project operations. These actions include improvements in urban and agricultural water use efficiency, conjunctive use with increased groundwater recharge.
- **Healthy Headwaters and Tributaries:** Healthy Headwaters and Tributaries include adaptation actions that improve environmental and water quality in the Central Valley and upper watershed areas. These actions include additional spring releases that resemble unimpaired runoff and additional Delta outflows in the fall to reduce salinity.
- **Delta Conveyance and Restoration:** Delta Conveyance and Restoration is designed to improve Delta export reliability by developing a new Delta conveyance facility in combination with improved environmental actions in the Delta. These actions include both alternative Delta conveyance combined with water management actions needed for Delta restoration objectives.
- **Expanded Water Storage and Groundwater:** Expanded Water Storage and Groundwater seeks to improve water supply reliability through implementing new surface water storage and groundwater management actions. These actions include increased surface storage in higher elevations of watersheds, expanded reservoir storage in the Sacramento and San Joaquin Basins, and conjunctive use with increased groundwater recharge.
- **Flexible System Operations and Management:** Flexible System Operations and Management includes actions designed to improve system performance without constructing new facilities or expanding the size of existing facilities. These actions include conjunctive use management with increased groundwater recharge.
- **Water Action Plan:** Water Action Plan includes all water management actions that were included in the California Water Action Plan (State of California, 2014). Essentially, this portfolio includes all the water management actions included in the other portfolios.

These seven distinct strategies and dynamic portfolios represent a range of different approaches for resolving future supply and demand imbalances and are not intended to represent all possible groupings. Based on the assessment of the effects of the strategy (see Figure 8–5), key portfolio findings include:

- Central Valley unmet demand was reduced by all portfolios. The Water Action Plan, Least Cost, and Regional Self-Reliance portfolios reduce the unmet demands by more than half but do not fully eliminate the unmet demands in the San Joaquin and Tulare Lake Basins.

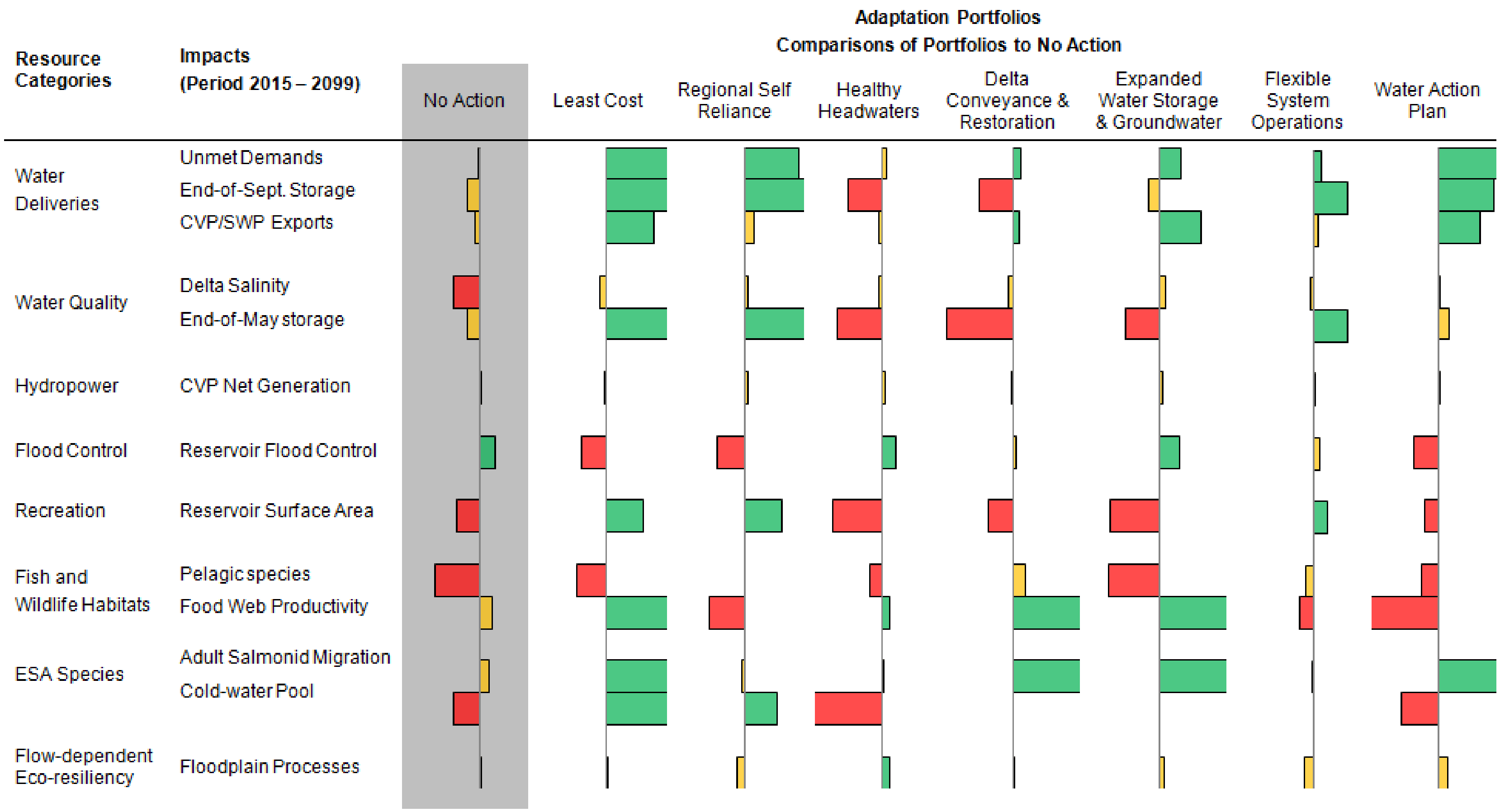


Figure 8–5. Summary comparisons of adaptation portfolios to the No Action Alternative (impacts of climate change without adaptation).

Green = Performance improved more than 10%, Yellow = Performance is within –10% to +10%, Red = Performance declined more than 10%. Source: Reclamation, 2016 [SSJ Basins Study]).

- Delta exports were substantially increased in the Least Cost, Expanded Water Storage, and Water Action Plan portfolios. Healthy Headwaters and Tributaries portfolio results in lower exports as higher spring river flows increased Delta outflow. The Regional Self-Reliance portfolio results in reduced exports by reducing south-of-the-Delta demands.
- Portfolios that include demand reductions through agricultural and M&I water use efficiency actions such as the Least Cost, Regional Self-Reliance, Water Action Plan, and Flexible System Operations increase reservoir storage conditions relative to No Action.
- The Healthy Headwaters and Tributaries, Regional Self-Reliance, and Water Action Plan portfolios show improvements in Delta salinity and habitat conditions, partially attenuating the impacts of future climate and sea level changes.

This Basins Study did not intend to result in the selection of a particular portfolio or any one action from any portfolio. Rather, the objective of the portfolio analysis was to demonstrate the effectiveness of different strategies at resolving future supply and demand imbalances and other system vulnerabilities. Section 3.2 describes completed or ongoing adaptation in the basin.

3.2 Current and Planned Adaptation Actions

The Basins Study explored a wide range of potential adaptation strategies to evaluate opportunities to address future climate and socioeconomic related impacts to water and related resources. As discussed above, current demands for water supplies across these resource categories have already exceeded the capacity of the existing water management system to meet all the potential needs. Consequently, Reclamation, the State of California, and many other stakeholder organizations have been seeking solutions addressing these issues for some time.

The Basins Study added valuable new information to these efforts by considering a longer-term perspective and by including uncertainties in both climate and socioeconomics to provide water managers with a more comprehensive understanding of potential future challenges. The development of the Basins Study adaptation strategies included assessments of many of these activities, programs, and proposals addressing water management concerns throughout the Central Valley and adjacent regions. Some of the current and future planned adaptation strategies similar to those considered in the Basins Study include:

- Reduce Water Demand: Through CalFED Water Conservation Grants and WaterSMART Grants, Reclamation continues to make cost-shared funding available to agricultural and municipal water management agencies in the basin, resulting in improvements in management and water use efficiency.
- Increase Water Supply: Through the CalFED Bay Delta Storage Projects investigations, Reclamation has recently completed planning documents addressing needed improvements in water supply reliability and water

quality (temperature and salinity) by increasing water storage in Sacramento and San Joaquin Basins. These plans are currently being reviewed prior to submission to Congress.

- Improve Operating Efficiency: Through the California Water Fix program (i.e., the Bay Delta Conservation Plan) Reclamation is coordinating with the State of California to develop a comprehensive plan addressing risks to California's current water management system, environment, and economy. Climate change adaptations, including new Delta water conveyance infrastructure, are included to address key vulnerabilities to water supply and the Delta environment from potential changes in climate and rising sea levels. The plan is currently considering public comments.

4 Coordination Activities

The challenges posed to water and related resources by changing climate and socioeconomic conditions throughout the 21st century highlight the need for Federal, state, and local agency partnerships to address the array of complex, interrelated impacts. In the Central Valley, multiagency coordination of water management already supports many important activities. The close coordination between Reclamation and California Department of Water Resources (DWR) in the operation of the CVP and SWP has been ongoing for decades. Management activities also involve other agencies such as U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife, and the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA Fisheries) in the coordination of reservoir releases for endangered species in rivers and the Delta. Similar coordination between agencies is also occurring in the implementation of the CVPIA and the Trinity and San Joaquin River Restoration Programs.

In addition to the new partnerships formed through the Sacramento and San Joaquin Basins Study and other WaterSMART activities, the Mid-Pacific Region has been collaborating closely with DWR in activities related to the California Water Plan. This coordination has led to the development of both a better understanding of the potential challenges of climate change and improved decision support methods and tools to formulate and evaluate adaptation strategies effectively. Other collaborative adaptation planning activities involving multiple Federal, state, and local partners include the Bay Delta Conservation Plan, CalFED storage project-feasibility investigations, and the California Landscape Conservation Cooperative. By building on this existing collaboration, Reclamation and partners have a strong foundation for addressing future challenges to the management of Central Valley water resources.

4.1 Ongoing Efforts to Enhance System Reliability

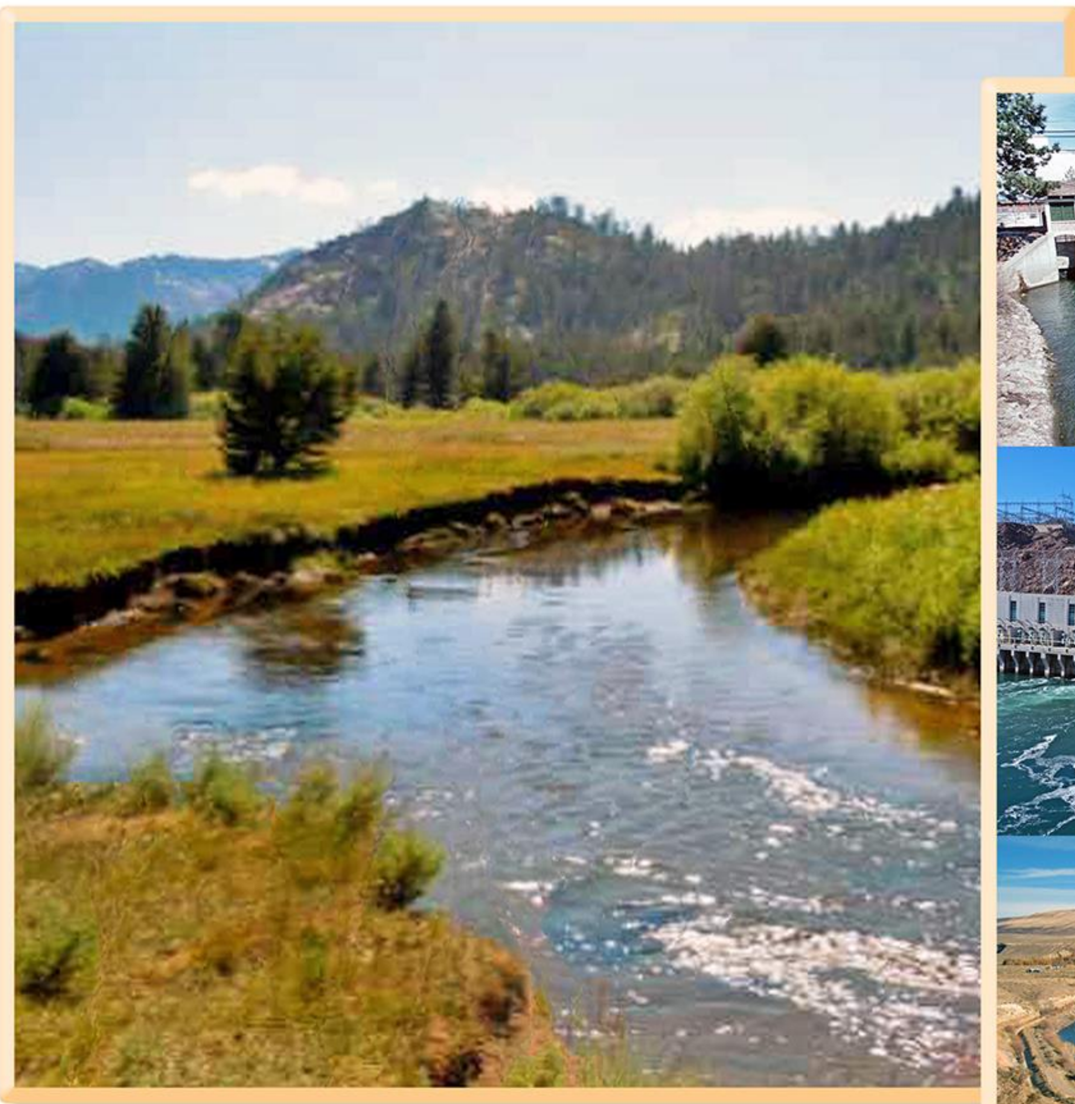
A variety of activities to address existing and projected system vulnerabilities to future climate uncertainties in the Central Valley region is currently ongoing or anticipated in the near future. As mentioned above, through CalFED and Reclamation's WaterSMART program, grants to water districts have been made to increase water use efficiency and water recycling. The projects range from canal lining to water conservation rebates to groundwater recharge. In partnership with the State of California, a WaterSMART Climate Analysis Tools research grant was also made to the University of Arizona to improve the knowledge of basin hydrology through an investigation of ancient tree ring growth and chronology. The results from this paleo-hydrology study were included in the Basins Study (Reclamation, 2016 [SSJ Basins Study]).

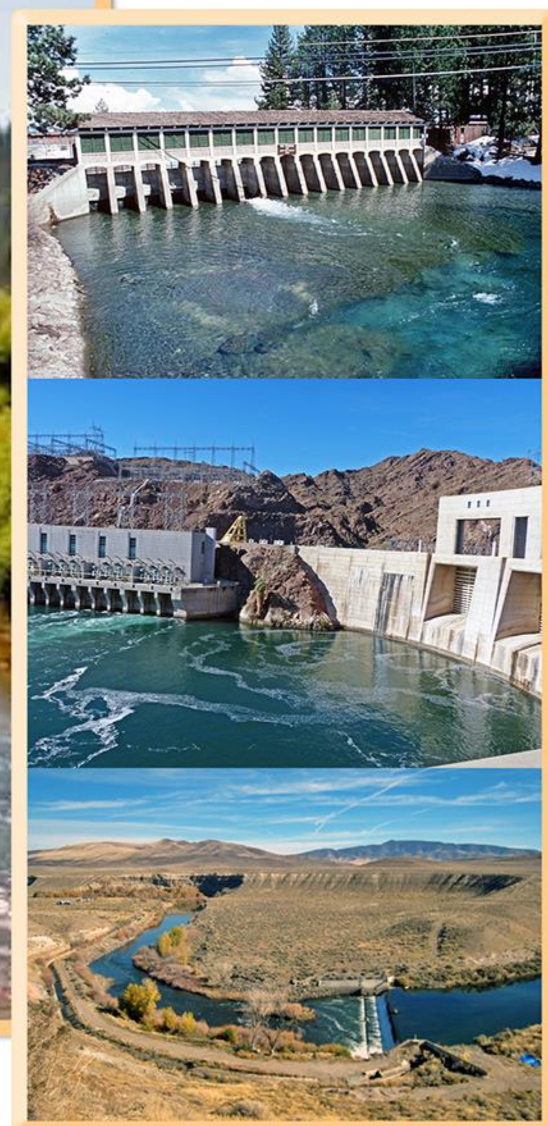
Reclamation's Mid-Pacific Region has also been participating in the California Landscape Conservation Cooperative. In collaboration with the USFWS and other Federal, State, and stakeholder partners, the California Landscape Conservation Cooperative has developed a comprehensive framework identifying knowledge gaps and research priorities and has awarded funds to 15 projects relevant to climate impacts and adaptation planning for species and habitats in the Central Valley and surrounding regions. Since 2011, the funding for these projects has totaled more than $2.6 million.

RECLAMATION

Managing Water in the West

Chapter 9: Truckee River Basin





U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011[1], which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

This chapter provides a basin-specific summary for the Truckee River Basin. This chapter is organized as follows:

- **Section 1**: Description of the river basin setting,
- **Section 2**: Overview of the implications for various water and environmental resources,
- **Section 3**: Potential adaptation strategies considered to address basin water supply and demand imbalances, and
- **Section 4**: Coordination activities within the basin to build climate resilience.

Truckee River Basin Setting
States: California and Nevada
Major U.S. Cities: South Lake Tahoe, Reno, Sparks
River Length: 119 miles
River Basin Area: 3,000 square miles
Major River Uses: Municipal (400,000 people), Agricultural (55,000 acres of land), Hydropower (4 megawatts), Recreation, Flood Control, Navigation, and Fish and Wildlife
Notable Reclamation Facilities: Lake Tahoe Dam, Boca Dam, Stampede Dam, and Marble Bluff Dam

This chapter provides updated information from Reclamation studies completed or initiated in the basin over the past five years. The key study referenced in this chapter is the Truckee River Basin Study, conducted through a partnership of the Bureau of Reclamation, Placer County Water Resources Agency, Tahoe Regional Planning Agency, Truckee Meadows Water Authority, and the Truckee River Flood Management Authority to identify strategies to address current and future water demands in the basin. Additional information relevant to the Truckee River Basin, including the latest climate and hydrology projections for the basin, is included in Chapter 2: Hydrology and Climate Assessment.

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[1] The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf.

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1 Basin Setting

From its origins in the high Sierra Nevada Mountains at elevations over 10,000 feet, the Truckee River is a vital source of water for more than 400,000 people in both California and Nevada. The Upper Truckee River originates in California with headwaters in the mountains near Carson Pass at Highway 88 where it flows northerly until it reaches Lake Tahoe (Figure 9–1). The mainstem of the Truckee River originates at the outlet of Lake Tahoe, and runs northeast to its terminus at Pyramid Lake, located approximately 50 miles (119 river miles) away in the desert of northwestern Nevada.

The Truckee River Basin includes the Lake Tahoe, Martis Valley, and Truckee Meadows sub-basins. The Truckee River Basin encompasses an area of approximately 3,060 square miles (1,958,400 acres) in the States of California and Nevada. Of the basin's total area, approximately 760 square miles (486,400 acres), or almost 25 percent of the basin is located within the State of California, where most of the precipitation occurs and where Truckee's reservoirs are located. The remaining 2,300 square miles (1,472,000 acres), or 75 percent of the basin, is located within the State of Nevada, where the most demand exists for Truckee water. This geographic imbalance between the basin's water supplies and water demands has led to disputes surrounding the rights to, and the uses of water resources within the Truckee River Basin.

The Truckee River Basin experiences wide fluctuations in annual runoff volumes ranging from high water year averages of about 2 million acre-feet to about 115,000 acre-feet in low water years. In an average water year, total runoff volume is about 580,000 acre-feet. Most water storage capacity in the Truckee River Basin is in Federal reservoirs, including Lake Tahoe, which is the largest, Prosser Creek, Stampede, Boca, and Martis Creek. Two non-Federal managed reservoirs at Donner and Independence Lakes are natural lakes where small dams have been constructed to increase storage capacity. All of these reservoirs are entirely in California except for Lake Tahoe, which is partly in California and partly in Nevada. Lake Tahoe has an average annual usable storage capacity of 557,100 acre-feet, while the other four Federal reservoirs combined store approximately 237,300 acre-feet in an average year (Table 9–1). The collective operation of these reservoirs provides the vast majority of water for the Truckee River, and they have a combined total capacity of about 1 million acre-feet.

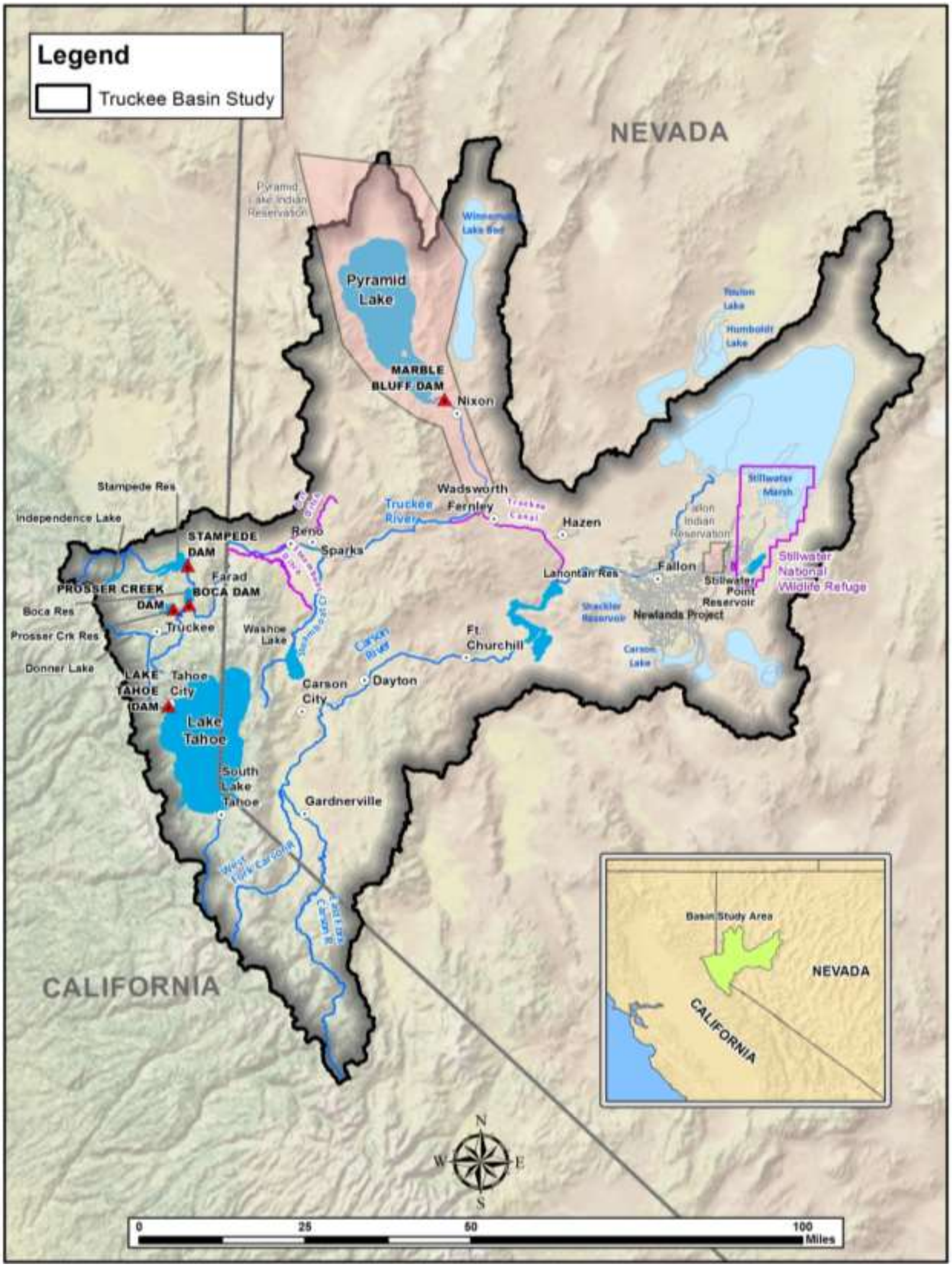

Figure 9–1. Truckee River Basin and the adjacent Carson River Basin.

Table 9–1. Truckee River Basin Storage Locations

Water Body	Elevation (feet)	Designed Maximum Storage Capacity (acre-feet)
California		
Lake Tahoe	6,229	744,600
Donner	5,936	9,500
Martis Creek Lake	5,838	20,000
Prosser Creek Reservoir	5,741	29,800
Independence Lake	6,949	17,500
Stampede Reservoir	5,949	226,500
Boca Reservoir	5,754	41,100
Lahontan Reservoir	4,164	313,000
Nevada		
Pyramid Lake	3,795	NA

Year-to-year variations in precipitation cause wide swings in river flows, leading to potential imbalances. For example, in very wet years, major floods have occurred along the lower Truckee, usually resulting in widespread property damage in the Reno-Sparks metropolitan area. The 1997 New Year's Day Flood, the flood of record, resulted in over $450 million (U.S. Army Corps of Engineers [USACE] 2013) in damages in six Nevada counties. Climate-related changes are predicted, which include increases in storm intensity and duration. These conditions make it harder to predict the potential frequency, duration, intensity and extent of floods along the Truckee River. Currently, the Truckee Meadows Water Authority (i.e., the Reno-Sparks metropolitan area) is working with USACE to design and build a flood management project to reduce damages from a potential 117-year flood. This project is estimated to cost approximately $1.6 billion dollars, and will be designed with climatic variations in mind.

Drought is also a problem. With a total storage capacity of less than two times the average inflow volumes, the ability of the Truckee reservoir system to provide adequate storage over a protracted drought is problematic. Recent studies indicate that potential climate changes in the Truckee watershed are projected to result in droughts of greater severity and duration. Paleo-records indicate that Lake Tahoe has regularly experienced extremely low water periods, suggesting that similar decades-long droughts may recur in the future. When droughts occur, the resulting low river water levels also adversely affect agriculture, fresh-water-migrating fish, resident fish, and domestic water supplies.

1.1 Truckee River Basin Study Overview

The Truckee River Basin provides a compelling demonstration of how changes in demands and/or a region's climate will influence both natural and human water uses. Packed into this relatively small basin are every form of water use and every type of water user that exist in the Western United States, including tribal lands and trusts; irrigated agriculture; municipalities and industry; mining and geothermal energy exploration; Federal water projects; hydropower generation; lake, stream, and reservoir recreation; and restoration efforts for diminished wetlands and endangered aquatic species. Correspondingly, the diversity of water uses within its borders has made the basin home to every type of water resources conflict.

Despite this natural conflict, communities in the basin have actively managed and adapted to water scarcity for as long as the arid region has been inhabited. Management activities include a number of massive water resource facilities, built through both Federal and local investment over the past century-and-a-half. In parallel with the construction of these facilities, regulations to govern their use have been promulgated in response to demands and provide the flexibility to deal with highly variable weather patterns. As in many basins in the West, water management practices in the Truckee River Basin, including diversion regulations, have been developed through a century of infrastructure improvements followed by decades of litigation. However, unlike in most basins, the closed hydrologic condition of this basin creates a zero-sum game for water. In the Truckee River each drop from its headwaters at Lake Tahoe to its terminus at Pyramid Lake is claimed and serves important human uses and ecological functions. As a result, even small changes in future conditions (e.g., increases in demand or changes in climate) are perceptible and potentially contentious.

The Truckee River Basin Study was conducted by Reclamation in partnership with four non-Federal cost-share partners: Placer County Water Agency, Tahoe Regional Planning Agency, Truckee Meadows Water Authority (TMWA), and Truckee River Flood Management Authority. Each of these partners represents a unique geopolitical position in the Truckee River Basin with diverse interests ranging from preserving Lake Tahoe's environmental conditions to increasing flood protection in the lower Truckee River Basin. The Basin Study was designed to analyze existing and future basin-wide water supplies and demands, identify potential risks of climate change to supplies and demands, and to identify potential adaptive measures to mitigate identified impacts on future supplies and demands.

2 Analysis of Impacts to Water Resources

The Truckee River Basin is located in the Great Basin, a hydrographic region that includes most of Nevada, half of Utah, and portions of California, Idaho, Oregon, and Wyoming. The Great Basin includes more than 180,000 square miles of contiguous, endorheic (also called "terminal") basins, having no river or ocean outlet. The Truckee Basin's climate is typical of areas within the Great Basin where snow accumulation and melt cycles have dominated the hydrologic processes.

- **Temperatures** vary widely in the region and are generally cooler in high elevation areas in the Sierra Nevada and Truckee River Basin, whereas the lower elevation areas (Carson Sink, Pyramid Lake) are generally warmer (Figure 9–2). The climate in the lower Truckee River Basin in Nevada is semiarid to arid, and summers have clear, warm days and cool nights.

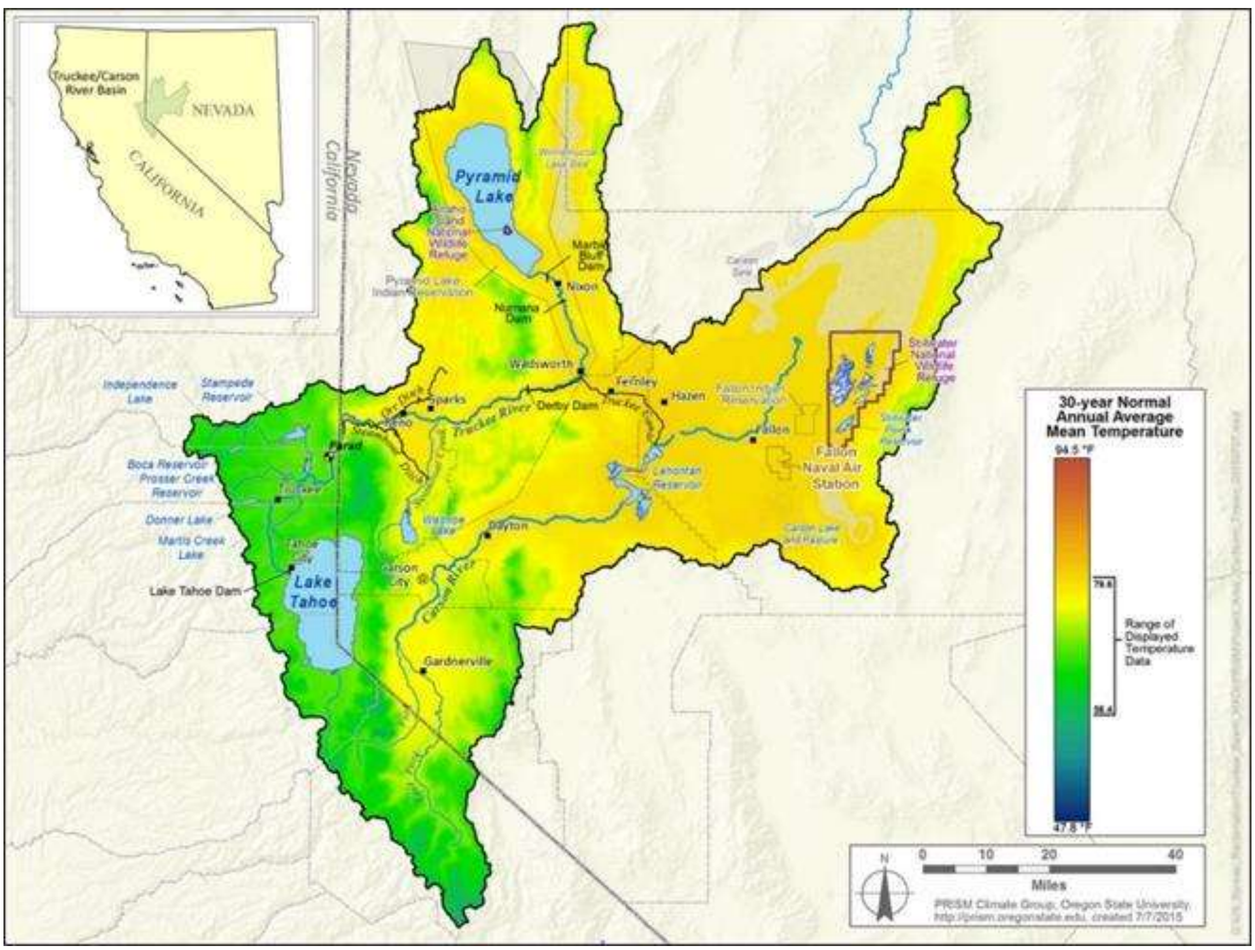

Figure 9–2. Average annual temperature in Truckee River Basin (1981 to 2010). Source: Truckee River Basin Study (2016).

- **Precipitation** also varies widely in the region. Areas in the mountains surrounding Lake Tahoe receive well over 70 inches of precipitation per year, whereas areas in Nevada receive less than 10 inches on average. The lower regions around the Carson River are especially dry, receiving on average less than 5 inches of precipitation each year. Average precipitation for 1981 to 2010 for is shown in Figure 9–3.

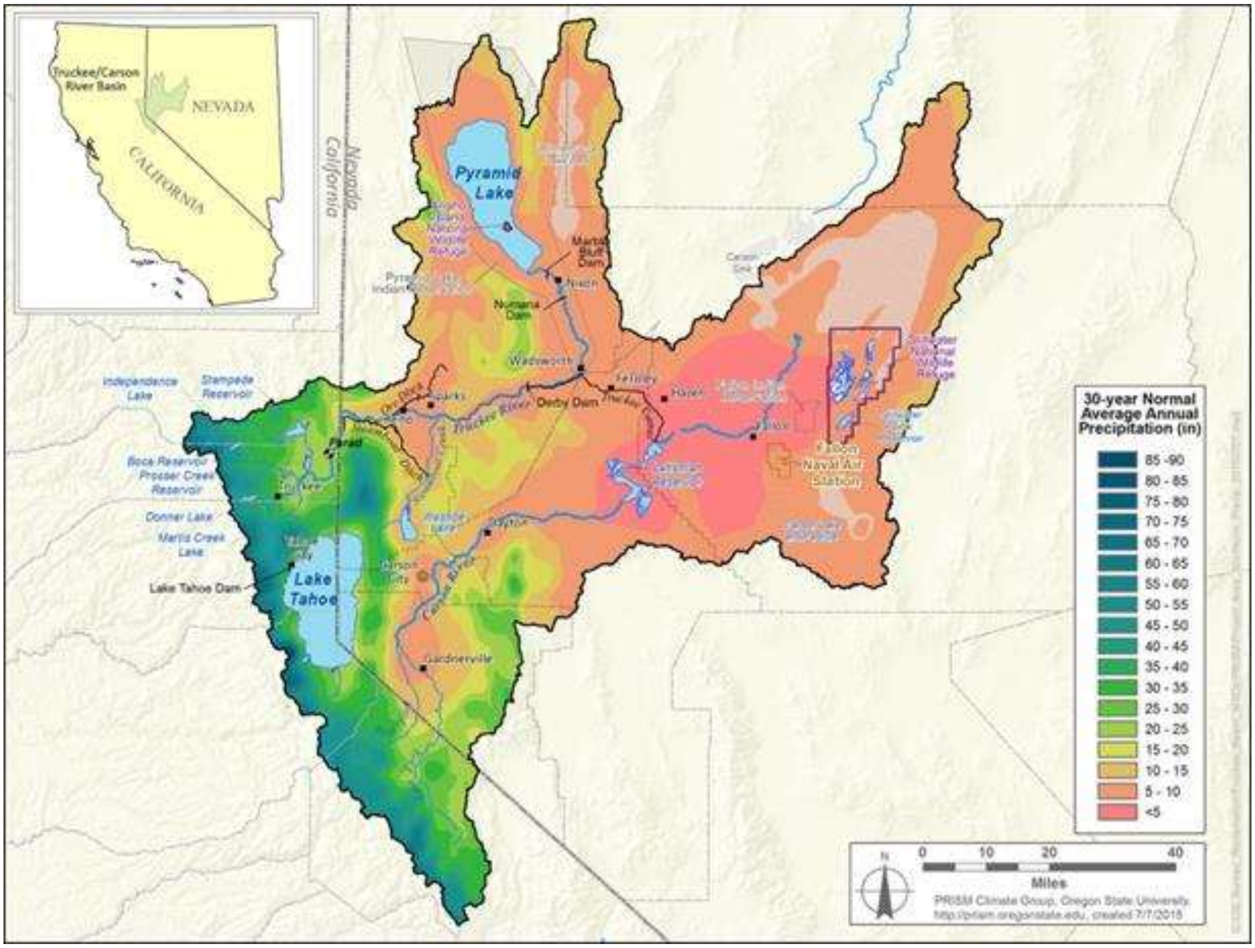

Figure 9–3. Average annual precipitation in Truckee River Basin (1981 to 2010). Source: Truckee River Basin Study (2016).

- **Extreme events:** The Truckee River Basin has historically been characterized by floods and periods of drought. There is high variability in flow throughout the historical record. Consecutive years of low precipitation in the Lake Tahoe Basin and Truckee River upstream from Farad produce dry conditions and meteorological drought cycles for the entire Truckee River Basin.

The Truckee River Basin Study modelled climate change impacts not only geographically, but also over time. Projections of future conditions for the Truckee River Basin's climate include a range of potential changes in both the volume of annual precipitation and the seasonal temperature conditions. Increases or decreases in average annual precipitation would directly influence the availability of water supplies by changing the amount of water running off into the basin's lakes, reservoirs, and rivers, as well as the amount of water recharging groundwater basins. Key findings related to projected changes in water supply due to climate change are presented below.

- **A wide range of uncertainty exists for Truckee River Basin water supplies.** At Pyramid Lake, the scenarios diverge to span a difference in lake surface elevation of more than 200 feet by the end of the century. The outer bounds are defined by the divergence between wetter and drier climate scenarios.
- **Increases in temperature will reduce water supplies**. While changes in precipitation remain highly uncertain, there is a consensus among climate models that the regional climate will warm. Warming temperatures will increase evaporation at the region's lakes and reservoirs, most notably at Tahoe and Pyramid lakes because of their vast surface area.
- **In comparison to the uncertainty in future supplies, the uncertainty in water demands is less significant**. Projected differences in demand affect end-of-century Pyramid Lake elevations by approximately 6 feet, temperatures by 28 feet, and precipitation by 161 feet.
- **Maintaining the historical balance between supply and demand may not be possible if the climate changes significantly, even with exceptional changes in human behavior.** In comparison to the future demand conditions, scenarios in which demand is held constant at 2012 levels produce approximately 16-foot higher elevations at Pyramid Lake for all future supply conditions. By inference, this is the maximum potential supply that would be generated if water demands were prevented from increasing over the coming century.

The Basin Study also assessed changes in demand for a range of current and potential future water diversions and in-river water uses in the Truckee River Basin. The basin's water rights are highly regulated, and its water uses have been carefully planned for by local communities, tribes, the States of California and Nevada, and the Federal Government. Key findings related to projected changes in demand due to climate change are summarized below.

- The added complexity of a changing climate also increases needs of ecosystems and crops.
- Changes in ambient temperatures and seasonality shifts in streamflow will alter the timing of breeding patterns of aquatic species.
- Climate changes are expected to affect water demand for native vegetation that supports migratory birds using Lahontan Valley wetlands and other lakes, as well as riparian and meadow areas along the Truckee and Carson rivers at resting points on the Pacific Flyway.

- Increased water demands will occur due to earlier plant growth and greater water needs for each acre of managed wetland. Bird migration patterns are expected to be affected by global climate changes across the entire migratory flyway, and shifts in arrival at Lahontan Valley wetlands would not match available food supplies.
- Changes in climate are also projected to increase overall crop demand. Future changes in climate (including maximum and minimum temperature, solar radiation, wind speed, humidity, and precipitation) will influence agricultural water use by changing crop water demands and irrigation requirements to meet these needs.
- Higher year-round temperatures can increase evapotranspiration rates that, unless offset by increased local precipitation, would require additional irrigation.
- Higher temperatures are also expected to prolong the growing season, which changes the seasonal demand for water for crops that mature earlier in time and, in turn, increases the volume and duration of irrigation water deliveries needed for every farm. Decreases in local precipitation would increase irrigation requirements to meet crop water demand.

Projected future conditions in the Truckee River Basin are expected to vary widely. Generally, the largest vulnerabilities in the Truckee River Basin stem from uncertainties in future supplies (i.e., future rates of precipitation and temperatures).

The Truckee River Basin has a diverse set of water users and interests, including municipal, agricultural, and environmental. Each water user has different goals and visions for how economic conditions, land uses, and other factors could change in the future and affect – or be affected by – water supply reliability. Additionally, the manner in which each type of water use occurs varies based on geography, diversion facilities and other infrastructure, and whether the source is surface water or groundwater. As with other assessments completed for the Basin Study, the risk and reliability assessment relies on the use of water user communities to describe concerns and conditions in a way that captures the variation throughout the basin.

The Basin Study used a set of performance indicators which were developed with input and guidance from water users and formed the basis for assessing reliability for each water user community. The SECURE Water Act water resources themes represent the range of reliability concerns for Basin communities, and provide important context for understanding the connections between water resources and water uses. Table 9–2 provides a general summary of some of the effects of climate change on future reliability in the basin for resources of concern to water users, organized under each of the SECURE Water Act themes.

Table 9–2. Projected Impacts by SECURE Water Act Themes in the Truckee River Basin
Source: Reclamation 2016 (Truckee)

Theme	Potential Impacts in the Truckee River Basin
Water Delivery and Allocation	Anticipated increases to evapotranspiration have a pronounced impact on water supplies from Lake Tahoe due to its large surface area, which puts one-third of typical Truckee River flows at risk. Warming temperatures also shift the timing of runoff, complicating the operation of reservoirs.
Hydropower	TMWA generates hydropower at several locations along the Truckee River; however this generation is not regionally significant and risks to its future availability correspond with the potential for reduced flow in the river. For the Newlands Project, which diverts Truckee River water, hydropower generation revenue provides 40 percent of the operating budget of Truckee-Carson Irrigation District (TCID), and reductions in future supplies at Lahontan Reservoir may present a risk to hydropower generation.
Recreation	Recreation resources could experience negative effects stemming from the shifts in the peak runoff, which could affect lake levels during peak recreation periods, flows for spot fisheries, and flows in-river for rafting and kayaking. Snow-dependent winter sports may also be diminished in value over time. See also the effects for "Fish and Wildlife Habitat."
Fish and Wildlife Habitat	Habitat requirements for sport fisheries would be challenged by difficulties in operating reservoirs for meeting primary benefits of the reservoirs (water deliveries, riverine fisheries) in a reliable manner. Also, riparian communities would be impacted by changes in timing and volume of runoff. See also the effects for "Endangered, Threatened or Candidate Species."
Endangered, Threatened or Candidate Species	Effects on cui-ui and Lahontan cutthroat trout are difficult to assess with certainty. The volumes of water available for fishery flows could be diminished, and sustaining them from February through August will be more difficult because of changes in the natural hydrology, especially under warmer/hotter or drier conditions. A significant uncertainty also exists in how the fisheries might adapt to changes in the natural flows. Scenarios with higher evaporative losses prevent migratory passage between Pyramid Lake and the Truckee River, which would prevent passage for both cui-ui and Lahontan cutthroat trout to current breeding areas. Also, Lahontan cutthroat trout in Independence Lake would be affected during spawning if spring lake levels flows into upper Independence Creek are not adequate.
Water Quality	Meeting water quality standards in the lower Truckee River is expected to be more difficult for TMWA to maintain as natural flows in the late summer recede. Clarity in Lake Tahoe is difficult to address under these general conditions, because lake clarity is the related to sedimentation and turbidity resulting from human activity and natural sources. The Basin Study did not include a predictive model that describes how climate change may change those influencing factors.
Flow and Water-dependent Ecological Resiliency	Water supplies for the Stillwater National Wildlife Refuge may be at risk, particularly for scenarios where spills from Lahontan Reservoir on the Carson River are lower. See also "Endangered, Threatened or Candidate Species."
Flood Control Management	Flood frequency relationships will change, with peak flows being higher in magnitude and frequency due to diminished snow accumulation and a greater potential for larger atmospheric rivers hitting the Sierra Nevada.

3 Potential Adaptation Strategies to Address Vulnerabilities

Water supply conditions for the coming century will affect Truckee River Basin water user communities in diverse ways. This Basin Study measured the risks and vulnerabilities of individual water user communities relative to a set of baseline conditions for the basin, and identified a set of strategies or actions that can be considered in an attempt to address future supply-demand imbalances.

The Basin Study team obtained input from stakeholders to identify individual actions, or "options," for responding to climate change. The options presented in this report were identified or suggested for investigation by Basin water users and other stakeholders, including municipalities, irrigators, Tribes, resource agencies, local and regional planning agencies, and environmental or conservation groups (Table 9–3).

3.1 Process for Evaluating Options

This Basin Study's process for evaluating options included an initial, high-level assessment for all options suggested by Basin water users, followed by a more detailed analysis using Basin Study tools for a select number of options based on the prioritization below.

Options were prioritized and selected for further evaluation based on:

- **Completeness**: In order to be evaluated, options must have a measurable or specified effect on Basin supplies, demands, or operations.
- **Applicability to Basin-Wide Vulnerabilities**: The options selected for further evaluation are those anticipated either to address water supply vulnerabilities for the entire Basin, or to help restore a balance between supplies and demands, and among users and uses.
- **Use of Basin Study Tools**: The use of an equivalent process to evaluate the different effects of options allows for more thorough comparisons. Where possible, options were tested using the Truckee River Operating Agreement (TROA)-light Planning Model.

The options evaluated in detail through the Basin Study process, along with key findings on performance and implementation considerations, are shown in Table 9–4.

Table 9–3. Options Identified by Water Users
Source: Reclamation 2016 (Truckee)

Adaptation Strategy	Grouping	Option
Institutional Changes	Basin-wide Planning	Define regional priorities and goals for water use
		Eliminate prior appropriation
	Surface Water Reservoir Management	Allow Truckee-Carson Irrigation District (TCID) carryover storage in Truckee River reservoirs
		Change balance of credit storage available to users at Truckee River reservoirs
		Remove storage limits at Truckee River reservoirs
		Modify flood control curves to adapt to climate
		Modify Operating Criteria and Procedures (OCAP) criteria at Lahontan Dam to improve success of refill
	Surface Water Rights Management	Allow management of water between Pyramid Lake fisheries and Lahontan Valley wetlands
		Create open water markets
		Consolidate agricultural water rights
Supply Augmentation	Alternative Sources	Interbasin transfer of groundwater
	Conveyance Facility Improvements	Augment Truckee Canal capacity
	Groundwater Storage	Enhanced groundwater recharge
	Modifications to the Hydrologic Cycle	Forestry-based watershed management
		Weather modification
		Wetland, meadow, and stream corridor restoration
	Surface Storage	Additional Carson River storage
		Increase Truckee River reservoir storage
Demand Management	Agricultural Use	Convert to low water-use crops
		Reduce conveyance losses
		Transfer agricultural water rights to municipal and industrial uses
		Water rights retirement
		Water use efficiency improvements
	Environmental Flows	Revise flow targets to correspond with peak flows under climate change
	Municipal & Industrial Use	Increase outreach and education on conservation
		Mandate efficiency improvements
		Outdoor use efficiency improvements
	Water Quality	Water quality improvements for the lower Truckee River

Table 9–4. Summary of Option Performance and Evaluations
Source: Truckee River Basin Study (2016)

Option	Ability of Options to Mitigate for Undesirable Future Conditions		Implementation Considerations
	Basin-wide Vulnerabilities	Water User Shortages	
Adapt Flood Management Operations	Mitigates for some seasonality shifts by capturing precipitation that would have been held in snowpack in the historical climate. Availability of storage space is much smaller than snowpack, and thus cannot completely mitigate for climate changes.	Small shifts in the timing of managed flows occur related to capture of additional water. Option does not fully restore the historical operating regime or the supply-demand balance under the Reference scenario. Reduces shortages for M&I and agriculture by 3 to 9 percent. Increases years with adequate spawning flows at Pyramid Lake by up to 15 percent. Reduces adult passage flows by up to 13 percent in drier scenarios. Shifts benefits among lifecycle stages for Pyramid Lake fisheries, challenging passage but improving spawning conditions.	Could affect flood management in the basin and would require balancing water supply benefits with flood risks. Entities required for implementation would likely include the USACE and the Truckee River Flood Management Authority for developing acceptable flood management strategies, and the Pyramid Lake Paiute Tribe for fisheries and water rights-related concerns.
Adapt OCAP Storage Targets	Mitigates for seasonality shifts by adjusting Newlands Project OCAP operations and end-of-month storage targets at Lahontan Dam. Does not mitigate for Basin-wide changes.	Helps Lahontan Reservoir refill at the end of the century when climate changes have the most pronounced effect on hydrology, but violates central tenets of OCAP by over-diverting Truckee River water in the earlier portions of the century when climate has subtle changes in hydrology.	Implementation would require detailed study and careful evaluation in close coordination with the Pyramid Lake Paiute Tribe and TCID to ensure the intended balance in water supplies is not disrupted.
Consolidate Agricultural Rights	Responds to increased crop water demands by reducing acreages of cultivation. Allows for an earlier beginning of the irrigation season, but does not otherwise mitigate Basin-wide changes.	Reduces frequency of shortages in the Newlands Project by up to 28 percent without significantly affecting any other water users in the basin.	Implementation would likely require major changes to water rights law and would need to be closely coordinated with parties to the *Orr Ditch* and *Alpine* decrees, TCID, and the Nevada State Engineer.
Truckee Canal Rehabilitation	Addresses seasonality shifts and reductions in precipitation by restoring Truckee Canal diversion and conveyance capacity.	Reduces the frequency of annual crop demand shortages for the Newlands Project by 4 to 12 percent. Increases spills to Lahontan Valley wetlands by 6 percent and reduces long-term shortages to wetlands by up to 3 years. Increases TCID hydropower generation by 4 to 14 percent.	Implementation is currently underway for a similar action. Reclamation is undertaking a NEPA process to document potential environmental effects, such as impacts to fisheries impacts at Pyramid Lake or groundwater for Fernley. Likely coordination among the Pyramid Lake Paiute Tribe, TCID, and the City of Fernley.

Option	Ability of Options to Mitigate for Undesirable Future Conditions		Implementation Considerations
	Basin-wide Vulnerabilities	Water User Shortages	
Additional Truckee River Basin Storage	Mitigates for some seasonality shifts and reductions in precipitation and snowpack by capturing and storing additional supply that would otherwise be spilled.	This option, tested in a conceptual manner, shows some ability for a new storage facility to reduce future shortfalls for all water users in the basin. Full mitigation for losses associated with climate change would require facilities that more than double the current available storage in the basin.	Implementation would require study by a project proponent to determine specific details of future storage, including potential locations and storage capacities. Other entities required for implementation would likely include the Pyramid Lake Paiute Tribe for fisheries and water rights-related concerns, and possibly USACE and the Truckee River Flood Management Authority for consideration of flood management operations.
Forest Management	Reduces evapotranspiration from forest cover. Could be an important contribution to water supplies originating in the upper Basin, but performance is uncertain.	Water supplies could be improved for all water users, but there may be limitations of this option during dry years and when supplies are most needed.	Implementation likely requires coordination with U.S. Forest Service (USFS), other public or private landowners, and the Tahoe Regional Planning Agency. Option requires vegetation maintenance across large areas of forested land, and likely requires periodic clearing of vegetation to maintain the water supply benefit. More rigorous study is needed to understand the full potential of this option to improve water supplies, particularly in dry conditions.
Raise Lahontan Dam	Increases storage of Carson River supplies for the Newlands Project, effectively increasing availability of supplies Basin-wide.	Reduces diversions from the Truckee River in wetter conditions only. Does not change reliability for the Newlands Project. Increases flow to Pyramid Lake by up to 5 percent, but reduce supply to Lahontan Valley wetlands by up to 9 percent.	Implementation would likely require study to determine effects on fisheries and water-dependent ecosystems at Pyramid Lake and Lahontan Valley wetlands. Entities required for implementation would include TCID and U.S. Fish and Wildlife Service (USFWS).
Adapt Fish Flow Regimes	Mitigates for seasonality shifts by changing the timing of flow regimes in the Truckee River. Does not otherwise mitigate Basin-wide changes.	Increases adult passage flows by 1 to 10 percent and spawning flows by 10 to 71 percent. Does not change duration of years with poor spawning flows.	Implementation would likely require involvement of the range of agencies that previously developed the six-flow regime for the Truckee River (TRIT 2003).

4 Coordination Activities

Truckee River water users and stakeholders have long understood that growing demands, coupled with the potential for reduced supplies due to climate change, may put water users and resources relying on the river at risk of prolonged water shortages in the future. The Basin Study is built on earlier work and is the next significant step in developing a comprehensive knowledge base and suite of tools and options that could address the risks posed by water supply-demand imbalances in the Truckee River Basin.

The Truckee River Basin Study indicates that water conservation, reuse, and augmentation projects could improve the reliability and sustainability of the Truckee River system to help meet current and future water needs. Addressing future imbalances in the Truckee River Basin will require diligent planning and collaboration that applies a wide variety of ideas at local, state, and Basin-wide levels. Central to this collaboration are partnerships and the recognition that pursuing further study must cultivate and build upon the broad, inclusive stakeholder process that was initiated by the Truckee River Basin Study.

4.1 Incorporation of Future Risks into Existing Water User Plans

While Reclamation's Basin Study Program provides standardized scientific information on how climate change affects water resources across the Western U.S., the processes for incorporating climate change into political and decision making forums varies widely by region and community. Effectively incorporating future risks identified by the Basin Study into existing water resources planning processes could be supported by locally or regionally driven efforts to expand upon the information generated through the Basin Study, such as:

- **Regional Planning Forums**: Plans and responses to climate change will have implications which would benefit from a common Basin-wide understanding of risks, transparency in the vision held by individual communities for the future, and/or a collective commitment to take action. A regional planning process with participants representing a broad coalition of interests could be helpful in achieving these by providing a common processes for the interpretation of future risks, options for responding to risks, tradeoffs among communities for future actions, and a mechanism for cost-sharing on future studies. Considerable investments have been made to develop a regional understanding about the implications of water use in the basin, particularly surrounding and through TROA negotiations and implementation. The efforts to support TROA implementation could serve as a useful model for a regional planning process.

- **Improvement of Indicators by Water Users**: An effort by water users and Basin communities to refine the performance indicators developed during the Basin Study could improve the degree to which the Basin Study's assessments can be used for future planning. The indicators developed for this Basin Study report on the quality of future conditions in a relative manner. For example, the frequency of water supply shortages experienced by a particular water user can be counted for each scenario, and scenarios with lower or fewer shortages will receive higher ratings among corresponding indicators. However, the Basin Study indicators do not provide objective value judgments; it may be possible that even the "worst" scenario can be accommodated by a given water user. Identifying whether conditions are either good or bad can depend on multiple considerations. From a technical standpoint, the effect of future conditions depends on the water requirements of each community, the capabilities of their existing infrastructure, and the characteristics of various available water supplies for managing their needs. Political and administrative considerations also provide important context for interpreting future conditions.

4.2 Development of Modeling Tools and Information

The Basin Study relied upon projected future conditions that were assembled before, and absent the context of, the key vulnerabilities that emerged from the Basin Study's risk and reliability assessment. As the first of its kind in the basin, the Basin Study presents an opportunity to inspect sources of uncertainty in supplies and demands and determine whether uncertainty in the analysis could be reduced or corrected with additional investments in modeling and analysis.

The following assessments and model development tasks were identified through input from technical stakeholders, or by the Basin Study team through the process of conducting analysis of vulnerabilities and adaptation options.

- **Refinement of ecosystem needs and vulnerabilities**: An understanding of the relationship between changes in the climate, changes in the needs of aquatic, wetland, and riparian ecosystems and migratory waterfowl and shorebirds that result from changes in the climate and the ability to accommodate these needs with existing supplies would benefit from further analysis and model development.
- **Incorporation of paleohydrology and updated climate information**: Inspection of the next phase of climate projections[2] would provide an updated understanding for whether uncertainties in the future climate have been converging or changing.

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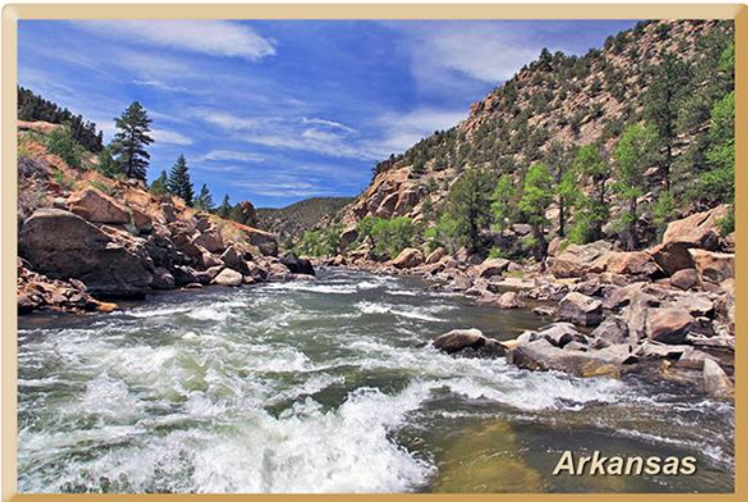
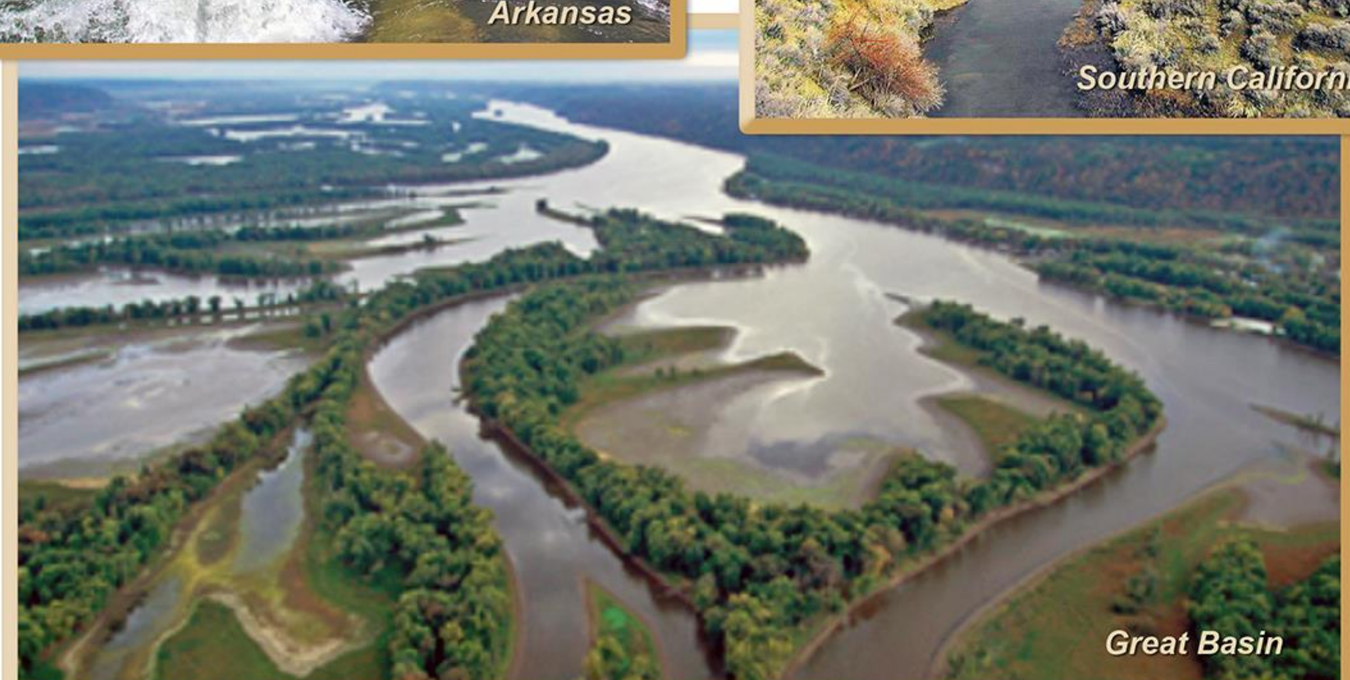
[2] Climate projections from the World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP) Phase 5.

- **Inclusion of the Carson River Basin**: Development of supply, demand, and infrastructure and operational conditions in the Carson Basin upstream of Lahontan Reservoir would benefit water users in this neighboring basin, including Reclamation's Newlands Project.
- **Coupled groundwater/surface water model developmen**t: The communities in the basin who rely on groundwater as a primary source of water supply would benefit from an improved understanding of how climate change may alter natural processes for groundwater recharge and storage.
- **Economics model for the Truckee River Basin**: For communities that rely heavily upon recreational uses of water, such as snow-dependent or lake recreation, the application of a regional socioeconomics model may provide further clarification about the implications of climate change on the goals of each community.
- **TROA implementation refinements**: Several aspects of the TROA-light Planning Model require further discussion and refinement before they may be implemented in the model, including the California Guidelines for recreation, and the use of credit storage for water quality on the lower Truckee River.

RECLAMATION
Managing Water in the West

Chapter 10: Other Western River Basins





U.S. Department of the Interior
Bureau of Reclamation

March 2016

About this Chapter

This summary chapter is part of the 2016 SECURE Water Act Report to Congress prepared by the Bureau of Reclamation (Reclamation) in accordance with Section 9503 of the SECURE Water Act. The 2016 SECURE Water Act Report follows and builds on the first SECURE Water Act Report, submitted to Congress in 2011[1], which characterized the impacts of warmer temperatures, changes to precipitation and snowpack, and changes to the timing and quantity of streamflow runoff across the West.

The SECURE Water Act identifies the eight major Reclamation river basins. This chapter provides a summary of activities conducted by Reclamation and its partners in other western river basins not specifically identified in the SECURE Water Act. This chapter is organized as follows:

Section 1: Coastal and Inland Basin Areas of Southern California,

Section 2: Great Basin, and

Section 3: Arkansas-Red-White River Basin

This chapter includes updated information from Reclamation studies completed or initiated in the basin over the past 5 years. The key studies referenced in this chapter include the following:

- Los Angeles Basin Study (ongoing)
- Santa Ana River Watershed Basin Study (completed)
- Mojave River Watershed Climate Change Assessment (completed)
- San Diego Watershed Basin Study (ongoing)
- Southeast California Regional Basin Study (completed)
- Upper Washita Basin Study (ongoing)
- Upper Red River Basin Study (ongoing)

1 The first SECURE Water Act Report, submitted to Congress in 2011 is available on the Reclamation website: www.usbr.gov/climate/secure/docs/2011secure/2011SECUREreport.pdf .

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Figures

1 Southern California Coastal and Inland Basins

Southern California consistently faces serious water supply threats from numerous factors: increasing population, reliance on imported water, flooding, and the overuse of groundwater. Recently, California ranked second among all states in the country for population increases (U.S. Census Bureau, 2011), and as of 2015, the state was struggling through its fourth consecutive year of one of the most severe droughts on record. In a region that experiences highly variable precipitation and periodic drought, climate change may exacerbate shortages in a system already operating on the edge with respect to water supply.

Coastal and Inland Basin Areas of Southern California

States: California

California Counties: Los Angeles, Ventura, Riverside, San Bernardino, and Orange

Basin Rivers: Los Angeles River, San Gabriel River, Santa Ana River, Whitewater River, Mojave River, San Diego River, New River, and Alamo River

Major Water Uses: Municipal Supply (more than 22 million people), Agricultural irrigation, Flood Control, Recreation, and Fish and Wildlife

1.1 Regional Setting

For this chapter, Southern California is separated into two distinct geographical areas: the Coastal Area, which is defined as the Los Angeles, Santa Ana, and San Diego Watershed Basins, and the Inland Basins Area, which is represented by the adjudicated boundary of the Mojave River basin and the Salton Trough region. Figure 10–1 presents the Coastal and Inland Basin Areas, as well as the location of Reclamation Basin Studies.

1.1.1 Coastal Area

The Coastal Area encompasses the Southern California watersheds bounded by Malibu to the north and San Ysidro to the south. Most of the water in the area is supplied by the Metropolitan Water District of Southern California (MWD), which provides water to 26 member agencies in a 5,200-square-mile service area that sustains approximately 19 million people.

The area is situated in an arid desert climate without enough local fresh water to support the growing population and major economic development, so it receives approximately 40 percent of its needed water from outside sources. In 2014, 22 percent of the total water supply was provided by the Colorado River (delivered via the 242-mile Colorado River Aqueduct); 17 percent was supplied by northern California (delivered via the 444-mile California Aqueduct); 33 percent was from local supply, which included groundwater, surface water, Los Angeles Aqueduct (from the Sierra Nevada Mountains), and groundwater recovery, and 28 percent of the supply was from conservation and water recycling (Reclamation, 2015 [Moving Forward]).

Figure 10–1. Map of Southern California showing locations of Basin Studies.

Figure 10–2. San Diego, California.
Source: Reclamation, 2015 (SCAO).

The metropolitan area population has increased by nearly 50 percent since 1980, adding more than 6 million to the municipal water-service-area population, while total annual water use increased by approximately 20 percent. On average, per capita water use rates have decreased by approximately 10 percent since 2000. Residential water use accounts for around 70 percent of the total water delivered by MWD (Reclamation, 2015 [Moving Forward]).

In February 2008, Governor Arnold Schwarzenegger introduced a seven-part comprehensive plan for improving the Sacramento-San Joaquin Delta. As part of this effort, the Governor directed state agencies to develop a plan to reduce statewide per capita urban water use by 20 percent by the year 2020. This marked the initiation of the 20x2020 Water Conservation Plan (20x2020Plan) process. Because of an unprecedented 4-year drought, Governor Jerry Brown declared a drought State of Emergency in January 2015 and directed state officials to take all necessary actions to prepare for water shortages. In April 2015, Governor Brown mandated a 25 percent water use reduction for cities and towns across California. For the June-August 2015 period, the cumulative statewide savings rate was 28.7 percent.

Although the majority of water resources within this area are used for urban and agricultural purposes, a variety of wildlife species thrive in southern California's coastal and marine environments, sage scrub and chaparral habitats, and marshes and riparian zones. Valuable area wetlands, including salt marshes and estuaries, freshwater marshes, riparian woodlands, and a number of reservoirs and lakes are essential resting stops for migrating birds on the Pacific Flyway and provide nesting areas for large numbers of wintering waterfowl (Reclamation, 2015b).

The Coastal Area has a Mediterranean climate with average summer temperatures ranging from 64 to 85 degrees Fahrenheit (°F) during August, the warmest month; average winter temperatures range from 46 to 70 °F during December, the coolest month. In the inland areas, the climate is semiarid, with colder winters and markedly hotter summers. Precipitation in the metropolitan area occurs primarily during the winter months and ranges from 10 to 17 inches per year (Reclamation, 2015b).

1.1.2 Inland Basins Area

The Inland Basin Area of southeastern California encompasses the Borrego, Coachella, and Imperial Valleys in the Salton Trough region and the high desert region of the Mojave Basin near Barstow, CA. This area includes the cities of Indio, Palm Desert, El Centro, Calexico, Victorville, and Barstow. Both of these areas are water supply limited, and growing municipal and commercial sectors (e.g., retail outlets, resorts, and casinos), a massive agricultural industry, and numerous recent regulatory and legal settlements require a delicate balance to manage existing supply and demand.

Bounded to the east and west by high-elevation mountain ranges that drain to the low-depression valley containing the Salton Sea, the Salton Trough is home to a diverse range of habitats that support more than 1,000 plant species and more than 400 animal species. The Salton Trough region consists of approximately 5,200 square miles and is home to 10 desert cities and four Indian reservations, which have a combined population of 750,000 full-time residents. In addition, millions of winter and spring visitors flock to the Palms Springs and Borrego Springs areas annually. The region is also home to California's largest inland lake, the Salton Sea, which is a critical component of the Pacific flyway. The three irrigation districts that service this vast area have a combined annual agricultural economic value of more than $2.5 billion dollars, and the region's tourism economy generates more than $8.4 billion dollars annually (Reclamation, 2014 [Southeast California]).

The Salton Trough region lies within the Sonoran desert geomorphic area, which has a typical subtropical desert climate—hot summers, mild winters, and 3 to 4 inches of annual precipitation. Temperatures in the summer are often in excess of 120^{o} F. Precipitation falls mainly during the winter months; however, monsoonal summer storms do occur (Reclamation, 2014 [Southeast California]). An estimated 124,000 shorebirds, including at least 25 different species, migrate through the Salton Sea, which is considered the third most important shorebird habitat west of the Rocky Mountains.

The population in the Salton Trough region has almost doubled since 1990, adding more than 230,000 to the municipal water service-area population. Total annual water use increased by approximately 143 percent over the same period. The most recent annual average (2008-2012 average) per capita use was estimated at 314 gallons per capita per day (GPCD). The high per-capita use rates for this metropolitan area are generally associated with large-scale turf irrigation in resort areas Reclamation, 2015 (Moving Forward).

In the Salton trough region, three distinct subareas—Borrego Valley, Coachella Valley, and Imperial Valley—have both unique and overlapping water supply-demand issues. The Borrego subarea is entirely dependent on groundwater. A draft U.S. Geological Survey (USGS) groundwater study (Faunt et al., 2015) of the area indicates the aquifer has an overdraft of 17,000 acre-feet per year (AFY) and estimates that the upper aquifer may be depleted in as little as 50 years. Coachella's challenge is a mix of both groundwater overdraft and Colorado River water supply issues. In addition, a portion of the Coachella subarea's water supply is derived from the State Water Project (SWP) imports and exchanged for

Colorado River water. The Imperial subarea's challenge is near-100-percent dependence on Colorado River water supply (Reclamation, 2014 [Southeast California]).

The Coachella Valley Water District (CVWD) began operation in 1918. It provides service to approximately 1,000 square miles from the San Gorgonio Pass to the Salton Sea, mostly within the Coachella Valley in Riverside County, California. CVWD provides water-related service to more than 303,000 people living in the nine cities of CVWD's service area. CVWD relies on three sources of water (groundwater, recycled water, and imported water) to provide service to its customers, either through the SWP (via exchange) or from the Colorado River via the Coachella Canal, a branch of the All-American Canal. In the CVWD service area, approximately 300,000 AFY of water delivered from the Coachella Canal was initially used exclusively by agriculture. As residential growth moved into the eastern valley, other water users, primarily golf courses and homeowner associations, began using Colorado River water for large landscape irrigation. From 2008 to 2012, more than 40 percent of the total CVWD deliveries were distributed to municipal and industrial (M&I) water users (Reclamation, 2015 [Moving Forward]).

The Imperial Irrigation District (IID), the largest irrigation district in the nation, was formed in 1911 to import and distribute raw Colorado River water, mainly to agricultural irrigation customers. IID delivers an average of 2.8 million acre-feet (AF) of water each year, and 97 percent is used for the irrigation of more than 400,000 acres. In addition, IID supplies water to approximately 178,000 people across seven municipalities. The largest cities included in the IID M&I service area are El Centro and Calexico. The IID diverts water at the Imperial Dam on the Colorado River through the 80-mile-long All-American Canal (Reclamation, 2015 [Moving Forward]).

The Mojave Basin is in the Mojave Desert and is classified as high desert. Elevations within the area range from 1,500 feet mean sea level (msl) in the east to 5,500 feet msl in the mountains to the south. The Mojave Water Agency (MWA) services water users in the adjudicated boundary of the Mojave Basin. Precipitation and runoff throughout the basin are highly variable. Most of the surface water originates from ephemeral streams; consequently, the MWA area has limited surface water supplies. Groundwater supplies are currently used to meet the vast majority of demand. Since groundwater production started in the 1900s, groundwater extraction has greatly expanded, and groundwater levels have been declining since the early 1950s. Since this time, the overdraft has reduced groundwater storage by an estimated 2 million acre-feet (MAF). MWA imports significant amounts of surface water from the SWP (Reclamation, 2013 [Mojave]).

The Colorado River Basin Water Supply and Demand Study (Reclamation, 2012 [CO Basin Study]) assessed historical water supply in the Colorado River Basin, and observations and conclusions of historical temperature and precipitation trends in the Lower Colorado River Basin are consistent with Southern California historical trends. Key findings related to projected changes in temperature, precipitation, snowpack, and runoff are presented below:

- **Increases in temperatures**: Studies consistently show that the temperatures in Southern California will continue to increase. Increases in both minimum and maximum temperatures may be expected, with increases in extreme warm temperatures and decreases in extreme cool temperatures. For the Los Angeles area, a mean temperature increase of 2 to 5 °F is expected by 2050.
- **Decreases in annual precipitation**: Studies suggest that the storm track in the Pacific Ocean may shift northward, resulting in less-frequent precipitation events along the coast of southern California. Changes in mean annual precipitation indicate a mean drying (i.e., less precipitation) of 2 to 5 percent since the mid-20th century, with little additional change by mid-21st century. Additional drying (mean reduction of 2 to 5 percent) could occur along the coastal areas of California.
- **Increases in extreme precipitation events**: Overall, precipitation may be less frequent but more intense, meaning that the contribution to annual precipitation by extreme precipitation events may increase. The heavy rainfall events may be interspersed with longer, relatively dry periods. The higher evaporation rates resulting from the rising temperature may decrease soil moisture, resulting in reduced storm runoff. The literature does not associate a specific return period to extreme precipitation events but rather discusses extreme precipitation events in general terms.

Water demand in the area is expected to increase due to changes in temperature and increased reservoir evaporation (Reclamation, 2013 [Santa Ana]). Key findings related to projected changes in demand are summarized below.

- Overall, there are expected to be two to three times as many extreme days (i.e., greater than 95 °F) in coastal areas and within the Los Angeles Basin. Inland areas were noted to have three to five times the number of extremely hot days (Reclamation, 2013 [Santa Ana]).
- Water demand in the Inland Basins Area is largely dominated by agriculture and, to a lesser extent, municipalities and golf courses. Increased temperatures can affect both agricultural and municipal demand by increasing evaporative demand on crops, golf courses, and lawns. From 1970 to 2003, agricultural demand in the Imperial Valley varied from 2.6 to 3.2 million AFY.
- Projections indicated more winter precipitation and less springtime precipitation. Increased winter precipitation could result in crop damages, and excessive summer heat could decrease yields. In addition, it is expected that as the climate changes, farmers will adapt by changing the types of crops planted, which might also affect demand (Reclamation 2014 [Southeast California]).

- Other drivers influencing demand include the population of the Coastal Southern California Metropolitan Area, which has increased by about 50 percent since 1980, adding more than 6 million to the municipal water service area population, while total annual water use increased by approximately 20 percent.
- Recent averages indicate that residential water use accounts for about 70 percent of the total water delivered by MWD. However, many factors affect future water demands, such as population growth, hydrologic conditions, public education, and economic conditions, among others.
- Municipal demand accounts for only 3 percent of historical Colorado River water deliveries in the Imperial Valley; however, the population is expected to more than double from approximately 162,000 to 365,000 between 2010 and 2050. This level of growth would result in a roughly 64,000-acre increase in urban area (Reclamation 2014 [Southeast California]).
- Since 1999, considerable growth within the Coachella Valley has resulted in the conversion of agricultural and desert lands to residential urban uses. There is a recognized overdraft and a 2002 water management plan set a number of water conservation goals for CVWD in order to reduce demand.
- In the Mojave River Basin, the population is projected to increase nearly 25 percent from 2010 through 2020, and total demand is projected to increase, assuming moderate conservation. For planning purposes, the Mojave Water Agency assumes that average natural water supply and agricultural depletion from storage will remain constant through 2035, while wastewater imports and return flows are projected to increase slightly. SWP imports are projected to increase by approximately 10 percent by 2035 (Reclamation 2013 [Mojave]).

1.2 Coordination Activities

The Coastal and Inland Basins Areas of Southern California are situated in an arid desert climate without enough local fresh water to support the growing population and burgeoning economy. As the area receives two-thirds of its needed water supplies from northern California (delivered via the 444-mile California Aqueduct), the Sierra Nevada Mountains (delivered by the 338-mile Los Angeles Aqueduct), and the Colorado River (delivered via the 242-mile Colorado River Aqueduct), water challenges are being addressed through Federal, state, tribal, and local partnerships. Reclamation is an active partner in activities to develop strategies for conservation, water recycling and reuse, salinity management, ground and surface water conjunctive management, storm water augmentation programs, and other watershed management opportunities.

In the Coastal Area, Reclamation has led or participated in multiple studies and activities. Some recent activities include Reclamation's partnership with the Los Angeles and San Gabriel Rivers Watershed Council and other agencies in a Water

Augmentation Study. The purpose of the study is to explore potential adaptation strategies such as reducing urban runoff pollution by increasing infiltration of stormwater runoff. This stormwater infiltration has the potential to augment local groundwater supplies by capturing and recharging stormwater runoff that otherwise would flow unused to the ocean. The Los Angeles Basin Study provides the opportunity for multiple water management agencies to participate in a collaborative process to plan for future local water supply scenarios.

Another example of integrated planning is Reclamation's partnership with the California Energy Commission and the Metropolitan Water District of Southern California to commission an innovative study to bring together energy utilities, water districts, wastewater sanitation districts, and state and local agencies to study the potential for integrated water and energy efficiency programs. This approach allowed water districts and energy utilities to take advantage of opportunities to leverage their limited resources and coordinate resource management efforts to meet future needs (Reclamation, 2015 [SCAO]).

In the Inland Basin Area, Reclamation is also actively involved in conservation initiatives and long-term water management planning. Studies have been conducted in partnership with multiple water agencies and irrigation districts. For example, the Southeast California Regional Basin Study was conducted in partnership with the Borrego Water District and other regional stakeholders. Reclamation also works with the newly created Borrego Water Coalition, which is addressing the significant risks associated with over drafting the Borrego Valley groundwater basin (Reclamation, 2015 [SCAO]).

1.2.1 Bureau of Reclamation Partnered Studies

Reclamation administers programs to develop and enhance water management throughout southern California. In cooperation with state and local water agencies, Reclamation programs address desalination research, conjunctive use of ground and surface water resources, stormwater runoff augmentation, watershed modeling that addresses both water quantity and quality, and the development of new water resources. Recent activities include long-term planning focused on options to provide water management assistance to address complex water issues on local, regional, and statewide levels, as well as water conservation-related projects through WaterSMART Grants to facilitate water conservation and efficiency improvements on Federal and non-Federal projects (Reclamation, 2015 [SCAO]). Recent and on-going Reclamation studies with partners in the Coastal and Inland Basin Areas include the following:

- **Colorado River Basin Water Supply and Demand Study**: Completed in 2012, the study evaluated future water supply and demand in the Colorado River Basin and adjacent areas receiving Colorado River water, including the Coastal and Inland Basin Areas (Reclamation, 2012 [CO Basin Study]).
- **Santa Ana Watershed Basin Study**: Completed in 2013, the study focuses on the Santa Ana Watershed Project Authority's integrated regional water

resources planning process, refined the region’s water projections, and identified potential strategies to help the region adapt to climate change (Reclamation, 2013 [Santa Ana] and Reclamation, 2013 [Santa Ana Summary]).

- **Mojave River Watershed Climate Change Assessment**: Completed in 2013, this report provides a detailed climate change assessment of the Mojave River watershed (Reclamation, 2013 [Mojave]).
- **Los Angeles Basin Study**: Reclamation is collaborating with the Los Angeles County Flood Control District for this ongoing, phased effort investigating long-term water conservation and flood-control impacts from projected climate conditions and population changes in the Los Angeles Basin. This study is expected to be completed in 2016.
- **San Diego Watershed Basin Study** – This study, expected to be completed in 2016, will assess the San Diego region’s water supply and demand and determine the potential effects from climate change impacts within the San Diego Integrated Regional Water Management planning region. It will also analyze the region’s existing infrastructure and develop adaptation strategies that can assist with addressing the uncertainties associated with climate change.
- **Southeast California Regional Basin Study**: Completed in 2014, the study addressed current and future supply and demand imbalances in the Coachella, Borrego, and Imperial Valleys of California, provided an assessment of existing infrastructure resources, and developed options and alternatives to solve identified issues and help plan for an uncertain water supply future (Reclamation, 2014 [Southeast California]).
- **Colorado River Basin Study *Moving Forward* Effort**: The Colorado River Basin Study was widely described as a “call to action.” In May 2013, the Department of the Interior and other stakeholders launched the *Moving Forward* effort to identify and implement, in a coordinated and collaborative manner, actions to address projected supply and demand imbalances that have broad-based support and provide a wide range of benefits. In Phase 1 of the effort, completed in 2015, three workgroups focused on water-use efficiency (urban and agricultural) and environmental and recreational flows throughout the Basin, including the Coastal and Inland Basins Areas (Reclamation, 2015 [Moving Forward]).

Reclamation basin studies and other planning efforts have demonstrated that the implementation of a broad range of options can help improve the Coastal and Inland Basins Areas’ resiliency to dry and variable hydrologic conditions. Actions to help ensure the sustainability of these areas are occurring at a variety of scales and locations, ranging from basin-wide initiatives to specific infrastructure improvements.

2 Great Basin

The Great Basin includes most of Nevada, western Utah, and small portions of bordering states, including Wyoming, Idaho, Oregon, and California. The southern boundary is less distinct. The Great Basin region has a population of roughly 3.2 million people. Major population centers include Salt Lake City, Utah, and Reno, Nevada, and the region is sparsely populated outside of the two major cities. Water uses include hydropower, irrigation, recreation, fish and wildlife, and municipal and industrial water supply.

Great Basin Setting

States: California, Idaho, Nevada, and Utah

Major U.S. Cities: Salt Lake City, Ogden, Reno, and Carson City

Longest River Length: 350 miles (Bear River)

River Basin Area: 140,000 square miles

Major River Uses: Municipal (6 million people), Agricultural, Flood Control, Navigation, and Recreation, and Ecological Uses

Reclamation Irrigation Projects in the Great Basin: Central Utah Project (Bonneville, Jensen, and Vernal Units), Humboldt Project, Hyrum, Newlands Project, Newton, Ogden River, Preston Bench, Provo River, Strawberry Valley, Truckee River Storage Project, Washoe Project, Weber Basin, and Weber River

2.1 Great Basin Setting

The Great Basin region consists of many small basins that together span an area of roughly 140,000 square miles. The region includes the Bear River, Great Salt Lake, Escalante Desert-Sevier Lake, Central Lahontan, and Central Nevada Desert Basins, and the Black Rock Desert-Humboldt subbasins. The Great Basin's longest (350 miles) and largest river is the Bear River in northern Utah; the largest single watershed is the Humboldt River drainage in north-central Nevada (17,000 square miles). Lake Tahoe, North America's largest alpine lake, is part of Great Basin's Central Lahontan subbasin.

The region is bounded by the Wasatch Mountains to the east, the Sierra Nevada Mountains to the west, and the Snake River Plain to the north (Figure 10–3). The Great Basin is a closed basin, with no drainage to the Pacific Ocean or the Gulf of Mexico. All precipitation in the region evaporates, sinks underground, or flows into lakes, most of which are saline. The Great Salt Lake, Pyramid Lake, and the Humboldt Sink are a few of the drains in the Great Basin.

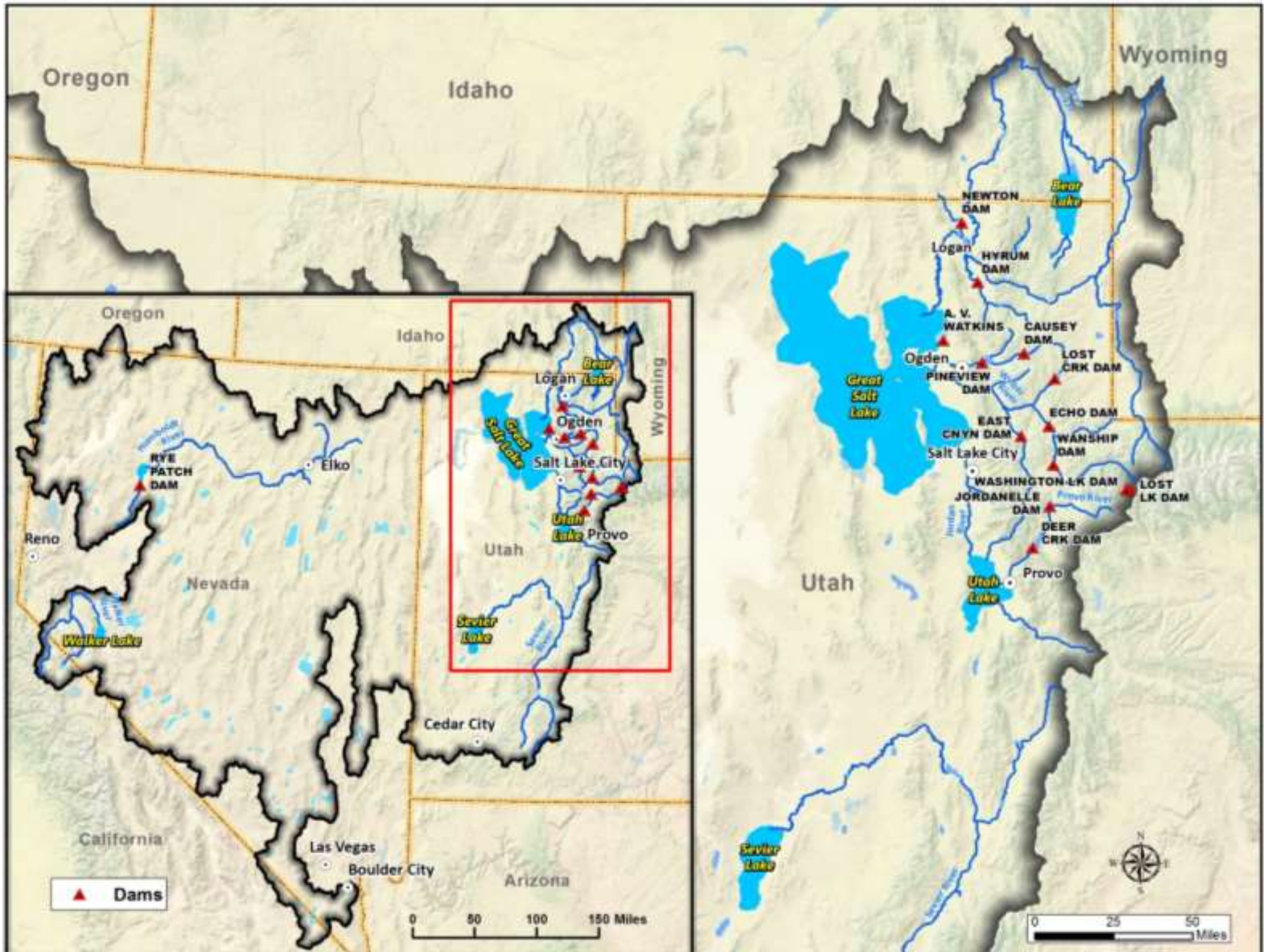

Figure 10–3. Map of the Great Basin.

Public and private development of the water resources of the Great Basin has resulted in the addition of many features for flood control, irrigation, hydroelectric power generation, recreation, improvement of fish and wildlife habitat, and municipal and industrial water supply. Most of the Federally directed water resources development in the basin has been undertaken by Reclamation. The Sacramento District of the U.S. Army USACE of Engineers (USACE) is involved in the management of some of these federal facilities. Reclamation has constructed thirteen irrigation projects in the Great Basin. Nine of these projects are administered by the Provo Area Office of the Upper Colorado Region, including:

- Central Utah Project (Bonneville, Jensen, and Vernal Units)
- Hyrum
- Newton
- Ogden River
- Preston Bench
- Provo River
- Strawberry Valley
- Weber Basin
- Weber River

The Central Utah, Provo River, and Strawberry Valley projects also utilize trans-basin diversions from the Green River system (a tributary to the Colorado River) to the Great Basin for project water supplies.

Reclamation's Lahontan Basin Area Office (LBAO) of the Mid-Pacific Region also has jurisdiction over a large area of the Great Basin, including most of the northern two-thirds of Nevada, with a small amount of overlap into California and Oregon. The main area of LBAO activities is in the Carson, Truckee, and Humboldt River basins, where there are four operating Reclamation projects:[2]

- Newlands Project
- Truckee River Storage Project
- Washoe Project
- Humboldt Project

Climate varies throughout the Great Basin by elevation, latitude, and other factors. Much of the Great Basin is characterized by a semi-arid or arid climate and by basin-and-range topography. Elevation in the region ranges from 283 feet below sea level, the lowest point in North America, to 14,505 feet less than 100 miles away at the summit of Mount Whitney, which is the highest point of the

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[2] Note: Chapter 9: Truckee River Basin Summary includes specific information on the Truckee River Basin setting, implications for various water and environmental resources, adaptation strategies, and coordination activities.

contiguous United States. The western areas of the basin tend to be drier than the eastern areas because of the rain shadow of the Sierra Nevada. Higher elevations tend to be cooler and receive more precipitation, with most Great Basin precipitation falling as snow. Average annual rainfall ranges from 1.5 inches in Death Valley to 40 inches in the Wasatch Mountains. Because of snowmelt processes, natural streamflow is historically highest in the late spring and early summer and diminishes rapidly by mid-summer. While flows in late summer through autumn sometimes increase following rain events, natural streamflow in the late summer through winter is generally low compared to spring and early summer. Key generalizations related to projected changes in temperature, precipitation, snowpack, and runoff are presented below:

- **Temperature** is projected to increase approximately 2.7 to 8.1 °F by the latter half of the 21st century for the Great Basin region. The largest increases are projected for the summer months. Reasonable consensus is also seen in the literature with respect to projected increases in extreme temperature events, including more frequent, longer, and more intense summer heat waves in the long-term future compared to the recent past (USACE, 2015).
- **Precipitation** projections in the study basin are less certain than projections associated with air temperature. Results of the studies reviewed here are roughly evenly split with respect to projected increases versus decreases in future annual precipitation. There is, however, moderate consensus among the reviewed studies that future storm events in the region will become more intense and more frequent compared to the recent past (USACE, 2015).
- **Streamflow** projections are variable. In some cases, models indicate minimal change in future streamflow, but in other cases indicate a potential increase in runoff and/or streamflow in the Great Basin region (USACE, 2015).

Potential climate change impacts on agricultural, municipal and industrial, and in-stream water demands are difficult to predict, and existing information on the subject is limited. It is widely accepted that water demands will change due to increased air temperatures; increased atmospheric carbon dioxide levels; and changes in precipitation, winds, humidity, and atmospheric aerosol and ozone levels. Furthermore, these natural-system changes must be considered in combination with socioeconomic changes, including infrastructure, land use, technology, and human behavior. Key projections related to changes in demand are summarized below.

- Agricultural irrigation is the predominant water demand in the Great Basin and throughout the greater western United States (Frederick, 2001). The seasonal volume of agricultural water demand could increase if growing seasons become longer, assuming that farmers could adapt to this opportunity by planting more crop cycles per growing season.

- Additionally, agricultural water demand could decrease due to crop failures caused by changes in pests and diseases in the future.
- In addition to changes in water demands associated with natural processes, which are difficult to quantify, municipal and industrial consumption is projected to increase due to population growth.
- Domestic water use is not very sensitive to changes in temperature and precipitation (Frederick, 2001), and water conservation measures may reduce potential increases in per capita water usage, thereby offsetting potential increase in population.
- Climate change also could result in changed demands for in-stream flows or reservoir releases to satisfy other system objectives, including ecosystem support, hydropower generation, municipal and industrial water deliveries, river and reservoir navigation, and recreational uses.
- Water demands for endangered species and other fish and wildlife could increase with ecosystem impacts due to warmer air and water temperatures and resulting hydrologic impacts (e.g., runoff timing).
- Diversions and consumptive use by industrial cooling facilities are predicted to increase, since these processes will function less efficiently with warmer air and water temperatures. The timing of these diversions and those for hydropower production also could be a factor in ecosystem demands and navigation and recreational water uses.

As climate change might affect water supplies and reservoir operations, the resultant effects on water allocations from year to year could increase pressure for water uses (e.g., crop types, cropping dates, environmental flow targets, transfers among different uses, hydropower production, and recreation). Such climate-related changes in water use would interact with market influences on agribusiness and energy management, demographics, land use changes, and other non-climate factors.

2.2 Coordination Activities

Interest in ensuring the sustainability of water resources in the Great Basin is broad and includes Federal, state, and local governments, tribes, agricultural users, purveyors of M&I water, power users, and conservation and recreation groups. Water management in the basin is complex, as are the challenges associated with balancing competing needs such as water delivery, hydropower generation, and environmental protection. To meet such challenges, various stakeholders have implemented programs and initiatives, each with its own set of goals, objectives, approaches, and processes, in various parts of the basin. These stakeholders recognize that cross-program coordination and information exchange are important strategies that can allow such programs to work together and focus resources to address basin-wide challenges.

2.2.1 Utah Reclamation Mitigation and Conservation Commission

The Utah Reclamation Mitigation and Conservation Commission (Mitigation Commission) is a Federal agency authorized under the Central Utah Project (CUP) Completion Act of 1992. The Act set terms and conditions for completing the Central Utah Project, which diverts, stores, and delivers large quantities of water from numerous Utah rivers to meet the needs of central Utah's citizens. The Mitigation Commission is responsible for designing, funding, and implementing projects to offset the impacts to fish, wildlife, and related recreation resources caused by CUP and other Federal water management projects in Utah.

Many mitigation projects require completing efforts initially administered by Reclamation and the Department of the Interior, now two of the Mitigation Commission's most important partners. Under the Mitigation Commission's umbrella authority, other Federal and Utah state agencies, local governments, universities, non-profit organizations, and the Ute Tribe cooperate through agreements with the Mitigation Commission to implement a wide variety of ecosystem restoration and wildlife conservation projects in Utah, including:

- Diversion dam modifications
- Provo River Restoration Project
- Angler access
- Wetland preservation and restoration
- Aquatic and riparian habitat restoration
- Native species recovery and sensitive species inventory
- June Sucker Recovery Implementation Program

Annual funding for Mitigation Commission projects depends on Congressional appropriations through the Secretary of the Interior as part of the Department of the Interior's Central Utah Project Completion program.

2.2.2 Weber River Collaboration

2.2.2.1 Weber River Management Plan

This Weber River Water Management Plan was prepared for the Weber River Water Users Association (WRWUA) with partial funding from a Reclamation Water Conservation Field Services Program grant. Cost share partners include WRWUA, Weber Basin Water Conservancy District, Davis and Weber Counties Canal Company, and the Weber River Water Rights Committee. Several other private, state, and Federal entities were also involved during the preparation of the Management Plan.

The Weber River and its tributaries are the sole source of water for three Reclamation projects (Weber River, Ogden River, and Weber Basin Projects), and a contributing source for a fourth (Provo River Project). Numerous other private developments also depend on the Weber River for water. Population in the Weber River basin area has increased significantly in the several decades since these projects were constructed. This growth is expected to continue into the future, placing increasing demands on the limited water supply. Because of the importance of the Weber River to the multiple agricultural, municipal, industrial, power, recreational, and environmental interests in the area, effective water management and planning are critical needs.

The Management Plan was prepared to provide a database of information related to the management and operation of the Weber River system, to describe the current operations of the major projects and facilities on the Weber River, and to identify and adopt measures for improving the management of the system.

2.2.2.2 *Weber River Symposium*

The Weber River is a valuable watershed to the people of Utah. It has shaped the charismatic landscape of northern Utah and it is the primary source of water for drinking, irrigation, recreation, and industrial uses. The Weber River also provides recreational opportunities, fish and wildlife habitat, and the cornerstone for current and future economic development. Over the past year, individuals representing cities, counties, water users, conservation districts, and private/state/Federal agencies have collaborated to establish the Weber River Partnership and a restoration framework through the development of a Weber River Watershed Plan. In conjunction with the plan, the Partnership established an annual forum where stakeholders can gather to discuss major conservation efforts, challenges, and realities throughout the watershed.

The Weber River Symposium is designed to bring together stakeholders with an interest in the Weber River, and to develop and strengthen partnerships. The inaugural Weber River Symposium was a 2-day event held in Ogden, Utah, in November 2014. The event was well attended by Federal, state, and local water managers, including Reclamation, as well as local officials and the public. Ogden City Mayor Mike Caldwell was the keynote speaker for the symposium.

2.2.3 Science and Technology Research

Since 2013, Reclamation’s Research and Development Office has provided funding through its Science and Technology Program to investigate climate change and variability impacts to water resources along the Wasatch Front. In one study, researchers are studying whether tree rings from local species can provide longer records of climate impacts for better future planning (Liljegren, 2013). City planners and others in the Wasatch Front area of Utah could utilize the results to determine previous climate impacts and forecast supplies in the future. Collaborators include Utah State University, Columbia University’s Lamont-Doherty Earth Observatory, Brigham Young University, and various Irrigation Districts.

In 2014 and 2015, Reclamation’s Research and Development Office also provided funding through its Science and Technology Program to investigate infrequent large groundwater recharge events and their importance for long-term groundwater availability, use, and management. This research was conducted in collaboration with the USGS Utah Water Science Center to address the information gap of climate change effects on groundwater and the resultant impacts to surface-water supply over the next several decades. This study assisted Reclamation in developing a methodology that could be applied drainage-basin by drainage-basin across the western United States. The assessment method consistently provides information about the relative importance of groundwater in support of basin-specific surface-water flow and illustrates how changing climate conditions (i.e., changes in groundwater recharge) might affect future stream-flow volumes in these drainage basins.

3 Arkansas-Red-White River Basin

The Arkansas-Red-White River Basin encompasses the entire state of Oklahoma and portions of Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, and Texas. The three basins (the Arkansas, Red, and White River Basins) drain about 280,000 square miles involving all or parts of eight states, 331 counties, and 28 congressional districts.

Arkansas-Red-White River Basin Setting

States: Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, Oklahoma, and Texas

Major U.S. Cities: Little Rock, Pueblo, Wichita, Springfield, Oklahoma City, Tulsa, Amarillo, and Wichita Falls

River Length: 1,500 miles

River Basin Area: 280,000 square miles

Major River Uses: Municipal (6 million people), Agricultural, Flood Control, Navigation, Recreation, and Ecological Uses

Key Studies Referenced in this Report: Upper Red River Basin Study and Upper Washita Basin Study

3.1 Basin Setting

Water uses in the basin include navigation, hydropower, irrigation, recreation, fish and wildlife, and municipal and industrial water supply. The region has a population of about 6 million and includes the following metropolitan areas:

- Fort Smith and Little Rock, Arkansas
- Pueblo, Colorado
- Dodge City and Wichita, Kansas
- Shreveport and Alexandria, Louisiana
- Tucumcari, New Mexico
- Springfield and Joplin, Missouri
- Oklahoma City and Tulsa, Oklahoma
- Amarillo and Wichita Falls, Texas

Public and private development of the water resources of the Arkansas, Red, and White River basins has resulted in the addition of many features for flood control, navigation, irrigation, generation of hydroelectric power, recreation, improvement of fish and wildlife habitat, and municipal and industrial water supply. Most of the Federally directed water resources development in these basins has been undertaken by the USACE. Reclamation has constructed only three irrigation projects in the Arkansas-Red-White River basins.

Arkansas River

The headwaters of the Arkansas River are fed by snowpack from the Sawatch Range of the Rocky Mountains near Leadville, Colorado. From its headwaters, the Arkansas River flows 1,460 miles through Kansas, Oklahoma, and Arkansas to its confluence with the Mississippi river near Arkansas City, Arkansas. The Arkansas River drainage basin covers nearly 161,000 square miles.

White River

The White River forms in the Boston Mountains of northwest Arkansas and flows for 722 miles to the Mississippi River in Desha County, Arkansas. The White River drains a watershed of 17.8 million acres across 60 counties in two states, Arkansas and Missouri.

Red River

The Red River is a major tributary of the Mississippi and Atchafalaya Rivers. It is formed by two branches, both originating in the Texas panhandle. The larger, southern fork, known as the Prairie Dog Town Fork, begins in Randall County, Texas. The smaller, northern fork, known as the North Fork, begins near Pampa, Texas, and flows eastward and then southward until it joins with the Prairie Dog Town Fork along the Texas-Oklahoma border. Combined, the two forks form the main stem of the Red River. The Red River's total length is 1,360 miles and its watershed covers 65,590 square miles throughout Arkansas, Louisiana, Texas, and Oklahoma, making it the second largest river basin in the southern Great Plains. The Red River Basin receives little precipitation, and flows can be intermittent in the portions above Arkansas. The basin's flat, fertile agricultural land is supported largely through groundwater.

3.2 Coordination Activities

Reclamation has recently initiated two Basin Studies in the Arkansas-Red-White River basin, the Upper Washita Basin Study and the Upper Red River Basin Study, which are described below (Figure 10–4).

Upper Washita Basin Study

Reclamation is collaborating with the Oklahoma Water Resources Board (OWRB), in partnership with the Foss and Fort Cobb Reservoir Master Conservancy Districts (MCD), to evaluate water management issues in the Upper Washita River Basin in west-central Oklahoma. The study area comprises more than 5,000 square miles of drainage area in west-central Oklahoma, along with the Texas panhandle. The area of study includes the Rush Springs aquifer, a critical agricultural supply source that supplies many springs and streams and provides unique environmental, recreational, and cultural values to the area. Reclamation's Washita Basin Project, composed of both Foss and Fort Cobb Reservoirs, provides 90 percent of the surface water supplies in the study area, including municipal water to 40,000 people and two power generation facilities.

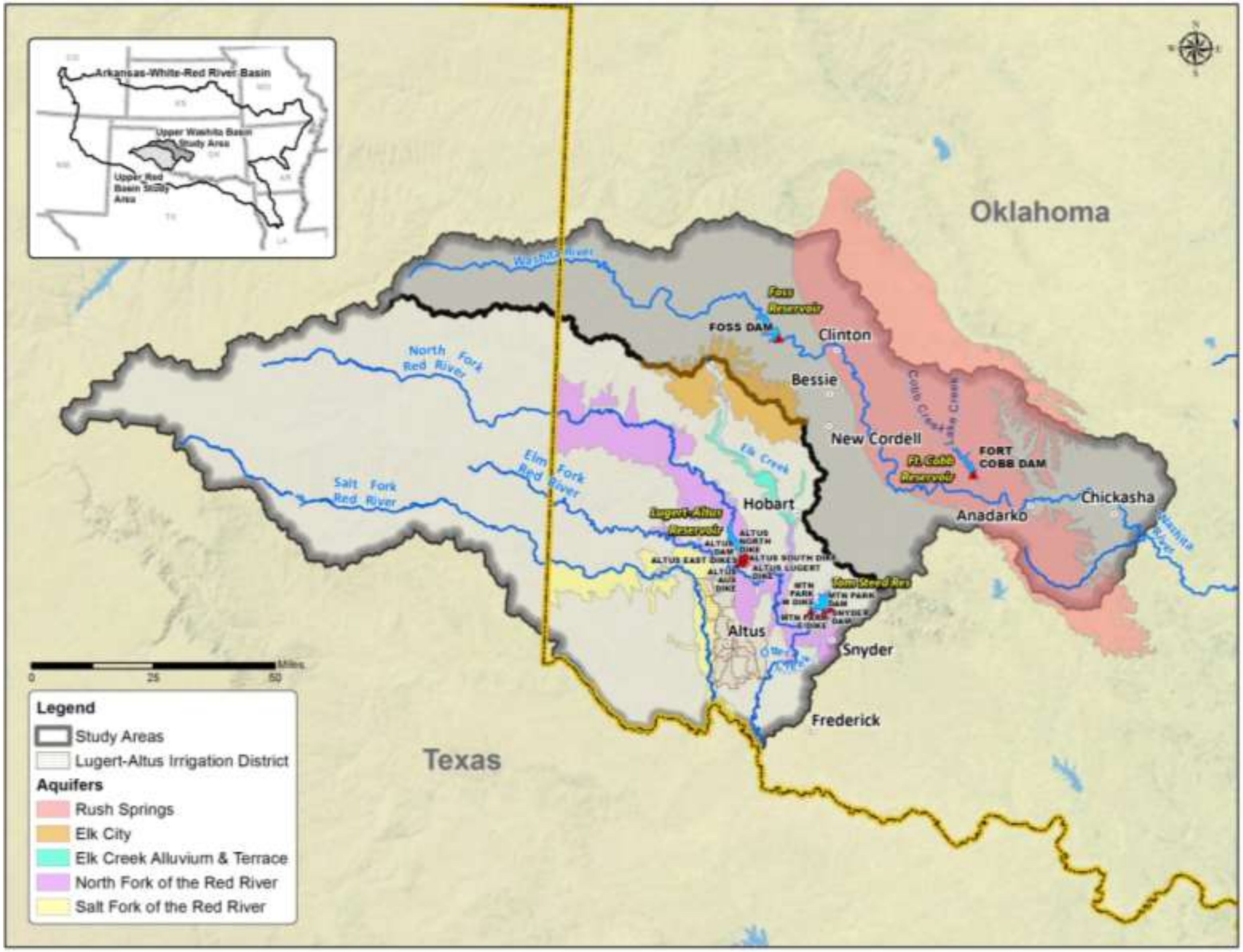

Figure 10–4. Location of on-going basin studies in the Arkansas-Red-White River Basin.

Both reservoirs are currently experiencing challenges due to aging, inefficient, and/or undersized infrastructure. Fort Cobb Reservoir MCD, for instance, has been unable to meet peak water demands for up to 4 months every year for the past 12 years due to an undersized and inefficient aqueduct system; Foss Reservoir MCD is having trouble meeting the immediate needs of its member cities due to the limited capacity of its treatment plant. Long-term supply reliability is also a challenge.

According to the recently completed 2012 Oklahoma Comprehensive Water Plan, demands are projected to increase substantially by 2060 for all uses in the study area. Under current permitting procedures, depletions in the Rush Springs aquifer are forecast throughout much of the study area by 2020. These depletions may reduce flows of Cobb Creek, which contributes to Fort Cobb reservoir's firm yield, and therefore threaten the reliability of Fort Cobb reservoir as a supply source. Also of concern are whether climate-related changes in precipitation, run-off and evaporation rates may affect aquifer recharge and reservoir yield.

The Upper Washita Basin Study, which is expected to be completed in 2016, will:

- Characterize and quantify surface and groundwater resources;
- Develop a surface water allocation model to evaluate various water management options, including protecting the future water supply capabilities of Foss and Fort Cobb reservoirs;
- Assess operational and infrastructure constraints associated with Foss and Fort Cobb reservoirs; and
- Evaluate alternatives to address water supply issues facing the study area, both now and in the future.

Upper Red River Basin Study

Reclamation is collaborating with the Oklahoma Water Resources Board (OWRB), in partnership with Lugert-Altus Irrigation District and Mountain Park Master Conservancy District to evaluate water management issues in the Upper Red River Basin in southwest Oklahoma. The Upper Red River Basin encompasses more than 4,000 square miles and all or part of nine counties in southwest Oklahoma. The region includes tributaries to the Red River, the largest being the North Fork, the Salt Fork, and the Elm Fork of the Red River. The basin contains two Reclamation reservoirs, Lugert-Altus and Tom Steed Reservoirs. These two reservoirs provide 99 percent of the surface water supply sources in the study area to almost 45,000 people and irrigation water for 48,000 acres of land.

The water supply needs in the study area are both immediate and severe due to water quantity and quality issues, as well as aging infrastructure. An extreme drought has stricken the area since 2011, and both Lugert-Altus and Tom Steed Reservoirs are at record lows. A large portion of the study area remains in exceptional drought. Groundwater depletions in the area are forecasted to be as high as 17,220 acre-feet per year by 2060, resulting in increased likelihood of localized impacts and potential effects on streamflow.

Additionally, the 2012 Oklahoma Comprehensive Water Plan Update analysis identified six of the twelve subbasins within the study areas that have been forecasted to face significant water supply challenges within the next 50 years. These challenges prompted stakeholders to develop a Southwest Oklahoma Water Supply Action Plan (May 2014) that outlines short-, mid-, and long-term solutions in the area. Using the Southwest Action Plan as a guide, the Upper Red River Basin Study, which is expected to be completed in 2018, will:

- Characterize and quantify surface and groundwater resources;
- Conduct hydrologic investigations on the North Fork of the Red River Alluvium and Terrace, Elk City Sandstone, and Salt Fork of the Red River Alluvium and Terrace to determine the amount of groundwater available for future appropriations;
- Develop a surface water allocation model to evaluate water management options, including protecting the future water supply capabilities of Lugert-Altus and Tom Steed Reservoirs;
- Assess current and future capabilities to meet demands, including operational risks and reliability of the system; and
- Evaluate alternatives to address water supply issues facing the study area, both now and in the future.

In addition to the Basin Study efforts, the USGS will work in collaboration with Reclamation on the Red River Basin Focus Area Study. The USGS will develop products that can support Bureau of Reclamation project that will include: (1) basin-wide water-use data by category (such as municipal, agricultural, and domestic); (2) a groundwater model upstream of the Denison Dam on Lake Texoma to quantify groundwater/surface-water interactions and effects of climate change and increased groundwater withdrawals; (3) expand an existing daily time-step Precipitation Runoff Modeling System model of natural streamflows for the entire Red River Basin, augmenting an ongoing project with the Gulf Coastal Plain and Ozarks Landscape Conservation Cooperative downstream of Lake Texoma; and, (4) an evaluation of future changes to fish assemblages due to changes in flow regime.

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