RECLAMATION
Managing Water in the West

Sacramento and San Joaquin Rivers Basin Study

Basin Study Report and Executive Summary

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.

Citation:
Reclamation, Sacramento and San Joaquin Basins Study, Report to Congress 2015. Prepared for: U.S. Department of the Interior, Bureau of Reclamation, Mid Pacific Region. Prepared By**:** CH2M Hill under Contract No. R12PD80946

Sacramento and San Joaquin Rivers Basin Study Report

U.S. Department of the Interior
Bureau of Reclamation

In Partnership with:
State of California, Department of Water Resources
El Dorado County Water Agency
Stockton East Water District
California Partnership for the San Joaquin Valley
Madera County Resource Management Agency

Disclaimer

The Sacramento and San Joaquin Basins Study was funded by the Bureau of Reclamation (Reclamation) and the California Department of Water Resources (DWR), El Dorado County Water Agency, Stockton East Water District, the California Partnership for the San Joaquin Valley and the Madera County Resource Management Agency and is a collaborative product of the study participants as identified in Section 1 of this report. The purpose of the study is to assess current and future water supplies and demands in the Sacramento, San Joaquin and Tulare Lake Basins and adjacent areas which contribute to or receive water from these basins, and to identify a range of potential strategies to address any projected imbalances.

The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of the Bureau of Reclamation, the Department of the Interior (DOI), or the funding partners (i.e. California Department of Water Resources, El Dorado County Water Agency, Stockton East Water District, California Partnership for the San Joaquin Valley and the Madera County Resource Management Agency). The study does not propose or address the feasibility of any specific project, program or plan.

Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

Acknowledgements

Basin Study Technical Team:

Reclamation-

- Arlan Nickel, Senior Project Manager, Reclamation, Sacramento, California
- Michael Tansey, PhD., Climate Change Coordinator, Reclamation, Sacramento, California

Basins Study Partners -

CH2M Hill-

- Armin Munevar, MS., PE., CH2M Hill San Diego, California
- Brian Van Lienden, MS., PE., CH2M Hill Sacramento, California
- Tapash Das, PhD., CH2M Hill, San Diego, California
- Heidi Chou, MS., PE., CH2M Hill Sacramento, California

Stockholm Environment Institute-

Charles Young, PhD., Stockholm Environment Institute, Davis, California

MWH Americas –

- Andrew Draper, PhD., MWH Americas, Sacramento, California

Technical Sufficiency Reviewers

- Carly Jerla, Lower Colorado Region, Reclamation
- Michael Dettinger, PhD., United States Geological Survey and Scripps Institute of Oceanography, San Diego, California
- Andrew Schwarz, California Department of Water Resources, Sacramento, California
- Raymond Hoagland, California Department of Water Resources, Sacramento, California
- Justin Huntington, PhD., Desert Research Institute, Reno, Nevada

Acronyms and Abbreviations

Basins Study	Sacramento and San Joaquin Basins Study
Bay	San Francisco Bay
California WaterFix	Bay Delta Conservation Plan
CCTAG	Climate Change Technical Advisory Group
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
Delta	Sacramento-San Joaquin Delta
DOF	State of California’s Department of Finance
DWR	California Department of Water Resources
EC	electrical conductivity
ESA	Endangered Species Act
ET	evapotranspiration
GCM	Global Climate Model
GHG	global greenhouse gas
Gulf	Gulf of California
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
M&I	municipal and industrial
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	NOAA National Marine Fisheries Service
NRC	National Research Council
OMR	Old and Middle River
Reclamation	Bureau of Reclamation
SECURE Water Act	The Omnibus Public Land Management Act of 2009 (Public Law 111-11)
SWE	snow water equivalents
SWP	State Water Project
SWRCB	California State Water Resources Control Board
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WaterSMART	Sustain and Manage America’s Resources for Tomorrow
WEAP-CV	Water Evaluation and Planning model of the Central Valley
WQCP	Water Quality Control Plan
WWEP	Western Watershed Enhancement Partnership

Abbreviations for Scenarios

(Used in tables and figures)

CEN	Central Tendency climate scenario
CEN_CT	Central Tendency climate/Current Trends socioeconomic scenarios
CT	Current Trends socioeconomic scenario
EG	Expanded Growth socioeconomic scenario
HD	Hot-Dry climate scenario
HD_CT	Hot-Dry climate/Current Trends socioeconomic scenarios
HD_EG	Hot-Dry climate/Expanded Growth socioeconomic scenarios
HW	Hot-Wet climate scenario
HW_CT	Hot-Wet climate/Current Trends socioeconomic scenarios
RF	Reference-No-Climate-Change climate scenario
RF_CT	Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios
RF_RF	Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario
SG	Slow Growth socioeconomic scenario
WD	Warm-Dry climate scenario
WD_CT	Warm-Dry climate/Current Trends socioeconomic scenarios
WW	Warm-Wet climate scenarios
WW_CT	Warm-Wet climate/Current Trends socioeconomic scenarios
WW_SG	Warm-Wet climate/Slow Growth socioeconomic scenarios

Measurements

°C	degrees Celsius
°F	degrees Fahrenheit
cfs	cubic feet per second
cm	centimeters
GWh	gigawatt hours
km	kilometers
MAF	million acre-feet
mm	millimeters
ppt	parts per thousand
TAF	thousand acre-feet
µS/cm	micro-siemens per centimeter

Executive Summary

The Central Valley and regions that depend on the Sierra Nevada and Coast Range mountains for water have been facing rising demands for water from rapidly increasing populations, changes in land use, and growing urban, agricultural and environmental demands. These demands already exceed the capacity of the existing water management system to supply adequate water—especially in droughts like the one California is now experiencing. Future climate changes are likely to increase the challenges that have already occurred in the 20th century. This Sacramento and San Joaquin Basins Study (Basins Study) builds on previous climate impact assessments and addresses both the potential impacts of climate and socioeconomic changes and explores how these challenges might be addressed (see Section 1. *Introduction* of this Report).

Sacramento and San Joaquin Basins Setting

State: California

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

River Length: Sacramento 445 miles and San Joaquin 366 miles

Sacramento and San Joaquin Basins Study Area: 60,000 square miles

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

Notable Reclamation Facilities: Central Valley Project(CVP) includes 20 dams, 11 power plants, and more than 500 miles of canals.

State Water Project **(SWP)** includes 34 dams, 20 pumping plants, 4 pumping-generating plants, 5 power plants, and more than 700 miles of open canals and pipelines.

Potential Impacts

To determine potential future impacts, this Basins Study evaluated the effects of projected 21st century climate changes along with assumptions about potential population increases and land use changes as summarized in Section 2. *Historic and Future Climate Conditions* of this Report. A range of climate scenarios were compared with a future without climate change as described in Section 3.2. *Climate Scenarios* of this Report.

Climate Impacts

This Basins Study differs from the previous climate impact assessment by using more recent socioeconomic and climate scenarios. In general, this Basins Study found that climate impacts include:

- **Temperatures** are projected to increase steadily during the century, with changes generally increasing from about 1.6 degrees Fahrenheit (˚F) in the early 21st century to almost 4.8 ˚F in the Sierra Nevada Mountains by late in the 21st century.
- **Precipitation** may be only slightly changed especially early in the century with a trend toward increased precipitation in the Sierra Nevada in the late century. However, increased forest evapotranspiration due to warming may reduce runoff from mountain watersheds.

- **Snowpack** will likely decline considerably due to warming particularly in the lower elevations of the mountains surrounding the Central Valley.

- **Runoff** will increase during fall and winter months. Peak runoff may shift by more than a month earlier in some watersheds. Spring runoff will decrease due to reduced winter snowpack.

- **Sea levels** are expected to increase. However, there is considerable uncertainty about the magnitude of increase—which may range from as little as 20 inches to as much as 55 inches in the Sacramento-San Joaquin Delta (Delta) by the end of century.

Socioeconomics trends show that increasing population and urban growth will increase urban water demands while expansion of urban areas into agricultural lands may decrease agricultural demands during the 21st century. This study developed three socioeconomic scenarios for both population and land use changes: Expansive Growth, Current Trends, and Slow Growth as described in Section 3.1. S*ocioeconomic Scenarios* in this Report and Section 7. *Adaptation Portfolios Evaluations* in this Report*.*

Resource Impacts

Impacts to resources identified in the Omnibus Public Land Management Act of 2009 (Public Law 111-11) Section 9503 (SECURE Water Act) were analyzed under five climate scenarios and three socioeconomic scenarios representing a broad range of potential future conditions (see Section 5.3 *Summary of Projected Impacts Under the No Action Alternative* in this Report).

A variety of performance indicators were used to assess how these key resources could be affected by climate change. Figure ES-1 provides a comparison between a future with no climate change and future under a “middle of the road” (central tendency) climate scenario. Green indicates that conditions improved, red that conditions declined, and yellow that there was less than a 10% difference.

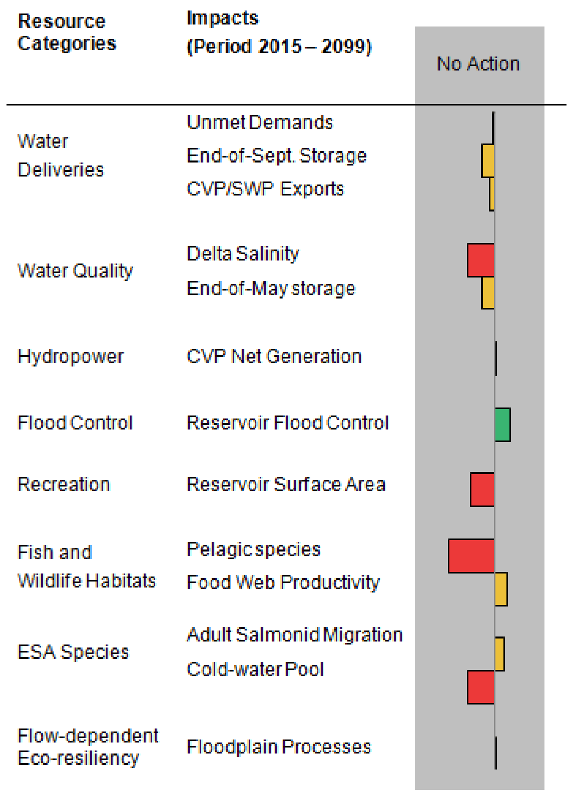


Figure ES-1. Climate impacts under the No Action alternative. (Changes from the Reference-No-Climate-Change to the Central Tendency climate scenario—both under the Current Trends socioeconomic scenario)[1] (Note that red and yellow to the left indicate negative values and the yellow and green to the right indicate positive values.)

For the central tendency scenario, climate impacts include:

- Impacts to **Water Delivery:** Unmet demands increased slightly because increased earlier seasonal runoff caused reservoirs to fill earlier, leading to the release of excess runoff and limiting overall storage capability for water supply and Delta exports.

- Impacts to **Water Quality:** Delta salinity increased significantly due to sea level rise causing increased salinity in the Delta. Storage of cold water in reservoirs was also reduced due to reservoir releases associated with earlier seasonal runoff.

[1] These results depend on the climate-socioeconomic scenarios used in the analysis, as some impacts are greater under scenarios with higher populations and land use and with more extreme variations in temperature and precipitation. Note that food web productivity and cold water pool are discussed in the Technical Report and not in this Report.

- Impacts to **Hydropower:** CVP net generation was relatively unchanged because power production and project use remained relatively balanced given relatively small changes in water supply and deliveries.

- Impacts to **Flood Control:** Increased early season reservoir releases resulted in increased availability of storage for late season flood management.

- Impacts to **Recreation:** Reduced reservoir storage and decreased surface area resulted in fewer recreational opportunities.

- Impacts to **Ecological Resources**

    - **Fish and Wildlife Habitats**: Increased sea level and higher salinity levels reduced habitat for Delta smelt in the San Francisco Bay-Sacramento-San Joaquin Delta (Bay-Delta).

    - **Endangered Species Act (ESA) Species:** Increased Delta salinity and reduced cold water pool availability both contribute to increased risks to Delta smelt and spawning salmon respectively, while reduced export pumping caused by higher salinity Delta conditions benefited adult salmon migration to upstream spawning habitats.

    - **Flow Dependent Ecological Resiliency:** Floodplain processes affecting riparian habits were relatively unchanged because spring reservoir releases were not significantly affected by changes in precipitation.

Addressing these Impacts

Resources specified under the SECURE Water Act were evaluated, and this analysis is detailed in Section 5. *System Risk and Reliability Assessment* in this Basins Study's accompanying Technical Report and summarized in Section 5. *Challenges: Risk and Reliability Assessment* in this Report. To examine what actions and strategies might be used to adapt to future risks to these water and related resources, the Bureau of Reclamation (Reclamation), partners, and other stakeholders worked together to develop and consider a wide range of water management actions to: reduce water demand; increase water supplies; and improve operational efficiency, resource stewardship, institutional flexibility, and data management. These are discussed further in Section 6.3. *Description and Characterization of Adaptation Actions* in the Technical Report. The results for impacts to each SECURE Water Act resource category and how the water management actions may address those impacts are summarized below.

- Actions to Address **Water Delivery:** Water management actions to increase water supplies and improve water use efficiencies and Delta conveyance were particularly effective in addressing impacts to water deliveries.

- Actions to Address **Water Quality:** None of the water management actions were very effective at reducing Delta salinity at either Jersey Point or Vernalis.

- Actions to Address **Hydropower:** None of the water management actions were particularly effective in changing net hydropower generation.

- Actions to Address **Flood Control:** Water management actions that reduced reservoir storage by increasing river flows in the spring and Delta outflows in the fall provided some reductions in potential flood control pool encroachments by reducing pre-winter reservoir storage. These changes were greatest in the Hot Dry climate scenario.

- Actions to Address **Recreation:** Water management actions that increased water storage and/or improved water use efficiency helped to improve the opportunities for recreational uses. However, none of water management actions could effectively mitigate the impacts in the Hot Dry climate scenario.

- Actions to Address **Ecological Resources**

  - **Flow Dependent Ecological Resiliency:** None of the water management actions were particularly effective in improving floodplain processes benefiting the establishment and survival of riparian habitats. Even in the wettest climate scenarios, floodplain processes were only slightly improved.

  - **Fish and Wildlife Habitats**: Water management actions that reduced water demands either by increased water use efficiency or operations intended to promote Delta restoration had some positive effects on improving habitat conditions for Delta smelt. However, these actions were effective only in the wetter climate scenarios.

  - **Endangered Species Act (ESA) Species:** Water management actions associated with the improved Delta conveyance helped to improve adult salmon migration to their upstream spawning habitat.

This Basins Study responds to a fundamental question:

> ***"How well will one or more water management actions work to alleviate anticipated impacts of changing climate conditions to water supplies, demands, infrastructure, and ESA species in the Central Valley?"***

To address these impacts, this analysis combined the water management actions into adaptation portfolios. These adaptation portfolios explore different strategies to address the identified impacts. Note that these portfolios are not mutually exclusive, and no attempt has been made to create a single optimum portfolio. Water management actions could be integrated into many other configurations of portfolios to reflect other management strategies in the Central Valley.

- **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.

- **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** 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** 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** seeks to improve water supply reliability through new surface water storage and groundwater management actions. These 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** 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** includes all water management actions that were included in the California Water Action Plan (California Department of

Water Resources [DWR] 2014). Essentially, this portfolio includes all the water management actions included in the other portfolios.

To understand how well an adaptation portfolio might improve or worsen conditions for a particular resource category under a particular climate-socioeconomic scenario, Figure ES-2 compares the adaptation portfolio performance with the No Action alternative. Green indicates that performance improved, red that performance decreased, and yellow that there was little change. The results presented in Figure ES-2 are for the "middle of the road" climate scenario. The severity of the impacts depends on the climate-socioeconomic scenario and indicators used in the analysis, as well as the resource category being analyzed. Therefore, the results would vary under other climate scenarios.

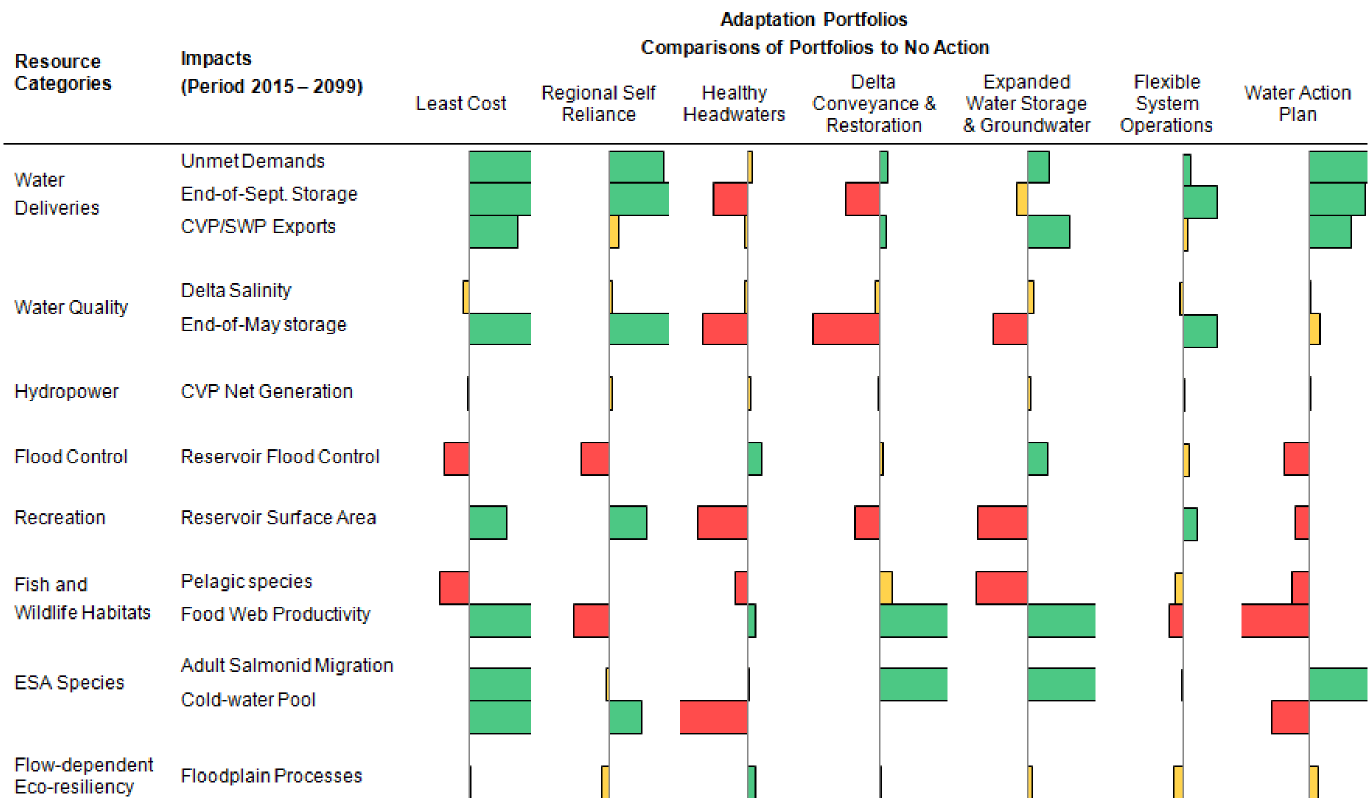


Figure ES-2. Comparisons of Portfolios to the No Action alternative (Changes in impacts under the Central Tendency climate/Current Trends socioeconomic scenario).

Although the Basins Study included a broader range of climate and socioeconomic scenarios, Section 7 *Adaptation Portfolios Evaluation* in this Report is focused on the results for the climate scenarios that represent a "middle of the road" future climate and for the driest and wettest climates with the Current Trends socioeconomic scenario. Section 7 *Adaptation Portfolios Evaluation* in the Technical Report provides this analysis for more climate and socioeconomic scenarios.

Conclusions and Next Steps

The Sacramento and San Joaquin Rivers Basin Study provides an updated climate assessment using the most recently available climate studies to improve our understanding of regional climate impacts relevant to each of the resource categories in the Secure Water Act. Of all climate impacts identified in this Basin Study, two impacts have the greatest potential consequences for water management:

- **Earlier runoff.** Earlier runoff will refill reservoirs earlier, which may force earlier discharge due to the flood rule curves in effect for each reservoir. Implementing adaptive flood rule curves would provide for increased flexibility under future conditions.

- **Sea Level Rise.** Impacts from median sea level rise projected of 90 centimeters (cm) (36 inches) by the end of the 21st century will likely be profound. These increases will cause salinity increases that will have negative effects on water quality for both people and endangered aquatic species such as the Delta smelt. Factors such as tidal and storm surge, combined with sea level rise, could result in Delta island levee failures and more sea water intrusion into the Delta. Implementing actions that improve water deliveries combined with Delta restoration can help to reduce some of these water supply reliability and environmental risks.

Ultimately, the Basin Study is intended to be a catalyst for future collaboration and planning. Developing these water management actions and incorporating them in adaptation portfolios represents an important initial step towards a more comprehensive long-range plan to meet future water demands.

Contents

Tables

Page

Figures

1. Introduction

1.1.Study Purpose and Objectives

This Sacramento and San Joaquin Basins Study (Basins Study) addresses two primary questions:

1. **What is the future reliability of the Central Valley water system in meeting the needs of Basin users during the 21st century?** This Basins Study analyzed potential impacts of climate change along with projections of future population growth and urban density. This study provides an overview of the current climate and hydrology of California's Central Valley (Sacramento, San Joaquin, and Tulare Lake Basins), an analysis of past trends in temperature, precipitation and hydrology, and climate projections developed from global climate models to evaluate the ways that future climatic and hydrologic changes could impact water availability, water demands, water management, and major resource categories within the Central Valley watersheds and surrounding areas receiving Central Valley Project (CVP) and State Water Project (SWP) supplies.

2. **What are the actions and strategies that can adapt to future risks to these water and related resources?** This study developed and evaluated a variety of adaptation portfolios, comprised of potential water management actions designed to address risks in each of the major resource categories.

1.2.WaterSMART: Authorization and Program

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 (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.

The SECURE Water Act and Secretarial Order 3297 established the WaterSMART (*Sustain and Manage America's Resources for Tomorrow*) Program, which authorizes Federal water and science agencies to work with State and local water managers to pursue and protect sustainable water supplies and plan for future climate change by providing leadership and technical assistance on the efficient use of water.

The Basin Study Program, as part of the U.S. Department of the Interior's (DOI) WaterSMART Program, addresses 21st century water supply challenges such as increased competition for limited water supplies and climate change. Through the Basin Studies, the Bureau of Reclamation (Reclamation) works with other Federal agencies, States, Indian tribes, non-governmental organizations, and local partners to identify strategies to adapt to and mitigate current or future water supply and demand imbalances, including the impacts of climate change and other stressors on water and power facilities.

1.3. Previous Studies

This Basins Study complements and builds on several previous climate change impact studies performed by Reclamation as well as other partners, stakeholders, researchers, and participants. Major studies include:

- **SECURE Water Act Report** (Reclamation 2011) was based on 112 climate change projections developed for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment report (IPCC 2007) as part of the World Climate Research Program's Coupled Model Intercomparison Project phase 3 (CMIP3). The primary focus of the 2011 SWA report was on 21st century changes in temperature, precipitation and their impact on "unimpaired" flows in the eight major Reclamation river basins, including the Sacramento and San Joaquin rivers. These flows were simulated to represent what would occur without current infrastructure, reservoir and project operations and regulatory requirements. The report also contained qualitative estimates of impacts on other SECURE Water Act resource categories.

- **The Central Valley Project Integrated Resource Plan (IRP)**, (Reclamation 2013) used the same climate change projections as Reclamation 2011, added sea level rise, and expanded the study area to include the entire CVP service area. The CVP IRP also used similar methods and models as this study to characterize future climate and socioeconomic uncertainties and their impact on water supply, demand, and some related resources. Most significantly, the CVP IRP included current reservoir and conveyance infrastructure, CVP/SWP operational criteria, and regulatory requirements. The CVP IRP provided an initial assessment of socioeconomic-climate impacts and used these results to develop and evaluate a variety of water management actions and portfolios.

- **The Sacramento and San Joaquin Basins Climate Impact Assessment** (Reclamation 2014). Along with an accompanying Technical Report, this impact assessment improved the methodologies and tools developed for the CVP IRP to include all water users in the Sacramento River, San Joaquin River, and Tulare Lake basins, and completed a more comprehensive assessment of impacts from potential climate change in all the resource categories identified by the Secure Water Act.

This Basins Study continues to build upon these earlier studies by:

- Refining climate projection methods and employing a longer historical climate record

- Improving the hydrology, crop water demand, and operations models

- Incorporating new climate projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5), including recent results from paleoclimate studies as well as extending new population and land use change scenarios developed for the latest California Water Plan Update 2013 (California Department of Water Resources [DWR 2014).

1.4.Coordination

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 operating 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 coordinating reservoir releases for endangered species in rivers and the Delta. Similar coordination between agencies is also occurring in implementing the Central Valley Project Improvement Act (CVPIA) and the Trinity and San Joaquin River Restoration Programs.

In addition to the new partnerships formed through this Basins Study and other WaterSMART Program activities, Reclamation’s Mid-Pacific Region has been collaborating closely with DWR in activities related to the California Water Plan (DWR 2014). This coordination has helped develop 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 (California WaterFix), CalFED storage project-feasibility investigations, and the Department of Interior’s 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.

1.5.Study Management Structure

This Basins Study was conducted in partnership with five cost-share partners including the State of California Department of Water Resources (DWR), California Partnership for the San Joaquin Valley, El Dorado County Water Agency, Madera County Resources Agency and the Stockton East Water District. Many other stakeholders, organizations, and the public also participated in the study.

2. Basin Settings

2.1. Water and Infrastructure

The Central Valley is divided into three basins: the Sacramento Valley, San Joaquin Valley, and the Tulare Lake Basin. The major rivers in these regions include:

- The Sacramento River is the largest river in California, with an historic mean annual flow of about 18 million acre-feet (MAF). It drains an area of about 27,000 square miles in the northern Sacramento Valley portion of the Central Valley.

- The San Joaquin River is the second largest river in California, with a mean annual flow of 6 MAF. It drains the San Joaquin Valley in central and southern portions of the Central Valley.

- The Kings, Kaweah, Tule, and Kern Rivers are the major rivers in the Tulare Lake Basin. They have a combined mean annual runoff of approximately 2 MAF. In wetter years, flow from the Tulare Lake region reaches the San Joaquin River.

The Sacramento and San Joaquin rivers both flow into Sacramento-San Joaquin Delta (Delta) which is the largest estuary on the west coast of the United States. In the Delta, these rivers mix under tidal influence with seawater in a complex maze of channels and man-made islands surrounded by levees with internal drains. The Delta drains about 40 percent of California’s land area and has a total area of about 1,150 square miles.

Because they are included in Reclamation’s Central Valley Project (CVP), this Basins Study also includes the upper 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 the CVP is located. The entire area is shown on Figure 1.

Figure 1. Sacramento and San Joaquin Basins study area.

The two major water management projects that provide water supplies to the Central Valley and surrounding areas are:

- **Central Valley Project (CVP).** Reclamation's Central Valley Project consists of 20 dams, 11 hydropower plants, and more than 500 miles of canals that serve many purposes. The CVP provides an average of 3,200 thousand acre-feet (TAF) of water per year to senior water rights holders, 2,200 TAF for CVP irrigation water contractors and approximately 310 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 1,200 TAF of annual supplies for environmental purposes.

- **State Water Project (SWP).** The State of California's State Water Project provides up to about 3,000 TAF/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. The Project includes 34 storage facilities, reservoirs and lakes; 20 pumping plants; 4 pumping-generating plants; 5 hydroelectric power plants; and about 701 miles of open canals and pipelines. The Project provides supplemental water to approximately 25 million Californians and about 750,000 acres of irrigated farmland.

2.2. Population

The Central Valley is carpeted by vast agricultural regions, and dotted with numerous population centers. About 6.5 million people live in the Central Valley today, and it is the fastest growing region in California. Four main population centers in the Central Valley, each roughly equidistant from the next: Redding, Sacramento, Fresno, and Bakersfield. These centers act as hubs for regional commerce and transportation. Other major population centers receiving CVP and SWP water include Stockton, municipalities in the eastern San Francisco Bay area, San Jose in the south Bay and southern California municipalities served by the SWP in the Los Angeles and San Diego regions.

2.3. Climates – Past, Present and Projected

2.3.1. Historic

The Central Valley's climate is referred to as a Mediterranean climate, characterized by hot and dry summers and cool and damp winters. Summer daytime temperatures can reach 90 degrees Fahrenheit (°F) with occasional heat waves bringing temperatures exceeding 115 °F. The majority of precipitation occurs from mid-autumn to mid-spring. The Sacramento Valley receives greater precipitation than the San Joaquin and Tulare Lake basins. In winter, temperatures below freezing may occur, with rare snow in the valley lowlands. Significant snowpack does accumulate in the Sierra Nevada Mountains.

2.3.1.1. Temperature

In California, average annual temperature varies considerably. In coastal regions, the cool waters of the Pacific Ocean keep temperatures relatively lower than in the eastward interior regions of the Central Valley and Mojave Desert (Figure 2). Elevation also plays an important role as seen in the cooler temperatures found in the Sierra Nevada and Coast Range mountains.

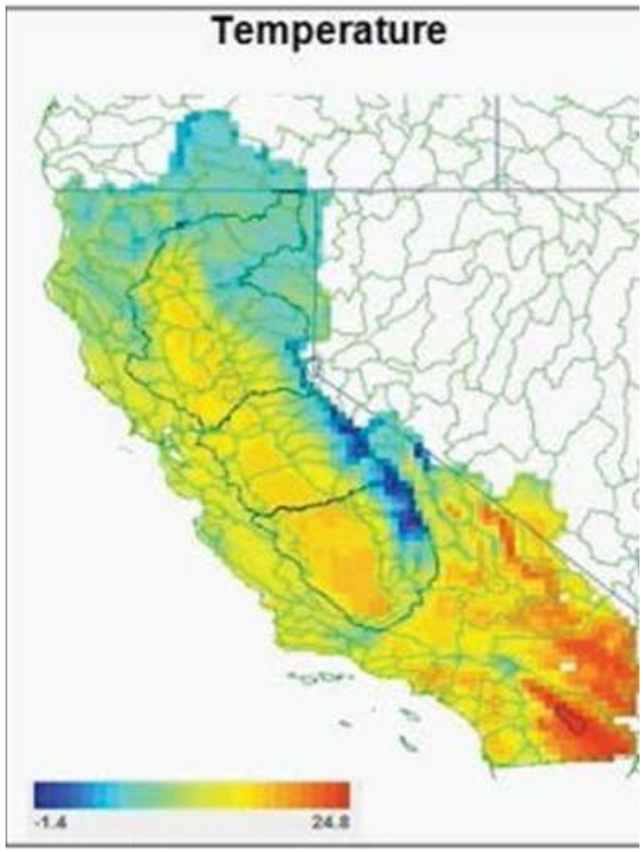


Figure 2. Average annual temperature in °C for 1981 to 2010 (Livneh et al. 2013).

Since the beginning of the 20th century, there has been an overall increase in average annual temperature in California of about 1 ^{o}F (0.6 degrees Celsuis [^{o}C]) (Figure 3). Although there were several periods of decreasing temperature before 1970, the warming trend that has occurred since the late 1970s has accounted for most of the increase. This warming trend also has been observed in North American and global trends. Corresponding trends have also occurred with increasing global greenhouse gas (GHG) atmospheric concentrations during this period.

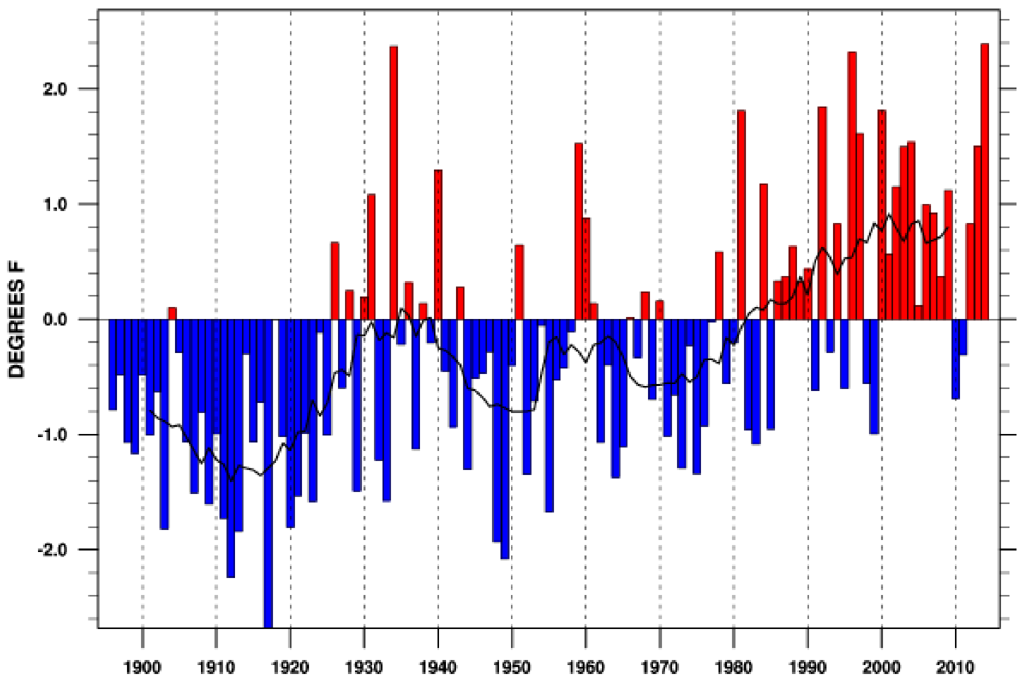


Figure 3. California statewide mean temperature departure (October - September). Notes: Departure of annual water year average surface air temperature for the entire state, 1896-2014. Bars: annual values; solid line: 11-year running mean.

2.3.1.2. Precipitation, Droughts and Floods

In California, precipitation occurs primarily in the late fall and winter months. Average annual precipitation varies considerably. There is a general trend toward increased precipitation in the northern part of the State relative to the south (Figure 4). Precipitation is also strongly influenced by elevation with greater amounts occurring in the coastal and Sierra Nevada mountain regions.

Annual precipitation shows substantial variability with alternating periods of dry and wet spells. Although there is no significant long term annual trend, the annual variability and frequency of high precipitation years appears to have increased in the latter half of the 20th century (Figure 5).

This increased annual variability in precipitation is reflected in the occurrence of drought and floods. Early settlers in the Central Valley struggled with repeated occurrences of floods that turned the valley into an inland sea until flood control measures were finally implemented in the early 20th century. Today, major urban and agricultural areas throughout the Central Valley are protected from flooding by an extensive system of levees and flood control bypasses. The low-lying Delta also depends on a complex network of levees and drains for protection from inundation and flooding. The early 20th century had relatively few extreme precipitation events. However, since 1950, the Central Valley region has experienced significantly more extreme events with major flooding in 1955, 1964, 1982, 1986, 1995, and 1997.

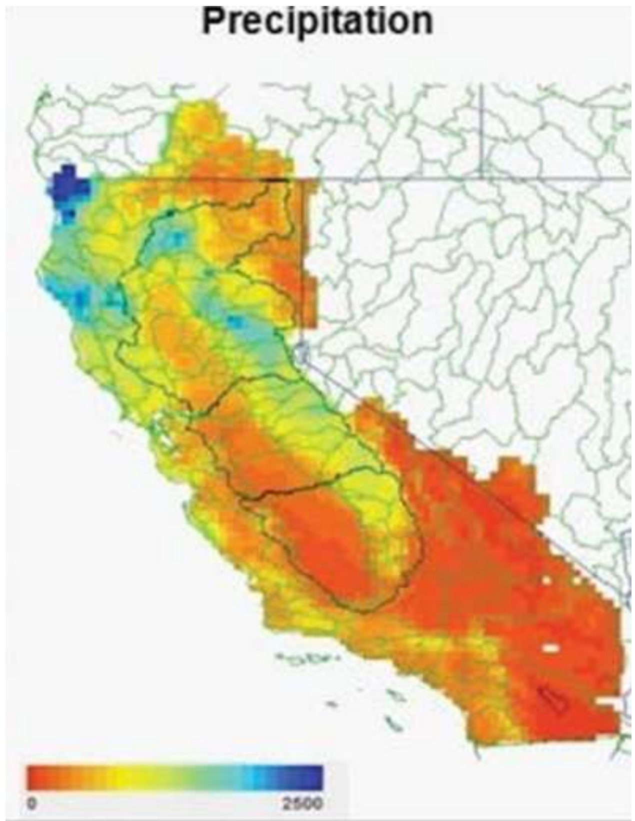


Figure 4. Average annual precipitation in millimeters for 1981 to 2010.

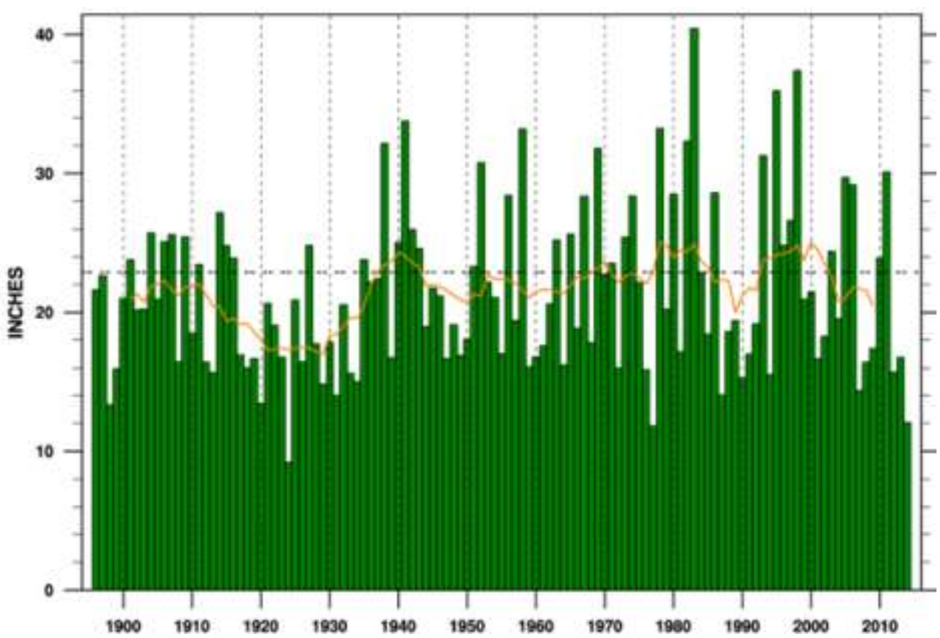


Figure 5. California statewide precipitation (Oct-Sep). Notes: Annual water year average precipitation for the entire state, 1896-2014. Bars: annual values; solid line: 11-year running mean. (Western Regional Climate Center 2015).

Drought has played an important role in shaping California's water supply history. Figure 6 shows some of the periods when the mean flows of the Sacramento and San Joaquin rivers were below their long-term means during the period from 1906 to 2014. The climate and hydrology within the Central Valley basins varies considerably from year to year, and there are frequent droughts. The eight year drought from 1924-1931 (not shown on Figure 6) and the very severe short-term drought from 1975-1977 are among the most significant to have affected the Central Valley and surrounding regions. The deficit that began in 1928 was the most severe in the observed record, lasting for 8 years and accumulating a deficit of more than 66 MAF. The 1976-1977 drought was the most severe 2-year period in the observed record, with an accumulated deficit of about 30 MAF, while the current drought that began in 2012 has accumulated nearly the same amount of deficit from 2012-2014.

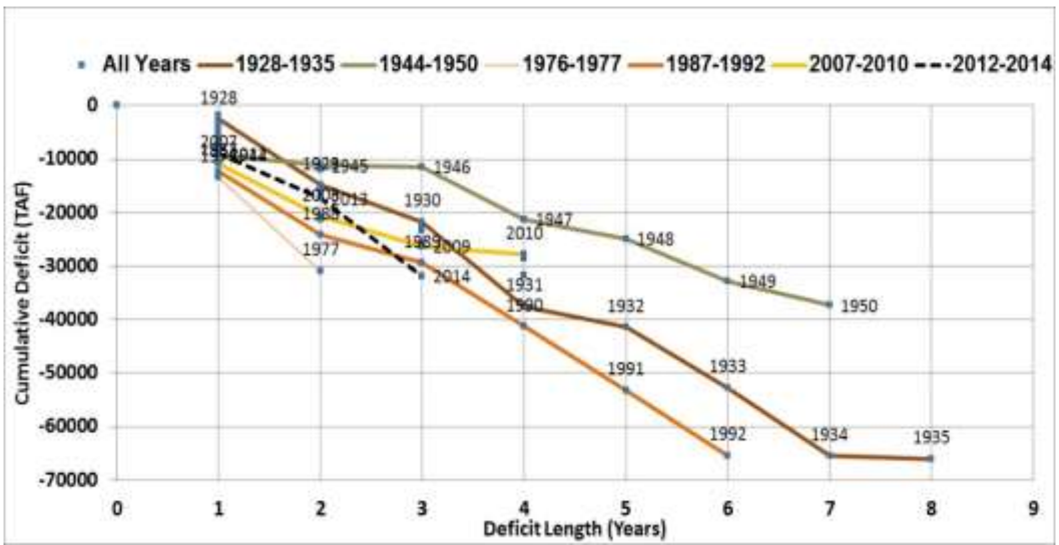


Figure 6. Droughts in Observed Natural Flow Records for the Sacramento and San Joaquin 8 River Index (1928-2014)[2]

Multiple droughts have also been identified in longer time period paleo-climate records (Meko et al. 2014). This paleo-climate analysis indicates that severe droughts of longer duration than eight years are not unique to the historical record.

[2] The Sacramento and San Joaquin 8 River Index is the sum of streamflows of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake. Deficit is defined as a 1-year mean below long-term mean. Note that droughts are defined as cumulative streamflow deficits.

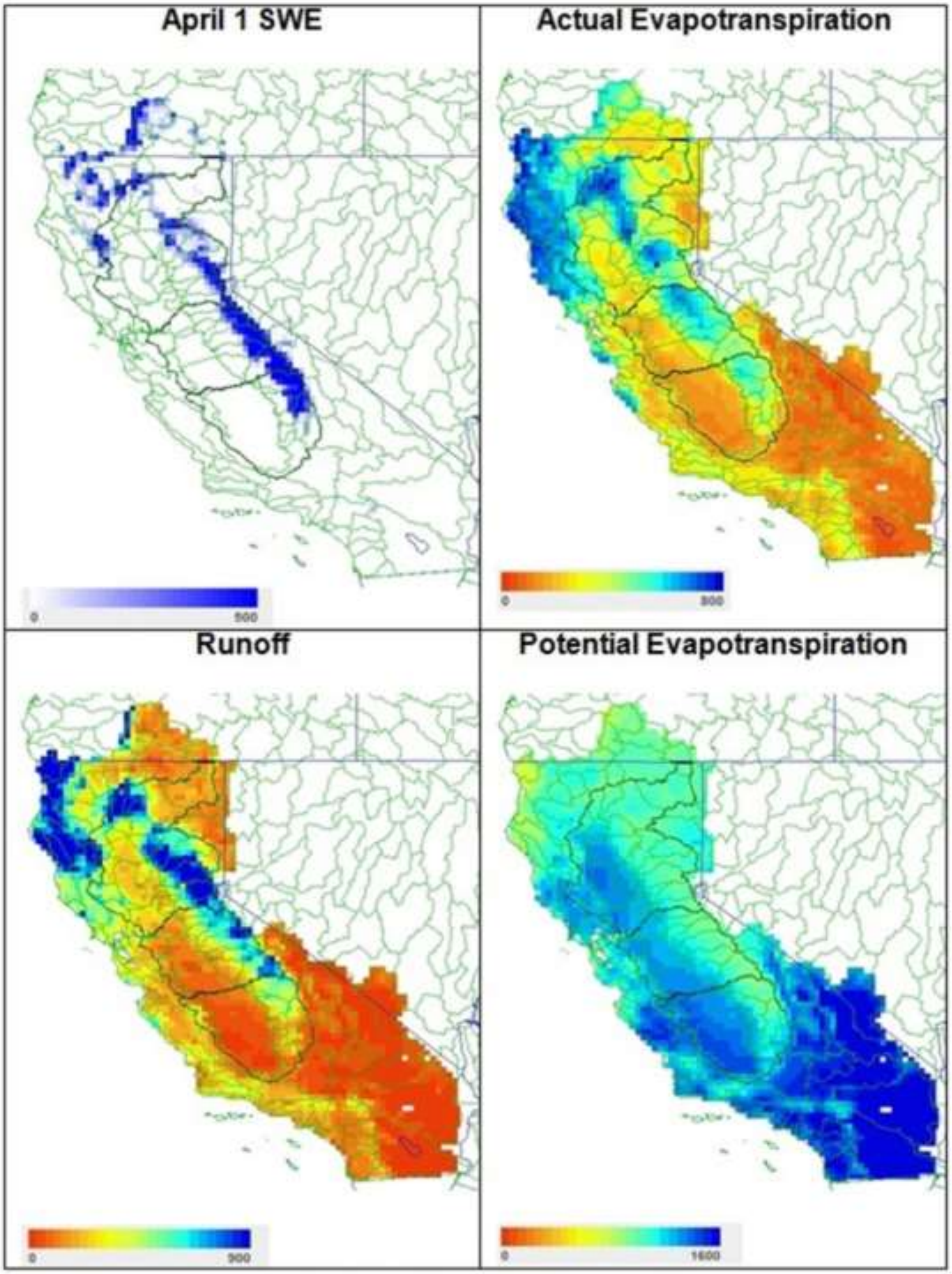
2.3.1.3. Snowpack, Runoff, and Other Hydrologic Processes

Water retained in the snowpack from winter storms forms an important part of the hydrological cycle and water supply in California. In the 20th century, widespread decreases in springtime snowpack have been observed consistently across the lower elevations of the western United States. Snowpack losses tend to be larger at low elevations because rising temperatures cause more precipitation to occur as rainfall at relatively warmer lower elevations. Rising temperatures have also caused the snowpack to melt earlier in the spring causing a shift in the timing of runoff. Changes in snow water equivalents (SWE), a measure of the water content of the snowpack fluctuate on decadal time scales. SWE was estimated to have declined from 1915 to the 1930s; rebounded in the 1940s and 1950s; and—despite a peak in the 1970s—has generally declined since mid-century.

For most Central Valley watersheds, a period of generally below-average runoff and reduced variability occurred before the mid 1930s. Runoff magnitude and variability both increased moderately from 1935 to 1976 (Figure 7). Since 1977, runoff variability increased significantly although the overall average runoff has remained similar to the long term average. Based on the Sacramento and San Joaquin 8 River Index, the total mean annual inflow to the Sacramento and San Joaquin valleys is approximately 23.1 MAF, [3] but annual flows ranged from almost a quarter of that amount (6.2 MAF in 1977) to more than double that amount (52.7 MAF in 1983) from 1922 to 2010 (Figure 8). The timing of runoff is changing because rising temperatures are causing more precipitation to occur as rainfall and snowmelt is occurring earlier in the spring. In the Sacramento and San Joaquin basins, the shift in the peak runoff from 1980 to 2010 is more than 60 days earlier relative to the overall period from 1922 to 2010 (Figure 8).

In the Sierra Nevada and Coast Range mountains, winter precipitation may accumulate temporarily as snowpack which when it melts in spring may either runoff or infiltrate into the ground. When precipitation exceeds the soil's infiltration capacity, runoff begins to occur. The Central Valley's water supply depends to a considerable degree on the balance between precipitation and evapotranspiration (ET). Much of the infiltrated water is returned to the atmosphere by plant transpiration and soil evaporation— leaving only a relatively small fraction of the seepage available for groundwater recharge. Figure 7 summarizes the snowpack, runoff, and evapotranspiration from 1981 to 2010.

[3] Note: 1 MAF = 1,000 TAF

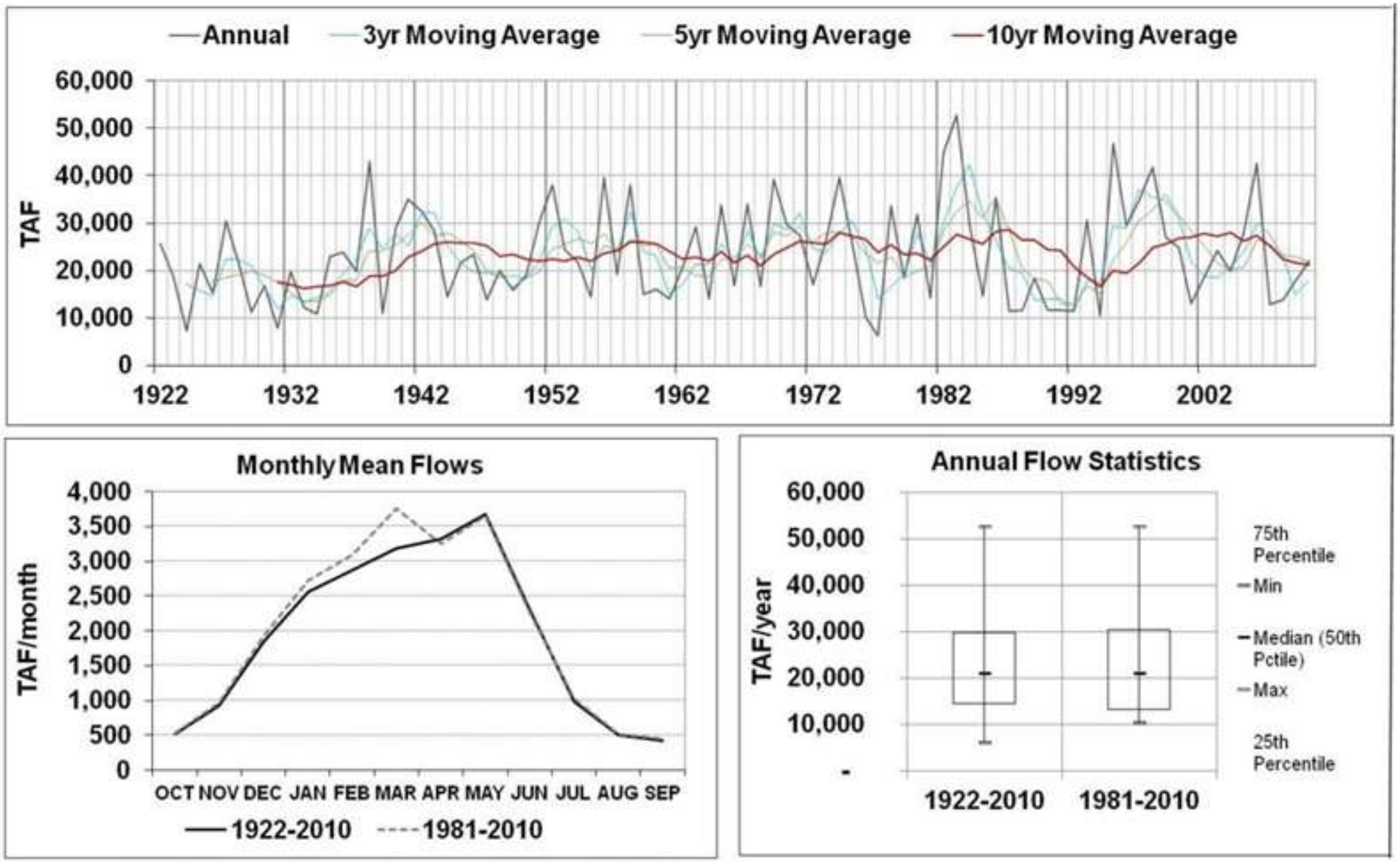


Source: Derived from historical VIC simulation as performed by Livneh et al. 2013

Figure 7. Estimated Average April 1 SWE, Runoff, and Actual and Potential ET from 1981 to 2010, in mm. (1 inch = 25.4 mm) (Livneh et al. 2013).[4]

---

[4] As the names imply, potential ET is the maximum that would occur if moisture supply was unlimited and actual ET is the result of physically limited soil moisture.



Note: The Sacramento and San Joaquin 8 River Index is the sum of streamflows of Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

Figure 8. Sacramento and San Joaquin 8 River Index natural streamflow snapshot analysis.

2.3.1.4. Sea Levels

During the 20th century, the mean sea level in San Francisco Bay has risen by an average of 2 millimeters (mm) (0.08 inches/year) per year and 8 inches per century (Anderson et al. 2008). Over the past several decades, sea level measured at tide gages along the California coast has risen at rate of about 6.7 to 7.9 inches (17 to 20 centimeters [cm]) per century (Cayan et al. 2009). Although there is considerable variability among gages along the Pacific Coast, primarily reflecting local differences in vertical movement of the land and length of gage record, these observed rates are similar to the global mean trend (NOAA 2012).

2.3.2. Projected Climate Changes

> **About this analysis:**
>
> Unless noted otherwise, the climate changes described in this section are based on the Central Tendency climate scenario, discussed in Section 3.2. *Climate Scenarios* in this Report.

It is always important to remember that climate projections are not predictions of future conditions—rather they are intended to provide information on how a variety of uncertain factors might impact future climate changes. The projected climate changes discussed in this section were developed from the most recent global climate change simulations of the Intergovernmental Panel on Climate Change (IPCC 2014) and the Coupled Model Intercomparison Project Phase 5 (CMIP5). The CMIP3 and CMIP5 projections vary within the Central Tendency climate scenario, but the range of climate scenarios and projected impacts remains similar to those identified in the Sacramento and San Joaquin Basins Climate Impact Assessment (Reclamation 2014). Both projections indicate that warming is projected to reduce snowpack in the basin and result in moisture falling as rain instead of snow at lower elevations, which will increase wintertime runoff and decrease summertime runoff. These global projections were spatially refined and adjusted to regional conditions by Reclamation (2013) to make them suitable for use in this Basins Study.[5] See Section 4.1.2. *Assessment of Future Water Supply* in the Technical Report.

2.3.2.1. Temperature

Temperatures are projected to increase steadily during the century, with generally greater changes occurring farther away from the coast, reflecting a continued ocean cooling influence. In the Central Valley, warming increases by about 1 ^{o}C (1.6 ^{o}F) in the early 21st century and about 2 ^{o}C (3.2 ^{o}F) at mid-century—reaching almost 3° C (4.8 ^{o}F) in the easternmost portions of the study area by late in the 21st century. Figure 9 shows these projected changes in average annual temperature, relative to averages from 1981 to 2010 period, during the early (2025), middle (2055), and late (2084) 21st century for the Central Valley and surrounding areas.

[5] As future climate conditions cannot be projected with certainty, this Basins Study used a suite of climate projections to look at a range of possible climate futures (described in the Climate Scenarios subsection of this Report and Section 2.1.2 *Socioeconomic and Climate Scenarios* of the Technical Report).

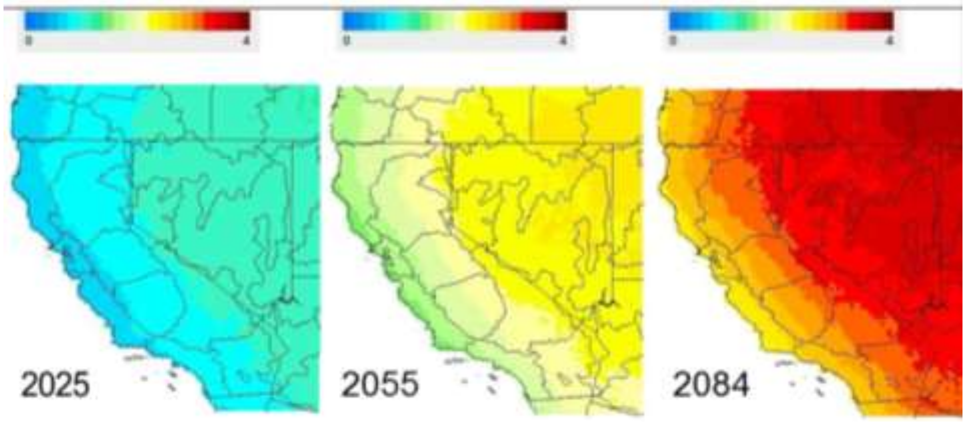


Figure 9. Projected annual average temperature changes (°C) in the early, mid, and late 21st century.

2.3.2.2. Precipitation, Droughts and Floods

Projections of future precipitation have a much greater range of variability than those for temperature. Trends in annual precipitation also are not as apparent as temperature trends. Figure 10 shows the projected changes in annual average precipitation expressed as a percentage change from 1981 to 2010 averages during the early (2025), middle (2055), and late (2084) 21st century for the Central Valley and surrounding areas.

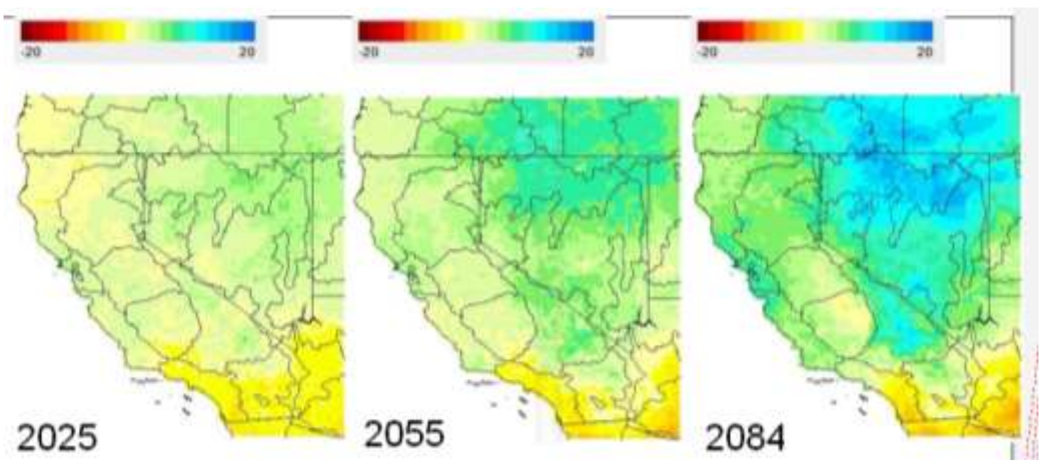


Figure 10. Projected annual average precipitation changes (percent) in the early, mid and late 21st century.

The projected changes in annual average precipitation in the Central Valley basins show a clear north to south trend of decreasing precipitation similar to historical conditions. This trend is projected to continue throughout the 21st century. In the northern part of the Sacramento Valley, projections indicate a slight increase of about 2 percent in precipitation around the mid-century period with increases continuing into the late century. In the San Joaquin Basin, the projected increase in precipitation is about 1% while the Tulare Lake Basin has a small decrease in precipitation at the mid-century period. These trends continue into the late

21st century (2080). The southern Sierra Nevada Mountains to the east of the Tulare Lake Basin show the largest increase in precipitation, especially in the late century (Figure 10).

As explained in Section 3, this Basins Study developed a wide range of climate scenarios. Although the climate scenarios were not explicitly developed to analyze for floods and droughts, it is possible to gain some insights from them:

- **Floods.** Comparing a climate scenario with the most moisture (Warm-Wet) against a climate scenario without climate change (Reference-No-Climate-Change) sheds some light on the high range of potential flood management impacts. The Warm-Wet climate scenario has a 20% more risk of flooding as indicated by the percentage of months when Folsom Reservoir will be within 10 TAF of the flood conservation pool (the amount of available reservoir storage dedicated to flood control). This is discussed further in Section 7.6. *Flood Control* and noted on Table 27 of this Report,

- **Droughts.** Comparing a future with the least moisture (Hot-Dry) against a scenario without climate change (Reference-No-Climate-Change) provides some insight on the high range of potential drought impacts. The Hot-Dry climate scenario has a 364% greater potential for drought as indicated by the potential occurrence of low carryover storage in the Sacramento Valley reservoirs. This is discussed in Section 7.2.2. *End-of-September Storage* and noted on Table 13 of this Report.

.

2.3.2.3. Snowpack, Runoff and other Hydrologic Processes

Snowpack as measured by April 1st SWE is projected to decrease continuously throughout the 21st century (Figure 11). The greatest changes will occur in the lower elevations of the basins. By 2025, the Sacramento Valley watershed is projected to experience decreases in the April 1st SWE in the range from 10% in the higher portions of the watershed to 70% in the lower elevations (Figure 11). By the end of the century, even the highest elevations may see a decrease of 70%. The San Joaquin and Tulare Lake basins will also experience considerable declines.

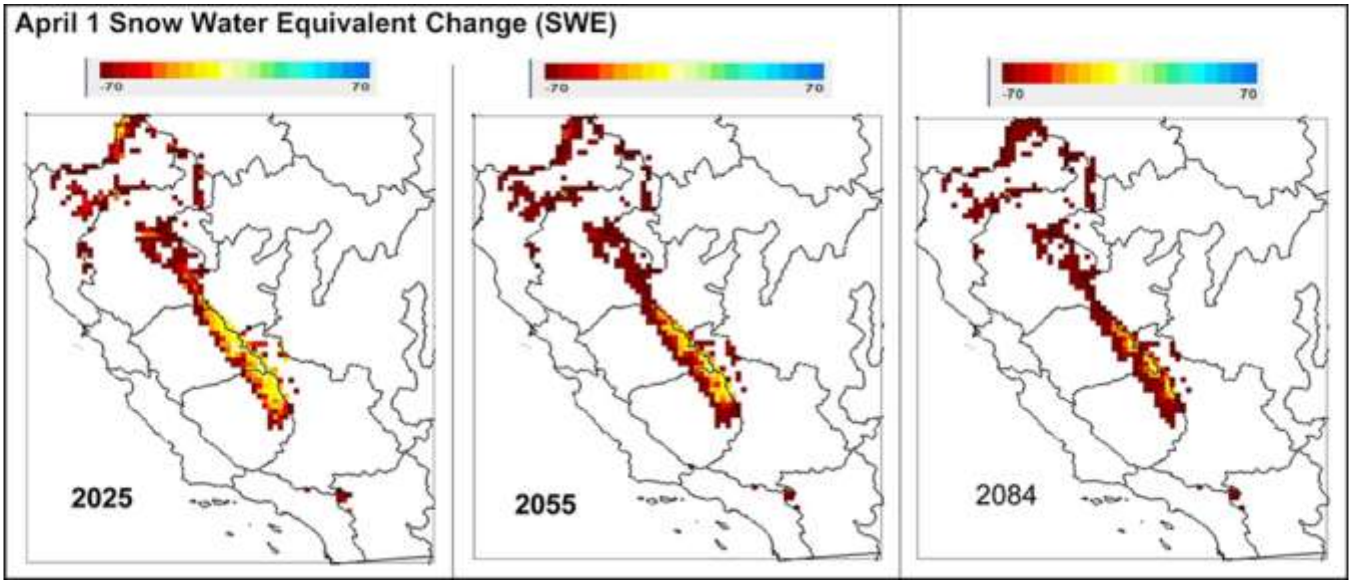


Figure 11. Median projected percent change in April 1 SWE for 2011-2040 (2025), 2041-2070 (2055), and 2070-2099 (2084).

Potential ET is projected to continuously increase during the 21st century (Figure 12). The greatest changes will occur in the lower elevations of the basins. By 2025, the Sacramento Valley watershed is projected to experience increases of up to 4%. By the end of the century, even the higher elevations may see an increase of 8%. The San Joaquin and Tulare Lake basins will also experience similar declines.

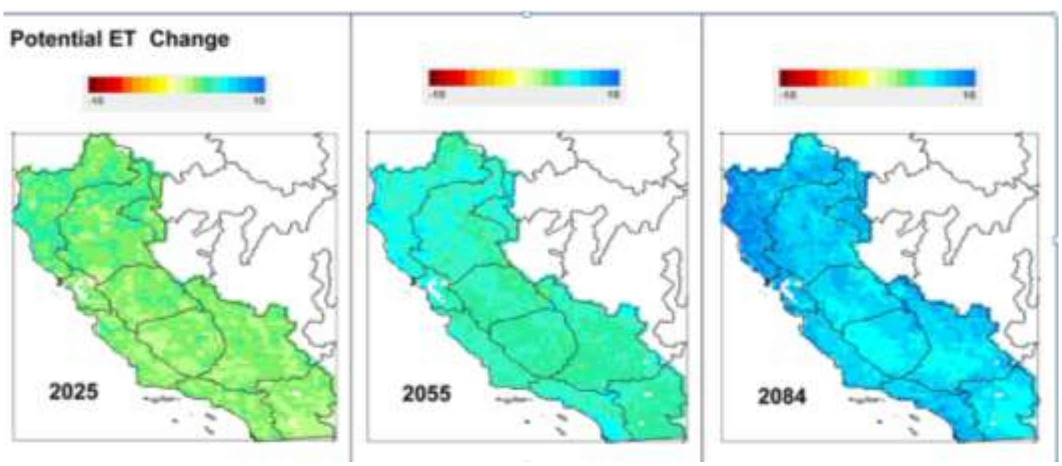


Figure 12. Median projected percent change in annual potential ET for 2011-2040 (2025), 2041-2070 (2055), and 2070-2099 (2084).

Actual ET is projected to increase continuously during the 21st century, primarily in higher elevations of the mountains surrounding the Central Valley. By the end of the century, a 15% increase in actual ET may occur in the forested regions of the northern and central Sierra Nevada Mountains (Figure 13). These higher watershed regions experience more pronounced impacts because increased warming will increase the length of the growth period—resulting in the forest vegetation transpiring more of the soil moisture.

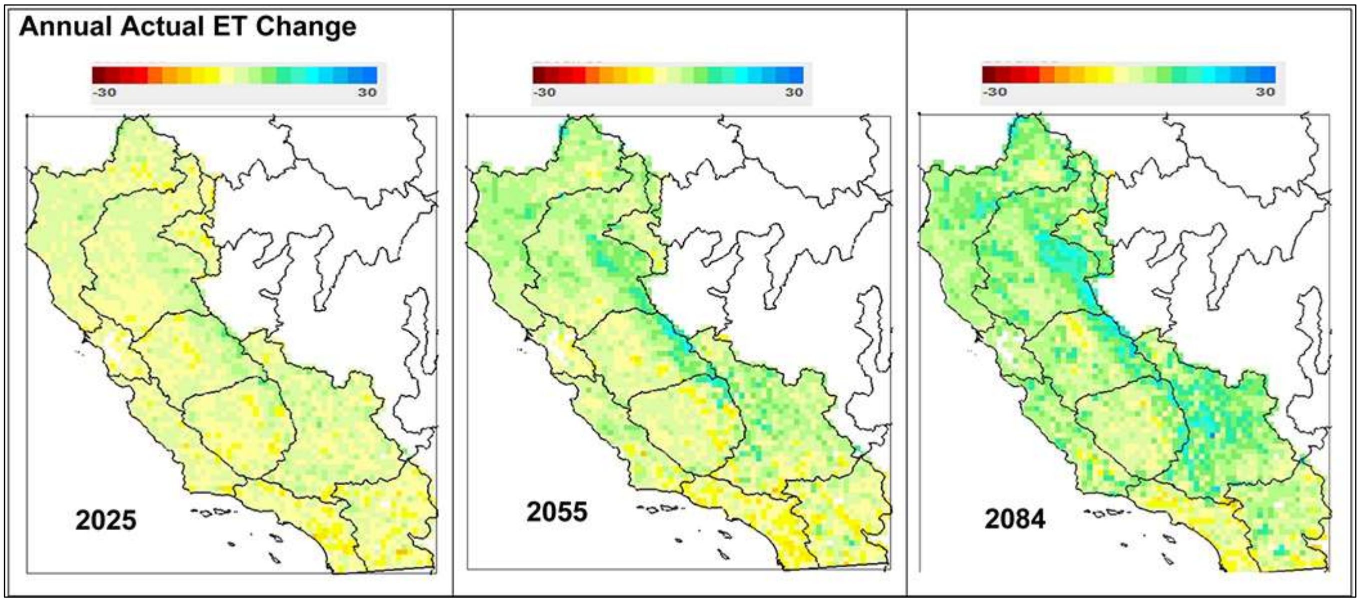


Figure 13. Median projected percent change in annual actual ET for 2011-2040 (2025), 2041-2070 (2055) and 2070-2099 (2084).

In the northern and central Sierra Nevada Mountains, runoff is projected to decrease continuously during the 21st century (Figure 14). By the end of the century, a 5 to 10% decrease may occur. While this trend is somewhat offset by a slight increase (2-5%) in runoff from the lower elevation Coast Range in the northwestern part of the Sacramento Valley, overall runoff will most likely be reduced because the Sierra Nevada Mountains contribute more runoff than the Coast Range.

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 causing 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.

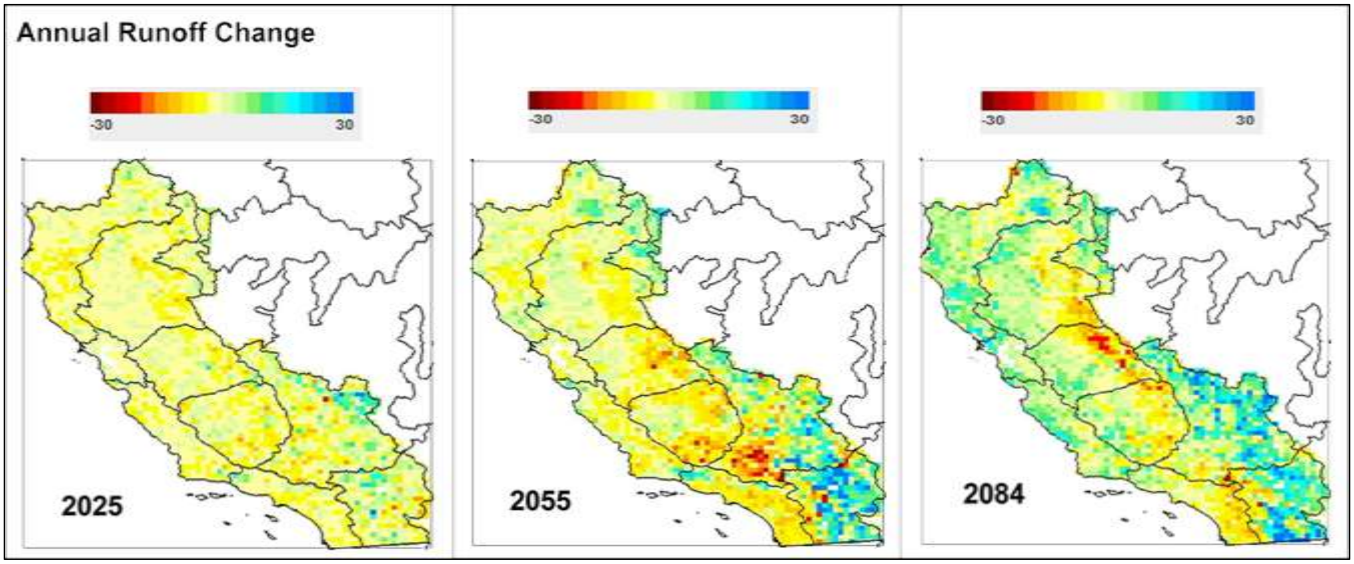


Figure 14. Median projected percent change in annual runoff for 2011-2040 (2025), 2041-2070 (2055) and 2070-2099 (2084)

2.3.2.4. Sea Levels

Most State and Federal planning processes in the Central Valley (such as the California WaterFix) have considered sea level rise through mid-century as it could impact levees that protect the Bay-Delta and increase salinity levels. Studies indicate a mid-range rise this century of 28 to 39 inches (70 to 100 cm), with a full range of variability of 50 to 140 cm (20 to 55 inches) (Rahmstorf 2007 and Vermeer and Rahmstorf 2009). Figure 15 shows various projected ranges of potential sea level change in the Bay-Delta through the year 2100.

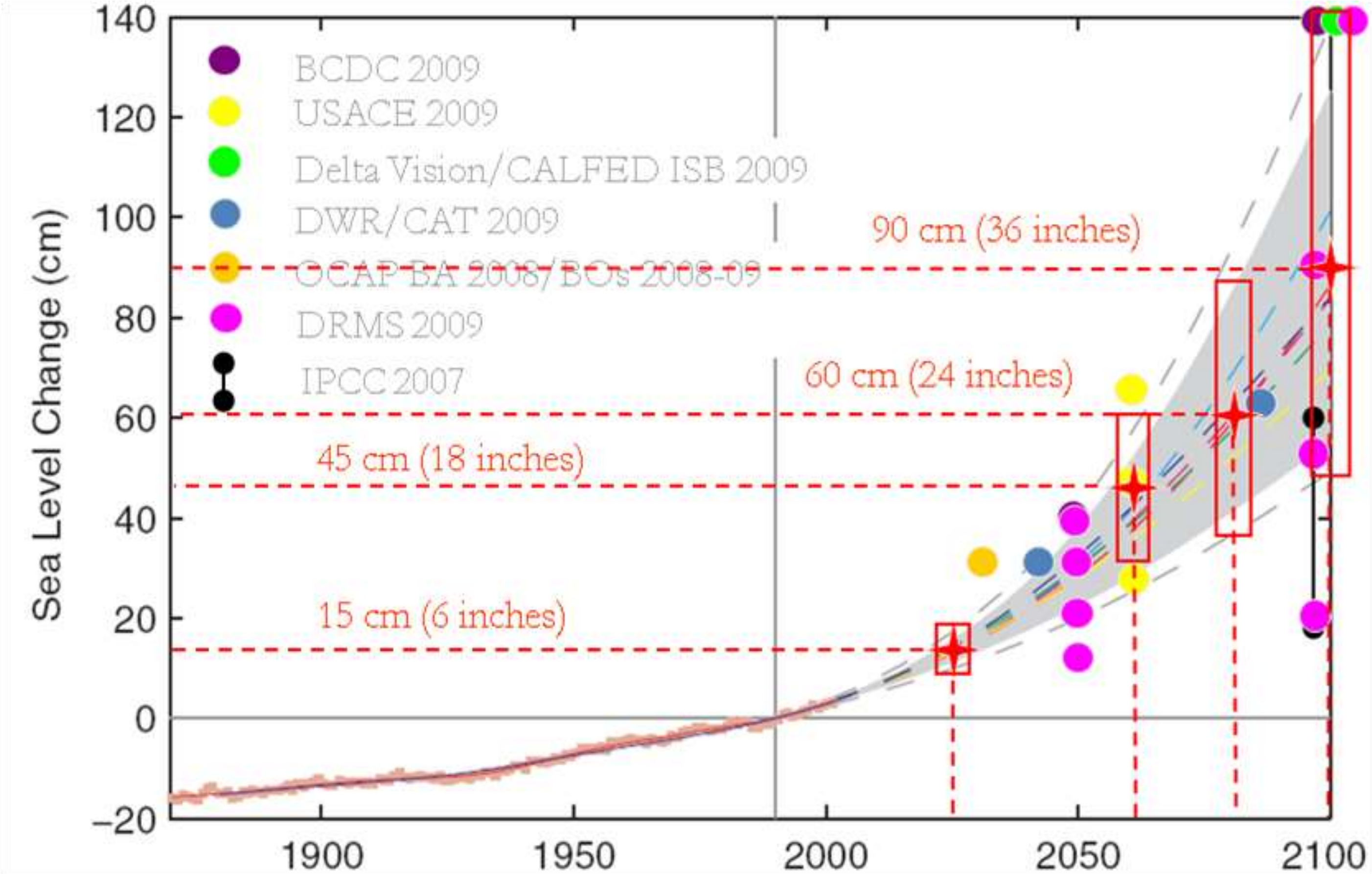


Figure 15. Range of future mean sea level based on global mean temperature projections and sea level rise values. On this figure, colored dots indicate various published projections of sea level rises.

3. Technical Approach and Analysis Process

The technical approach was designed specifically to evaluate the impacts of climate change on water and related resources during the 21st century. As illustrated in Figure 17, the steps involved in the overall analysis process were:

- **Address uncertainties.** Since we do not know how humans are going to behave, what energy sources they will be using, or how much carbon dioxide they will emit into the atmosphere, any projection of future socioeconomic conditions or climate changes is uncertain. Future socioeconomic and climate conditions are two major uncertainties affecting the results.

- **Develop scenarios.**

    - *Socioeconomic conditions.* Uncertainties in future socioeconomic conditions were based on population projections from present day to 2050 developed by the State of California's Department of Finance (DOF) and that have been used in the California Water Plan (DWR 2014)**.** Uncertainties in population and urban growth on agricultural land use were incorporated by developing three socioeconomic scenarios with alternative views of how the future population and urban density might unfold. (See Section 3.1.1. *Socioeconomic Scenarios* in this Report and Section 2.1.2.1 *Socioeconomic Futures* in the Technical Report).

    - *Climate conditions.* The climate uncertainties were addressed by including multiple 21st century dynamic projections of temperature and precipitation based on Global Climate Model (GCM) simulations that represent a wide range of potential future climate conditions (See Section 3.1.2. *Climate Scenarios* in this Report and Section 2.1.2.2 *Climate Futures* in the Technical Report).

- **Use models to simulate dynamic processes into the future.** Although future climate and socioeconomic conditions involve significant degrees of uncertainty, it is clear that they are dynamic. To address this, the study used a transient analysis, which captures changes over time rather than in static time periods. (See Section 3.2. *Modeling Approach and Tools* in this Report and Section 1.3. *Modeling* in the Technical Report).

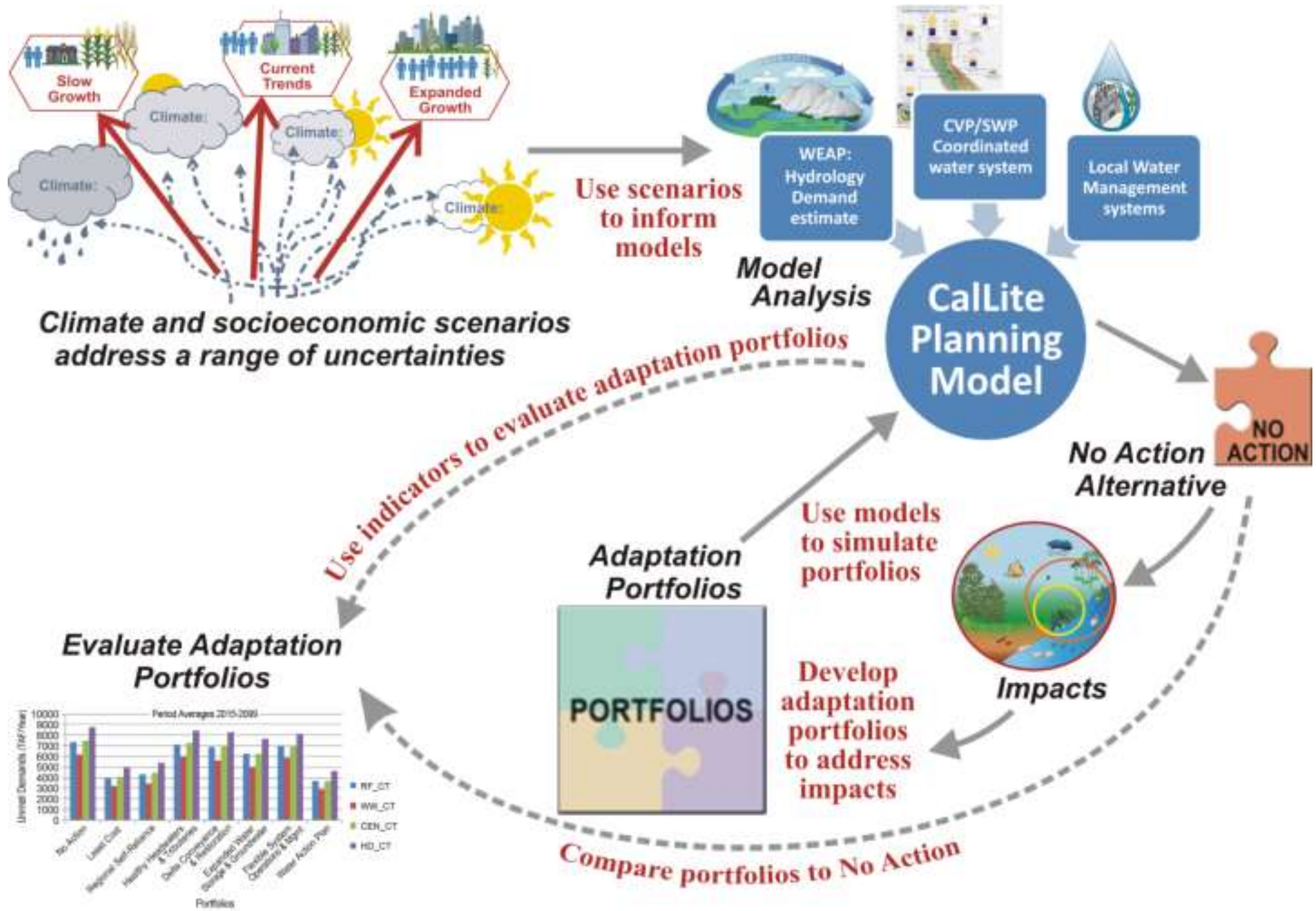


Figure 16. Technical approach and analysis process.

- **Analyze water supply and demand.** A series of models were used to simulate the hydrological processes for a water supply and demand analysis. (See Section 4. *Water Supply and Demand* in this Report and Section 4. *Water Demand Assessment* in the Technical Report).

- **Develop a No Action alternative.** The models simulated conditions into the future under the wide range of climate and socioeconomic scenarios to develop a No Action alternative: the most likely futures if no additional actions are taken to adapt to changing conditions (See Section 5. *Challenges: Risk and Reliability Assessment* in this Report and Section 5. *System Risk and Reliability Assessment* the Technical Report).

- **Develop Adaptation portfolios.** Water management actions to address vulnerabilities that may exist under future socioeconomic and climate scenarios were considered and developed into adaptation portfolios. (See Section 6. *Adaptation Portfolios* in this Report and Section 6. *Water Management Actions and Adaptation Portfolios* in the Technical Report).

- **Evaluate Adaptation portfolios.** The same models were used to simulate future conditions under each of these adaptation portfolios, so that they could be compared consistently with the No Action alternative across a wide range of climate scenarios (See Section 7. *Adaptation Portfolios Evaluation* in this Report and Section 7. *Adaptation Portfolios Evaluation* in the Technical Report).

3.1. Socioeconomic Scenarios

As population increases, municipal, commercial, and industrial water demands tend to increase. These demands are dynamic and depend on a variety of factors, such as urban development and land use density. Agricultural demand is also influenced by socioeconomic trends but to a lesser degree.

Three socioeconomic "storylines" or scenarios were developed to describe how water demands might evolve with changing populations and land use:[6]

About this analysis:

Note that all comparisons in this Report are to the Current Trends socioeconomic scenario. See the Technical Report for analyses under the other scenarios.

- **Expanded Growth (EG).** This scenario assumes a high population growth rate and a low urban density, expanding urban development and land use.

[6] These socioeconomic scenarios are based on information developed for the California Water Plan Update 2013 (DWR 2014).

- **Current Trends (CT).** This scenario was used as a baseline for comparison and projects the trend on current population growth and land use changes. The DOF population projections which go from present day to 2050 were extended to the end of the century.

- **Slow Growth (SG).** This scenario assumes a low population growth rate and a high urban density, slowing the rate of urban expansion.

The Slow Growth and Expanded Growth scenarios represent bounding high and low growth projections. These scenarios are not predictions or forecasts of the future. Figure 17 shows how populations grow and Figure 18 shows how irrigated land use decreases in the three basins in the three socioeconomic scenarios.

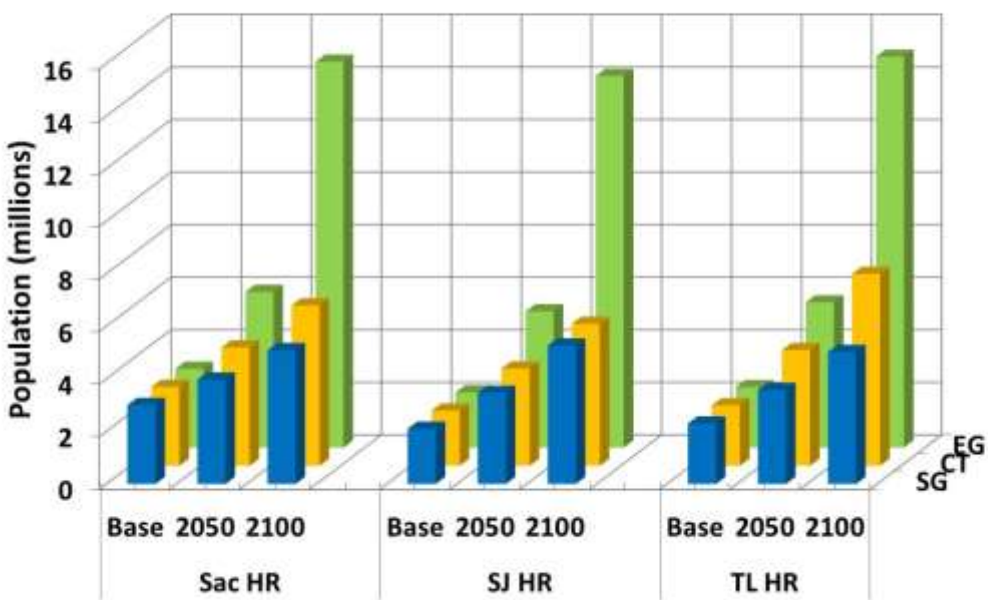


Figure 17. Population scenarios for the Sacramento (SAC) River, San Joaquin (SJ) River, and Tulare Lake (TL) hydrologic regions ([HR] also termed “basins”) for the three socioeconomic conditions used in this Basins Study.

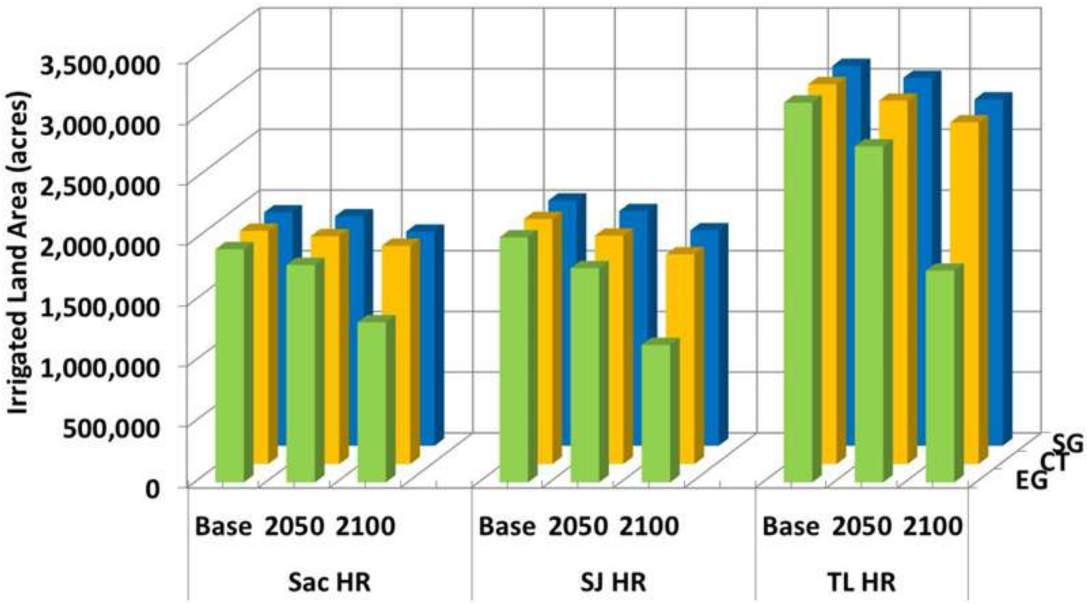


Figure 18. Irrigated Land Acreage scenarios in the Sacramento (SAC) River, San Joaquin (SJ) River, and Tulare Lake (TL) hydrologic regions (HR) for the three socioeconomic conditions used in this Basins Study.

Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario. To focus this analysis on potential changes due to changes in atmospheric conditions and climate, this analysis also used a reference socioeconomic scenario that did not include population or land use changes. The Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario assumes that the land use and population in place in 2006 remains constant throughout the next century. While this is unrealistic, it provides a consistent basis of comparison to isolate climate changes within the analysis.

3.2. Climate Scenarios

Similar to the way the uncertainties in future socioeconomic conditions were addressed, a range of potential future climate conditions were developed, as discussed in the following subsections.

3.2.1. No Climate Change

To compare future impacts with historic climate conditions, it is also desirable to include simulations using the historic climate conditions "projected" into the future climate period. This simulation is referred to as the Reference-No-Climate-Change climate scenario.

3.2.2. Ensemble Climate Scenarios

A total of five representative climate futures were developed using results from recent GCM simulations (IPCC 2013) that had been further refined for use climate studies such as Reclamation (2011). These are usually referred to as "ensemble" scenarios as they are assembled from an ensemble group of climate projections. By using only five representative future climates, it was possible to efficiently assess the impacts of a range of potential climate futures without having to perform an excessive number of simulations.

About this analysis:

This Report uses the Central Tendency, Warm-Wet, and Hot-Dry to represent a range of climate scenarios. For information on analyses under the other scenarios and details about how these five representative climate scenarios were created are provided in the Technical Report.

The representative climate futures were created by combining together multiple individual GCM projections that occur within defined representative climate categories. These representative climate scenarios are shown conceptually in Figure 19 and listed below. Bolded scenarios are discussed in this Report:

- **Central Tendency (CEN) scenario** is in the middle of the range of all the projected temperatures and precipitations. It consists of a large number of projections and be viewed as better through not certain estimate of what the future climate may be.
- Warm-Dry (WD) scenario consists of a small number of projections that are not as warm as the central tendency but are significantly drier.
- **Warm-Wet (WW) scenario** consists of a small number of projections that are not as warm as the central tendency but are significantly wetter
- **Hot-Dry (HD) scenario** consists of a small number of projections that are significantly warmer and drier than the central tendency.
- Hot-Wet (HW) scenario consists of a small number of projections that are significantly hotter and wetter than the central tendency projection.

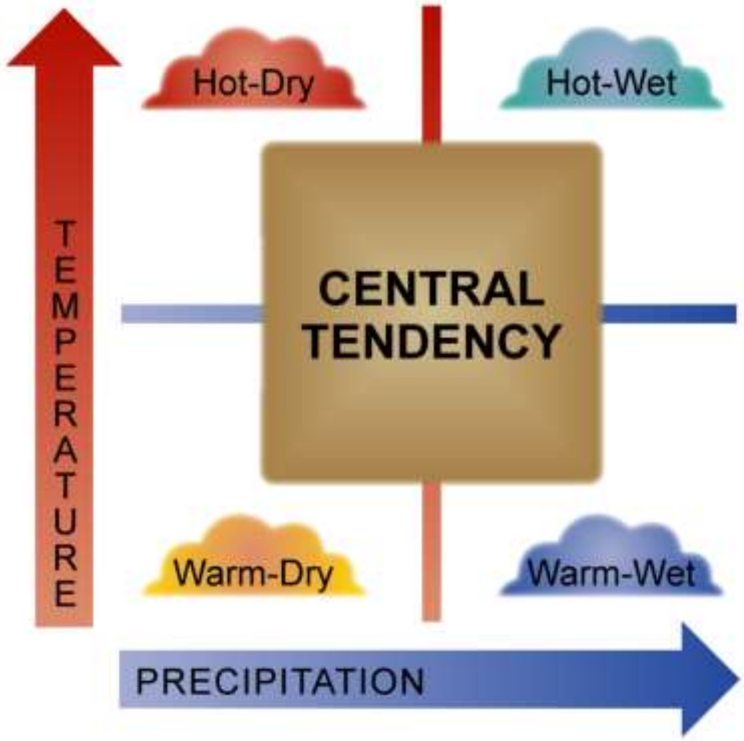


Figure 19. Conceptual representation of ensemble climate scenarios to relate the concept of developing a wide range of ensemble projections. Actual projections used are not shown on this figure.

3.2.3. California Climate Technical Advisory Group (CCTAG)

An additional 12 climate scenarios were included in some of this Basins Study's analysis because DWR used them in previous climate change assessment studies, and it was desirable to include them for comparisons. Unlike the ensemble scenarios, each of these scenarios is based on a single GCM simulation. These 12 projections were selected based on recommendations of the State's California Climate Technical Advisory Group and are referred to as CCTAG scenarios.

3.2.4. Sea Level Projections

Transient sea level changes were also included in the climate scenarios. The amount of sea level rise was based on National Research Council (NRC) median projection for sea level rise, The NRC report suggested that by 2100, sea levels could rise by about 90 centimeters (cm), with a projected range between 42 cm through 166 (NRC 2012).

3.3.Modeling Approach and Tools

The modeling approach and analysis tools for this Basins Study were developed as part of the Central Valley Project Integrated Resource Plan and the Sacramento and San Joaquin Basin's Climate Risk Assessment Report (Reclamation 2014) and further improved for this Basins Study. Figure 20 illustrates how models were used to evaluate the socioeconomic and climate scenarios and the No Action alternative and Adaptation portfolios. Critical uncertainties and scenario development (left side of Figure 20) were used in the Water Evaluation and Planning model of the Central Valley (WEAP-CV) hydrology model to simulate water supply and demands (center of figure). These results were used as inputs to the CalLite-CV model (center right on the figure) to simulate how the CVP, SWP, and other water management systems operate to meet urban, agriculture, and environmental needs. Results from the CalLite-CV model were used as the basis for the Supply and Demand imbalance analysis and as inputs to other Performance Assessment Tools (lower left on figure). The next step was to use the models to evaluate the portfolios.

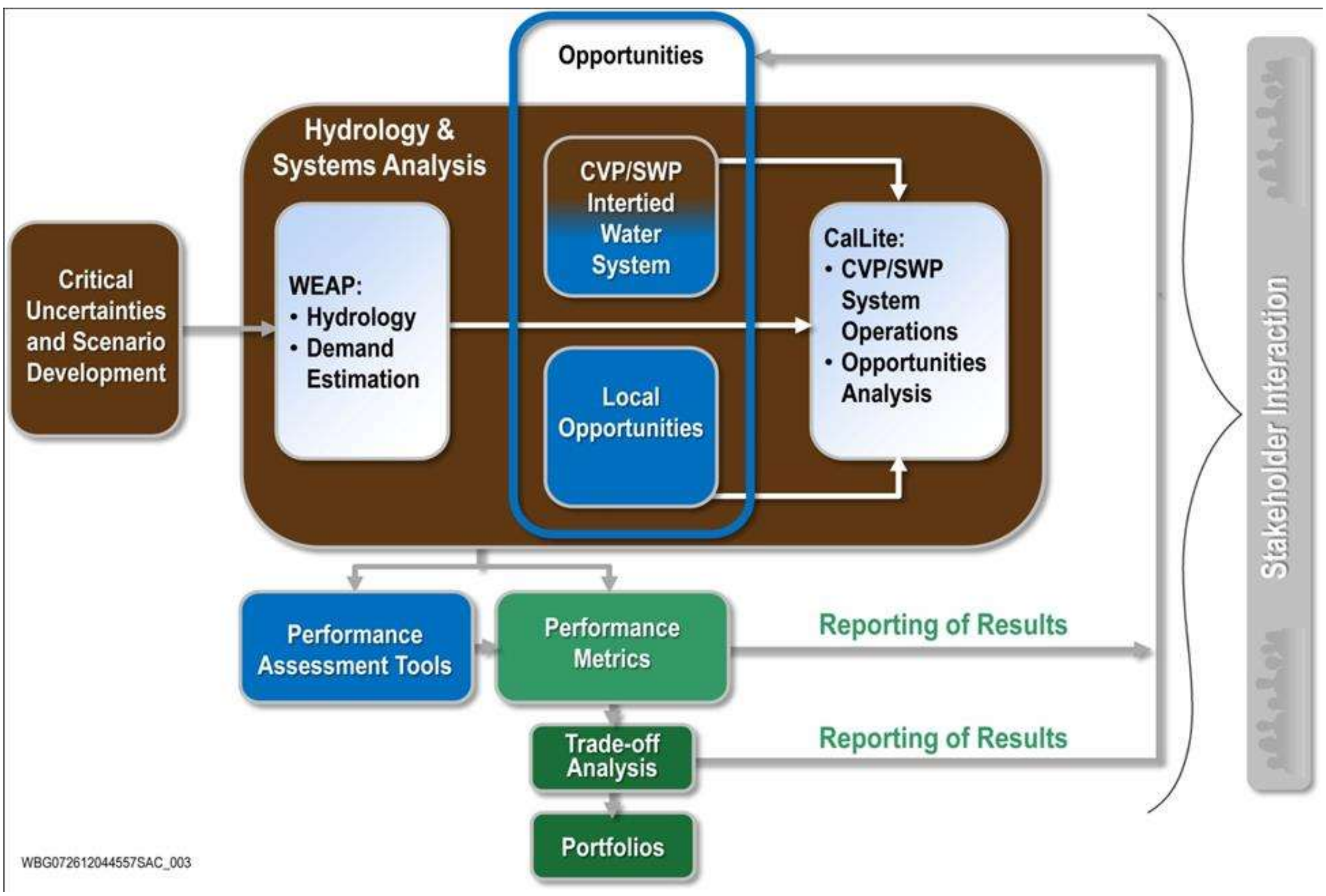


Figure 20. Sacramento and San Joaquin Basin's climate modeling approach.

Table 1 shows the models used to perform the risk assessment and portfolio evaluation. Indicators are described in Section 5. *Challenges: Risk and Reliability Assessment* in this Report and the results of these assessments for both the No Action alternative and the adaptation portfolios are summarized in Section 7. *Adaptation Portfolios Evaluations.* Detailed descriptions of each of these models are provided in the Technical Report and appendices.

Table 1 Models Used for Resource Category Assessments

Resource Category	Models	Indicator Metrics
Delivery Reliability	CalLite-CV	Unmet demands
		CVP & SWP Delta exports
		Surface reservoir storage
		Change in groundwater storage
Economics[7]	LCPSIM & OMWEM	Urban economics
	SWAP	Agricultural economics
	BAWQM & LCRBWQM	Salinity management costs
Water Quality	CalLite-CV	Delta salinity
		Reservoir storage
Hydropower & GHG emissions	LTGen & SWP_Power	CVP & SWP net generation
Flood Control	CalLite-CV	Reservoir storage & penstock releases
Recreation	CalLite-CV	Surface area in CVP & SWP reservoirs
Ecological Resources	CalLite-CV	Delta salinity
		Delta outflow and instream river flows

[7] Note: Economics is not a resource category mandated in the Secure Water Act and is not discussed in this Report. However, the Basins Study is a long range exploratory planning activity in which assessing economics at a reconnaissance level is important to help inform subsequent evaluations. The Technical Report provides a discussion of this economics analysis, which was performed at a preliminary, reconnaissance level.

4. Water Supply and Demand

This section provides a quantitative evaluation of recent historic and projected future water supplies as well as agricultural and urban demands in the major Central Valley hydrologic regions. Water supplies are identified in this Basins Study as a function of streamflows. Demands discussed in this report are applied water demands, in other words, agricultural and urban water demands which cannot be satisfied directly by precipitation.

For more detailed analyses, see the Technical Report

This Basins Study includes future water supply projections developed from all of the climate scenarios discussed in Section 3.2. *Climate Scenarios* in this Report. However, to provide a snapshot of possible futures, this Report summarizes future water supply projections only with the ensemble and Reference-No-Climate-Change and selected climate scenarios combined with the Current Trends socioeconomic scenario. For a discussion of other scenarios, see Section 3.2.2. *Future Projected Water Supply* in the Technical Report.

4.1. Historic Supplies

The mean annual flow of the Sacramento and San Joaquin River 8 Index is approximately 23.1 million acre-feet (MAF), but annual flows ranged from almost a quarter of that amount (6.2 MAF in 1977) to more than double that amount (52.7 MAF in 1983) from 1922 to 2010. For most locations, greater variability and more frequent events of greater magnitude occur after the 1970s. Generally, lower flows are observed from the mid-1930s to the mid-1960s, and a slightly downward trend in flows is observed in all locations for this time period.

4.2. Future Projected Supplies

Each basin has a different monthly pattern, reflecting differences in hydroclimate and watershed characteristics within the basin. In each basin, the water supplies are similar. However, streamflows shift from spring to winter under all climate scenarios from the Reference-No-Climate-Change climate scenario. This projected shift occurs because higher temperatures during winter cause earlier snowmelt runoff. This seasonal shift is greater in basins where the watershed is at lower elevations and thus is more susceptible to warming-induced changes from snow to rain.

4.2.1. Streamflow

The Sacramento River provides most of the water for the Central Valley. While streamflows in the Central Tendency climate scenario would be very similar to the Reference-No-Climate-Change climate scenario, scenarios have a variable range of variability—with a 60 percent change in the Tulare Basin from 30% less water under the Hot-Dry climate scenario to 30% more water under Warm-Wet climate scenario. Table 2 summarizes period average annual streamflow (in TAF/year) for the projected changes in mean annual streamflow in the Sacramento, San Joaquin, Eastside Streams and Delta, and Tulare regions shown as percent changes in the ensemble climate scenarios from the Reference-No-Climate-Change climate scenario.

Table 2. Summary of Annual Streamflow (in TAF/year) under the Reference-No-Climate-Change climate scenario and Changes (%) from that Scenario in Selected Climate Scenarios

	Reference_CT (TAF/Yr)	Warm-Wet_CT (% change from Reference_CT)	Central_CT (% change from Reference_CT)	Hot-Dry_CT (% change from Reference_CT)
Sacramento River System	21,649	25.6%	2.9%	-16.0%
Eastside Streams and Delta	911	47.9%	2.8%	-26.6%
San Joaquin River System	6,379	29.8%	0.2%	-22.8%
Tulare Lake Region	3,504	31.1%	-4.3%	-30.0%

4.2.2. Peak Flow

Shifts in the timing of peak runoff shifts depend on elevation and topography.

- **Low elevations.** Lower elevations, such as the Sacramento Valley as represented by Lake Shasta, are dominated by rainfall. Thus, fall and winter flows are more prominent, and the peak runoff times generally shifts from spring to winter months, as shown on Figure 21.

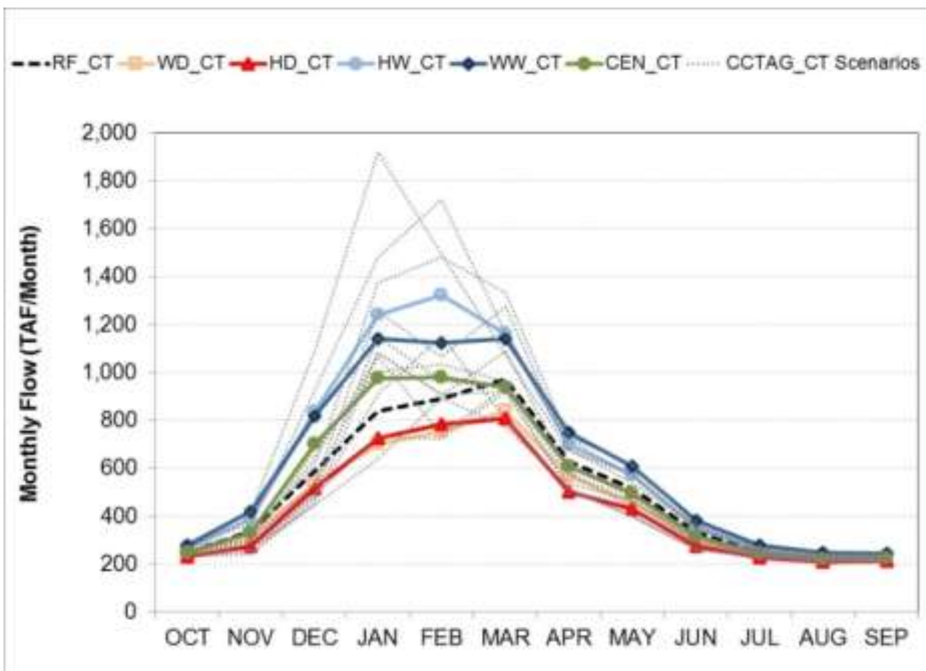


Figure 21. Projected average streamflow in each month into Lake Shasta in each climate scenario (long-term average over Water Years 2070 through 2099).[8]

[8] In Figure 21, the dashed line (Reference-No-Climate-Change [RF_CT]) climate scenario provides a basis of comparison. Hot-Dry (HD_CT) is red, Warm-Wet (WW_CT) is dark blue, and Central Tendency (CEN_CT) is green.

- **Intermediate elevations.** Intermediate basins, such as San Joaquin River Basin, as represented by Millerton Lake, rely both on snow and rain. Thus, they have a greater shift in peak runoff times. Peaks in April to June runoff in the Reference-No-Climate-Change climate scenario (black dotted line in Figure 22), can be months earlier under some climate change scenarios.

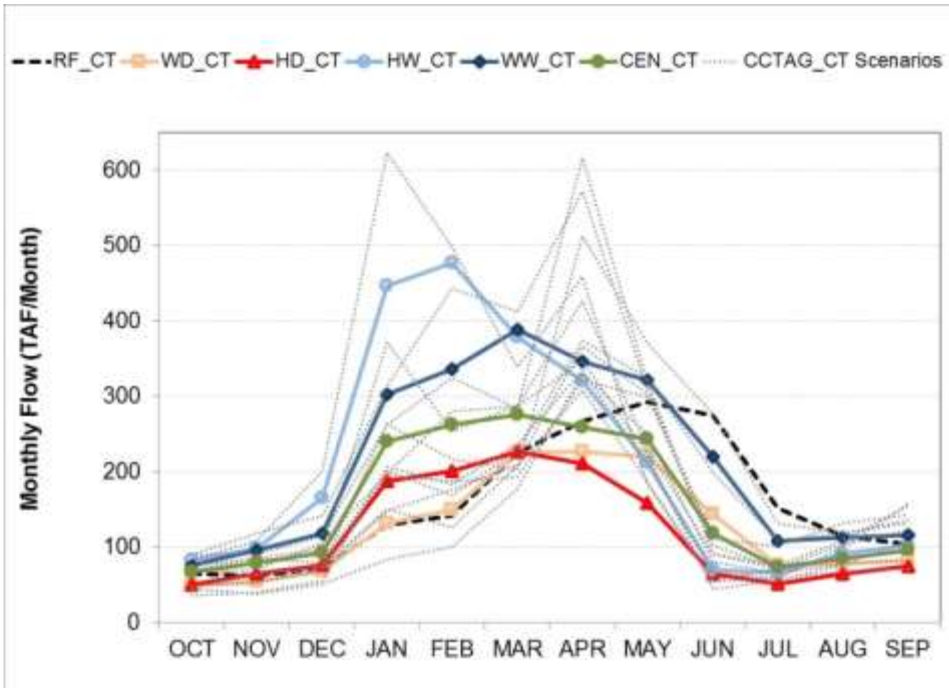


Figure 22. Projected average streamflow in each month into Millerton Lake in each climate scenario (long-term average over water years 2070-2099).[9]

- **Higher elevations.** In high elevation basins such as the Tulare Basin, represented by the Pine Flat reservoir, snowfall predominates. Thus, warming trends do not affect the runoff timing as much, and the peak flow is not as shifted as in lower and intermediate elevations (Figure 23).

[9] In Figure 21, the dashed line (Reference-No-Climate-Change [RF_CT]) climate scenario provides a basis of comparison. Hot-Dry (HD_CT) is red, Warm-Wet (WW_CT) is dark blue, and Central Tendency (CEN_CT) is green.

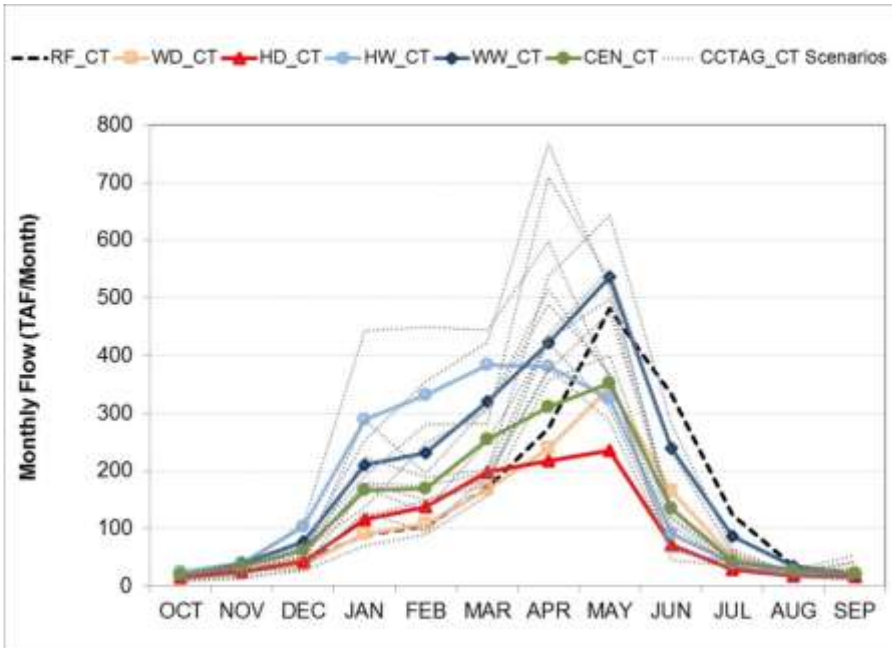


Figure 23. Projected average streamflow in each month into Pine Flat in each climate scenario (long-term average over water years 2070-2099.[10]

4.3. Historic Demands

For the recent period from 1998 to 2010, Central Valley total annual demands averaged 26.7 MAF, of which agricultural demands constituted 92% of the total. Total demands ranged from a low of about 20 MAF in 1998 (a wet year) to 29.7 MAF in dry year of 2008. Overall demands were highest in the Tulare Lake Basin and lowest in the San Joaquin Basin. In Table 3, agricultural, urban, and total demands for the Sacramento Valley, San Joaquin Valley, and Tulare Lake hydrologic regions are reported.

To gain some additional insights into historical water demands over a longer period of time, a historical reference climate combined with a reference Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF-RF) was employed. This scenario assumed the historical climate that occurred between 1923 and 2010 and fixed applied agricultural and urban water demands at the 2006 level of development. To project what future demands would be if these climate and socioeconomic conditions occurred in the 21st century, the applied water demand results are reported on a monthly basis from 2015 to 2099 (Figure 24). The simulation provides a reference point for comparisons with the other projected socioeconomic-climate scenarios presented in the following sections.

---

[10] In Figure 23, the dashed line (Reference-No-Climate-Change [RF_CT]) climate scenario provides a basis of comparison. Hot-Dry (HD_CT) is red, Warm-Wet (WW_CT) is dark blue, and Central Tendency (CEN_CT) is green.

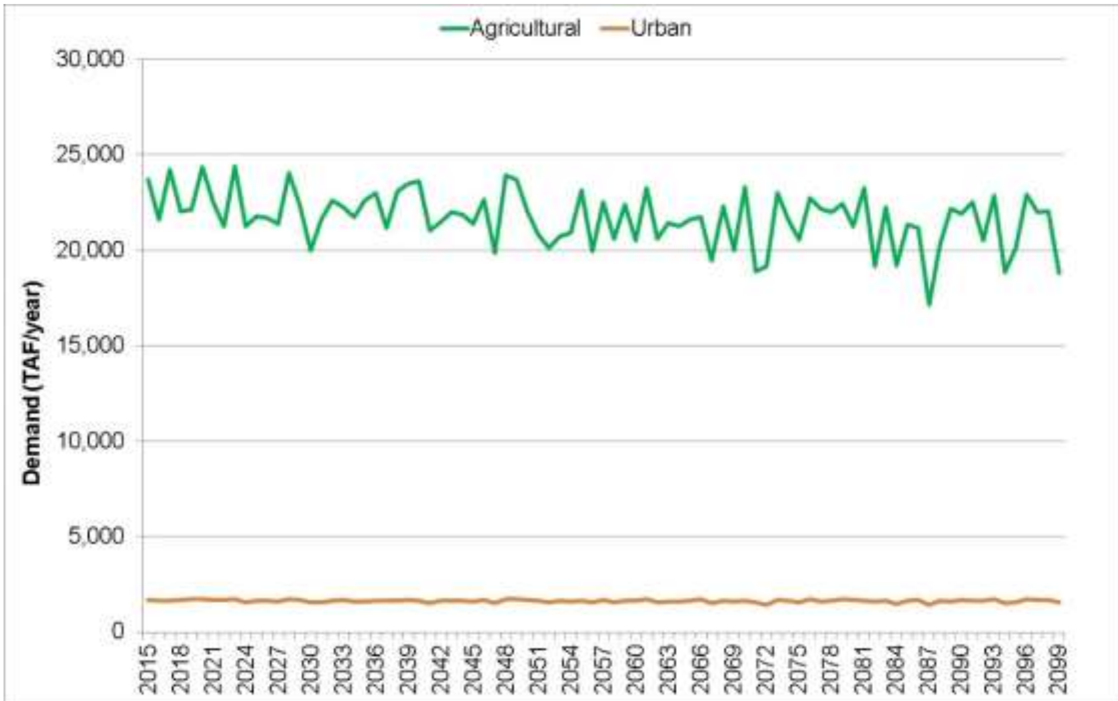


Figure 24. Annual time series of simulated recent historical agricultural and urban water demands in the Central Valley.

Table 3. Historical Water Demands in the Central Valley Basins in TAF/year. Source: DWR, 2014.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Sacramento River Basin													
Agricultural	5,841	7,828	7,927	7,782	8,020	7,078	8,503	6,968	7,297	8,451	8,385	7,905	6,959
Urban	718	763	851	869	906	882	915	803	944	904	944	894	871
Total	6,559	8,591	8,778	8,650	8,926	7,960	9,418	7,771	8,241	9,355	9,329	8,798	7,830
San Joaquin River Basin													
Agricultural	5,079	7,069	6,556	6,794	7,139	6,568	7,059	6,123	6,545	7,653	7,743	7,505	6,621
Urban	541	580	583	609	574	596	617	631	651	690	727	701	668
Total	5,620	7,649	7,139	7,403	7,713	7,163	7,675	6,755	7,196	8,342	8,470	8,206	7,289
Tulare Lake Basin													
Agricultural	7,831	10,138	10,006	9,976	10,514	9,969	10,659	9,298	9,919	10,74	11,142	11,366	10,188
Urban	535	592	638	664	683	770	819	704	738	792	790	716	667
Total	8,367	10,730	10,643	10,640	11,197	10,739	11,479	10,002	10,657	11,53	11,931	12,082	10,855
Total Central Valley													
Agricultural	18,752	25,036	24,489	24,552	25,673	23,615	26,221	22,390	23,760	26,84	27,269	26,775	23,768
Urban	1,794	1,935	2,072	2,141	2,162	2,248	2,351	2,138	2,334	2,386	2,461	2,311	2,207
Total	**20,545**	**26,970**	**26,561**	**26,693**	**27,836**	**25,862**	**28,572**	**24,528**	**26,094**	**29,23**	**29,730**	**29,086**	**25,975**

Source: DWR 2014

The simulation also demonstrates that the results are reasonably similar to the estimated historical demands and indicates that the models are well calibrated. Because acreages of agricultural crops and urban population did not change in this simulation, the year-to-year variability in demand was due primarily to changes in temperature, precipitation, and other meteorological factors affecting evapotranspiration (ET).

Agricultural demands varied from 17 MAF to 24 MAF from 1923-2010 (simulation years 2015-2099) similar to the range reported in Table 3. Agricultural demands increased in drier years such as the 1976-1977 (simulation years 2068-2069) and 1986-1992 (simulation years 2078-2084) drought periods and significantly decreased in the period of very wet years from 1992-1998 (simulation years 2084-2090). Urban demands were fairly consistent across all years of the simulation because urban water demands are not as sensitive to climate as agricultural demands. Table 4 shows the period average annual agricultural, urban, and total demands by region.

Table 4. Period Average Annual Agricultural and Urban Historical Water Demands in TAF/year)

	Agricultural	Urban	Total
Total Central Valley	24,933	2,029	26,961
Sacramento River System	4,541	610	5,150
Delta and Eastside Streams	1,545	107	1,652
San Joaquin River System	4,695	342	5,037
Tulare Lake Region	14,152	970	15,123

The period is 1923-2010 historical years simulation 2015-2099 years under Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios.

4.4. Future Projected Demands

Future water demands depend upon changes in population and land use as well as climate changes. As urban population increases, adjacent agricultural land is often incorporated into urban areas, thus reducing the agricultural land area to varying degrees. Consequently, with fewer acres of future irrigated lands, projected agricultural water demands tend to decline over time. Correspondingly, future urban demands may be anticipated to increase with increasing populations. The agricultural and urban demands and growth vary by regions.

For more detailed analyses, see the Technical Report

This Basins Study includes future water demand projections developed from all of the socioeconomic and climate scenarios discussed in Section 3.2. Climate Scenarios in this Report. The water demands discussed in this section refer to “applied water demands,” which are the irrigated water demands over and above precipitation. The amount of contracted water supplies available to the CVP/SWP users remained unchanged throughout the analysis.

This Report summarizes analytical results from the Current Trends socioeconomic scenario. To analyze a wider range of potential population growth and land changes, the Expanded Growth and Slow Growth socioeconomic scenarios were also analyzed and results for these socioeconomic scenarios are provided in Section 4 of the Technical Report. It is important to note that these scenarios are not forecasts and were developed solely cover a wide range of potential future conditions. For a discussion of these other scenarios, see Section 4. *Water Demand Assessment* in the Technical Report.

4.4.1. Agricultural Water Demands

Agricultural water demands are affected by climate, population, and land use as well as other factors such as the types of crops and agricultural water management practices. The crop types, acreages, and changes in irrigated land area are based on the scenarios developed from the DWR analysis in the California Water Plan (DWR 2014). While current crop types are used for projections into the next century, new types of crops will likely be developed. Nonetheless, this is a useful analysis to highlight future needs for agricultural water supplies.

Under the assumptions used in the Current Trends socioeconomic scenario for population growth and land changes, agricultural land in the Central Valley is projected to gradually decline from 6.5 million acres in 2012 to 5.8 million acres in 2040 and 5.4 million acres by 2099. The analysis assumed that as irrigated acreage declines, the higher value crops (e.g., orchards) would remain. Even though irrigated acreages were simulated as declining, the amount of contracted water supply available to the CVP/SWP contractors was not reduced. Details regarding the crop types, irrigated acreages, growing seasons, and other parameters used in the agricultural demands assessment as well as further analyses are described in Section 4. *Water Demand Assessment* in the Technical Report.

If there were no climate change, then the projected average annual agricultural demands in the Central Valley would decline from about 21.7 MAF to 19.1 MAF in 2070 - 2099. This decline reflects both a decrease in irrigated crop acreage and changes in climate—especially increasing carbon dioxide levels and temperature increases that exceed crop water stress thresholds, resulting in reduced crop water use. This result occurs because the hotter climate scenarios have higher temperatures as well as higher levels of carbon dioxide than the other climate scenarios. These changes do not become significant until the latter part of the 21st century. Figure 25 presents the annual time series from 2015 to 2099 of projected total agricultural demands in the Central Valley for all the climate-socioeconomic scenarios. The short-term variability is highly correlated with the variability in annual precipitation. These effects are discussed in more detail in Section 4. *Water Demand Assessment* in the Technical Report.

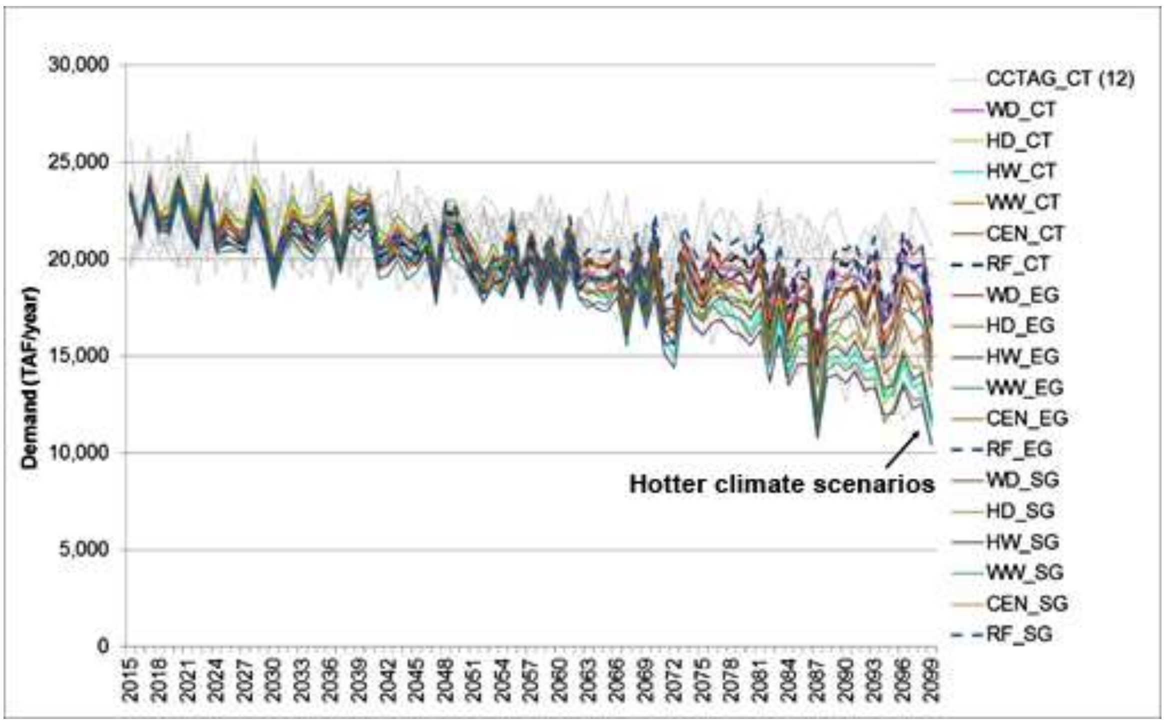


Figure 25. Annual time series of agricultural applied water demand in the Central Valley in each scenario.

In all basins, agricultural demands showed a strong relationship to the climate scenarios, with the Warm-Wet climate scenario having less agricultural water demand than the Hot-Dry climate scenario (Table 5). The short-term variability is highly correlated with the variability in annual precipitation. In years of low precipitation, demand is higher; and in years of high precipitation, agricultural demands decrease. The longer term trends are related to land use changes as well as climate changes, whose effects become more significant in the latter half of the century. Table 5 shows the average annual agricultural water demands for the Central Valley and sub-basin regions.

Table 5. Average Annual Agricultural Water Demands in TAF/year under the Reference-No-Climate-Change Climate Scenario Compared with the Ensemble Climate Scenarios in the Central Tendency Socioeconomic Scenario

Location	Period	Reference_CT	Hot-Dry_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	21,722	22,456	21,416	21,946
	2040-2069	20,135	20,211	19,373	19,990
	2070-2099	19,081	15,864	17,905	17,695
	2015-2099	**20,230**	**19,337**	**19,456**	**19,756**
Sacramento River System	2015-2039	4,746	4,896	4,724	4,828
	2040-2069	4,339	4,404	4,253	4,372
	2070-2099	4,107	3,627	3,980	3,951
	2015-2099	**4,377**	**4,275**	**4,295**	**4,357**
Delta and Eastside Streams	2015-2039	1,655	1,712	1,637	1,683
	2040-2069	1,523	1,508	1,448	1,497
	2070-2099	1,438	1,075	1,339	1,290
	2015-2099	**1,532**	**1,415**	**1,465**	**1,479**
San Joaquin River System	2015-2039	4,880	5,065	4,807	4,930
	2040-2069	4,553	4,591	4,341	4,516
	2070-2099	4,247	3,414	3,945	3,884
	2015-2099	**4,541**	**4,315**	**4,338**	**4,415**
Tulare Lake Region	2015-2039	10,442	10,783	10,248	10,506
	2040-2069	9,720	9,708	9,330	9,606
	2070-2099	9,289	7,748	8,641	8,569
	2015-2099	**9,780**	**9,333**	**9,357**	**9,505**

4.4.2. Urban Water Demands

Urban demands are an important portion of Reclamation's water deliveries. Understanding how these demands might change in the future and how they may be affected by changing population and climate is key to effective long-term planning. Urban demands now account for about one-twelfth of the water use in the Central Valley. Urban demands are driven largely by population and therefore tend to change steadily over time based on the assumed level of population, municipal, commercial, and industrial growth associated with each of the socioeconomic scenarios.

In the Reference-No-Climate-Change climate scenario, the total Central Valley urban demand grows from 2 MAF in 2015 to almost 3 MAF in 2099. Short-term variability and longer-term trends both exist in urban water demands. Although there is much less variability in urban demands than agricultural demands, short-term demand variability in urban demand is much more clearly correlated with the variability in annual precipitation as shown in Figure 26. The longer term trends clearly reflect the assumptions about population growth with the highest demands occurring in the Expanded Growth socioeconomic scenario and less demand growth in the Current Trends and Slow Growth socioeconomic scenarios (see Section 4. *Water Demand Assessment* in the Technical Report for this analysis).

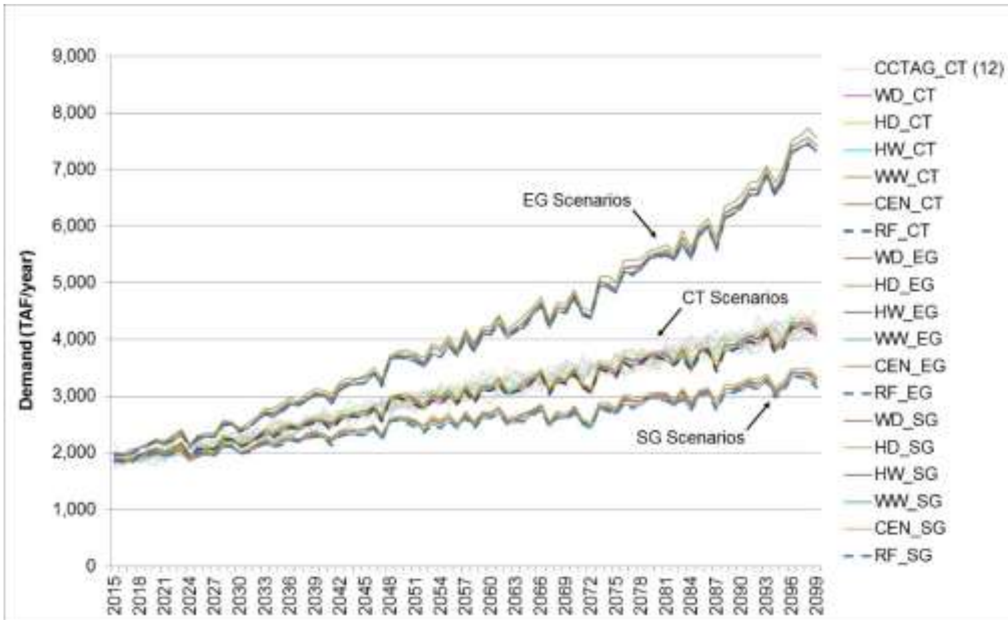


Figure 26. Annual time series of total urban water demands in the Central Valley for each scenario (CT is Current Trends Socioeconomic Scenario, EG is Expanded Growth, and SG is Slow Growth).

Urban demands also vary between regions, for example, Tulare Basin demands grow by almost 800 TAF and the Delta and Eastside varies only by 50 TAF. To provide a general breakdown of the subregions. Table 6 shows the average annual urban water demands in the Central Valley, Sacramento River, East Side streams and the Delta, San Joaquin River, and Tulare Lake regions.

Table 6. Average Annual Urban Water Demands in TAF/year based on the Central Tendency Socioeconomic Scenario

Location	Period	Reference_CT	Hot-Dry_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	2,152	2,211	2,153	2,178
	2040-2069	2,920	3,036	2,933	2,986
	2070-2099	3,701	3,851	3,705	3,769
	2015-2099	2,970	3,081	2,976	3,025
Sacramento River System	2015-2039	744	761	743	753
	2040-2069	946	979	946	961
	2070-2099	1,116	1,162	1,117	1,137
	2015-2099	947	980	947	962
Delta and Eastside Streams	2015-2039	127	131	127	129
	2040-2069	171	177	171	174
	2070-2099	208	218	208	212
	2015-2099	171	178	171	174
San Joaquin River System	2015-2039	447	458	445	452
	2040-2069	621	646	620	633
	2070-2099	781	820	780	798
	2015-2099	626	652	625	638
Tulare Lake Region	2015-2039	833	861	837	845
	2040-2069	1,183	1,234	1,195	1,217
	2070-2099	1,597	1,651	1,601	1,622
	2015-2099	1,226	1,271	1,233	1,250

5. Challenges: Risk and Reliability Assessment

Guided by the question, **"What is the future reliability of the Central Valley water system in meeting the needs of Basin users during the 21st century?"** a risk and reliability assessment was conducted as part of this Basins Study to identify the challenges facing water user communities in the Central Valley and the potential challenges and risks that future conditions may pose.

Determining the reliability and performance of water infrastructure in the Sacramento and San Joaquin Basins is important since it's not only required by the SECURE Water Act but also provides a gauge of the ability to meet needs now and in the future. The system reliability analysis uses metrics to measure the potential impacts of future water supply changes on resource categories identified in the SECURE Water Act:

- Water Delivery
- Water Quality
- Hydropower and GHG emissions[11]
- Flood Control
- Recreational Use
- Ecological Resources

About this risk assessment:

This risk and reliability assessment analyzed the water-related conditions and resources that partners and stakeholders identified as most important to them.
Basin-wide vulnerabilities consider the ability to operate and manage infrastructure to meet key objectives in the Central Valley under a full range of future supply and demand conditions.

5.1. Indicators

Indicators are a metric used in this Basins Study to illustrate how a change in hydrology, climate, and socioeconomic conditions may affect the performance of the CVP, SWP, and other water management systems in the Central Valley. Indicators provide the most direct evidence of the changes in the complex and interrelated resource categories. The Basins Study team worked with partners and stakeholders to develop specific indicators to identify how certain water resources-related concerns would fare in the future under a range of different supply and demand conditions. Each indicator describes a relative set of favorable and unfavorable conditions related to a specific resource or issue

For more detailed analyses, see the Technical Report

This Report discusses key indicators, and full analysis is in the Technical Report's Section 5. *System Risk and Reliability Assessment* and Section 7. *Adaptation Portfolio Evaluation.*

[11] Section 5.2.5.2. *Greenhouse Gas Emissions* and 7.5.2 *Greenhouse Gas Emissions* in the Technical Report.

identified. Performance metrics were then identified for each indicator to measure the ability of Central Valley water infrastructure to meet resource needs under future scenarios. The Basins Study team used these indicators to:

- Analyze conditions under the No Action alternative
- Determine which adaptation portfolios performed well for the resources in question
- Help demonstrate how different resources were sensitive to changes in supply or demand, both independently and together.

5.2. Resources

5.2.1. Water Delivery

Meeting water demands in California is a challenge, no matter what the future brings. Increases in population, land use changes, and environmental and other regulatory uses increases water demands. The CVP and SWP provide water to settlement contractors in the Sacramento Valley, exchange contractors in the San Joaquin Valley, agricultural and municipal and industrial (M&I) water service contractors in both the Sacramento and San Joaquin Valleys, Tulare Lake Basin, and wildlife refuges both north and south of the Delta. Unmet demands indicate the inability to meet these water contracts. For example, in 2015, CVP contractors did not get any water, and reduced amounts were provided for urban uses.

INDICATOR

Unmet Demands. Currently, Federal and State agencies work closely together to address gaps between supply and demand with water conservation, management actions, and investments in infrastructure. Effectively meeting these demands in the future relies on understanding how the current gap between supply and demand may change.

Figure 27. Canals in the Central Valley

End-of-September Storage. Typically, the CVP and SWP systems are operated to maintain sufficient carryover storage to meet demand requirements during drought periods of several years. Reclamation determines the allocation of CVP water for agricultural, environmental, and municipal and industrial purposes based upon many factors, including carryover storage (storage in reservoirs at the end of September).

Delta Exports. Although water from the Delta only accounts for less than 10% of California's total water use, it is nonetheless a critical component of the state's water supply, providing at least a portion of the water supply for two-thirds of the state's population as well as irrigating 3 million acres of farmland. The CVP and SWP store and release water upstream of the Delta and export water from the Delta to areas generally south and west of the Delta. Most of the water enters the Delta from the north through the Sacramento River, while the San Joaquin River arrives from the south. Freshwater flowing out of Delta pushes against the tides bringing saltwater upstream, creating a barrier that enables the CVP and SWP to pump fresh water instead of salt water.

Change in Groundwater Storage. Groundwater is an important part of the area's water supply. Reliance on groundwater will continue to increase as the population grows, as limitations on available surface water continue, and as potential impacts of climate change occur.

5.2.2. Water Quality

In 1978, the State Water Board adopted water right D-1485 and the Water Quality Control Plan (WQCP) for the Sacramento–San Joaquin Delta and Suisun Marsh to protect Delta resources by maintaining them under conditions that would have occurred in the absence of CVP and SWP operations.

Delta Salinity. Within the Bay, fresh water from the Sacramento and San Joaquin rivers mixes with salt water from the Pacific Ocean. This mixing is affected in part by tides, waves, and fresh water inflow and itself affects water quality, sediment transport, and ecology in the Bay and Delta. DWR and Reclamation manage flow releases to the Delta to regulate salinity levels to protect municipal and industrial, agricultural, and fish and wildlife uses. Water quality standards for the Delta include salinity levels, which indicate the health of the Bay-Delta ecosystems, levels of seawater intrusion, and fresh water availability.

Figure 28. Shasta Dam.

End-of-May Storage. The reservoir storage in Shasta and other major CVP and SWP reservoirs is managed from May through September to provide an adequate cold water pool for salmon. The end of May storage is correlated to the availability of sufficient cold water to manage downstream water temperatures for Chinook salmon egg incubation and rearing at critical times during the spring, summer, and early fall.

5.2.3. Hydropower

Both the CVP and SWP generate hydropower at reservoirs and use it to pump and convey water to users in the Central Valley of California as well as outside the study area. Both projects use some of their hydropower resources to reduce the cost of operations and maintenance and to repay the cost of project facilities. Hydropower from the projects is a renewable energy source that comprises approximately 36 percent of the online capacity of California hydroelectric facilities and nearly 7 percent of the total online capacity of California power plants.

Net hydropower generation and greenhouse gas emissions are analyzed in the technical report. However, as these two concepts are interrelated—the more net power generation, the more greenhouse gas emissions are offset—this Report provides results for the **net hydropower generation analysis**.

5.2.4. Flood Control

CVP and SWP reservoirs are managed by storage and release rules established by the Corp of Engineers for the flood control season from October to June. These flood rule curves were developed to provide sufficient storage space (the “flood conservation pool”) to control runoff that is generated by large precipitation events. Reservoirs play a crucial role in the Central Valley Flood Protection Plan, a comprehensive new framework for system-wide flood management and flood risk reduction in the Sacramento and San Joaquin River Basins.

Both flood control storage availability and the frequency of releases over the amount of water that can go through a penstock for a hydropower plant were analyzed to determine potential challenges for flood control. However, as availability of flood control storage indicates the increase or decrease in flood management risks, this Report provides results for **flood control storage.**

Figure 29**. Boats on Lake Shasta**

5.2.5. Recreation

Only a limited number of Reclamation managed projects have site-specific authority to plan, develop, and manage recreation facilities and improvements. However, the CPV and SWP reservoirs offer many opportunities for water-based recreation.

Reservoir surface area. Reclamation’s recreational uses focus on water based recreation. As reservoir water surface area shrinks, water-based recreational opportunities diminish in quantity and quality.

5.2.6. Ecological Resources

The Ecological Resources Section covers three resource categories mandated by the SECURE Water Act, discussed below. Additional indicators and analyses are provided in Section 7 of the Technical Report.

5.2.6.1. Fish and Wildlife and Endangered Species Act

5.2.6.1.1. Pelagic Species Habitat

Pelagic species are fish that live and spawn in open water in the estuaries of the Bay-Delta. This estuarine habitat fluctuates in response to river flows, ocean tides, and weather. The extent of this habitat depends on the salinity concentration and geographic features in the interior Delta.

In the Delta, these pelagic species include delta smelt, longfin smelt, threadfin shad, and striped bass. The delta smelt, a 3-inch fish found only in the Sacramento-San Joaquin Delta, is listed as under the Endangered Species Act (ESA). Its habitat includes a relatively lower salinity zone that is found from the Suisun Bay in the western Delta upstream into the eastern Delta and Yolo Bypass area. Delta smelt are sensitive to different levels of salinity during their life cycle. Delta smelt are considered especially sensitive because they live just one year, have a limited diet, and exist primarily in brackish waters (a mix of river-fed fresh and salty ocean waters that is typically found in coastal estuaries).

Salinity Zone in the Delta. The extent of the pelagic fish habitat is reflected by the location of the two parts per thousand (ppt) salinity concentration level in the interior Delta. This location is referred to as the X2 and is measured in kilometers (km) from the Golden Gate Bridge in San Francisco Bay. An X2 location of less than 74 km in spring months is one of the goals specified in the U.S. Fish and Wildlife Service's Biological Opinion and the California State Water Resources Control Board's (SWRCB) Water Rights Decision D-1641. Thus, a greater percentage of months exceeding this standard is not desirable. Reclamation and DWR release water from their reservoirs to increase Delta outflows and/or reduce Delta exports to maintain the X2 location at distances that are favorable to maintain suitable habitat conditions for the Delta smelt. The Technical Report also analyzes the X2 position from September through November.

5.2.6.1.2. Adult Salmon Migration

Export pumping by CVP and SWP can actually reverse the natural discharge of the Old and Middle River (OMR) channels of San Joaquin River, especially in the fall months when river flows are normally low. These reverse OMR flows can confuse adult salmon entering the western Delta as they migrate upstream to their spawning grounds as well as draw Delta smelt southward into the export pumping region where there are increased risks of mortality for both of these endangered species.

Figure 30**. Chinook salmon spawning**

Frequency of OMR reverse flows. The frequency of negative (upstream) flows in the OMR channels of the San Joaquin River in the Delta affects anadromous salmon, foodweb productivity, and delta smelt entrainment. These are discussed in more detail in the Technical Report. This Report presents results for the frequency of flows more negative than -5,000 cubic feet per second (cfs) in the OMR channels from October through December.

5.2.6.2. Flow-dependent Ecological Resiliency

Riparian habitat is key to supporting numerous aquatic, terrestrial, and avian species in the Central Valley. These habitats depend on winter and spring flows of sufficient magnitude and duration to promote the creation of fresh point bar surfaces at the edge of river's floodplain. These riparian habitats depend on flows to provide flooding by the river and a water table within reach of plant roots. They support species of plants and wildlife that are adapted to the timing of fluvial events such as flooding, drought, sediment transport, and channel movement.

Flows in the Sacramento River at Keswick Reservoir. Flows above 15,000 cfs are usually associated with winter storms and large spring snowmelt events. An increasing percentage of months with flows less than 15,000 cfs indicates downstream flow conditions that are less favorable to establishment and maintenance of conditions favorable to riparian habitats. The Technical Report discusses two other flow indicators: flows over 10,000 cfs at the mouth of Feather River and flows over 3,000 cfs for the American River flows at Natoma.

5.3. Summary of Projected Impacts Under the No Action Alternative

Section 7 of this Report presents potential climate impacts on selected indicators and compares the adaptation portfolios' performance with No Action in meeting the challenges of a potentially changing climate. The full set of indicators is discussed in Sections 5 and 7 of the Technical Report. Note that the metrics include location information if performance depends on location and the metrics were used in either a quantitative or qualitative manner. Additional details of the specific characteristics of each of the performance metric indicators can be found in Section 5 of the Technical Report.

Figure 31 provides a comparison between a future with no climate change and future under a "middle of the road" climate scenario. These comparisons were grouped into three levels of potential impacts representing improving, little change or deteriorating conditions. Although these groupings are qualitative, they provide some initial insights into how climate change might impact the resource categories. Percent differences are from the Central Tendency climate scenario compared to the Reference-No-Climate-Change climate scenario from 2015 to 2099.

- Green = Conditions improved more than 10%
- Yellow = Conditions are within -10% to +10%
- Red = Conditions declined more than 10%

Table 7 provides the impacts shown in
Figure 31 as percentages and provides a short discussion of contributing factors. Each of these percentages is explained in more detail and in context in the respective sections of Section 7. *Adaptation Portfolios Evaluation* in this report. See Section 5 *System Risk and Reliability Assessment* in the Technical Report for further analysis of these impacts under the No Action alternative.

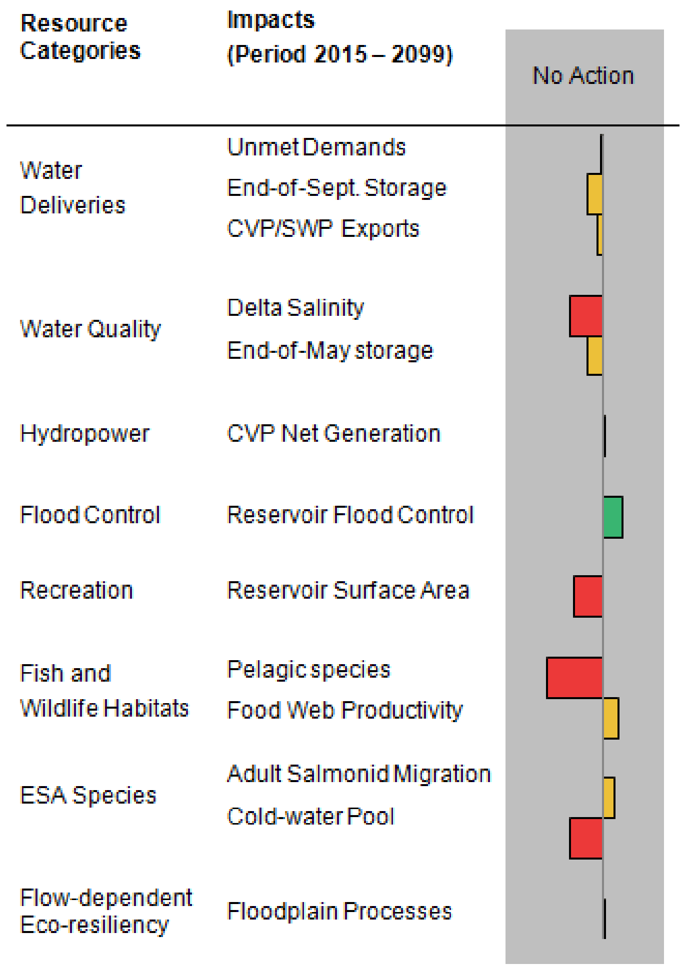


Figure 31. Climate impacts under the No Action alternative (Changes from the Reference-No-Climate-Change to the Central Tendency climate scenario—both under the Current Trends socioeconomic scenario).[12]

[12] These results depend on the climate-socioeconomic scenarios used in the analysis, as impacts are greater under scenarios with higher populations and land use and with more extreme variations in temperature and precipitation. Note that food web productivity and cold water pool are discussed in the Technical Report and not in this Report.

Table 7. Summary of Projected Impacts

Resource Category	Change Metrics	Overall 21st Century Projected Impacts	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, thus increasing unmet demands and decreasing reservoir storage.
	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 at Jersey Point	Projected to increase by 20%	Projected sea level rise would contribute to increased salinity levels in the Delta, thus decreasing water quality.
	End-of-May storage at Shasta Lake	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
ESA Species	Adult salmonid migration	Projected to increase by 7%	Reduced Delta OMR flows in fall would contribute to increasing salmonid migration
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	Projected to increase by 1%	Projected decreased in CVP reservoir storage would contribute to reduced generation but projected decreased CVP exports would result in reduced power use.
Recreation	Reservoir surface area	Projected to decrease by 17%	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%	Increased early season runoff would contribute to releases earlier in the flood control period providing more flood storage.

6. Adaptation Portfolios

6.1. Development of Water Management Actions

This Basins Study responds to a fundamental question:

> "***What are the actions and strategies that can be implemented that reduce climate-related risks to water and related resources in the Basins Study area?***

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. The general approach for developing the adaptation strategies from the Basins Study is summarized below:

Solicit input. To examine a broad range of potential actions, the Study Team participants, interested stakeholders, and the general public were asked to submit actions. The Study Team held a number of meetings where members of the public, partners, water agencies and stakeholders submitted ideas and proposals for water management actions. During this process, the Study Team also compiled an initial list of actions based on those included in other basin studies and planning projects. The culmination of this process resulted in more than 70 water management actions.

Organize actions. The responses were reviewed and organized into seven broad functional objectives:

- **Reduce water demand.**[13] Suggestions included increased agricultural and M&I water use efficiency through conservation and changes in water uses.

- **Increase water supply.** Suggestions included: desalination projects along the Pacific Ocean, along the Gulf of California (Gulf), or brackish water desalinization, wastewater recycling and reuse; and application of precipitation enhancement such as cloud seeding, fog collection, or rainwater harvesting.

- **Improve operational efficiency.** Suggestions included: groundwater management methods such as groundwater banking, conjunctive use

[13] Text color corresponds to colors in Table 9. Summary of Water Management Actions Included in Each Adaptation Portfolio (Colors indicate functional objectives).

management, and well deepening; water quality improvements and management relating to the Delta, salinity, temperature, and runoff management; system operational efficiency such as enhanced environmental flows, hydropower-water supply optimization, system reoperation, and improved CVP/SWP integration; conveyance system improvements including canal capacity restoration and expansion, new conveyance, and canal lining; new or enlarged/expanded surface storage in the Sacramento Valley, San Joaquin Valley, Upper Watershed, or Delta; and water acquisition or transfers.

- **Improve resource stewardship.** Suggestions included: forest restoration and stand management for increased runoff, land fallowing, sediment management, and protection of recharge areas.

- **Improve institutional flexibility.** Suggestions were related to improved regulatory flexibility and adaptability, enhanced environmental flows, and improved SWP/CVP integration.

- **Improve data and management.** Suggestions focused on better monitoring and data management including system automation improvements and improved hydro- meteorological instrumentation.

Develop water management actions. From these functional groupings, individual water management actions were developed. The proposed actions were primarily based on information from long range planning studies, including the California Water Plan Update 2013 (DWR 2014), Mid Pacific Region long term planning studies such as the Central Valley Integrated Resource Plan (Reclamation 2014), and available literature sources. Actions were evaluated at a reconnaissance/appraisal level. Limitations associated with screening a broad range of actions included:

- **Limited levels of analysis.** Limiting the level of analysis helped ensure that all actions were considered at a high level, but also added uncertainty to the results because all of the potential challenges associated with action development and implementation may not have been considered.

- **Inconsistent availability of information.** A detailed assessment by individual location for actions was beyond the scope of the study. Some actions considered had more detailed information available from similar projects and other studies.

- **Implementability.** Considerations such as costs, permit requirements, and long-term feasibility are still highly uncertain.

Characterize actions. Each action was characterized using a set of both quantitative criteria (e.g., potential yield, timing of implementation, annualized cost per acre-foot, energy use) and qualitative criteria (e.g., technical feasibility and implementation risk). Within these broad categories, 20 representative water management actions were evaluated for 11 different criteria shown in Table 8. This information provided an ability to rank each action across these performance criteria and allowed the development of a summary of performance for each action. Figure 32 shows these rankings. In addition, the actions were also sorted based on the cost, quantity of yield or water provided, and timing (Figure 33). See Appendix A: *Detailed Action Evaluation Factors* in the Technical Report.

Table 8. Evaluation Factors Used to Analyze and Compare Water Management Actions.

Evaluation Factors	Summary Description of Criteria
Does this action increase the water supply?	
Quantity of Yield	The estimated long-term quantity of water generated by the action—either an increase in supply or a reduction in demand
Technical Feasibility	Technical feasibility of the action based on the extent of the underlying technology or practices
When could this be implemented? How much would this cost?	
Timing	Estimated first year that the action could begin operation
Cost	The annualized capital, operating, and replacement cost per acre-foot of yield
How doable is the project?	
Implementation Risk	Risk to achieving successful implementation and operation of the action based on factors such as funding mechanisms, competing demands for critical resources, challenging operations, or challenging mitigation requirements
Permitting	Level of anticipated permitting requirements and precedent of success for similar projects
Legal	Consistency with current legal frameworks and laws, or precedent with success in legal challenges
Policy Considerations	Extent of potential changes to existing Federal, State, or local policies that concern water, water use, or land management
What are the long-term considerations?	
Long-term Viability	Anticipated reliability of the action to meet the proposed objectives over the long term
Operational Flexibility	Flexibility of the action to be employed from year to year with limited financial or other impacts
Energy Needs and Sources	Energy required to permit full operation of the action, including treatment, conveyance, and distribution, and the energy source to be used to allow the action to be operational

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 32. 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).

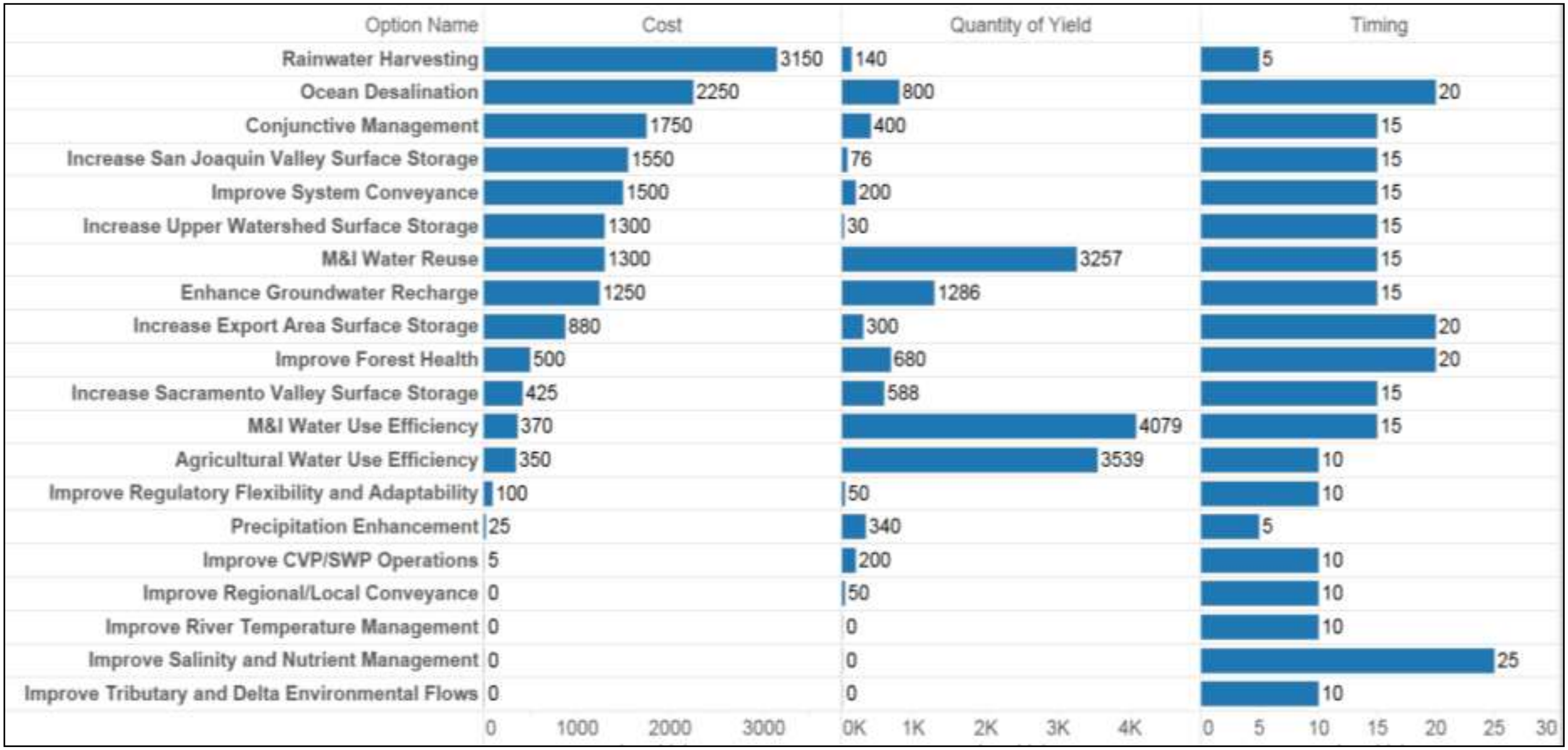


Figure 33. Estimated median cost, quantity, and timing for each of the actions. (Costs are in dollars per acre-foot per year ($/AFY) of supply improvement or demand reduction. Quantity of new supply or demand reduction yield is in thousand acre-feet per year (TAF)

6.2. Development of Adaptation Portfolios

No single action is likely to be adequate to meet all of the future demands of the Basin resources. Therefore, combinations of actions (adaptation portfolios) were developed to address identified risks to the reliability of Central Valley water management systems. The adaptation portfolios identified below were developed over several meetings with the Study Team and were later presented to stakeholders and others at meetings in mid-2015. The adaptation portfolios developed in the Basins Study are described below:

About the Adaptation Portfolios:

Each portfolio developed in this Basins Study consists of a unique selection of water management actions intended to address vulnerabilities that may exist under future climate and socioeconomic conditions.

- **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.

- **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 as well as conjunctive use with increased groundwater recharge.

- **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** 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** 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** 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** includes all water management actions that were in the California Water Action Plan (DWR 2014). Essentially, this portfolio includes all the water management actions included in the other portfolios.

The portfolio analysis was used to demonstrate the effectiveness of different strategies at resolving future supply and demand imbalances and other system vulnerabilities—not to select or recommend a particular portfolio or action. The portfolios are not intended to represent all possible combinations of actions.

The water management actions included in each portfolio are shown in Table 9. The colors used in the table are to highlight the functional objectives for water management actions: **reduce demand (green), increase supply (blue), improve operational flexibility (purple), improve resource stewardship (orange),** and **improve institutional flexibility (grey).** Note that improve data and management is an overarching action for all portfolios and is not shown in this table. Evaluation of these adaptation portfolios is discussed in Section 7.

Table 9. Summary of Water Management Actions Included in Each Adaptation Portfolio (Colors indicate functional objectives).

Water Management Action	Least Cost	Regional Self-Reliance	Healthy Headwaters & Tributaries	Delta Conveyance and Restoration	Expanded Water Storage	Flexible System Operations	Water Action Plan
Increase Agricultural Water Use Efficiency	Reduce Demand	Reduce Demand					Reduce Demand
Increase Urban Water Use Efficiency	Reduce Demand	Reduce Demand					Reduce Demand
Increase Regional Reuse		Increase Supply					Increase Supply
Increase Ocean Desalination		Increase Supply					Increase Supply
Precipitation Enhancement	Increase Supply	Increase Supply					Increase Supply
Rainwater Harvesting		Increase Supply					Increase Supply
Conjunctive Groundwater Management		Operations			Operations	Operations	Operations
Enhance Groundwater Recharge		Operations			Operations	Operations	Operations
Improve Tributary Environmental Flows			Operations				Operations

Water Management Action	Least Cost	Regional Self-Reliance	Healthy Headwaters & Tributaries	Delta Conveyance and Restoration	Expanded Water Storage	Flexible System Operations	Water Action Plan
Improve System Conveyance	Operations			Operations	Operations		Operations
Increase Sac Valley Surface Storage	Operations				Operations		Operations
Increase SJ Valley Surface Storage					Operations		Operations
Increase Export Area Surface Storage	Operations				Operations		Operations
Increase Upper Watershed Surface Storage					Operations		Operations
Improve Forest Health	Resource		Resource				Resource
Improve Regulatory Flexibility/Adaptability	Institutions					Institutions	Institutions

7. Adaptation Portfolios Evaluations

7.1. Objective and Approach

This Basins Study responds to a fundamental question:

> ***"How well will one or more climate adaptation actions work to alleviate anticipated impacts of changing climate conditions to water supplies, demands, infrastructure and ESA species in the Central Valley?"***

To answer this question, this Basins Study compared how each of the proposed adaptation portfolios might perform against how well the No Action alternative would perform for the resources discussed in Section 5. *Challenges: Risk and Reliability Assessment*

This Basins Study evaluated the adaptation portfolios by making comparisons to determine portfolio performance and climate sensitivity. Three climate scenarios were used to represent the range of possible climate change:

For more detailed analyses see the Technical Report

This Basins Study includes future water demand projections developed from all of the socioeconomic and climate scenarios discussed in Section 3.2. *Climate Scenarios* in this Report.

This Report summarizes analytical results from the Current Trends socioeconomic scenario from 2015-2099. To analyze a wider range of potential population growth and land use changes, the Expanded Growth and Slow Growth socioeconomic scenarios were also analyzed, and results for these socioeconomic scenarios are provided in Section 4 of the Technical Report. For a discussion of these projections combined with the Expanded Growth and Slow Growth scenarios, along with the full complement of climate scenarios, see Section 7. *Adaptation Portfolio Evaluation* in the Technical Report.

- **Warm-Wet** climate scenario represents wetter and cooler conditions than the Central Tendency climate scenario.

- **Central Tendency** climate scenario represents a "middle of the road" approach and is the mostly likely future climate outcome.

- **Hot-Dry** climate scenario represents hotter and dryer conditions than the Central Tendency scenario.

A Reference-No-Climate-Change climate scenario with historical conditions projected into the future was used as a basis of comparison. Taken together, these climate scenarios provide a reasonable range of climates without presenting results for all of climate-socioeconomic scenarios. Note that this Report uses the Current Trends socioeconomic scenario only, and other socioeconomic scenarios are in the Technical Report.

This section presents the results of model evaluations of the No Action alternative and the adaptation portfolios described in the previous section for the resource categories discussed in the Section 5 *Challenges: Risk and Reliability Assessment* in this Report. Each subsection summarizes the same key resource category performance indicators:

- **Driver.** Factors and considerations influencing the use of this indicator.
- **Climate influences.** An overview of potential climate considerations.
- **Indicator.** An explanation of the indicator.
- **Conditions under No Action.** All changes in No Action are based on the Central Tendency climate/Current Trends socioeconomic scenarios at the end of the 21^{st} century.
- **Portfolios.** An overview of portfolio performance.

For each resource indicator described in Section 5. *Challenges: Risk and Reliability Assessment*, portfolio performance and climate sensitivity are discussed:

- **Portfolio performance. How well do portfolios compare with the No Action alternative?** This type of comparison is typically done in planning and environmental impact studies. This comparison provides a way to understand how well a portfolio might improve or worsen conditions for a particular resource category for a particular climate-socioeconomic scenario. This performance is discussed in a subsection for each indicator (*Adaptation Portfolio Performance)*.
- **Climate sensitivity. How well do portfolios perform under a variety of climate scenarios compared to a future without climate change?** To determine climate sensitivity, each portfolio's performance under a range of potential future climates is compared to the Reference-No-Climate-Change climate scenario. This type of comparison is typically done in sensitivity analysis studies to determine how much an action (e.g., an adaption portfolio) is affected by a given factor (e.g., climate). These climate sensitivities are discussed in a subsection for each indicator (*Adaptation Portfolio Climate Sensitivity*).

7.2. Summary and Interpretation

To understand how well an adaptation portfolio might improve or worsen conditions for a particular resource category under a particular climate-socioeconomic scenario, Figure 34 shows the adaptation portfolio performance with the No Action alternative.

Percent differences are from the Central Tendency climate scenario compared to the Reference-No-Climate-Change climate scenario from 2015 to 2099.[14]

- Green = Performance improved more than 10%
- Yellow = Performance is within -10% to +10%
- Red = Performance declined more than 10%

The following process is an example of a way to use Figure 34 in a decision-making context. The first column in in Figure 34 compares the impacts under the No Action alternative from a climate scenario for a "middle of the road" future (Central Tendency) with a future without climate change (Reference-No-Climate-Change). For example, pelagic species habitat in the Delta declined under the No Action alternative in the Central Tendency climate scenario compared to the Reference-No-Climate-Change. The next columns show the effectiveness of each adaptive portfolio to reduce salinity levels in the Delta, which could promote pelagic species habitat. Looking horizontally along this row, it can be observed that the Delta Conveyance and Restoration portfolio is the only adaptation portfolio that improves this outcome. Looking vertically within the Delta Conveyance and Restoration portfolio column can help determine tradeoffs that might occur if this portfolio were implemented—in this case, slight improvements in reducing unmet demands and more improvements in adult salmon migration. (These improvements are the result of improved conveyance.) However, the tradeoffs are decreased end-of-September storage and reduced recreation. (These tradeoffs occur because increasing Water Deliveries result in reduced reservoir storage, which affects both these indicators negatively.)

About Scenarios Used:

These results depend on the climate-socioeconomic scenario used in the analysis. Therefore, it is essential to clearly define and understand the analysis and the range of scenarios used as a foundation for a collaborative process that engages with stakeholders across the range of resource categories prior to making any decision about implementation of any of the adaptation portfolios.

For More Information:
This Report describes only selected scenarios from the wide range of those analyzed. For a discussion of the analysis for each indicator under all ensemble climate scenarios, as well as a further discussion of all performance indicators, see the Technical Report's Section 7 *Adaptation Portfolios Evaluation*.

[14] See Section 3. *Technical Approach and Analysis Process* in this Report for descriptions of these scenarios

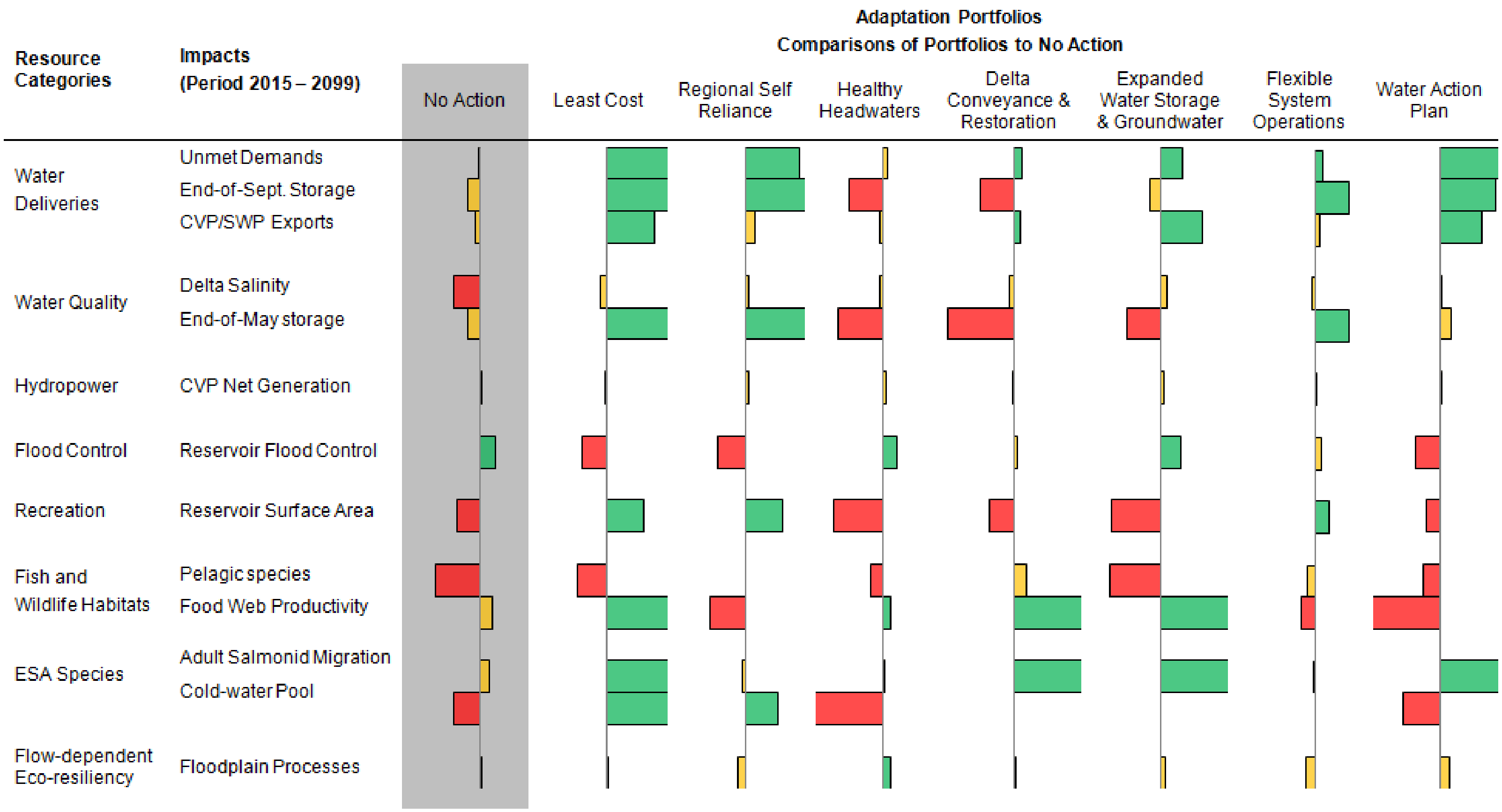


Figure 34. Summary Comparisons of Adaptation Portfolios to the No Action Alternative. [15]

[15]Changes in the No Action alternative column show changes from the Central Tendency climate scenario compared to the Reference-No-Climate-Change climate scenario. Changes in the other columns (adaptation portfolio)s show impacts under the Central Tendency climate/Current Trends socioeconomic scenario from 2015 – 2099 compared to the No Action alternative. Note that food web productivity and cold water pool are discussed in the Technical Report and not in this Report.

7.3. Water Delivery

As discussed in Section 5 *Challenges: Risk and Reliability* of this Report, indicators used to evaluate water deliveries are: unmet demands, end-of-September reservoir storage, CVP-SWP Delta exports, and the change in groundwater storage. The analysis showed that reducing unmet demands and maintaining Delta exports are important challenges to reliable future water deliveries and thus are highlighted in this summary. Further information is in Section 7.2 *Water Delivery Reliability* in the Technical Report.

- **Unmet Demands.** Unmet demands represent the difference between total agricultural and urban water needs and the supply available from surface water sources, groundwater pumping, and water recycling. *Decreases in the unmet demand indicator would imply that water delivery reliability is increasing.*

- **End-of-September Storage.** Maintaining adequate carryover storage at the end of the September when water use typically decreases mitigates the impacts of reduced precipitation over a period of several years. *Decreases in this end-of-September storage indicator would imply that there are fewer months with low storage, so therefore water delivery reliability is increasing.*

- **CVP/SWP Delta exports.** The Central Valley Project (CVP) and State Water Project (SWP) systems are operated to meet State and federally mandated criteria for maintaining Delta salinity below certain levels. To meet these criteria, Delta exports have to be reduced and Delta outflow to the Pacific Ocean increased. With rising sea levels and increasing salinity, less water will be available to export for water deliveries to project contractors. *Increases in Delta exports would imply that water delivery reliability is increasing.*

- **Change in Groundwater Storage.** Changes in groundwater storage reflect the balance between aquifer recharge and groundwater pumping. *Increases in groundwater storage would imply that the groundwater supply reliability is increasing.*

7.3.1. Unmet Demands

The CVP, SWP, and most other water supply systems in the Central Valley were envisioned and constructed during the early to mid- 20th century when water demands were much lower. Increasing population, land use changes, new environmental water needs and climate changes have all contributed to an increasing imbalance between water supplies and demands.

Unmet demands typically increase in years with reduced precipitation—especially when accompanied by hot and dry atmospheric conditions such as typically occur during the summer season in the Central Valley. Agricultural demands, driven largely by crop irrigation, are more susceptible to these influences than urban demands, driven more by population.

Unmet demands represent the difference between total agricultural and urban water needs and the supply available from surface water sources, groundwater pumping, and water recycling. *Decreases in the unmet demand indicator would imply that water delivery reliability is increasing.*

Unmet demands varied considerably depending on future climate conditions. The Warm-Wet climate scenario had the lower unmet demands than the Reference-No-Climate-Change climate scenario. Unmet demands were slightly more in the Central Tendency climate scenario and significantly more in the Hot-Dry climate scenario when compared to the Reference-No-Climate-Change climate scenario.

All adaptation portfolios had less unmet demands than the No Action alternative. The Least Cost, Regional Self Reliance, and Water Action Plan all resulted in significant reductions in unmet demands. Unmet demands were least in the Warm-Wet climate scenario and greatest in the Hot-Dry climate scenario relative to the Reference-No-Climate-Change climate scenario.

7.3.1.1. Adaptation Portfolio Performance

In all climate scenarios, all adaptation portfolios performed better than the No Action alternative (Figure 35). The Water Action Plan (which consists of all the water management actions employed in the other portfolios) had the lowest unmet demands. Both the Least Cost and Regional Self-Reliance performed nearly as well as the Water Plan. The Healthy Headwaters and Tributaries, Delta Conveyance and Restoration, and Flexible Operations and Management portfolios had the least effect on reducing unmet demands. These improved performances are mostly related to water management actions that increased water supplies and improved water use efficiencies.

Table 10 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

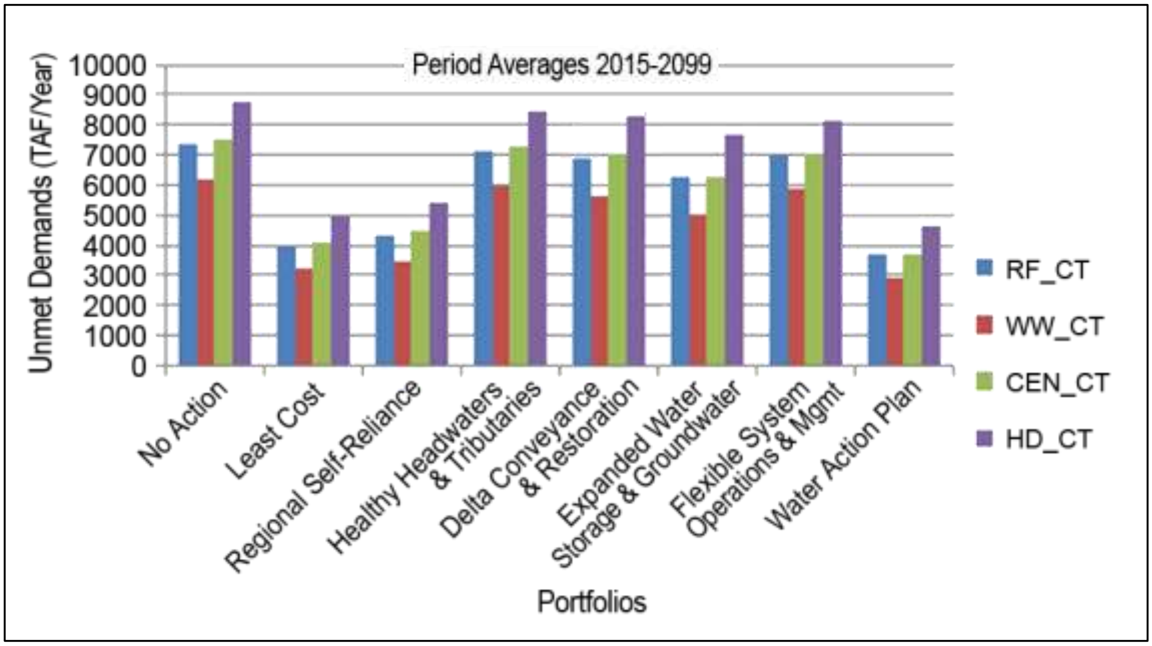


Figure 35. Average annual unmet demands in the Central Valley in each adaptation portfolio.[16] (Lower numbers indicate increased benefits)

[16] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry.

Table 10. Unmet Water Demands: Adaptation Portfolio Performance Compared to the No Action Alternative (% change) (Negative numbers indicate increased benefits)

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-47	-48	-46	-44
Regional Self-Reliance	-41	-44	-41	-38
Healthy Headwaters and Tributaries	-3	-4	-3	-4
Delta Conveyance and Restoration	-7	-8	-6	-5
Expanded Water Storage and Groundwater	-15	-19	-16	-12
Flexible System Operations and Mgmt	-5	-5	-6	-7
Water Action Plan	-50	-52	-50	-48

7.3.1.2. Adaptation Portfolio Climate Sensitivity

Table 11 shows how unmet demands varied over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All adaptation portfolios and the No Action alternative had **significantly fewer** unmet demands than the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All the adaptation portfolios and the No Action alternative had s**lightly more** unmet demands.

- **Hot-Dry.** All adaptation portfolios and the No Action alternative had **significantly more** unmet demands.

Table 11. Unmet Water Demands: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits)

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-16	2	19
Least Cost	-18	3	26
Regional Self-Reliance	-20	3	25
Healthy Headwaters and Tributaries	-17	2	18
Delta Conveyance and Restoration	-18	3	20
Expanded Water Storage and Groundwater	-20	1	23
Flexible System Operations and Mgmt	-16	1	17
Water Action Plan	-20	2	25

7.3.2. End-of-September System Storage

Major reservoirs in the Central Valley are managed to maintain adequate water supplies to mitigate the risks of reduced precipitation over a period of several years. This requires maintaining adequate carryover storage at the end of the September when water use typically decreases.

Projected increases in warming will likely result in earlier runoff which cannot be stored during the fall and winter flood management period. Warming will also increase reservoir evaporation and may increase watershed evapotranspiration—further reducing runoff and water storage.

Water system managers typically target a certain volume of water in reservoirs at the end of September to maintain adequate water supplies to provide some level of water deliveries in the event of reduced precipitation in future years. In this study, the indicator is meeting storage targets. This indicator is measured by how many times the storage target is not met, that is that the percentage of years that Sacramento Valley storage is less than 10% of historical end-of-September storage as represented by the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF)[17] scenario. *Decreases in this end-of-September storage indicator would imply that there are fewer months with low storage, so therefore water delivery reliability is increasing.*

End-of September storage varied considerably, depending on future climate projections. The Central Tendency and Hot-Dry climate scenarios had more frequent periods of low reservoir storage than under the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF),[17] while the Warm-Wet climate scenario had fewer periods of low reservoir storage.

All portfolios showed more frequent periods of below reservoir storage. The largest increases occurred in the Hot-Dry climate scenario with the Healthy Headwaters and Delta Conveyance adaptation portfolios tying for the largest increases while the Least Cost adaptation portfolio had the smallest increase. The Least Cost, Regional Self Reliance, Flexible System Operations, and the Water Action Plan adaption portfolios performed consistently better than No Action.

[17] Note: The Reference-No-Climate-Change climate/2006 Historic Demands (RF_RF) scenario uses the same no climate change reference historic climate as RF_CT but does not include future changes in population or land use.

7.3.2.1. Adaptation Portfolio Performance

All adaptation portfolios showed increases in storage under the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF)18 (Figure 36). The Least Cost portfolio performed better than any of the others, including the Water Action Plan portfolio that includes all the water management actions employed in the other portfolios. Regional Self Reliance portfolio performed nearly as well as Least Cost especially in the wetter climate (Warm-Wet). The improved performance of these portfolios is mostly related to including water management actions that increased water supply, provided new conveyance and/or improved water use efficiency. The Healthy Headwaters and Delta Conveyance adaptation portfolios performed less well than No Action.

Table 12 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

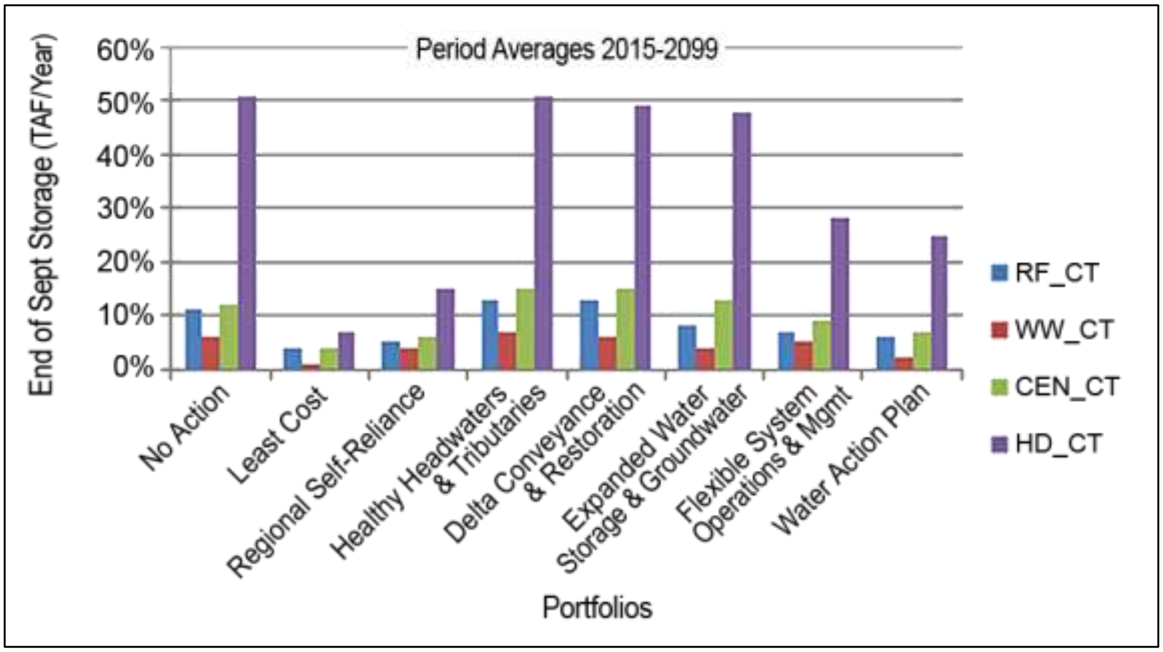


Figure 36**. Frequency of missing end-of-September storage targets (percentage of years with Sacramento Valley end-of-September storage less than the 10th percentile of storage in the No Action alternative under Reference-No-Climate-Change climate scenario in each portfolio.[19]**
(Lower numbers indicate increased benefits)

[19] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate. Note that this indicator is from the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario.

Table 12. Frequency of Missing End-of-September Storage Targets: Adaptation Portfolio Performance (% Change from the No Action Alternative). (Negative numbers indicate increased benefits)

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-64	-83	-67	-86
Regional Self-Reliance	-55	-33	-50	-71
Healthy Headwaters and Tributaries	18	17	25	0
Delta Conveyance and Restoration	-27	-33	8	-6
Expanded Water Storage and Groundwater	-27	-33	8	-6
Flexible System Operations and Mgmt	-36	-17	-25	-45
Water Action Plan	-45	-67	-42	-51

7.3.2.2. Adaptation Portfolio Climate Sensitivity

Table 13 shows how availability of end-of-September storage over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All adaptation portfolios and the No Action Alternative had **significantly fewer** occurrences below historic reservoir storage levels.

- **Central Tendency.** All adaptation portfolios and the No Action Alternative had **more** occurrences below historic reservoir storage levels.

- **Hot-Dry.** All adaptation portfolios and the No Action Alternative had **significantly more** occurrences below historic reservoir storage levels.

Table 13. Frequency of Missing End-of-September Storage Targets: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-45	9	364
Least Cost	-75	0	75
Regional Self-Reliance	-20	20	200
Healthy Headwaters and Tributaries	-46	15	292
Delta Conveyance and Restoration	-54	15	277
Expanded Water Storage and Groundwater	-50	63	500
Flexible System Operations and Mgmt	-29	29	300
Water Action Plan	-67	17	317

7.3.3. Delta Exports (CVP and SWP)

DRIVER	The CVP and SWP export water from the southern Sacramento-San Joaquin Delta for delivery to project contractors in southern Central Valley, Central Coast and South Coast regions. These exports occur by pumping water from the Jones (CVP) and Banks (SWP) pumping plants into the Delta-Mendota Canal and California Aqueduct
CLIMATE INFLUENCES	The Delta is the largest estuary on the Pacific coast and the salinity of waters is influenced by daily tidal changes. With increased warming, global sea levels will rise and further increase the salinity of Delta.
INDICATOR	The CVP and SWP exports are curtailed whenever State and Federally mandated Delta water quality and flow standards are exceeded. *Increases in Delta exports would imply that water delivery reliability is increasing.*
NO ACTION	Delta exports had a significant sensitivity to future climate with the maximum exports occurring in the wetter (Warm-Wet) and the minimum in the drier (Hot-Dry) climate scenario. Exports were intermediate in the Central Tendency climate scenario.
PORTFOLIOS	Most of the adaptation portfolios resulted in more Delta exports than under the No Action alternative. However, the Healthy Headwaters had fewer Delta exports than the No Action alternative under all climate scenarios. The Least Cost and Expanded Water Storage and Groundwater adaptation portfolios had the most exports and were especially effective relative to No Action in the Hot-Dry climate scenario. Exports were only slightly increased in the Warm-Wet climate scenario but significantly decreased in the Hot-Dry climate scenario relative to Reference-No-Climate-Change climate scenario.

7.3.3.1. Adaptation Portfolio Performance

The Least Cost adaptation portfolio performed better than all of the others, including the Water Action Plan adaptation portfolio (Figure 37). The Expanded Storage and Groundwater portfolio also performed well. These improved performances were mostly related to the expanded surface and groundwater storage actions combined with improved Delta conveyance. The Healthy Headwaters and Tributaries portfolio actually performed worse than the No Action alternative—primarily because of increased reservoir releases to create higher spring river flows and Delta outflows.

Table 14 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

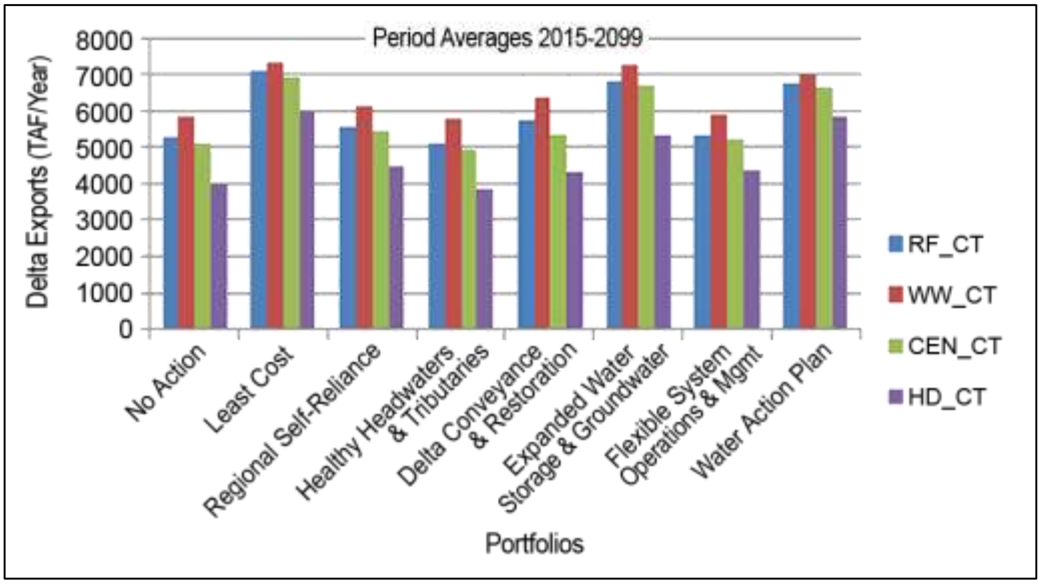


Figure 37. Average annual total Delta exports in each portfolio (in TAF/Year). (Higher numbers indicate increased benefits)

Table 14. Delta Exports: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Positive numbers indicate increased benefits)

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	35	25	36	51
Regional Self-Reliance	6	5	7	12
Healthy Headwaters and Tributaries	-3	-1	-3	-3
Delta Conveyance and Restoration	9	9	5	8
Expanded Water Storage and Groundwater	30	25	32	33
Flexible System Operations and Mgmt	2	1	3	10
Water Action Plan	28	19	31	47

7.3.3.2. Adaptation Portfolio Climate Sensitivity

Table 15 shows how Delta exports over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All adaptation portfolios and the No Action Alternative had **increased** exports compared to the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All adaptation portfolios and the No Action Alternative had **slightly reduced** exports compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All adaptation portfolios and the No Action Alternative had **significantly reduced** exports compared to the Reference-No-Climate-Change climate scenario.

Table 15. Delta Exports: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Positive numbers indicate increased benefits)

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	11	-3	-24
Least Cost	3	-3	-15
Regional Self-Reliance	10	-2	-19
Healthy Headwaters and Tributaries	13	-3	-24
Delta Conveyance and Restoration	11	-6	-25
Expanded Water Storage and Groundwater	7	-2	-22
Flexible System Operations and Mgmt	10	-2	-18
Water Action Plan	3	-1	-13

7.3.4. Change in Groundwater Storage

Groundwater is a major source of water supply in the Central Valley and coastal regions. In some areas, groundwater is the only source but in most basins groundwater is used as a supplemental supply when surface water is not sufficient during dry years and drought periods. Groundwater is also the major source of supply in many urban areas. Increasing groundwater storage mitigates the risks of water shortages.

During dry years and especially during drought periods, aquifer recharge is reduced and agricultural and urban pumping increases—both of which result in decreases in groundwater storage.

Changes in groundwater storage reflect the balance between aquifer recharge and groundwater pumping. When recharge exceeds pumping, storage increases and when pumping exceeds recharge storage decreases. *Increases in groundwater storage would imply that the groundwater supply reliability is increasing.*

Groundwater storage changes corresponded closely with increasing precipitation. The maximum increase occurred in the wetter (Warm-Wet) and the minimum in the drier (Hot-Dry) climate scenario. The change in the Central Tendency climate scenario was intermediate.

Most of the adaptation portfolios resulted in more groundwater storage than under the No Action alternative. The maximum increase occurred in the Water Action Plan in the Warm-Wet climate scenario. The Least Cost and Regional Self-Reliance portfolios also performed well in all climate scenarios. The only adaptation portfolio with less storage was the Flexible Systems Operation and Management. Storage increased significantly for both the Warm-Wet and Central Tendency climate scenarios but decreased in the Hot-Dry climate scenario relative to the Reference-No-Climate-Change climate scenario.

7.3.4.1. Adaptation Portfolio Performance

All the adaptation portfolios and the No Action alternative resulted in more groundwater storage (Figure 38). These increases were partly due to the long-term decline in agricultural water demands. As discussed in Section 4, these declines are related to changes in land use as well as changes in climate especially in the late 21st century. The maximum increase in groundwater storage occurred with the Water Action Plan. The Least Cost and Regional Self Reliance portfolios also performed well—primarily due to combining increased water storage with better water use efficiency actions. With the exception of Flexible Systems Operations which lacked improved water use efficiency actions, all portfolios performed better than No Action.

Table 16 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

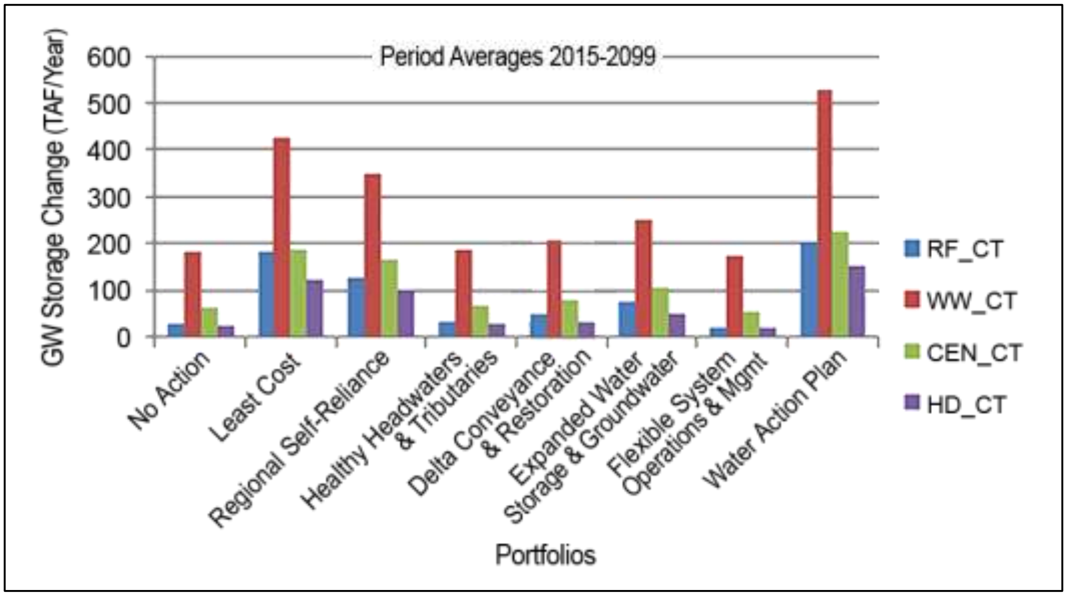


Figure 38. Average annual groundwater storage in the Central Valley in each adaptation portfolio.[20] (Higher numbers indicate increased benefits).

Table 16. Groundwater Storage: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Positive numbers indicate increased benefits)

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	503	136	191	388
Regional Self-Reliance	317	93	156	300
Healthy Headwaters and Tributaries	17	4	6	16
Delta Conveyance and Restoration	63	15	23	36
Expanded Water Storage and Groundwater	157	38	63	104
Flexible System Operations and Mgmt	-37	-4	-13	-20
Water Action Plan	583	191	253	512

[20] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

7.3.4.2. Adaptation Portfolio Climate Sensitivity

Table 17 shows how groundwater storage differed over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All portfolios and the No Action alternative had **significantly more** groundwater storage than in the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** Most portfolios and the No Action alternative had **significantly more** groundwater storage than in the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** Most portfolios and the No Action alternative had **significantly less** groundwater storage than in the Reference-No-Climate-Change climate scenario.

Table 17. Groundwater Storage: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Positive numbers indicate increased benefits)

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	503	113	-17
Least Cost	136	3	-33
Regional Self-Reliance	180	31	-20
Healthy Headwaters and Tributaries	437	94	-17
Delta Conveyance and Restoration	324	61	-31
Expanded Water Storage and Groundwater	223	35	-34
Flexible System Operations and Mgmt	811	195	5
Water Action Plan	157	10	-25

7.4. Water Quality

As discussed in Section 5 *Challenges: Risk and Reliability* of this Report, indicators used to evaluate water quality are below. Further information is in the Section 7.4 *Water Quality* in the Technical Report.

- **Delta Salinity.** Salinity standards were established by the SWRCB for water quality in the Delta. Reclamation and DWR are required to release water from upstream reservoirs to meet these standards. *Decreases in Delta salinity would imply that water quality is improving.*

- **End-of May Storage.** End-of May storage at Lake Shasta indicates the ability to provide cold water to maintain favorable habitat conditions for native fish, including endangered salmon. *Decreases in the frequency of end-of-May storage below historic levels would imply that water quality is improving.*

7.4.1. Delta Salinity

DRIVER	Delta salinity is regulated by SWRCB to protect beneficial urban, agricultural and environmental uses. Reclamation and DWR are required to meet these seasonally changing standards by releasing water stored in Shasta, Oroville, Folsom and New Melones reservoirs and/or by adjusting export pumping rates to reduce the inflow and mixing of high salinity sea water eastward into the interior Delta regions.
CLIMATE INFLUENCES	During dry years and drought periods when inflows of fresh water into the Delta are reduced, salinity tends to increase. With increased warming, global sea levels will continue to rise and further increase the salinity of Delta.
INDICATOR	Salinity standards were established by the SWRCB at several locations in the Delta including Emmaton, Rock Slough and Jersey Point in the western Delta and at Vernalis in the south Delta. Salinity is expressed as electrical conductivity (EC) and measured in units of micro-siemens per centimeter (µS/cm). *Decreases in Delta salinity would imply that water quality is improving.*
NO ACTION	At Jersey Point, the average April-to-August EC increased the most in Hot-Dry climate scenario relative to the Reference-No-Climate-Change climate scenario. At Vernalis, there was a similar increasing trend in EC in the Central Tendency and Hot-Dry climate scenarios.

None of the adaptation portfolios achieved any significant reductions in salinity relative to No Action. At both Jersey Point and Vernalis, all adaptation portfolios had significant increases in salinity in the Hot-Dry and Central Tendency climate scenarios than the Reference-No-Climate-Change climate scenario. In the Warm-Wet climate scenario, significant decreases in salinity occurred at Vernalis while only slight changes occurred at Jersey Point.

7.4.1.1. Adaptation Portfolio Performance

7.4.1.1.1. Jersey Point

Due to increasing sea level throughout the 21st century, Delta salinity increased at Jersey Point in the Hot-Dry and Central Tendency climate scenarios under all the adaptation portfolios and the No Action alternative (Figure 39). In the Warm-Wet climate scenario, the Least Cost, Regional Self-Reliance, Flexible System Operations and Water Plan portfolios slightly reduced Delta salinity relative to the No Action alternative.

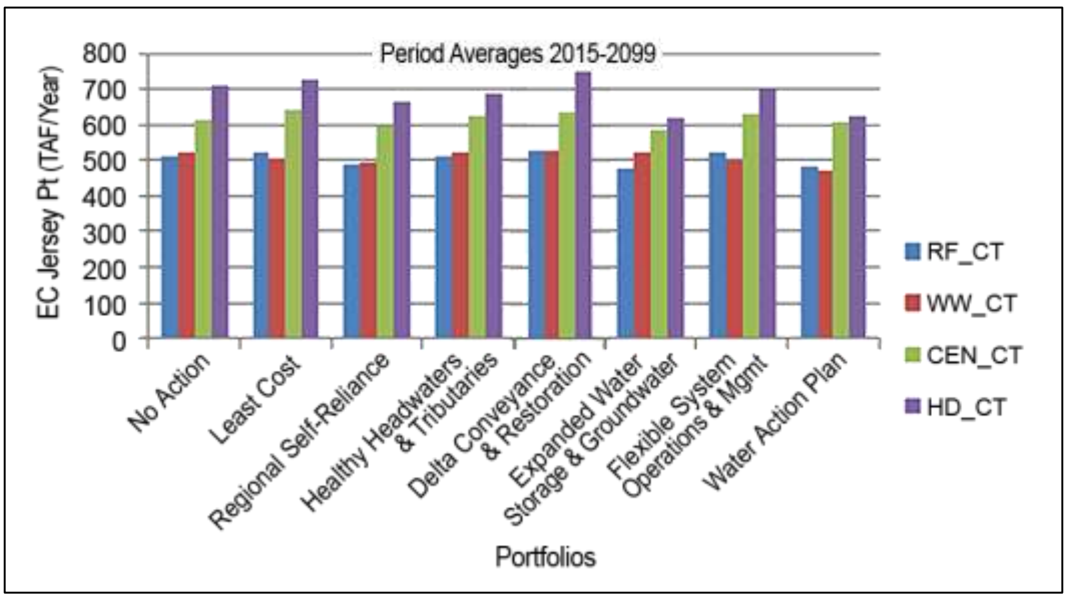


Figure 39. Average April-August salinity levels at Jersey Point in each adaptation portfolio. (Lower numbers indicate increased benefits).

Table 18 shows details of the performance of each of the portfolios relative to No Action in each of the four climate-socioeconomic scenarios.

Table 18. April-August Salinity Levels at Jersey Point: Adaptation Portfolio Performance Compared to the No Action Alternative Percent Change (%) (Negative numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	2	-4	4	3
Regional Self-Reliance	-5	-6	-2	-6
Healthy Headwaters and Tributaries	0	0	2	-3
Delta Conveyance and Restoration	3	2	4	6
Expanded Water Storage and Groundwater	-7	0	-4	-12
Flexible System Operations and Mgmt	2	-4	3	-1
Water Action Plan	-5	-9	-1	-12

7.4.1.1.2. Vernalis

There are higher Delta salinity levels in all the adaptation portfolios and the No Action alternative (Figure 40) in the Hot-Dry and Central Tendency climate scenarios than in the Reference-No-Climate-Change climate scenario at Vernalis. In the Warm-Wet climate scenario, salinity was reduced in all portfolios and No Action. This reduced salinity is primarily related to the increased flows of the San Joaquin River at Vernalis in the warm-wet scenario. Table 19 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

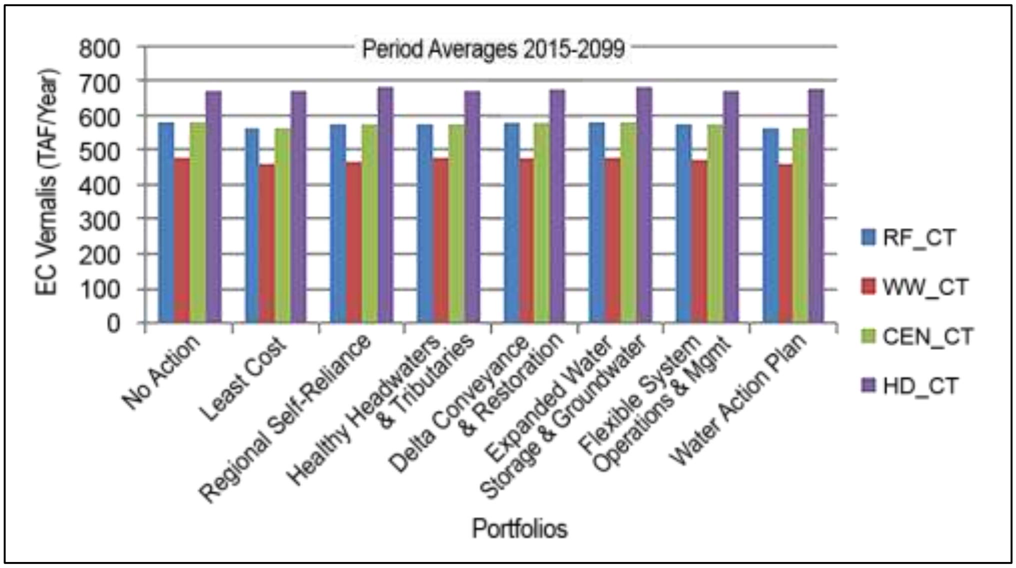


Figure 40. Average annual salinity levels at Vernalis in each adaptation portfolio.[21] (Lower numbers indicate increased benefits).

Table 19. Annual Salinity Levels at Vernalis: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits)

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-3	-4	-3	0
Regional Self-Reliance	-1	-2	-1	1
Healthy Headwaters and Tributaries	-1	-1	0	0
Delta Conveyance and Restoration	0	0	0	1
Expanded Water Storage and Groundwater	0	0	1	2
Flexible System Operations and Mgmt	-1	-1	-1	0
Water Action Plan	-3	-4	-2	1

7.4.1.2. Adaptation Portfolio Climate Sensitivity

7.4.1.2.1. Jersey Point

Table 20 shows how April-August salinity in EC (µS/cm) at Jersey Point over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

---

[21] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

- **Warm-Wet.** Only a **few of portfolios had slightly lower salinity** than the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All portfolios and the No Action Alternative had **significantly higher salinity** than the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action Alternative had **higher salinity** than the Reference-No-Climate-Change climate scenario.

Table 20. April-August Salinity in EC (µS/cm) at Jersey Point: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (%) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	2	20	38
Least Cost	-4	23	40
Regional Self-Reliance	1	23	36
Healthy Headwaters and Tributaries	2	22	34
Delta Conveyance and Restoration	1	21	43
Expanded Water Storage and Groundwater	10	23	30
Flexible System Operations and Mgmt	-4	21	35
Water Action Plan	-2	26	29

7.4.1.2.2. Vernalis

Table 21 shows how April-August salinity in EC (µS/cm) at Vernalis over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All portfolios and the No Action Alternative had **lower** salinity levels than the Reference-No-Climate-Change climate scenario

- **Central Tendency.** All portfolios and the No Action Alternative were **not significantly different** salinity levels than the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action Alternative had **higher** salinity levels than the Reference-No-Climate-Change climate scenario.

Table 21. Annual Salinity in EC (µS/cm) at Vernalis: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-17	-1	16
Least Cost	-18	0	19
Regional Self-Reliance	-18	0	19
Healthy Headwaters and Tributaries	-18	0	17
Delta Conveyance and Restoration	-18	0	17
Expanded Water Storage and Groundwater	-18	0	17
Flexible System Operations and Mgmt	-18	-1	17
Water Action Plan	-19	0	20

7.4.2. End-of- May Storage

DRIVER	Major reservoirs in the Central Valley are obstacles to the upstream migration of aquatic species such as steelhead and salmon to their natural habitats in the Sierra Nevada and Coast Range mountains. However, these reservoirs are now important sources of cold water for the maintenance of suitable habitats in river channels downstream of the dams.
CLIMATE INFLUENCES	Reduced precipitation as well as changes in the seasonality of runoff may result in reduced reservoir storage. With increasing temperatures, more precipitation occurs as rainfall and runoffs into reservoirs rather than accumulating as mountain snowpack. During the fall-winter season, some of this runoff may exceed the reservoir's safe storage capacity and need to be quickly released, thereby reducing water storage—even without a reduction in precipitation.
INDICATOR	The end-of-May storage indicator is a measure of the magnitude of the "cold water pool" available to support aquatic habitat below major reservoirs during the hot summer and fall months. It is expressed by the percentage of months that projected end-of-May storage is less than the 10^{th} percentile of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF). Shasta Reservoir was chosen to represent all the other major Central Valley reservoirs. *Decreases in this indicator would imply that water quality is improving.*
NO ACTION	End-of May storage varied considerably depending on future climate. The Central Tendency climate scenario had a slight increase in the frequency of below reservoir storage and significantly larger increases in the Hot-Dry climate scenario. In the Warm-Wet climate scenario, the occurrences of low storage were significantly reduced.
PORTFOLIOS	All adaptation portfolios showed increases in the frequency of end-of-May storage below historic levels. The largest increases occurred in the Hot-Dry climate scenario. Only the Least Cost and Regional Self Reliance adaptation portfolios performed consistently better than the No Action alternative.

7.4.2.1. Adaptation Portfolio Performance

All adaptation portfolios and the No Action alternative had increased frequencies of below historic period storage under the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (Figure 41). The Least Cost and Regional Self-Reliance adaptation portfolios performed better than the others, including the Water Action Plan (which includes all the water management actions employed in the other adaptation portfolios). These improved performances are primarily related to actions that increased storage and/or improved water use efficiency. The Heathy Headwaters and Tributaries, Delta Conveyance and Restoration, and Expanded Water Storage and Groundwater adaptation portfolios performed less well than the No Action alternative, primarily because of increased spring releases and Delta outflows that more closely resemble unimpaired flow conditions.

Table 22 shows details of the performance of each of the adaptation portfolios relative to No Action in each of the four climate scenarios.

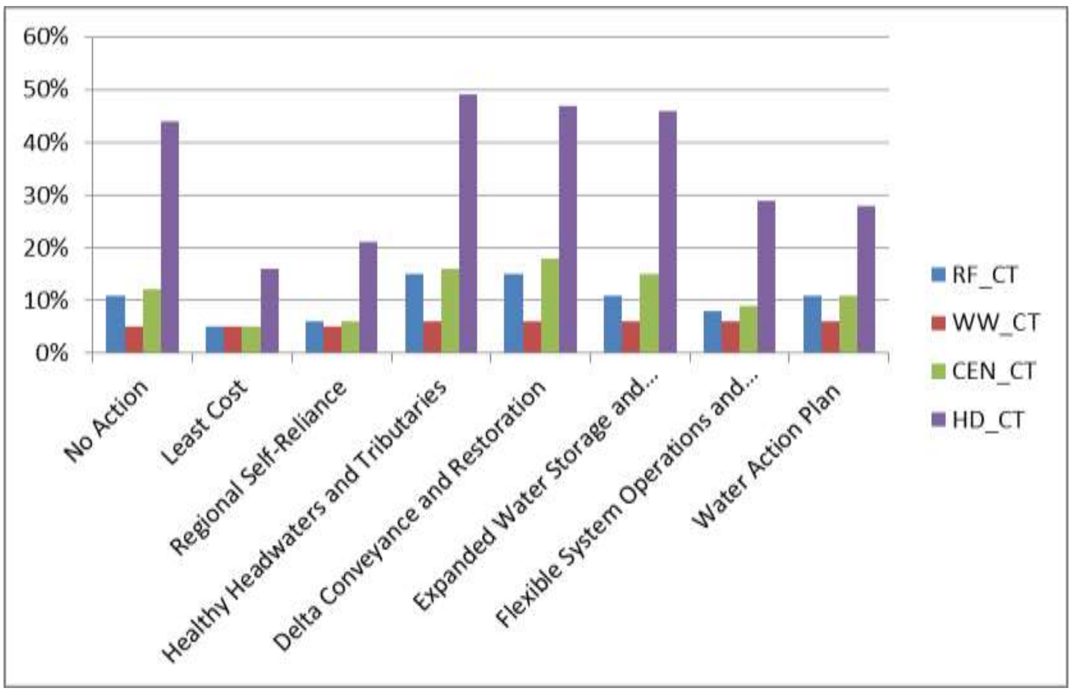


Figure 41. Percentage of years with Lake Shasta End-of-May storage less than the 10th percentile of storage in the No Action alternative in each adaptation portfolio.[22] (Lower numbers indicate increased benefits).

[22] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

Table 22. Lake Shasta End-of-May Storage: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-55	0	-58	-64
Regional Self-Reliance	-45	0	-50	-52
Healthy Headwaters and Tributaries	36	20	33	11
Delta Conveyance and Restoration	36	20	50	7
Expanded Water Storage and Groundwater	0	20	25	5
Flexible System Operations and Mgmt	-27	20	-25	-34
Water Action Plan	0	20	-8	-36

7.4.2.2. Adaptation Portfolio Climate Sensitivity

Table 23 shows how Lake Shasta end-of-May Storage over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** Most portfolios had **significantly fewer** occurrences of end-of-May storage below historic reservoir storage levels.

- **Central Tendency.** Most portfolios **had increased** occurrences of end-of-May storage below historic reservoir storage levels, and some of these had **significantly increased.**

- **Hot-Dry.** Most portfolios had **significantly more** occurrences of end-of-May storage below historic reservoir storage levels.

Table 23. Lake Shasta End-of-May Storage: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-55	9	300
Least Cost	0	0	220
Regional Self-Reliance	-17	0	250
Healthy Headwaters and Tributaries	-60	7	227
Delta Conveyance and Restoration	-60	20	213
Expanded Water Storage and Groundwater	-45	36	318
Flexible System Operations and Mgmt	-25	13	263
Water Action Plan	-45	0	155

7.5. Hydropower

As discussed in Section 5. *Challenges: Risk and Reliability* of this Report, indicators used to evaluate hydropower was net power generation for the CVP. Further information on this and other indicators for hydropower is in Section 7.5. *Hydropower and GHG Emissions* in the Technical Report.

Net hydropower generation. Hydropower provides important benefits to the CVP. Net hydropower generation is the difference between CVP hydropower production and project use. *Increases in net generation imply that hydropower benefits are increasing.*

The hydropower generated by the CVP and SWP systems comprises nearly 7% of the total online capacity of California power plants. Hydropower is especially important resource because of its ability to meet peak electrical grid demands. CVP power plants generate about 4.5 gigawatt hours (GWh) in an average water year. About a third of the electricity generated by the CVP is used for pumping water throughout the project. The rest is made available to the Western Area Power Administration for sale and distribution in the western United States.

Hydropower generation increases in proportion to the volume of reservoir storage. Reduced precipitation as well as changes in the seasonality of runoff may result in reduced reservoir storage. With increasing temperatures, more precipitation occurs as rainfall and runs offs into reservoirs rather than accumulating as mountain snowpack. During the fall-winter season, some of this runoff may exceed the reservoir's safe storage capacity and need to be quickly released, thereby reducing water storage and hydropower capacity—even without a reduction in precipitation.

Net hydropower generation is the difference between hydropower production and use. Generation increases with increasing reservoir storage during wet years while hydropower use generally declines in drier years because less power is used to make project water deliveries. Net generation is measured in GWh per year. *Increases in net generation imply that hydropower benefits are increasing.*

Net hydropower generation corresponded closely with the climate projections. The highest net generation occurred in the Warm-Wet while the lowest occurred in the Hot-Dry climate scenario.

All portfolios performed about the same as the No Action alternative.

7.5.1. Adaptation Portfolio Performance

The Regional Self-Reliance and Healthy Headwaters had consistent but only very slight increases in performance relative to No Action in all climate scenarios because using hydropower for water deliveries is less in these portfolios (Figure 42). The Delta Conveyance and Restoration adaptation portfolio had slightly reduced performance—primarily because of its increased use of hydropower for CVP pumping.

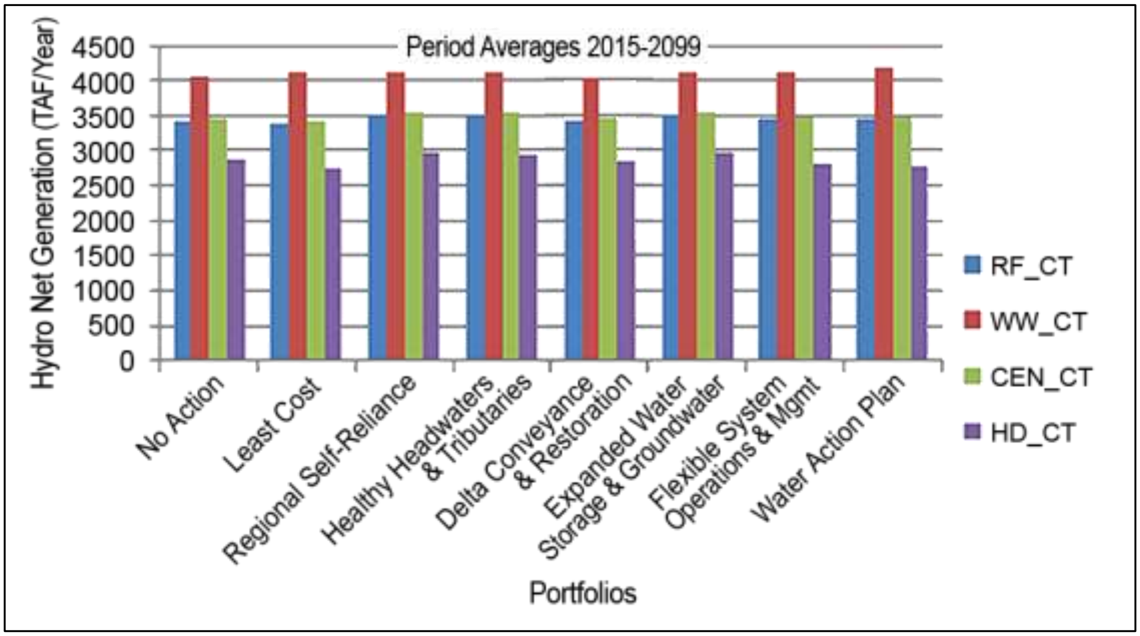


Figure 42. Average annual net energy generation (GWh/year) in the CVP system in each adaptation portfolio.[23] (Higher numbers indicate increased benefits).

Table 24 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

[23] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

Table 24. Annual Net Energy Generation: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Positive numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-1	2	-1	-4
Regional Self-Reliance	2	2	2	3
Healthy Headwaters and Tributaries	3	2	3	2
Delta Conveyance and Restoration	-1	-1	0	-1
Expanded Water Storage and Groundwater	2	2	2	3
Flexible System Operations and Mgmt	0	2	0	-2
Water Action Plan	1	4	1	-3

7.5.2. Adaptation Portfolio Climate Sensitivity

Table 25 shows how hydropower differed amongst the range of climate scenarios.

- **Warm-Wet.** Some portfolios and the No Action alternative had **significantly more** net generation than the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All portfolios and the No Action alternative had only **very slight increases** in net generation compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action alternative had **less** net generation than the Reference-No-Climate-Change climate scenario.

Table 25. Annual Net Energy Generation: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Positive numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	18	1	-17
Least Cost	22	1	-19
Regional Self-Reliance	17	1	-16
Healthy Headwaters and Tributaries	18	1	-17
Delta Conveyance and Restoration	17	1	-17
Expanded Water Storage and Groundwater	17	1	-16
Flexible System Operations and Mgmt	20	1	-18
Water Action Plan	21	1	-19

7.6. Flood Control

As discussed in Section 5. *Challenges: Risk and Reliability* of this Report, an indicator used to evaluate flood control was the availability of reservoir storage below the flood control pool. Further information on this and other indicators is Technical Report, Section 7.6. *Flood Control*.

Flood-conservation pool. Reclamation is required to maintain reservoir storage levels below the flood conservation pool based on criteria established by the U.S. Army Corps of Engineers. As reservoir levels increase, there is a decrease in availability of storage to control floods Therefore, higher reservoir storage levels imply less availability of flood control storage. *Decreases in this indicator would imply that there is more storage availability and thus flood control management is improving.*

The DWR has estimated that nearly $600 billion of buildings, crops, and infrastructure as well as over 7 million people are at risk of damages resulting from flooding.

Increased runoff during the fall and winter months increases the potential need for reservoir releases to prevent water levels from encroaching into the flood conservation pool. With increased warming, the proportion of fall and winter runoff increases even without increased precipitation.

The percentage of months when reservoir storage is within 10 TAF of the flood conservation pool at Folsom Reservoir during the flood control months from October to June is the indicator used to represent reservoir flood management. *A decrease in this indicator signifies a reduction in flood risk while an increase means less available flood conservation storage and increased risk.*

Flood conservation storage corresponded closely with the climate projections. The lowest conservation storage occurred in the Warm-Wet climate scenario, while the highest occurred in the Hot-Dry climate scenario.

The Healthy Headwaters and Tributaries adaptation portfolio was the only portfolio that consistently had better performance than the to No Action alternative. The Least Cost, Regional Self-Reliance, and Flexible Systems Operations adaptation portfolios all resulted in increased occurrences of potential encroachment into the flood control pool. All adaptation portfolios had significant sensitivity to climate with a more frequent potential flood pool encroachment in the Warm-Wet climate scenario and the less in the Hot-Dry climate scenario.

7.6.1. Adaptation Portfolio Performance

The Healthy Headwaters and Tributaries adaptation portfolio was the only one that resulted in consistently reduced flood risks relative to No Action (Figure 43). This improved performance is associated with the reduced storage from water management actions that result in the reservoir releases to increase spring tributary and Delta outflows. The Least Cost, Regional Self-Reliance, and Expanded Water Storage portfolios all resulted in moderate increases in flood management risks, primarily because these portfolios operate to increase reservoir storage for later water deliveries.

Table 26 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

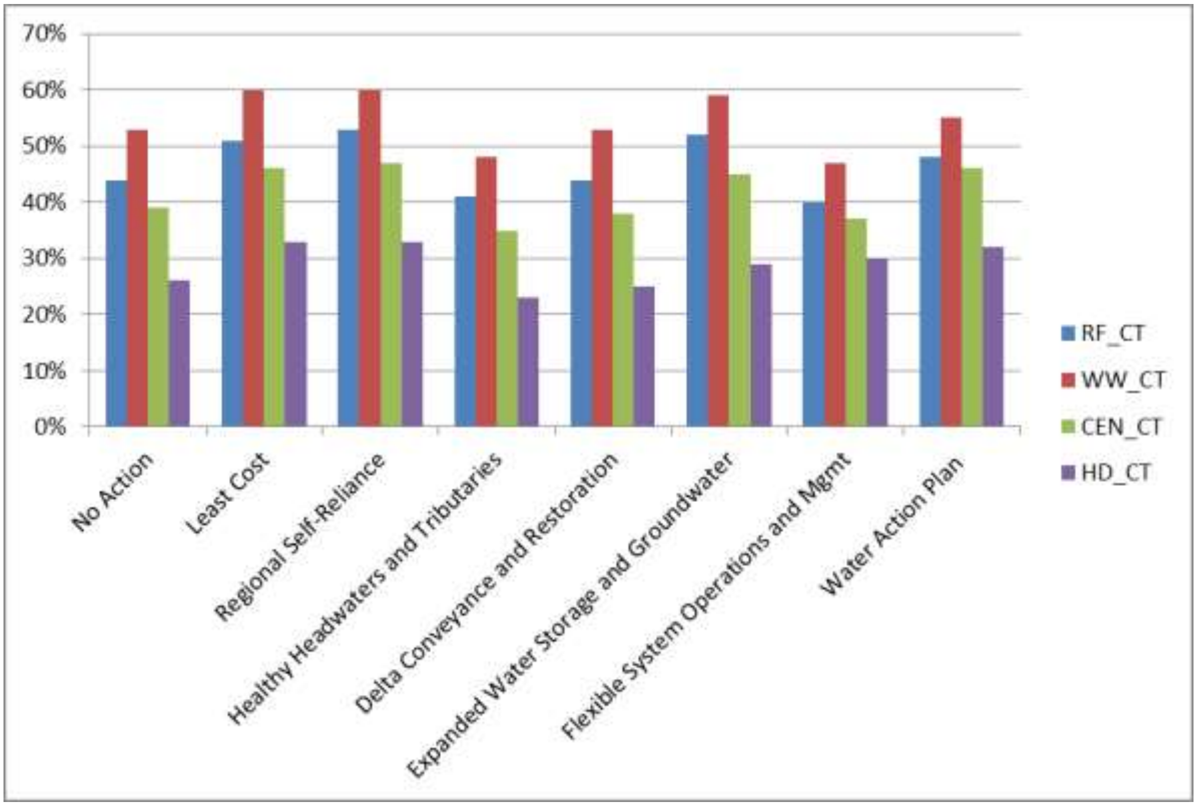


Figure 43. Percentage of months from October through June that Folsom Lake storage is within 10 TAF of the flood conservation pool in each adaptation portfolio.[24] (Lower numbers indicate increased benefits).

Table 26. Folsom Lake Storage: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	16	13	18	27
Regional Self-Reliance	20	13	21	27
Healthy Headwaters and Tributaries	-7	-9	-10	-12
Delta Conveyance and Restoration	0	0	-3	-4
Expanded Water Storage and Groundwater	18	11	15	12
Flexible System Operations and Mgmt	-9	-11	-5	15
Water Action Plan	9	4	18	23

[24] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

7.6.2. Adaptation Portfolio Climate Sensitivity

Table 27 shows how flood control differed amongst the range of climate scenarios.

- **Warm-Wet.** All portfolios and the No Action alternative had **reduced** potential for flood conservation pool storage compared to the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All portfolios and the No Action alternative had **more** potential for flood conservation pool storage compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action Alternative had **significantly more** potential for flood conservation pool storage compared to the Reference-No-Climate-Change climate scenario.

Table 27. Folsom Lake Storage: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	20	-11	-41
Least Cost	18	-10	-35
Regional Self-Reliance	13	-11	-38
Healthy Headwaters and Tributaries	17	-15	-44
Delta Conveyance and Restoration	20	-14	-43
Expanded Water Storage and Groundwater	13	-13	-44
Flexible System Operations and Mgmt	18	-8	-25
Water Action Plan	15	-4	-33

7.7. Recreation

As discussed in Section 5 *Challenges: Risk and Reliability* of this Report, the area of surface water for reservoirs is an important metric for boating and other forms of water-based recreation. This section discusses Lake Oroville, and further information on this and other indicators for recreation is in Section 7.8.3 *Floodplain Processes* in the Technical Report.

- **Reservoir surface area.** This indicator is measured by the percentage of months from May through September that reservoir surface area is reduced. *Therefore, decreases in this indicator (in other words, more reservoir area) would imply that recreational opportunities are improved.*

The CVP, SWP, and other major reservoirs in the Central Valley offer many recreational opportunities for boating, fishing, water sports and vacationing.

Reduced precipitation as well as warming induced changes in the seasonality of runoff may result in reduced reservoir water levels. Warming also increases lake evaporation and contributes to additional reductions in reservoir surface area.

Reduced reservoir storage decreases the reservoir's surface area, which in turn reduces potential recreational uses on the reservoir. The recreational use indicator is the percentage of months from May through September that reservoir surface area is less than the reservoir's historic period median surface area. Lake Oroville, a popular recreational SWP reservoir located in the Sacramento Valley was selected as representative of other Central Valley reservoirs. Other Central Valley reservoirs are discussed in Section 7.7 *Recreation* in the Technical Report. *Decreases in this indicator (in other words, more reservoir area) would imply that recreational opportunities are improved.*

Recreational use indicator corresponded closely with the climate projections. Both the Hot-Dry and Central Tendency climate scenarios had more months with reduced reservoir surface areas than the Reference-No-Climate-Change climate scenario while the Warm-Wet climate scenario had fewer months.

PORTFOLIOS

The Least Cost and Regional Self-Reliance adaptation portfolios were the only ones that resulted in significantly improved performance than the No Action alternative. All other adaptation portfolios had moderate to significant increases in the occurrence of decreased surface area. All portfolios had significant sensitivity to climate with fewer months of reduced surface areas in the Warm-Wet climate scenario and the more months in the Hot-Dry climate scenario.

7.7.1. Adaptation Portfolio Performance

The Least Cost and Regional Self-Reliance adaptation portfolios consistently had improvements relative to the No Action as a result of water management actions that increased water storage and improved water use efficiency (Figure 44). Moderate to significant decreases in performance were associated with the other portfolios.

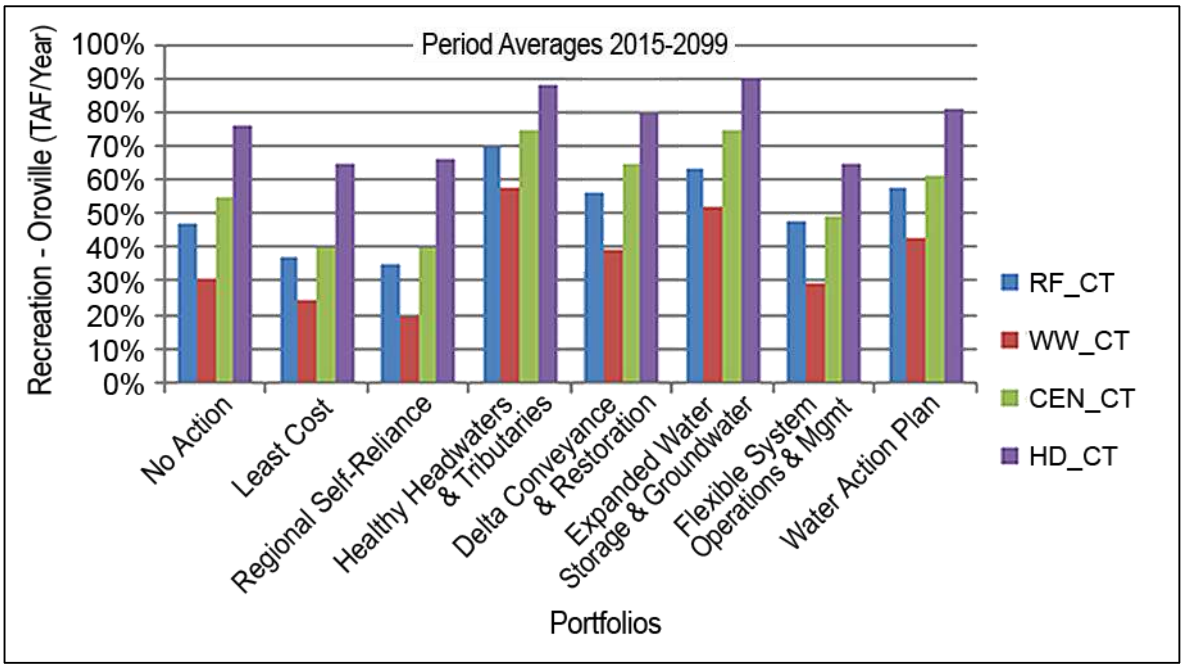


Figure 44. Percentage of months from May through September that Lake Oroville surface area is less than the monthly median in the No Action alternative for each adaptation portfolio[25] (Lower numbers indicate increased benefits).

[25] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

Table 28 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

Table 28. Lake Oroville Surface Area: Adaptation Portfolio Performance Compared to No Action (Percent Change (%) (Negative numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-21	-23	-27	-14
Regional Self-Reliance	-26	-39	-27	-13
Healthy Headwaters and Tributaries	49	87	36	16
Delta Conveyance and Restoration	19	26	18	5
Expanded Water Storage and Groundwater	34	68	36	18
Flexible System Operations and Mgmt	2	-6	-11	-14
Water Action Plan	23	39	11	7

7.7.2. Adaptation Portfolio Climate Sensitivity

Table 29 shows how reservoir surface area differed amongst the range of climate scenarios

- **Warm-Wet.** All portfolios and the No Action Alternative had **more potential for recreational opportunities** than the Reference-No-Climate-Change climate scenario.
- **Central Tendency.** All portfolios and the No Action Alternative had **less potential for recreational opportunities** than the Reference-No-Climate-Change climate scenario.
- **Hot-Dry.** All portfolios and the No Action Alternative had **significantly less potential for recreational opportunities** than the Reference-No-Climate-Change climate scenario.

Table 29. Lake Oroville Surface Area: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-34	17	62
Least Cost	-35	8	76
Regional Self-Reliance	-46	14	89
Healthy Headwaters and Tributaries	-17	7	26
Delta Conveyance and Restoration	-30	16	43

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Expanded Water Storage and Groundwater	-17	19	43
Flexible System Operations and Mgmt	-40	2	35
Water Action Plan	-26	5	40

7.8. Ecological Resources

As discussed in Section 5 *Challenges: Risk and Reliability* of this Report, the Ecological Resources section covers portfolio evaluations for three resource categories under the SECURE Water Act:

- Flow-dependent Ecological Resiliency (Floodplain processes)
- Fish and Wildlife Habitats (Pelagic species)
- ESA Species (Anadromous fish)

This Report only presents portfolio evaluations for some of the change indicators. Further information is in the Technical Report, Section 7.8. *Ecological Resources.*

7.8.1. Pelagic Species Habitat

This indicator is included in the Fish and Wildlife Habitat and the ESA Species resource category. Pelagic species are fish that live and spawn in open water and include the endangered Delta smelt species. These fish are sensitive to the levels of salinity in the Delta. Further information on this and other indicators for pelagic species habitat is in Section 7.8.4. *Pelagic Species Habitat.* in the Technical Report.

- **Salinity levels indicated by the X2 location.** X2 is the location of the two parts per thousand (ppt) salinity concentration in the interior Delta (termed “X2”). Maintaining an X2 location of less than 74 km from the Golden Gate Bridge is important for Delta smelt habitat conditions. *Therefore, decreases in this indicator would imply that the habitat conditions for Delta smelt are improving.*

Pelagic species, and especially the delta smelt, have been declining at an increased rate. First listed as threatened in 1993, the Delta smelt has declined markedly, especially since 2002. Salinity levels in the Delta mark their habitat extent. Salinity levels are a function of both the freshwater Delta outflow and sea level which affects tidal saltwater mixing in the Delta. Reclamation and DWR release water from their reservoirs to increase Delta outflows and/or reduce Delta exports to maintain the X2 location.

During dry years and drought periods when inflows of fresh water into the Delta are reduced, salinity tends to increase. With increased warming, global sea levels will continue to rise and further increase the salinity of Delta and require additional reservoir releases and reductions in exports to maintain suitable habitats

The X2 location is a function of both the freshwater Delta outflow and sea level which affects tidal saltwater mixing in the Delta. Greater X2 positions indicate that salinity has moved farther eastward into the Delta reducing the low salinity zone habitat. Maintaining an X2 location of less than 74 km from the Golden Gate Bridge is one of the goals specified in the U.S. Fish and Wildlife Service's Biological Opinion and the SWRCB's Water Rights Decision D-1641. *Thus, greater percentages of months exceeding this location are not desirable.*

Changes in the X2 location corresponded closely with the climate projections. The Hot-Dry and Central Tendency climate scenarios had more months when the X2 location was more than 74 km than the Reference-No-Climate-Change climate scenario. The Warm-Wet climate scenario had significant fewer months when the X2 location was more than 74 km than the Reference-No-Climate-Change climate scenario.

The Delta Conveyance and Restoration and Regional Self-Reliance adaptation portfolios resulted in consistently fewer months with X2 locations exceeding the 74 km standard than the No Action alternative. All adaptation portfolios showed significant climate sensitivity with more months exceeding the X2 standard in the Hot-Dry and Central Tendency climate scenarios and fewer months in the Warm-Wet climate scenario than in the Reference-No-Climate-Change climate scenario.

7.8.1.1.1. Adaptation Portfolio Performance

The Regional Self-Reliance and Delta Conveyance and Restoration adaptation portfolios were the only portfolios resulted in consistently better performances than No Action (Figure 45) as they have reduced water demands—either by increased water use efficiency (Regional Self-Reliance) or by water management operations intended to promote restoration (Delta Conveyance and Restoration). The Least Cost and Expanded Water Storage adaptation portfolios both resulted in moderate to significant more exceedences, primarily because of reduced Delta outflows.

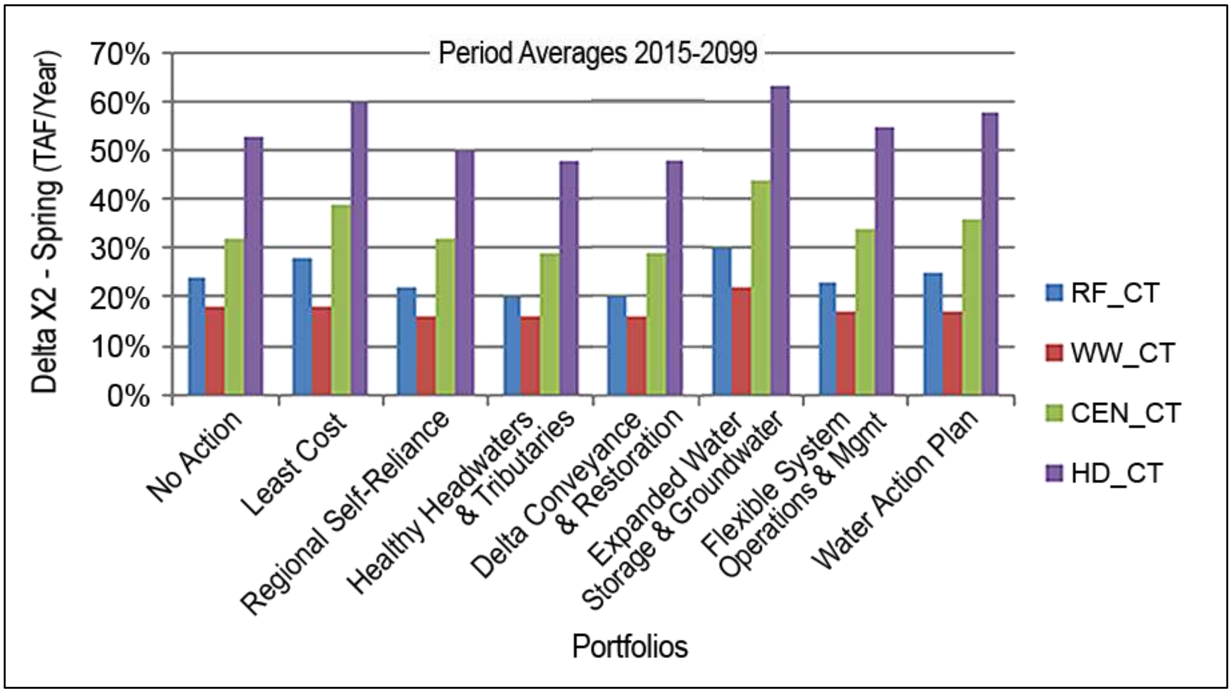


Figure 45. Percentage of months that the February-to-June X2 position is greater than 74 km in each adaptation portfolio.[26]
(Lower numbers indicate increased benefits).

Table 30 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

Table 30. February-to-June X2 Position: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits).

Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	17	0	22	13
Regional Self-Reliance	-8	-11	0	-6
Healthy Headwaters and Tributaries	-17	-11	-9	-9
Delta Conveyance and Restoration	8	11	9	4
Expanded Water Storage and Groundwater	25	22	38	19
Flexible System Operations and Mgmt	-4	-6	6	4
Water Action Plan	4	-6	13	9

[26] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

7.8.1.1.2. Adaptation Portfolio Climate Sensitivity

Table 31 shows how the February-to-June X2 position over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All portfolios and the No Action alternative had **significantly more** potential for improved pelagic species habitat than the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** All portfolios and the No Action alternative had **significantly less** potential for improved pelagic species habitat compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action alternative had **significantly less** potential for improved pelagic species habitat compared to the Reference-No-Climate-Change climate scenario.

Table 31. February-to-June X2 Position: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-25	33	121
Least Cost	-36	39	114
Regional Self-Reliance	-27	45	127
Healthy Headwaters and Tributaries	-20	45	140
Delta Conveyance and Restoration	-23	35	112
Expanded Water Storage and Groundwater	-27	47	110
Flexible System Operations and Mgmt	-26	48	139
Water Action Plan	-32	44	132

7.8.2. Adult Salmon Migration

Adult salmon migration is included in the ESA Species resource category. Further information on this and other indicators for ESA species habitat is in Section 7.8.4 *Pelagic Species Habitat* in the Technical Report.

- **Old and Middle River Reverse Flows.** Export pumping by CVP and SWP can actually reverse the natural flow direction in the Old and Middle River (OMR) channels of San Joaquin River, especially in the fall months when river flows are normally low. Reverse OMR flows can confuse adult salmon entering the western Delta as they migrate upstream. *Decreases in the occurrence of reverse OMR flows (i.e., fewer reverse flows) would imply that anadromous fish migration conditions could improve.*

Adult winter-run salmon pass under the Golden Gate Bridge from November through May and enter into the Sacramento River starting in December. The winter-run chinook salmon spawn in the upper reaches of Sacramento River and its tributaries during the spring and summer months. Starting in the 1970s, the population experienced a dramatic decline and was classified as endangered under the federal Endangered Species Act in 1994.

Reverse flows in the fall is directly influenced by the timing and magnitude of precipitation as well as the amount of reservoir storage available to avoid reverse flows in the OMR channels. Increased warming and shifts in the timing of runoff can both contribute to reduced reservoir storage and releases in fall.

Increased entrainment of adult salmonids migrating to spawning habitat is positively correlated with the frequency of reverse flows that are more 5,000 cfs (shown as a negative number, -5,000) in the OMR channels from October through December. The indicator is the frequency of reverse flows in the OMR channels of the San Joaquin River in the Delta.

Changes in OMR reverse flows corresponded closely with the climate projections. The largest reductions in reverse flows occurred in the Hot-Dry climate scenario because export pumping is reduced during dry conditions while only moderate to small reductions occurred in the Central Tendency and Warm-Wet scenarios relative to the Reference-No-Climate-Change climate scenario.

The Least Cost, Delta Conveyance and Restoration, Expanded Water Storage and Groundwater, and Water Action Plan adaptation portfolios all had significantly fewer months that exceeded the OMR indicator relative to No Action

7.8.2.1.1. Adaptation Portfolio Performance

The Least Cost, Delta Conveyance and Restoration and Expanded Water Storage and Groundwater as well as the Water Action Plan adaptation portfolios all had fewer occurrences of reverse OMR flows in all climate scenarios than the No Action alternative (Figure 46). For these portfolios, the migration risk was lowest in the Warm-Wet climate scenario because of additional Delta outflows. These improved portfolio performances are associated with the Delta conveyance action which avoids reverse flows by not conveying water to the export pumps through the OMR channels.

The Regional Self-Reliance, Healthy Headwaters and Flexible Systems Operations adaptation portfolios were only slightly different than the No Action alternative because OMR flows are still influenced by export pumping.

Table 32 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

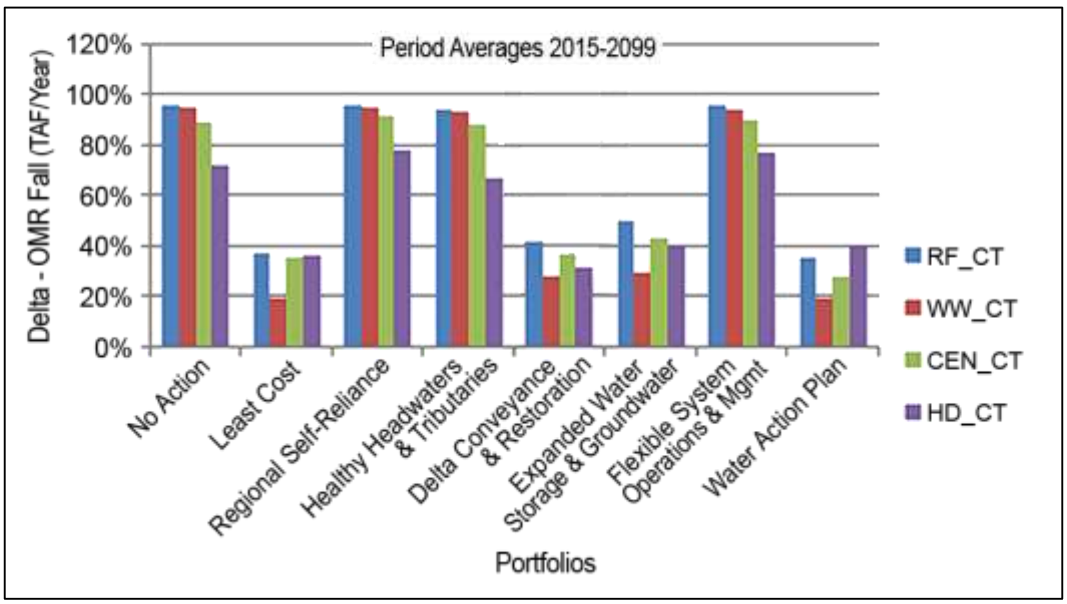


Figure 46. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than -5,000 cfs in each adaptation portfolio. (Lower numbers indicate increased benefits).

Table 32. October-through-December OMR Flow: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits).

Adaptation Portfolios	Reference_CT	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Least Cost	-61	-80	-61	-50
Regional Self-Reliance	0	0	2	8
Healthy Headwaters and Tributaries	-2	-2	-1	-7
Delta Conveyance and Restoration	-57	-72	-60	-57
Expanded Water Storage and Groundwater	-48	-69	-52	-44
Flexible System Operations and Mgmt	0	-1	1	7
Water Action Plan	-64	-80	-70	-44

7.8.2.1.2. Adaptation Portfolio Climate Sensitivity

Table 33 shows how the October-through-December OMR flow over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario. The largest changes occurred in the Warm-Wet climate scenario.

- **Warm-Wet.** All portfolios and the No Action alternative **showed potential improvements in the adult salmon migration** compared to the Reference-No-Climate-Change climate scenario. However, the performance varied considerably between portfolios.

- **Central Tendency.** All portfolios and the No Action alternative **showed some potential improvements in the adult salmon migration** compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** Most of the portfolios and the No Action alternative showed **significant potential improvements in the adult salmon migration** compared to the Reference-No-Climate-Change climate scenario. This improvement occurs because export pumping is significantly reduced if water supplies are limited.

Table 33. October-through-December OMR Flow: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-1	-7	-25
Least Cost	-49	-5	-3

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
Regional Self-Reliance	-1	-5	-19
Healthy Headwaters and Tributaries	-1	-6	-29
Delta Conveyance and Restoration	-34	-12	-24
Expanded Water Storage and Groundwater	-42	-14	-20
Flexible System Operations and Mgmt	-2	-6	-20
Water Action Plan	-46	-23	14

7.8.3. Floodplain Processes

The Flow-dependent Ecological Resiliency resource category is represented by floodplain process. As discussed in Section 5 *Challenges: Risk and Reliability* of this Report, indicators used to evaluate floodplain processes were low flows at Keswick. Further information on this and other indicators for floodplain processes is in Section 7.8.3 *Floodplain Processes* in the Technical Report.

- **Low Winter and Spring River Flows.** High flows are important floodplain processes because they promote the creation of riparian habitats. This indicator increases with increasing occurrences of months with low flows. *Therefore, decreases in this indicator would imply that floodplain processes are improved.*

Floodplain processes are important to create and maintain the riparian habitats that support numerous aquatic, terrestrial, and avian species in the Central Valley. Riparian habitat are a key component of these habitats, and their survival depends on winter and spring flows of sufficient magnitude and duration to promote creating new point bars at the edge of river's floodplain and provide sufficient water for the survival of newly germinated riparian seedlings.

Increased warming, which changes the timing of peak runoff and reduces spring flows, has the potential to negatively impact the survival of riparian habitats.

Flows in the Sacramento River at Keswick Reservoir are typically maintained at a rate of less than 15,000 cfs. Flows above this rate are usually associated with winter storms and large spring snowmelt events. Increasing percentages of months with flows less than 15,000 cfs indicates downstream flow conditions that are less favorable to establishment and maintenance of conditions favorable to riparian habitats. *Decreases in this indicator would imply that floodplain processes are improved.*

The floodplain process indicator changes corresponded closely with the climate projections. The Hot-Dry climate scenario had more months with flows less than 15,000 cfs than the Reference-No-Climate-Change climate scenario. The Central Tendency and Warm-Wet climate scenarios had fewer months with these flows than the Reference-No-Climate-Change climate scenario.

Most adaptation portfolios resulted in only slight changes relative to the No Action alternative. Performance corresponded closely with projected climate with slight improvements in the Warm-Wet climate scenario and slight declines in the Hot-Dry climate scenario relative to the Reference-No-Climate-Change climate scenario.

7.8.3.1. Adaptation Portfolio Performance

The Healthy Headwaters, Delta Conveyance and Restoration, Expanded Storage and Water Action Plan adaptation portfolios all resulted in consistently fewer months of flows with less than 15,000 cfs than the No Action alternative, primarily because these portfolios increase reservoir releases which contribute to increased winter and spring flows (Figure 47). This indicates that they actually increased the potential for the establishment of new point bars and riparian vegetation. The Regional Self-Reliance portfolio resulted in slight decreases in beneficial flows because it is primarily a demand reduction action which reduces reservoir releases.

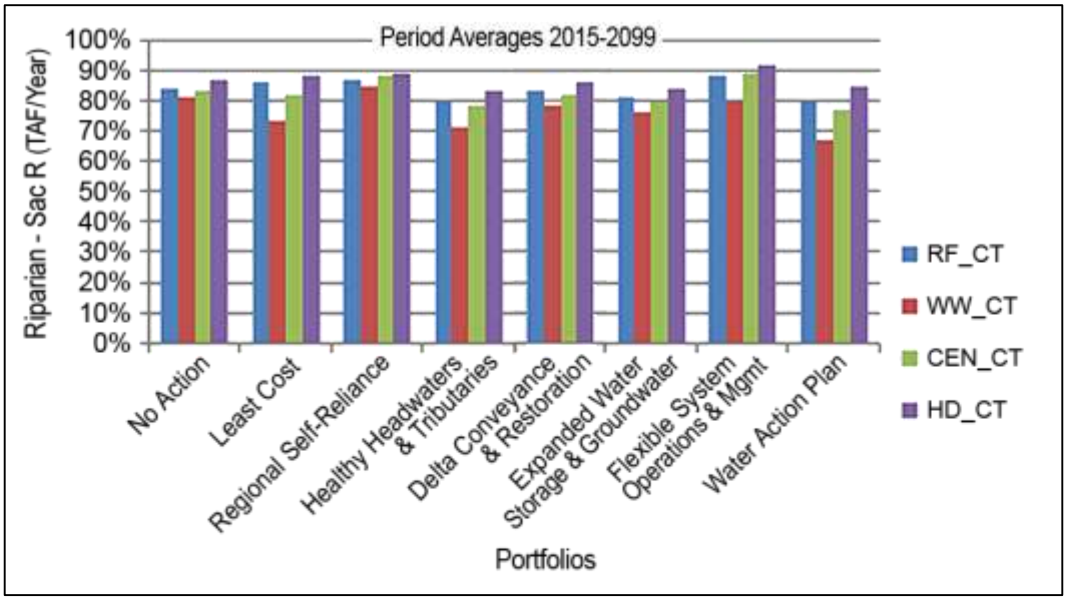


Figure 47. Percentage of months from February through June that flows on the Sacramento River at Keswick are less than the 15,000 cfs in each adaptation portfolio.[27] (Lower numbers indicate increased benefits).

Table 34 shows details of the performance of each of the portfolios relative to No Action in each of the four climate scenarios.

Table 34. Keswick Flows: Adaptation Portfolio Performance (% Change from the No Action Alternative) (Negative numbers indicate increased benefits).

Portfolios	Reference _CT	Warm-Wet_CT	Central_C T	Hot-Dry_CT
Least Cost	2	-10	-1	1
Regional Self-Reliance	4	5	6	2
Healthy Headwaters and Tributaries	-5	-12	-6	-5
Delta Conveyance and Restoration	-1	-4	-1	-1
Expanded Water Storage and Groundwater	-4	-6	-4	-3
Flexible System Operations and Mgmt	5	-1	7	6
Water Action Plan	-5	-17	-7	-2

[27] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

7.8.3.2. Adaptation Portfolio Climate Sensitivity

Table 35 shows how Keswick flows over the range of climate scenarios when compared with the Reference-No-Climate-Change Climate Scenario.

- **Warm-Wet.** All portfolios and the No Action alternative showed **more** potential for improved floodplain processes compared to the Reference-No-Climate-Change climate scenario.

- **Central Tendency.** Some portfolios and the No Action Alternative showed slightly **more** potential for improved floodplain processes compared to the Reference-No-Climate-Change climate scenario.

- **Hot-Dry.** All portfolios and the No Action Alternative had **less** potential for improved floodplain processes compared to the Reference-No-Climate-Change climate scenario.

Table 35. Keswick Flows: Climate Scenario Sensitivity of Adaptation Portfolios (% Change from the Reference-No-Climate-Change Climate Scenario) (Negative numbers indicate increased benefits).

Portfolios	Warm-Wet_CT	Central_CT	Hot-Dry_CT
No Action Alternative	-4	-1	4
Least Cost	-15	-5	2
Regional Self-Reliance	-2	1	2
Healthy Headwaters and Tributaries	-11	-3	4
Delta Conveyance and Restoration	-6	-1	4
Expanded Water Storage and Groundwater	-6	-1	4
Flexible System Operations and Mgmt	-9	1	5
Water Action Plan	-16	-4	6

7.9. Economics

Economics were evaluated using preliminary, reconnaissance level cost estimates for the adaptation portfolios and for potential benefits from increased water supply and reduced demands for urban and agricultural regions in the Central Valley, eastern and southern San Francisco Bay areas, and South Coast region, including water quality costs associated with rising salinity levels in the Delta. Note that economics is only analyzed under the Central Tendency climate/Current Trends socioeconomic scenarios. Further information is in Section 7.3 *Economics* in the Technical Report.

The urban and agricultural regions of Central Valley and surrounding CVP and SWP service areas are major contributors to the economy of California and the United States. This economy depends on having a reliable supply of high quality water for their economic activities.

Dry years and drought periods affect both the supply and quality of water available to urban and agricultural areas. With increased warming, global sea levels will continue to rise and further increase the salinity of Delta and increase costs associated urban water treatment and agricultural drainage.

Economic benefits from increased water supply reliability and costs associated with obtaining dry year replacement supplies and urban water treatment are an important aspect of evaluating the overall performance of any individual or combination of water management actions. The metrics used in the portfolio evaluations are: total water supply and demand benefit (TAF/yr), annualized costs ($M/yr) and unit costs ($/yr).

Projected increases in population and reductions in deliveries would result in reductions in urban net benefits. Salinity management costs increase due to increased salinity due to sea level rise.

The Least Cost and Regional Self-Reliance adaptation portfolios provided considerably more total water supply and demand benefits than the No Action alternative. The Heathy Headwaters and Tributaries Adaptation portfolio has the slightest amount of increases over the No Action alternative, but had the lowest annualized costs.

The Least Cost and Regional Self Reliance adaptation portfolios both performed nearly as well as Water Action Plan with respect to the total water supply and demand benefits (Figure 48). However, the Least Cost adaptation portfolio did so with significantly lower annualized and unit costs. The Healthy Headwaters and Tributaries adaptation portfolio performed best with respect to annualized costs but provided very little total water supply and demand benefits.

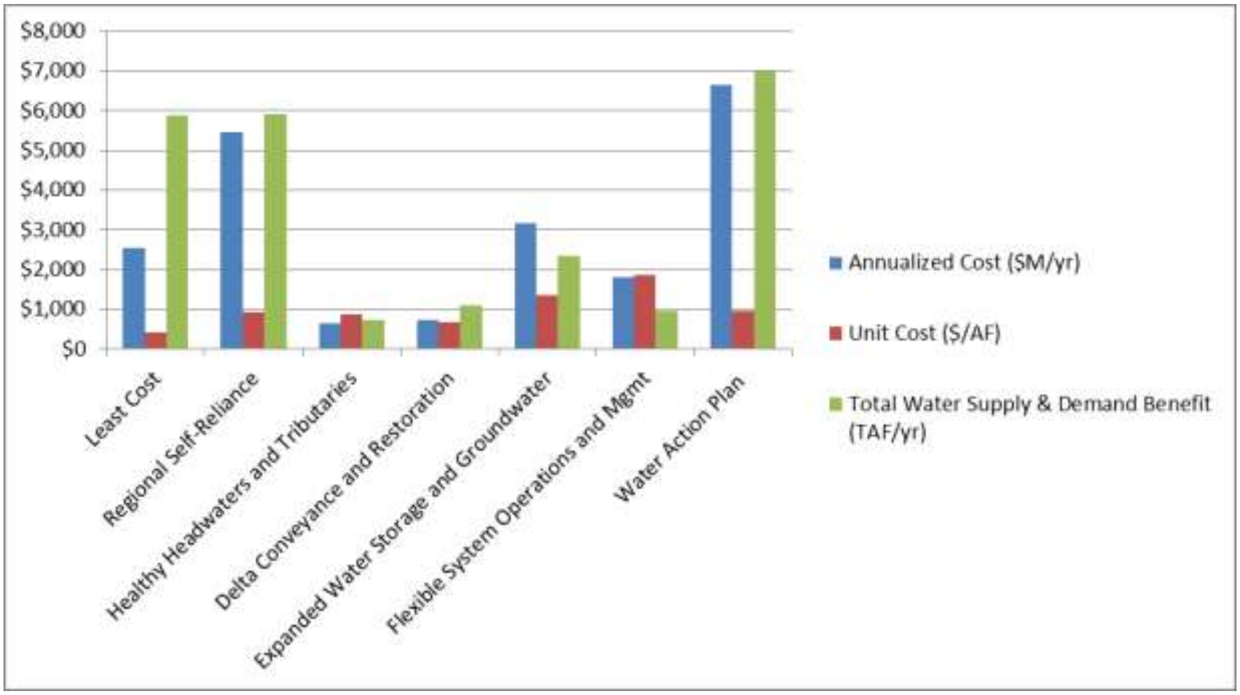


Figure 48. Annualized portfolio cost (in $millions/year) and unit cost per water supply and demand benefit (in $/af) in the Central Tendency climate scenario scenario in each adaptation portfolio relative to the No Action alternative.[28]

Table 36 shows details of the performance of each of the portfolios in the Central Tendency climate scenario.

Table 36. Economics: Benefits and Costs of Adaptation Portfolios

Portfolios	Total Water Supply & Demand Benefit (TAF/yr)[1]	Annualized Cost ($M/yr)	Unit Cost ($/AF)
Least Cost	5,876	$2,536	$432
Regional Self-Reliance	5,903	$5,466	$926

[28] Figure abbreviations are for the climate scenarios under the Current Trends (CT) socioeconomic scenario: RF: Reference-No-Climate-Change, WW: Warm-Wet, CEN: Central Tendency, HD: Hot-Dry climate.

Healthy Headwaters and Tributaries	735	$644	$876
Delta Conveyance and Restoration	1,111	$738	$664
Expanded Water Storage and Groundwater	2,342	$3,163	$1,351
Flexible System Operations and Mgmt	970	$1,806	$1,863
Water Action Plan	6,984	$6,647	$952

Note that these costs and benefits were analyzed at a preliminary, reconnaissance level for comparison purposes only.

8. Conclusions and Suggested Next Steps

8.1. Conclusions

Water managers and stakeholders in the Basins Study area have long understood that growing demands in the Sacramento, San Joaquin and Tulare Lake Basins, coupled with the potential for reduced supplies, may put water users at risk of prolonged water shortages in the future. Demands for water supplies in the Basins Study area, particularly in the regions of the Central Valley south of the Sacramento-San Joaquin Delta, frequently exceed the capacity of the existing water management system to meet all the potential needs. The magnitude and timing of these risks differ spatially across the three basins which comprise the Central Valley. In particular, the San Joaquin and Tulare Lake Basins, where demand often exceeds available supplies, is at greater risk than the Sacramento Basin.

The Basins Study builds on earlier work such as the Central Valley Project Integrated Resources Plan. By developing a comprehensive knowledge base and suite of tools that analyze the risks posed by climate change to future water supplies and demands in the Sacramento, San Joaquin, and Tulare Lake basins, this Basins Study represents the next significant step in water planning in the Central Valley and its surrounding watersheds. It also adds valuable new information to past efforts by considering a longer-term planning horizon and by including a robust analysis of uncertainties in both climate and socioeconomics—attributes which provide water managers with an improved understanding of the range of potential uncertainties and future challenges.

Of all climate impacts identified in this Basins Study, two impacts have the greatest potential consequences for water management:

- **Earlier runoff.** Warming conditions cause earlier runoff in mountain regions surrounding the Central Valley. With approximately 40% of annual storage in the basin consisting of snowpack, reduced snowpack and earlier runoff due to warming conditions will impact reservoir operations in several important ways. Earlier runoff will fill reservoirs earlier, which may force earlier discharge due to the flood rule curves in effect for each reservoir. Implementing adaptive flood rule curves could provide for increased flexibility under future conditions.

- **Sea Level Rise.** Sea level rise has been called a “slow emergency” and may significantly impact the Sacramento –San Joaquin Delta in a number of ways. The National Academy of Science has developed sea level rise estimates (2012) which project a range of sea levels from 42cm. to 166cm. by the end of century. With a median sea level rise projected of 90 cm (36 inches), impacts to the Delta will likely be profound. Factors such as tidal and storm surge, added with sea level rise, could result in Delta island levee failures which would result in sea water intrusion into the Delta. If one or more Delta island levees fail, the resulting massive inflow of seawater would disrupt environmental conditions and water management in the Delta for a significantly long period.

8.2. Other Current and Ongoing Activities

A variety of other activities to address existing and projected system vulnerabilities to future climate uncertainties in the Central Valley region are currently ongoing or anticipated in the near future.

8.2.1. WaterSMART

Through Reclamation's WaterSMART program, grants to water districts have been made to increase water use efficiency and water recycling. WaterSMART grants were awarded to nine water management agencies in the Central Valley, San Francisco Bay, and central Coastal areas between 2012 and 2015. These grants totaled more than $5 million and resulted in an estimated annual water savings of more than 23,000 acre-feet (AF), along with improved management of an additional 29,000 AF. The projects range from canal lining to water conservation rebates to groundwater recharge.

In partnership with the State of California, a WaterSMART research grant was also made to improve the knowledge of basin hydrology through an investigation of ancient tree ring growth and chronology. The drought periods represented in the paleo-hydrology data provide an important contribution for future resiliency planning in the Central Valley. The results from this paleo-hydrology study were included in this Basins Study (Reclamation, 2015a).

8.2.2. California Landscape Conservation Cooperative

Reclamation's Mid-Pacific Region has also been participating in the California Landscape Conservation Cooperative (CALCC). In collaboration with the USFWS and other Federal, State, and stakeholder partners, the CALCC has developed a comprehensive framework identifying knowledge gaps and research priorities. CALCC has also 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 CALCC funding for these projects has totaled more than $2.6 million. These current programs and activities have been considered in the characterization of the portfolios used in the Basins Study, for example:

- **Reduce Water Demand:** Reclamation's WaterSMART Program which has provided approximately $5 million in grants to municipal water management agencies in the basin resulting in improvements in management and water use efficiency for about 50,000 AF (acre feet) of water supplies.

- **Evaluate Potential for Increasing Water Supply Reliability:** Through the CalFED Bay Delta Storage Projects investigations, Reclamation either has or is expected to complete planning documents addressing water supply reliability and water quality (temperature and salinity) concerns in Sacramento and San Joaquin Basins.

- **Improve Operating Efficiency:** Through the California Water Fix program (a.k.a. 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. Potential actions include a new Delta water conveyance and 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.

8.3. Basins Study

This Basins Study confirms that, in particular, the San Joaquin and Tulare Lake Basins face a range of potential future imbalances between supply and demand. Addressing such imbalances will require diligent planning which cannot be resolved through any single approach or option. Instead, a multi-faceted approach that applies a wide range of strategies at local, state, regional, and Basin-wide levels is needed. Reclamation, the State of California, and other partner and stakeholder organizations have been evaluating a wide variety of strategies to address these issues.

It is important to note that none of the portfolios and strategies analyzed in the Basins Study will fully mitigate the impacts of climate and socioeconomic change in the Basins; this fact underscores the need to look at a broad set of actions which provide improved resiliency under future conditions.

This Basins Study's exploration of various portfolios demonstrates that a broad range of strategies and options together can reduce Basin resource vulnerabilities and improve overall resiliency to climate conditions while also meeting increasing demands in these Basins.

Study results indicate that conservation, groundwater and surface augmentation projects and operational improvements can improve the reliability and sustainability of the Central Valley Project and State Water Project systems to meet current and future water needs. In summary, there are several future steps that Reclamation, its partners and stakeholders could cooperatively investigate to resolve imbalances in these Basins. Precursor steps are identified below:

- Further refine and analyze the underlying actions which make up the portfolios to identify and resolve any uncertainties regarding the water management actions.
- Explore and pursue opportunities to advance and improve the resolution of future climate projections and enhance the operational and planning tools used in the Sacramento and San Joaquin Basins to better understand the vulnerabilities of the water-dependent uses, including environmental flows, should be explored.
- Identify and investigate costs, permitting issues, and energy needs relating to projects.
- As projects, policies, and programs are developed, Reclamation should participate in a long-term cooperative framework with stakeholders, partners and others to investigate ways sustain a wide-range of activities that benefit water users.

Potential activities to implement next steps to resolve the current and potentially significant future imbalances in the Basins Study should consider, but not be limited to further investigation of the water management actions identified in the Basins Study as suggested below:

- **Institutional Flexibility**. Work cooperatively with the Army Corps of Engineers to evaluate allowing adaptive management of flood rule curves for reservoirs. The objective is to develop improvements to the static rule curves which may require releases earlier under climate change conditions. Under climate-related runoff seasonality changes, reservoir management using adaptive flood rule curves could potentially provide for increased annual and multi-year carry-over storage.
- **M& I Water Use and Agriculture Water Use Efficiency**. Investigate continued improvements in water use efficiencies for all users and apply for Reclamation programs such as WaterSMART Grants and Title XVI projects. These actions continue to have significant potential to reduce unmet Central Valley water demands for both urban and agricultural water users and as shown by the Basins Study can be implemented efficiently and cost effectively.
- **River Temperature Management.** Development and refinement of modeling tools to improve our ability to meet State and Federal river temperature criteria. The objective is to meet criteria in a more efficient

manner (e.g using targeted release volumes at specific times) resulting in conserving more water in various upstream reservoirs. An example is the temperature models developed by Placer County Water Agency for the American River sub-basin of the Sacramento River Basin.

- **Forest Health.** Continue work initiated under Western Watershed Enhancement Partnership (WWEP) Interagency Agreement between DOI (Reclamation) and the U.S. Department of Agriculture (USDA) (U.S. Forest Service [USFS]) for cooperative watershed management to reduce wildfires, preserve forest health and assist in forest thinning to augment snowpack retention and runoff. Reclamation and partners should develop a long term structure for continued cooperation with the U.S. Forest Service, the State of California's Sierra Nevada Conservancy, The Nature Conservancy, and non-governmental organizations as well as academic institutions such as the Sierra Nevada Institute at the University of California at Merced.

- **Groundwater**. Improve assumptions and analyses of current and future groundwater conditions, including assumptions regarding recently initiated state groundwater regulations. Investigate increased use of strategic groundwater storage. This Basins Study identifies a recharge potential in the Central Valley using precipitation runoff from the foothill and mountain regions. As ambient temperatures increase in the Central Valley, groundwater storage can provide a resilient drought reserve particularly since groundwater storage isn't susceptible to increasing surface evaporation under warming conditions.

- **System Conveyance**. Continue to cooperate with the State of California in their investigation for California WaterFix. This Basins Study identifies sea level rise as having a potentially profound impact on water management in the Delta. While a Delta conveyance concept is controversial, the steady rise of sea levels will slowly increase risks to water deliveries as well as negatively impact water quality in the Delta both for municipal and environmental water needs by reducing reservoir storage that maintains water temperature and riparian habitats in the upstream watersheds.

Ultimately, the Basin Study is a catalyst for future collaboration and planning. Developing water management actions and incorporating them in adaptation portfolios represents an important new step towards a more comprehensive long-range plan to meet future water demands.

References

Citation	Reference
Andersen et al 2008	Anderson, J., F. Chung, M. Anderson, L. Brekke, D. Easton, M. Ejeta, R. Peterson, and R. Synder. 2008. “Progress on Incorporating Climate Change into Management of California’s Water Resources.” Climatic Change, Volume 89, Supplement 1, pp. 91-108. Published online 12-22-207. ISSN: 0165-009 (Print) 1573-2480 (online) DOI: 10.1007/s10584-007-9353-1
Cayan et al. 2009	Cayan, D., Tyree, M., Dettinger, M., Hidalgo, H., Das, T., Maurer, E., et al. (2009). Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarious Assessment. Sacramento, CA: California Climate Change Center. Publication #CEC-500-2009-014-F, 64 pages, August.
DWR 2014	California Department of Water Resources (DWR). 2014 (Water Plan). *California Water Plan Update 2013*. Sacramento, California.
IPCC 2007	IPCC, 2007: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (ML Parry, OF Canziani, JP Palutikof, PJ van der Linden, and CE Hanson [eds]). Cambridge University Press; Cambridge, UK, 976pp.
IPCC 2014	IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Field CB, VR Barros, DJ Dokken, KJ Mach, MD Mastrandrea, TE Bilir, M Chatterjee, KL Ebi, YO Estrada, RC Genova, B Girma, ES Kissel, AN Levy, S MacCracken, PR Mastrandrea, and LL White [Editors]). Cambridge University Press; Cambridge, United Kingdom and New York, New York, United States; 1132 pages.
Livneh et al. 2013	Livneh, B., E. A. Rosenberg, C. Lin, V. Mishra, K. Andreadis, E. P. Maurer, and D.P. Lettenmaier. 2013. A long-term hydrologically based data set of land surface fluxes and states for the conterminous U.S.: Update and extensions, Journal of Climate, DOI: 10.1175/JCLI-D-12-00508.1.
Meko et al. 2014	Meko David M., Connie A. Woodhouse, and Ramzi Touchan. 2014. Klamath/San Joaquin/Sacramento Hydroclimatic Reconstructions from Tree Rings. Draft Final Report to California Department of Water Resources. Agreement 4600008850. Available at: http://www.water.ca.gov/waterconditions/docs/tree_ring_report_for_web.pdf
NOAA 2012	National Oceanic and Atmospheric Administration. Center for Operational Oceanographic Products and Services. 2012. http://tidesandcurrents.noaa.gov/sltrends/sltrends_states.shtml?region=ca

Citation	Reference
NRC 2012	National Research Council (NRC). 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Committee on Sea Level Rise in California, Oregon, and Washington; Board on Earth Sciences and Resources; Ocean Studies Board; Division on Earth and Life Studies. The National Academies Press. Washington, D.C.
Rahmstorf 2007	Rahmstorf, S. 2007. A Semi-Empirical Approach to Projecting Future Sea-Level Rise. *Science* 315(5810): 368–370, doi: 10.1126/science.1135456.
Reclamation 2011	Reclamation, 2011. West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections. Technical Memorandum No. 86.68210-2011-01, prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado, 138pp.
Reclamation 2013	Reclamation 2013. Summary Report Central Valley Project Integrated Resource Plan. Prepared by U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.
Reclamation 2014	Reclamation 2014. Sacramento and San Joaquin Basins Climate Risk Assessment. Prepared by U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.
Reclamation et al. 2013	Reclamation, Climate Analytics Group, Climate Central, Lawrence Livermore National Laboratory, Santa Clara University, Scripps Institution of Oceanography, U.S. Army Corps of Engineers, and U.S. Geological Survey, 2013. Downscaled CMIP3 and CMIP5 Climate Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with Preceding Information, and Summary of User Needs. http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/ techmemo/downscaled_climate.pdf.
Vermeer and Rhamstorf 2009	Vermeer M, and S. Rahmstorf. 2009. Global Sea Level Linked to Global Temperatures. Proceedings of the National Academy of Sciences.
Western Regional Climate Center 2013.	Western Regional Climate Center. 2013. http://www.wrcc.dri.edu/monitor/ cal-mon/frames_version.html. Accessed July 2013.