RECLAMATION
Managing Water in the West

Sacramento and San Joaquin Rivers Basin Study

Basin Study Technical Report

U.S. Department of the Interior
Bureau of Reclamation

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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.

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Sacramento and San Joaquin Rivers Basin Study Report

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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.

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Acronyms and Abbreviations

AET	actual ET
AMO	Atlantic Multi-decadal Oscillation
ANN	artificial neural network
AR5	Fifth Assessment Report
Basins Study	Sacramento and San Joaquin Basins Study
Bay	San Francisco Bay
BCSD	Bias Correction and Spatial Downscaling
BMP	best management practices
CAT	Climate Action Team
CCTAG	Climate Change Technical Advisory Group
California WaterFix	Bay Delta Conservation Plan
CCF	Clifton Court Forebay
CDEC	California Data Exchange Center
CDF	cumulative distribution function
CII	commercial, institutional, and industrial
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
CWP	California Water Plan Update 2013
Delta	Sacramento-San Joaquin Delta
DOF	State of California’s Department of Finance
DOI	Department of the Interior
DWR	California Department of Water Resources
EC	electrical conductivity
EDCWA	El Dorado County Water Agency
EID	El Dorado Irrigation District
ENSO	El Niño Southern Oscillation
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
MWD	Metropolitan Water District of Southern California
NOAA	National Oceanic and Atmospheric Administration
NODOS	North-of-Delta Offstream Storage
NRC	National Research Council
O&M	operation and maintenance
OMR	Old and Middle River channels of the San Joaquin River
PDO	Pacific Decadal Oscillation
PET	potential ET
PP	pumping plant
RCP	Representative Concentration Pathways
Reclamation	Bureau of Reclamation
SECURE Water Act	The Omnibus Public Land Management Act of 2009 Public Law 111-11
SLWRI	Shasta Lake Water Resource Investigation
Summary Report	Sacramento and San Joaquin Basins Study Report
SWE	snow water equivalents
SWP	State Water Project
SWRCB	California State Water Resources Control Board
Thermalito	Hyatt-Thermalito Power Plant Complex.
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service

USFWS	U.S. Fish and Wildlife Service
VPD	vapor pressure deficit
WaterSMART	Sustain and Manage America's Resources for Tomorrow
WCRP	World Climate Research Program
WQCP	Water Quality Control Plan
WWEP	Western Watershed Enhancement Partnership

Models

CalLite	
CUP	crop water use model
LCPSIM	Least Cost Planning Simulation model
LCRBWQM	Lower Colorado River Basin Water Quality Model
OMWEM	Other Municipal Water Economics model
PGM	Plant Growth Model
SBWQM	South Bay Water Quality model
SWAP	Statewide Agricultural Production model
VIC	Variable Infiltration Capacity
WEAP-CV	Water Evaluation and Planning model of the Central Valley

Abbreviations for Scenarios

Used in tables and figures only

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 scenario
WW_CT	Warm-Wet climate/Current Trends socioeconomic scenarios
WW_SG	Warm-Wet climate/Slow Growth socioeconomic scenarios

Measurements

AFY	acre-foot per year
°C	degrees Celsuis
°F	degrees Fahrenheit
af	acre-foot
cfs	cubic feet per second
cm	centimeters
GWh	gigawatt hours
kPa	kilo Pascals
kWh	kilowatt hours
km	kilometers
MAF	million acre-feet
mm	millimeters
mTCO2e	metric tons of carbon dioxide equivalents
ppm	parts per million
TAF	thousand acre-feet
µS/cm	microSiemens per centimeter

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Preface: About this Technical Report

This Technical Report supplements the Sacramento and San Joaquin Basins Study Report (Summary Report) by providing greater detail on the technical approach employed in this analysis, including assumptions, methodologies and results not included in this Report. See the Summary Report for a discussion of the Basin Study program context (Section 1), basin settings (Section 2), and historic and projected climate (Section 2). Figure P-1 shows the geographic area included in the study.

Figure P-1. Sacramento and San Joaquin Basins study area

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 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 the Summary 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 Sacramento and San Joaquin Basins Study (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 the Summary 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 °F 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 the Summary Report and Section 7. *Adaptation Portfolios Evaluations* in the Summary 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 the Summary 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.

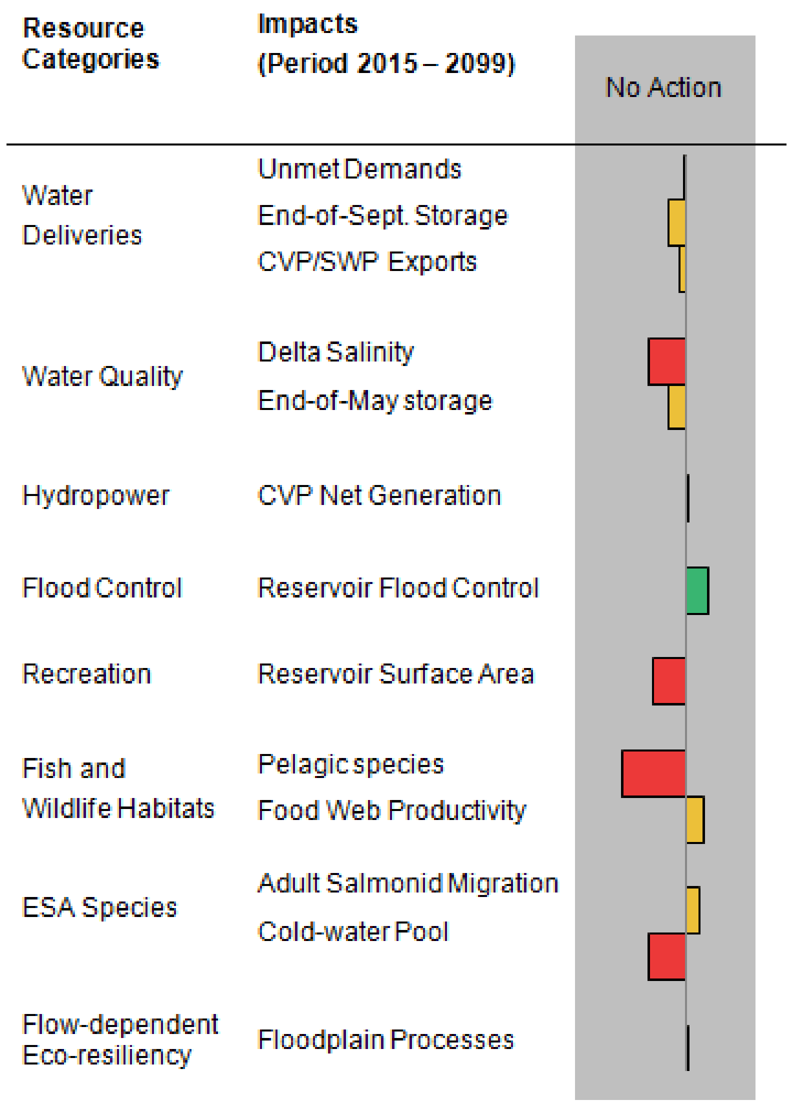

Figure ES-1. Climate impacts under the No Action alternative.
(Changes from the Reference-No-Climate-Change to the Central Tendency climate scenario—both under the Current Trends socioeconomic scenario)[1]
(Note that red and yellow to the left indicate negative values and the yellow and green to the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

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[1] 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.

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.

- 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 winter and 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 Technical 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 this 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 helped to expand surface and groundwater storage and 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.

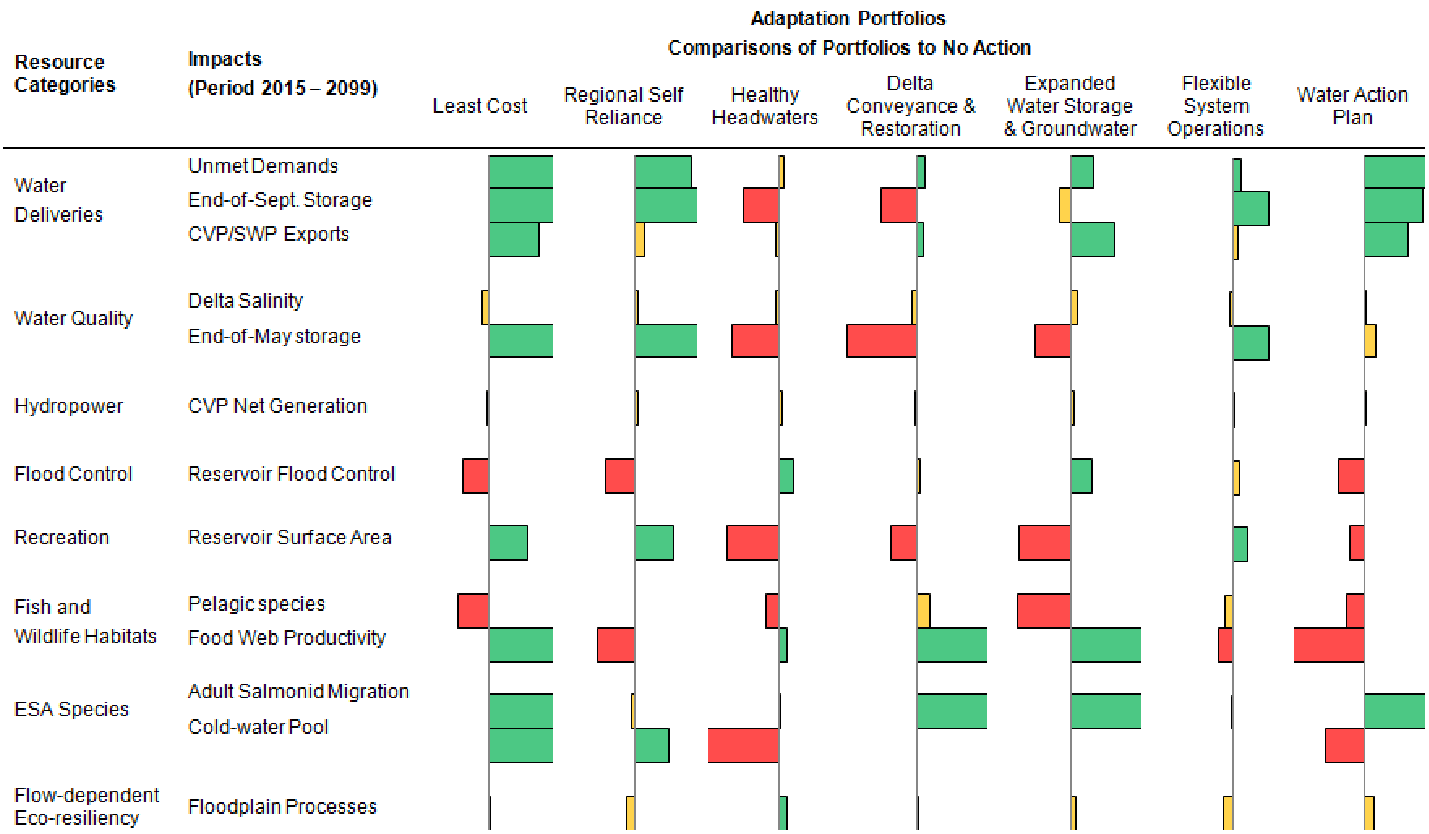


Figure ES-2. Comparisons of Portfolios to the No Action alternative (Changes in impacts under the Central Tendency climate/Current Trends socioeconomic scenario).

Although the Basins Study included a broader range of climate and socioeconomic scenarios, Section 7. *Adaptation Portfolios Evaluation* in the Summary 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 this 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.

1. Technical Approach

1.1. Study Objectives

The Study objectives center on addressing two primary questions:

- ***What is the future reliability of the Central Valley water system in meeting the needs of Basin users during the 21st century?***

- ***What are the actions and strategies that can adapt to future risks to these water and related resources?***

The overall approach for this Basins Study is shown in Figure 1-1. 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 1-1, 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. Two major uncertainties affecting the results are future socioeconomic and climate conditions.

- **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 the Summary Report and Section 2.1.2.1 *Socioeconomic Futures* in this 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 the Summary Report and Section 2.1.2.2 *Climate Futures* in this Technical Report).

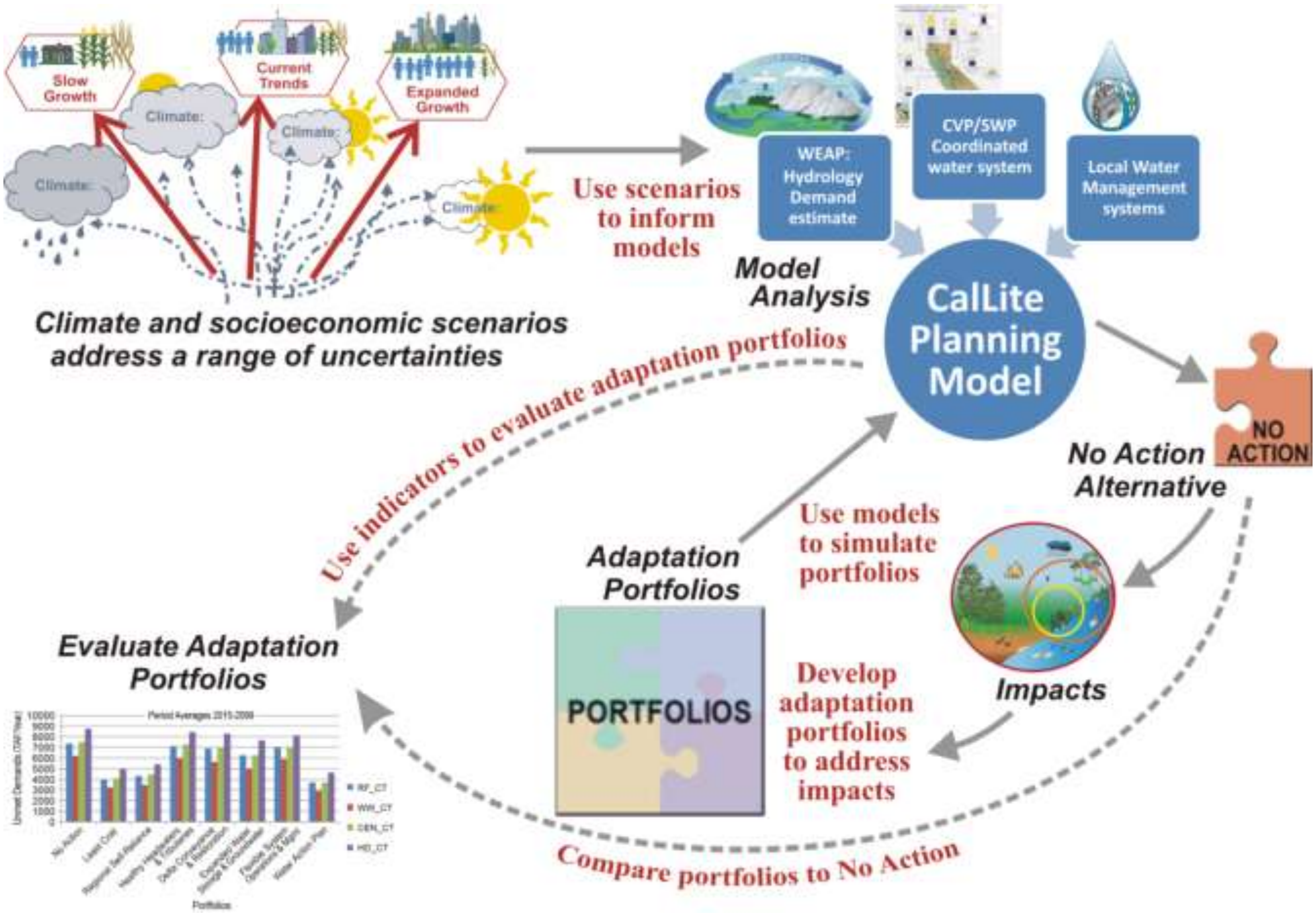


Figure 1-1. Technical approach and analysis process.

- **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 the Summary Report and Section 1.3. *Modeling* in this Technical Report).

- **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 the Summary Report and Section 4. *Water Demand Assessment* in this 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 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 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 Technical Report).

1.2. Scenarios to Address Uncertainties

The technical approach employed in this Basins Study was designed to evaluate the impacts of climate change on water and related resources during the 21st century. An important aspect of the assessment is how to address the uncertainties involved in the analysis. Two major uncertainties affecting future impacts are climate and socioeconomic conditions. Although both involve significant degrees of uncertainty, it is clear that both climate and socioeconomic conditions are dynamic in nature. This aspect of the assessment was addressed by employing a transient analysis in which both climate and socioeconomic conditions are changing over time. The climate uncertainties were addressed by including multiple 21st century continuously changing projections of temperature and precipitation using Global Climate Model (GCM) simulations to represent a wide range of potential future climate 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) (2007) and include assumptions about the effects of urban growth on agricultural lands.

These socioeconomic projections are embedded in the 2013 California Water Plan. Additional information related to how the socioeconomic and climate projections were developed is provided in Section 2. *Socioeconomic-Climate Futures* in this Technical Report.

1.3. Modeling

The modeling approach and tools shown in Figure 1-2 were developed as part of Central Valley Project Improvement Act Integrated Resource Plan (CVP IRP) and further improved for the Sacramento and San Joaquin Basin's Climate Risk Assessment Report (Reclamation 2014 [Climate]), which employed a scenario-based planning approach to evaluate the effectiveness of potential water management actions to increase supply and reduce demand under a range of potential future climate and socioeconomic conditions. Additional information on the modeling tools is available in CVP IRP report (Reclamation 2013 [CVP IRP])[2].

In the Critical Uncertainties and Scenario Development task (left side of Figure 1-2) three socioeconomic projections were combined with multiple GCM-based climate projections to form future scenarios representing a wide range of potential 21st century socioeconomic-climate uncertainties. The scenarios were developed using data from climate projections in the Coupled Model Intercomparison Project Phase 5 (CMIP5) study (IPCC 2014).

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 [Climate]) and further improved for this Basins Study. Figure 1-2 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 1-2) 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 as input 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 1-2 shows the models used to perform the risk assessment and portfolio evaluation. Indicators are described in Section 5. *Challenges: Risk and Reliability Assessment* in the Summary 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* in the Summary Report. Detailed descriptions of each of these models are provided in the Technical Report and appendices.

[2] The CVP IRP report can be downloaded from http://www.usbr.gov/mp/SSJBasinStudy/documents.html

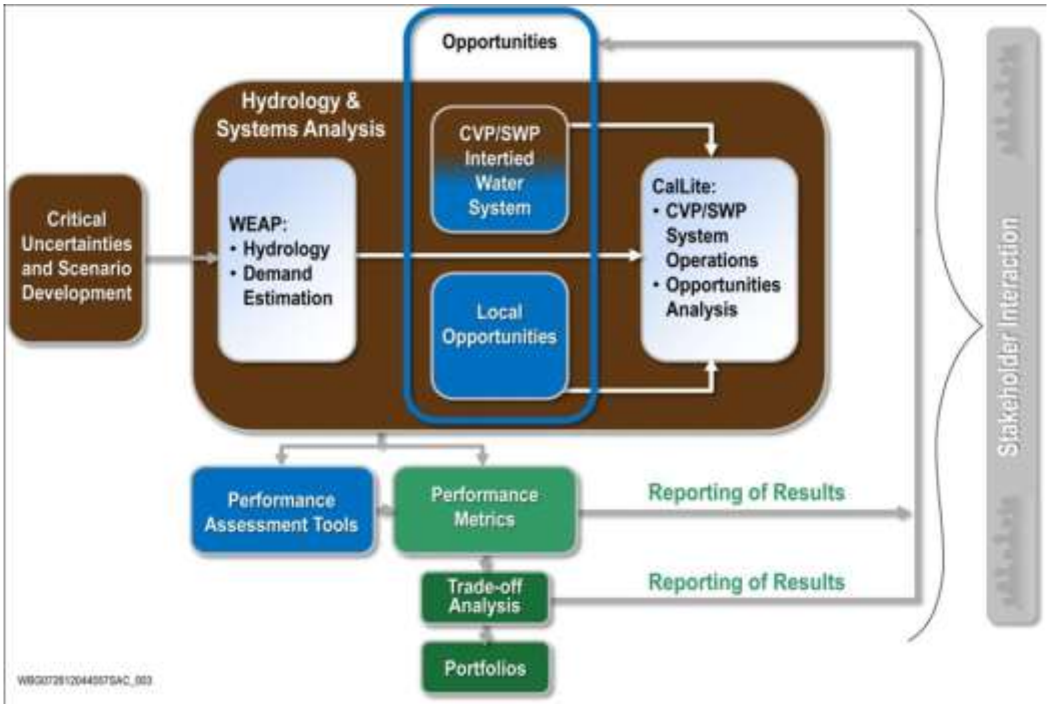


Figure 1-2. Sacramento and San Joaquin Basin's climate modeling approach.

The socioeconomic-climate scenarios developed for this analysis were used as inputs to the WEAP hydrology model (center left on figure) to simulate watershed runoff, reservoir inflows, river flows, groundwater recharge and demands for urban and agricultural water uses. These results were subsequently used as inputs to the CalLite-CV model (center right on the figure) which simulates how the CVP, SWP and other water management infrastructure are operated to supply water to meet system demands including 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) for evaluating impacts on water temperature, hydropower, greenhouse gas (GHG) emissions, as well as urban and agricultural economics.

The next step was to assess the significance of the impacts by comparing the modeling results to Performance Metrics (lower center on figure) associated with a variety of resource categories important to the management of water resources in the study area. Subsequently these impacts were addressed by developing representative local, regional and system wide adaptation actions (bottom and left side of figure). Finally, promising actions were combined into portfolios which were quantitatively and qualitatively assessed to determine their effectiveness and tradeoffs between these actions. More detailed descriptions of the technical approach and assessment results are provided in the following sections for each resource category.

2. Socioeconomic-Climate Future Scenarios

Water supplies and demands in the 21st century have uncertainties associated with both changing climate and evolving socioeconomic conditions. Climate is the most important factor influencing gross water supplies. Changes in the amount of precipitation directly affect water supplies. In addition, changes in the seasonality of precipitation or the amount of precipitation falling as snow versus rain will affect the ability to store water supplies, which in turn will affect water supply availability for particular needs. Temperature is one of several climate characteristics that can influence water supplies through its effect on reservoir evaporation and crop evapotranspiration. While increasing temperature tends to increase evapotranspiration by vegetation leading to a decrease in runoff, other climate changes such as increasing atmospheric carbon dioxide tend to reduce evapotranspiration; thereby, offsetting some of the effects of increasing temperature. Similarly, these effects may tend to reduce water demands by some agricultural crops.

Socioeconomic conditions have a direct effect on water demands. As population increases, water demands for municipal, commercial, and industrial water supplies tend to increase. Furthermore, land-use changes also have important effects on water demands. How urban growth occurs has important influences on adjacent agricultural lands and the demand for agricultural water supplies.

2.1. Scenario Development

To address uncertainty, this study evaluated adaptation portfolios under various socioeconomic scenarios, or alternative views of how the future population and urban density might unfold, and climate scenarios, or alternative views on the amount of climate change. Each scenario reflects factors related to a particular socioeconomic future and a particular climate future, resulting in a range of scenarios that were used to assess future water supply and demand. The following section summarizes the approach to scenario development.

2.1.1. Objective and Approach

Rather than predictions or forecasts of the future, scenarios they are alternative views of how the future might unfold. Figure 2-1 illustrates this concept. At present, an understanding of the state of the Central Valley water system exists as indicated by the single point labeled “Today” on the x-axis of the figure. A range of plausible futures, represented by the funnel, can be identified. The suite of scenarios used in the planning effort should be sufficiently broad to span the plausible range of the funnel.

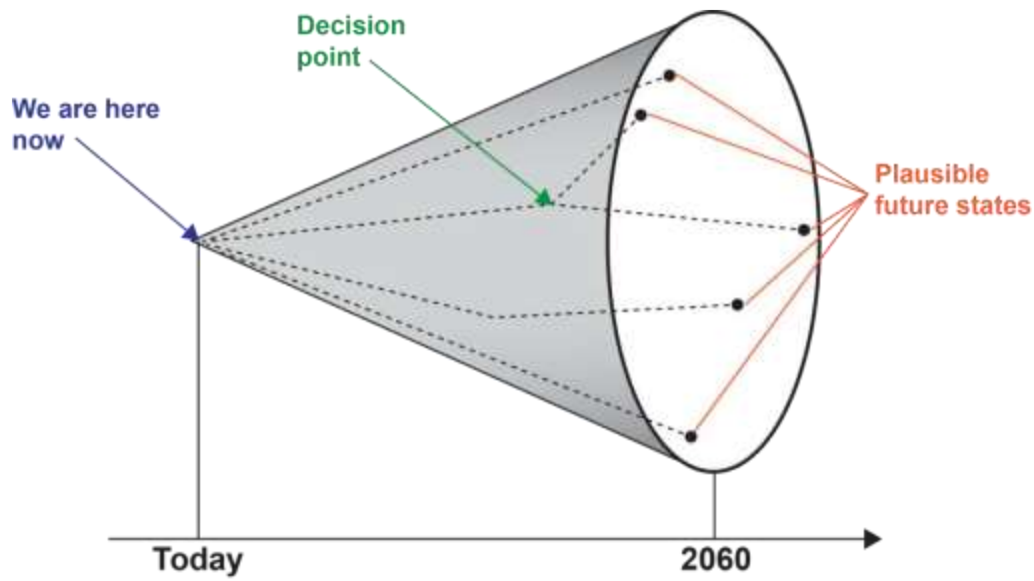


Figure 2-1. Conceptual Representation of the Uncertain Future of a System, termed “The Scenario Funnel” Adapted from Timpe and Scheepers (2003)

The scenario planning process involved:

- Identifying the key forces that would likely drive future water supply and water demand

- Ranking the driving forces (the factors that likely would have the greatest influence on the future state of the system and thereby the performance of the system over time) by their relative importance and uncertainty

- Using the most highly uncertain and highly important driving forces (“critical uncertainties”) to identify various themes and “storylines” (narrative descriptions of scenarios) to describe how water supply and water demand may evolve in the future

Quantification of the storylines resulted in water supply and water demand scenarios used to assess future system reliability.

2.1.2. Socioeconomic and Climate 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. Future scenarios were developed, each of which was analyzed for the period from October 2014 to September 2099 using a transient approach in which the climate and socioeconomic factors change as the simulation moves through time. The following sections describe the socioeconomic and climate futures that were used in this Basins Study for each future scenario.

Two current level or "reference" scenarios were used as a basis of comparison to evaluate the effects of the socioeconomic-climate future scenarios:

- Socioeconomic: **2006 Historic Demands socioeconomic scenario** projects population and land use in 2006 in future simulations.

- Climate: **Reference-No-Climate-Change climate scenario** projects hydroclimate conditions under historical climate in future simulations.

In addition, to account for a range of uncertainty in future conditions, a suite of scenarios was developed to reflect a range of future conditions. Each of these scenarios reflected a combination of a socioeconomic future and a climate future.

2.1.2.1. Socioeconomic Futures

For long range planning, characterization of major sources of uncertainty is important to understanding system risks. From the perspective of urban water needs and to lesser extent those of agriculture, estimates of future changes in population and land use especially the conversion of agricultural land to urban, commercial and industrial uses are essential.

2.1.2.1.1. Summary of Socioeconomic Scenarios

Three socioeconomic "storylines" or scenarios were developed to describe how water demands might evolve with changing populations and land use. These scenarios are not predictions or forecasts of the future. These socioeconomic scenarios[1] include:

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

- **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.

- **2006 Historic Demands socioeconomic scenario (RF).** This is a current level or "reference" scenario, which includes current level population and land use factors.

The Slow Growth and Expanded Growth scenarios represent bounding high and low growth projections.

2.1.2.1.2. Background for Developing Socioeconomic Scenarios

For this report, three projections of these water demand factors were used to characterize a plausible range of potential changes in population and land use during the 21st century. These scenarios were based on information developed for the California Water Plan Update 2013 (CWP) (DWR 2014 [Water Plan]). The CWP developed 9 conceptual growth scenarios from a combination of three population growth and development density assumptions. These are shown in Table 2-1. For this Basins Study, three of the CWP conceptual growth scenarios were used to develop projections combining different assumptions about the rate of population and urban land use growth were developed to represent Slow Growth, Current Trends, and Expansive Growth socioeconomic scenarios (shown in Table 2-2).

Table 2-1. CWP Conceptual Growth Scenarios

Scenario	Population Growth	Development Density
LOP-HID	Lower than Current Trends	Higher than Current Trends
LOP-CTD	Lower than Current Trends	Current Trends
LOP-LOD	Lower than Current Trends	Lower than Current Trends
CTP-HID	Current Trends	Higher than Current Trends
CTP-CTD	Current Trends	Current Trends
CTP-LOD	Current Trends	Lower than Current Trends
HIP-HID	Higher than Current Trends	Higher than Current Trends
HIP-CTD	Higher than Current Trends	Current Trends
HIP-LOD	Higher than Current Trends	Lower than Current Trends

Source: *California Water Plan 2013, Volume 1 Chapter 5* (DWR 2014)

Table 2-2. Socioeconomic Scenarios Used in This Basins Study

Scenario	Acronym in Tables	Population Growth Assumption	Urban Density Assumption
Current Trends	CT	Current Trends Population	Current Trends Density
Expansive Growth	EG	High Population	Low Density
Slow Growth	SG	Low Population	High Density

Figure 2-2 and Figure 2-3 show population and irrigated land use changes for the Sacramento, San Joaquin and Tulare Lake hydrologic basins in the years 2005 (Base), 2050 and 2100 for these three scenarios. These projections were based on data developed by the California Department of Finance (DOF) (2007). The DOF developed a single population projection through 2050 for each county; these projections were then extended to the year 2100 using data developed by the Public Policy Institute of California (Johnson 2008), which was adjusted to make the projections consistent with the DOF projections for the 2010–2050 period. The projected changes in irrigated lands were developed from information used in the CWP Update 2009. These land use projections were extended from 2050 to 2100 by methods used for the CVP IRP (Reclamation 2013 [CVP IRP]). As shown in Figure 2-3, irrigated land acreages decline during the 21st century in all three hydrologic regions in proportion to the increase in population under the assumption that urban growth results in some loss of agricultural land.

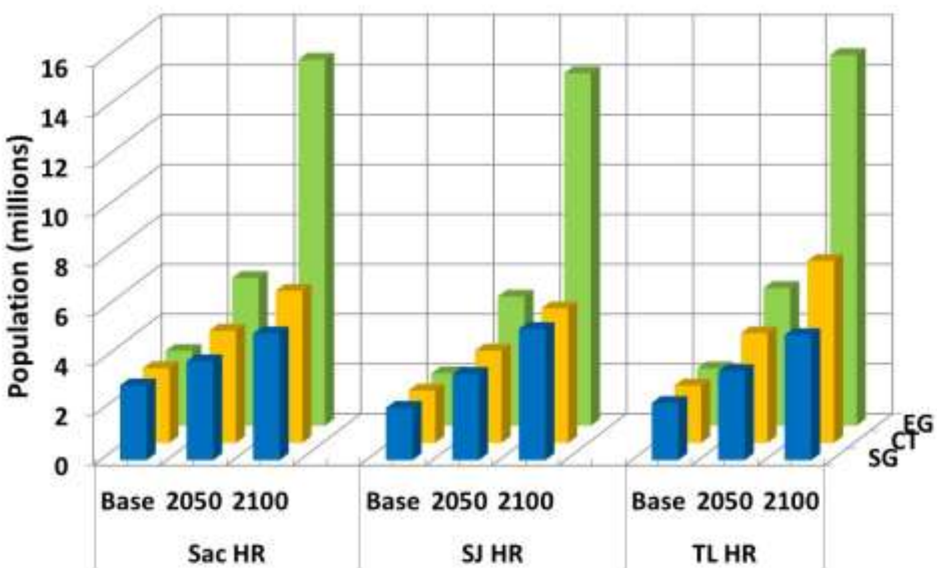


Figure 2-2. Valley Population Projections in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions under Each Scenario

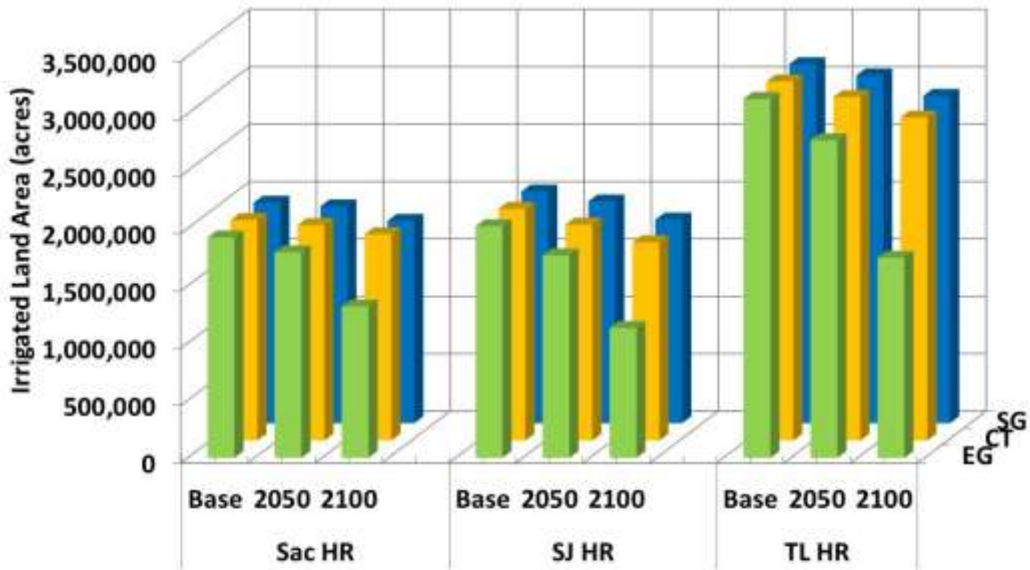


Figure 2-3. Irrigated Land Area Projections in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions under Each Scenario

2.1.2.1.3. Reference-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 scenario that did not include population or land use (socioeconomic) changes. The Reference-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.

2.1.2.2. Climate Futures

Future projections of climate are typically drawn from global climate models (GCM) forced by a range of plausible atmospheric compositions. Climate science is a rapidly evolving field with frequent release of new information that refines our understanding of the range of potential future climate. The current generation of climate models results included in the Coupled Model Intercomparison Project Phase 5 (CMIP5) has been released recently (Taylor et al. 2012). The climate models in the CMIP5 were driven using a set of newly developed emission scenarios called Representative Concentration Pathways (RCP). There are four RCPs (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) used in the CMIP5 (van Vuuren et al. 2011).

The CMIP5 climate model data is the basis for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) recently released (IPCC 2014). Reclamation and other collaborators have developed a downscaled GCM projection database using the Bias Correction and Spatial Downscaling (BCSD) method using the CMIP5 climate models, similar to what has been developed for the BCSD World Climate Research Program (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) Climate and Hydrology Projections. Future climate scenarios based on the BCSD downscaled climate projections using the CMIP5 climate simulations have been developed to ensure that this Basins Study includes the most current science available at the time of its release.

Climate projections were developed based on CMIP5 were used to characterize a wide range of future hydroclimate uncertainties. For each of these scenarios, temperature and precipitation projections were developed for the future period of 2014 through 2099. The following projections were included in this analysis:

- **Reference-No-Climate-Change scenario,** which included simulations of hydroclimatic conditions under historical climate.
- **Future Climate – Ensemble Scenarios** used five scenarios developed based on downscaled GCM projections included in CMIP5
- **Future Climate – CCTAG Downscaled Climate Projections.** The DWR Climate Change Technical Advisory Group (CCTAG) has identified 10 GCMs that DWR and the State of California's Climate Action Team (CAT) will use in climate studies in California.

2.1.2.2.1. Reference-No-Climate-Change Scenario (RF)

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. The Reference-No-Climate-Change scenario was developed using newly developed historical climate daily data constructed based on monthly PRISM (Daly et al. 1994) and daily Livneh et al. (2013). The historical climate sequence from water years 1923 through 2010 was used to simulate the same future period as the other 17 climate projections.

2.1.2.2.2. Ensemble Climate Projections

A total of five representative climate futures were developed using results from recent GCM simulations (IPCC 2014) 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.

The ensemble climate projections were developed from 175 GCM simulations which had been bias-corrected and spatially downscaled (BCSD) by Reclamation and others (Reclamation 2013 [CVP IRP] and 2014 [Climate]). Using statistical techniques, the wide range of future temperature and precipitation uncertainties expressed in the large ensemble of 175 projections were represented in these ensemble projections. The ensemble approach maps projected changes in climate derived from an ensemble of downscaled climate model projections to a sequence of observed meteorology using a quantile method. Projected temperature and precipitation for selected 30-year future climatological periods are compared to a historical reference period and the changes are computed. The changes in temperature and precipitation are then mapped onto a historical observed meteorological pattern using a quantile mapping method which transforms the historical records into a modified sequence that incorporates the projections of future climate change (see Section 3. *Water Supply Assessment* and Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections* for more details).Details of the methodology can also be found in Reclamation (2013 [CVP IRP]).

All of the future climate ensembles include an increase in temperature, from a more moderate increase (“Warmer”) to a more severe increase (“Hotter”), and either an increase (“Wetter”) or decrease (“Drier”) in precipitation. The central tendency ensemble represents a condition somewhat similar to an “average” of all future climate projections:

- **Hot-Wet (HW)**: formed from the 10 individual climate projections closest to the 95th percentile temperature and 95th percentile precipitation changes
- **Hot-Dry (HD):** formed from the 10 individual climate projections closest to the 95th percentile temperature and 5th percentile precipitation changes
- **Warm-Wet (WW):** formed from the 10 individual climate projections closest to the 5th percentile temperature and 95th percentile precipitation changes
- **Warm-Dry (WD)**: formed from the 10 individual climate projections closest to the 5th percentile temperature and 5th percentile precipitation changes
- **Central Tendency (CEN):** formed from all the projections between the 25th and 75th percentiles of both temperature and precipitation

In addition, atmospheric carbon dioxide concentrations for each of the five climate projections were computed from the CMIP5 RCP scenarios associated with the individual GCM projections included in the ensemble.

Table 2-3 summarizes the Reference-No-Climate-Change Scenario and the 5 ensemble climate scenarios. For each scenario, temperature and precipitation projections were developed for the period from 2011 through 2099.

Table 2-3.Ensemble Climate Scenarios

Scenario	Acronym in Tables	Description	Emission Scenarios
Reference-No-Climate-Change	RF	Reference Climate	Not applicable (uses historical climate)
Warm/Dry	WD	Drier and less warming	Derived from mixtures of RCP4.5, RCP6.0 and RCP8.5
Hot/Dry	HD	Drier and more warming	Derived from mixtures of RCP4.5, RCP6.0 and RCP8.5
Hot/Wet	HW	Wetter and more warming	Derived from mixtures of RCP4.5, RCP6.0 and RCP8.5
Warm/Wet	WW	Wetter and less warming	Derived from mixtures of RCP4.5, RCP6.0 and RCP8.5
Central	CEN	Central tending climate scenario	Derived from mixtures of RCP4.5, RCP6.0 and RCP8.5

2.1.2.2.3. CCTAG Scenarios

DWR Climate Change Technical Advisory Group (CCTAG) has selected a subset of CMIP5 GCMs that can be used for California climate and water resources assessments. Table 2-4shows the 10 CMIP5 GCMs, listed alphabetically by model-abbreviated name. These GCMs were selected by the CCTAG based on their ability to “reasonably” simulate historical climatic conditions including seasonal precipitation, temperature and variability of annual precipitation in California as well as important global climate conditions such as tropical Pacific Ocean sea surface temperatures associated with the El Niño Southern Oscillation. Six GCMs were selected for use in this Basins Study reports (shown in column 3). GHG emissions scenarios were simulated by each of the six models— yielding the 12 CCTAG climate projections (6 GCMs with 2 emission scenarios each).

Table 2-4. GCMs Selected by DWR CCTAG for California Climate and Water Resources Assessments

CMIP5 Climate Modeling Group	GCM name	GCM Selected for Basins Study
CSIRO (Commonwealth Scientific and Industrial Research Organization, Australia), and BOM (Bureau of Meteorology, Australia)	ACCESS-1.0	
National Center for Atmospheric Research	CCSM4	X
National Science Foundation, Department of Energy, National Center for Atmospheric Research	CESM1-BGC	X
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC-CMS	
Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	CNRM-CM5	X
Canadian Centre for Climate Modeling and Analysis	CanESM2	
Geophysical Fluid Dynamics Laboratory	GFDL-CM3	X
Met Office Hadley Centre	HadGEM2-CC	
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HadGEM2-ES	X
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	X

These scenarios were used to perform the water supply, water demand, system risk and reliability, water management actions, and adaptation strategy assessments described in the following sections.

To bracket the range of future climatic uncertainties, high (RCP8.5) and low (RCP4.5) GHG emissions scenarios were simulated by each of the six models yielding the 12 CCTAG climate projections (6 GCMs x 2 emission scenarios).

Figure 2-4 presents an example of projected temperature and precipitation for each of the eighteen climate projections (Reference-No-Climate-Change climate scenario, 5 ensemble, and 12 CCTAG climate projections) for the Sacramento River hydrologic region. The temperature and precipitation in the Reference-No-Climate-Change projections (dashed line) is also shown for comparison. Figure 2-5 shows the transient projected temperature and precipitation departures over time for the ensemble climate scenarios.

All of the ensemble projections and CCTAG projections were consistent in the direction of the temperature change relative to the Reference-No-Climate-Change projections, but varied in terms of climate sensitivity. Trends in the precipitation projections were less apparent because of naturally occurring interannual and multi-decadal precipitation variations.

Figure 2-4. Temperature projections

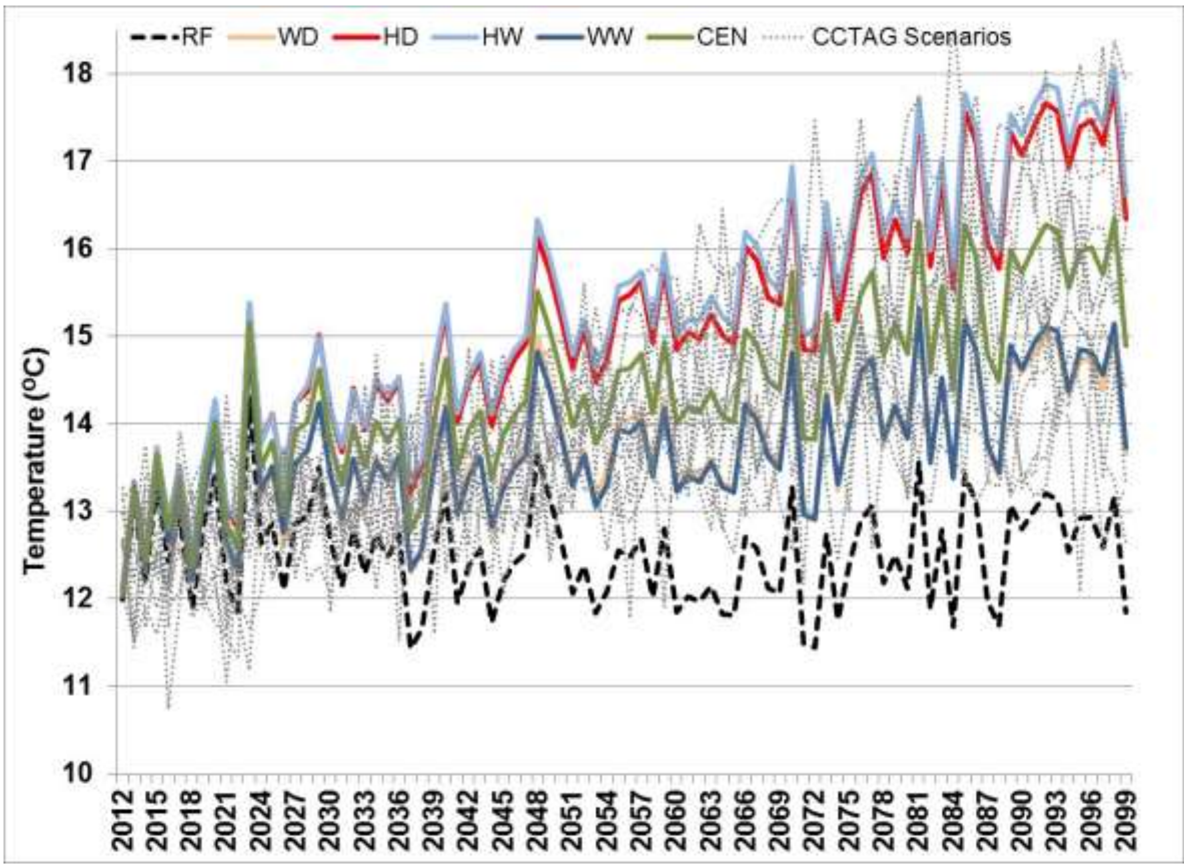


Figure 2-4a. **Temperature** projections under each climate scenario for the **Sacramento River** hydrologic region.

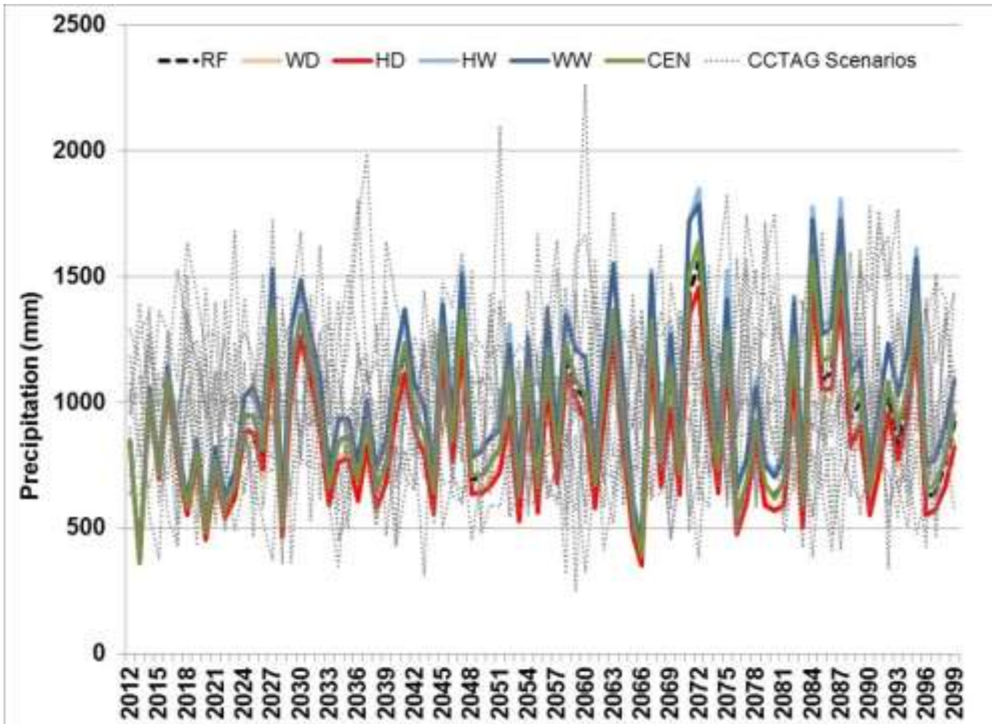


Figure 2-4b. **Precipitation** projections under each climate scenario for **Sacramento River** hydrologic region.

Figure 2-5. Temperature changes in ensemble climate scenarios

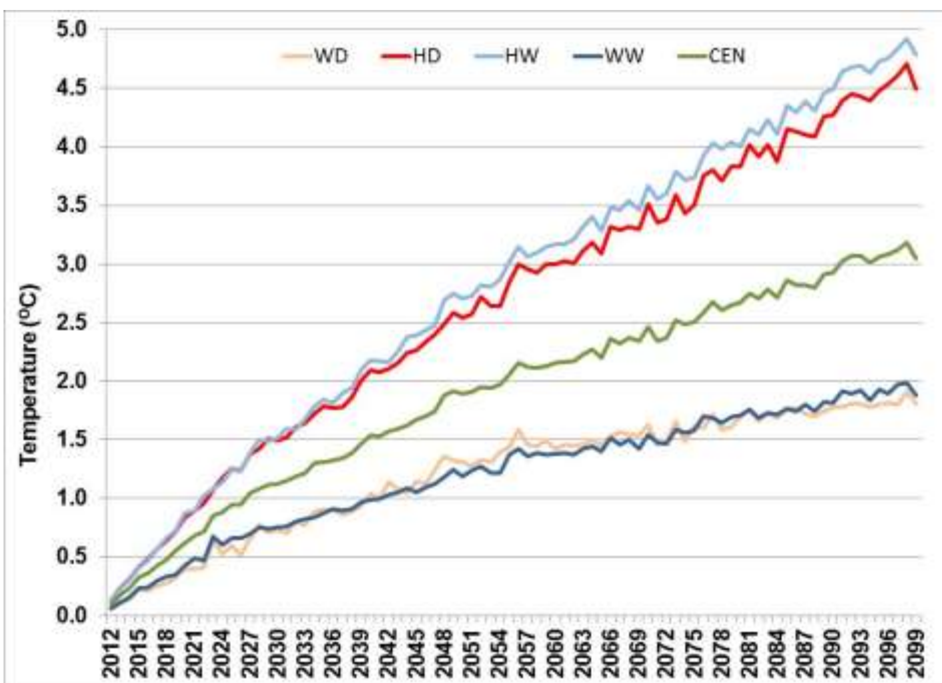


Figure 2-5a. Projected changes in **temperature for ensemble climate scenarios** for **Sacramento River** hydrologic region.

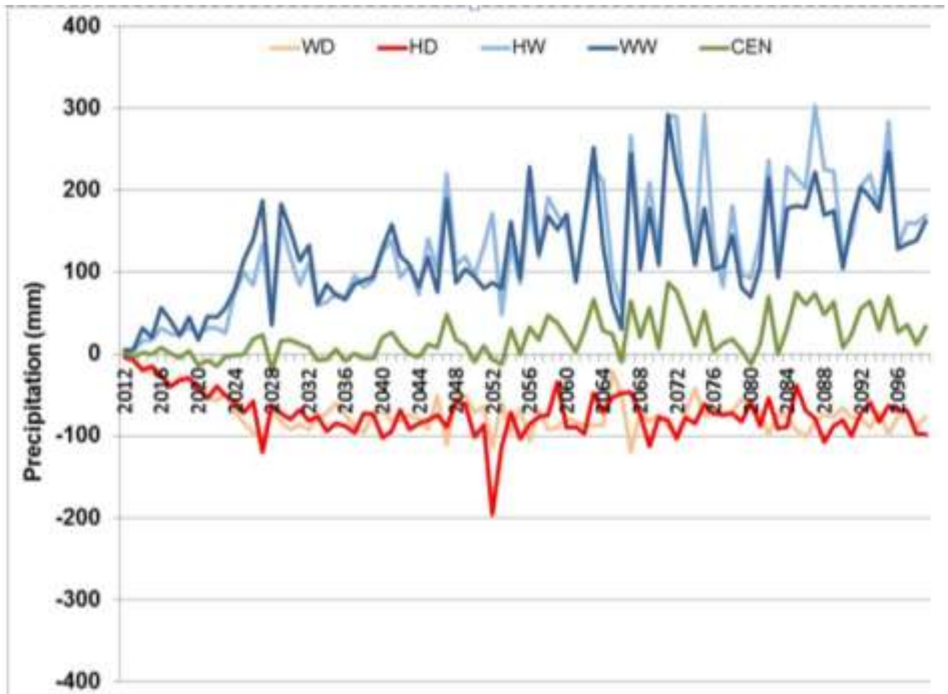


Figure 2-5b. Projected changes in **precipitation for ensemble transient climate scenarios for Sacramento River** hydrologic region.

2.1.2.3. Combined Socioeconomic and Climate Scenarios

To capture a large range of potential future impacts, the climate projections were combined with the socioeconomic scenarios to form future scenarios to represent a wide range of potential 21st century uncertainties. This Basins Study has analyzed the following combinations of socioeconomic and climate futures:

- Three future socioeconomic scenarios (Expanded Growth, Current Trends, and Slow Growth) in combination with the Reference-No-Climate-Change scenario and the five ensemble climate scenarios) (18 total)

- The Current Trends socioeconomic future in combination with the twelve CCTAG climate futures (12 total)

These combinations are represented in Figure 2-6.

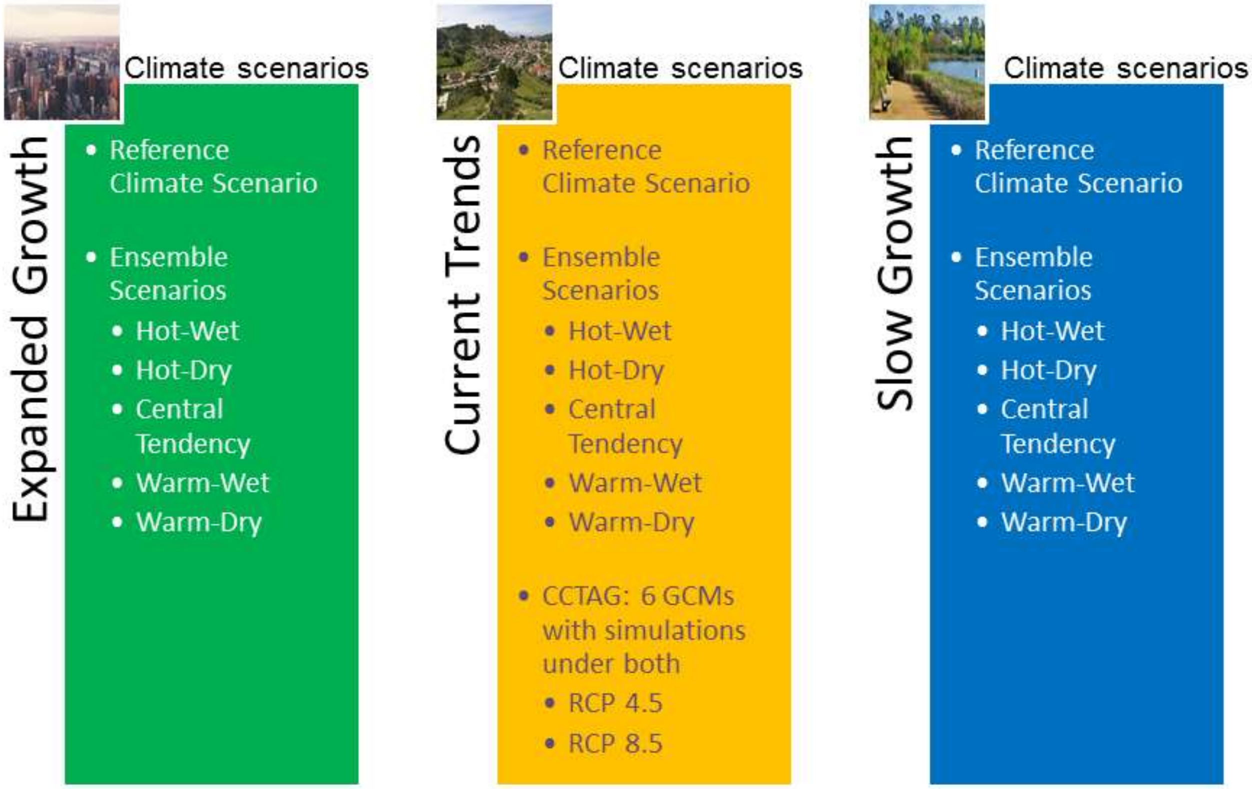


Figure 2-6. Combinations of climate and socioeconomic scenarios.

These scenarios were used to perform the water supply, water demand, system risk and reliability, water management actions, and adaptation strategy assessments described in the following sections.

2.2. Sea Level Changes

Transient sea level changes were also included in the climate scenarios. The same sea level rises were considered in each of 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 cm, with a projected range between 42 cm through 166 (NRC 2012).

2.2.1. Background for Analyzing Sea Level Changes

Global and regional sea levels have been increasing steadily over the past century and are expected to continue to increase throughout this century. Most State and Federal planning processes in the Central Valley (such as the Bay Delta Conservation Plan [California WaterFix]) have considered sea level rise through mid-century. In these studies, sea level increases of 2 to 3 feet (60 to 90 cm) have been simulated using existing hydrodynamic models.

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, this observed rate in mean sea level is similar to the global mean trend (National Oceanic and Atmospheric Administration [NOAA] 2012). Global estimates of projected sea level rise made in the assessment by the IPCC (2007) indicate a range of 7.1 to 23.2 inches (18 to 59 cm) this century.

Estimates by Rahmstorf et al. (2007), Vermeer and Rahmstorf (2009), and others suggest that the sea level rise may be substantially greater than the IPCC projections (Figure 2-7). Using empirical models based on the observed relationship between global temperatures and sea levels which have been shown to better simulate recent observed trends, these 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). Figure 2-7 shows various projected ranges of potential sea level change in the San Francisco Bay (Bay)-Delta through the year 2100.

In 2011, the U.S. Army Corps of Engineers (USACE) issued guidance on incorporating sea level change in civil works programs (USACE 2011). The guidance document reviews the existing literature and suggests use of a range of sea level change projections, including the “high probability” of accelerating global sea level rise. The ranges of future sea level rise were based on the empirical procedure recommended by the NRC (1987) and updated for recent conditions. The three scenarios included in the USACE guidance suggest end-of-century sea level rise in the range of 20 to 59 inches (50 to 150 cm), consistent with the range of projections by Rahmstorf et al. (2007) and Vermeer and Rahmstorf (2009).

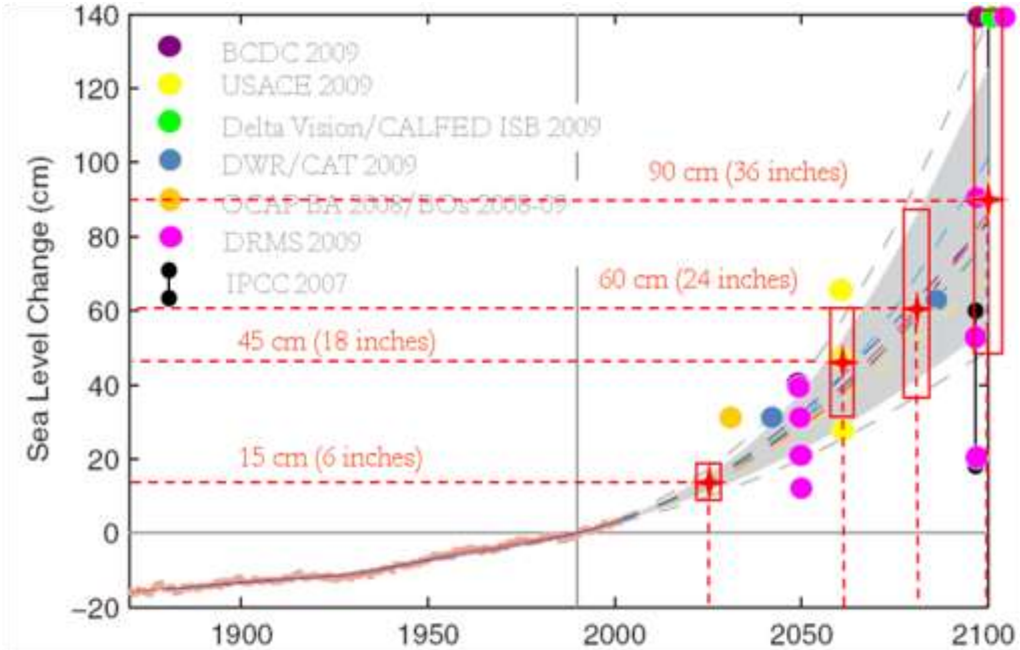


Figure 2-7. Range of future mean sea level based on global mean temperature projections and sea level rise values (Adapted from Rahmsdorf et al. 2007).

2.2.2. Method for Incorporating Sea Level Changes into Climate Scenarios

As part of the transient climate change analysis approach, sea level rise was assumed to gradually increase. The transient sea level rise projections have been developed based on the NRC reported projections.

The CALFED Science Program, NRC, and others have made assessments of the range of potential future sea level rise throughout the twenty-first century (Healey 2007 and NRC 2012). These studies indicate that as sea level rise progresses during the century, the hydrodynamics of the San Francisco Bay–Sacramento-San Joaquin Delta (Bay-Delta) estuary will change, causing the salinity of water in the Delta estuary to increase. This increasing salinity most likely will have significant impacts on water management throughout the Central Valley and other regions of the state.

The recent NRC study on west coast sea level rise relies on estimates of the individual components that contribute to sea level rise and then sums those to produce the projections (NRC 2012). The recent NRC sea level rise projections for California have wider ranges, but the upper limits are not as high as those from Vermeer and Rahmstorf's (2009) global projections. The National Academy of Sciences' reported projections have been adopted by the Coastal and Ocean Working Group of the Climate Action Team (CAT) as guidance for incorporating sea level rise projections into planning and decision making for projects in California.

The NRC report (2012) suggested sea level rise projections at three future times relative to 2000 (2030, 2050, and 2100), along with upper-and lower-bound projections for San Francisco as shown in Table 2-5. The sea level rise by the year 2100 ranges between approximately 42 centimeters (cm) through 166 cm, with a mean of about 90 cm.

Table 2-5. NRC Sea Level Rise Projections Relative to 2000 in San Francisco

Year	Mean Projection (in cm)	Lower Bound Projection (in cm)	Upper Bound Projection (in cm)
2000	0	0	0
2030	14.4	4.3	29.7
2050	28.0	12.3	60.8
2100	91.9	42.4	166.5

Source: NRC 2012

In the model simulations, an artificial neural network (ANN) embedded in the CalLite model was used to simulate salinity requirements and conditions in the Delta. This ANN included adjustments to reflect changes in Delta conditions from sea level rise. To simulate the effects of the projected sea level rise on the Bay-Delta system, relationships between flow and salinity were developed and incorporated into the CalLite-CV model. These relationships were developed using results derived from three-dimensional UnTRIM model (MacWilliams et al. 2008), which simulates Delta hydrodynamics and water quality and has also been used to study the effects of sea level rise.

In each of the scenarios, sea level rise was assumed to change the water surface elevation and flow-salinity dynamics of the Delta, but the basic configuration of the Delta (levees and islands) was assumed to be unchanged because of the difficulty in making defensible assumptions about Bay-Delta adaptation measures. However, it is important to note that with the current configuration of the Bay-Delta and levees, sea level rise has a reasonable potential to inundate many of the Delta islands. Such large-scale levee failures cannot be simulated with the modeling tools employed in this study.

3. Water Supply Assessment

The water supply assessment was performed for the climate scenarios developed as described in the preceding section. This section provides an overview of climate and hydrology in the historical period and describes projected changes in climate and hydrology based on results from these future scenarios.

3.1. Objective and Approach

The Water Supply Assessment characterizes and quantifies the magnitude and variability of historical period and projected future natural flows in the basins. Natural flow represents the flow that would have occurred at a location if depletions and reservoir regulation had not been present upstream of that location. The technical approach employed the tools and methods described in this and previous sections.

The assessment of historical and future supply conditions focuses on four main groups of water supply indicators, as shown on Figure 3-1. The water supply indicator groups are inter-related: climate influences hydrologic processes, hydrologic processes generate streamflow, and teleconnections seek to relate the oscillation of oceanic-atmospheric conditions with precipitation patterns. Although streamflow assessments provide an understanding of the cumulative effect of various climate-hydrologic processes, it is important to understand the relative influence of the specific processes to gain a better understanding of the hydroclimatic processes that drive water supply. Precipitation, temperature, and other meteorological parameters combine to drive the precipitation quantity, timing, and type (snow or rain) falling on the land surface. Soils provide storage capacity for infiltration of precipitation, and snowpack provides seasonal above-ground water storage. Sublimation from the snowpack, soil evaporation and plant transpiration vary considerably across the Sacramento and San Joaquin basins and determine the net loss of potential supply.

Through a combination of historical gridded climate datasets, hydrologic modeling, and literature and research review, an assessment of the trends and relative sensitivity of key processes was produced. The primary climate factors considered in this assessment are temperature and precipitation. The hydrologic process indicators include runoff, evapotranspiration (ET), snowpack accumulation (snow water equivalent [SWE]), and soil moisture. The climate teleconnection indicators included El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal Oscillation (AMO) indices.

Finally, the streamflow indicators are natural flows at selected key locations in the Central Valley basins.

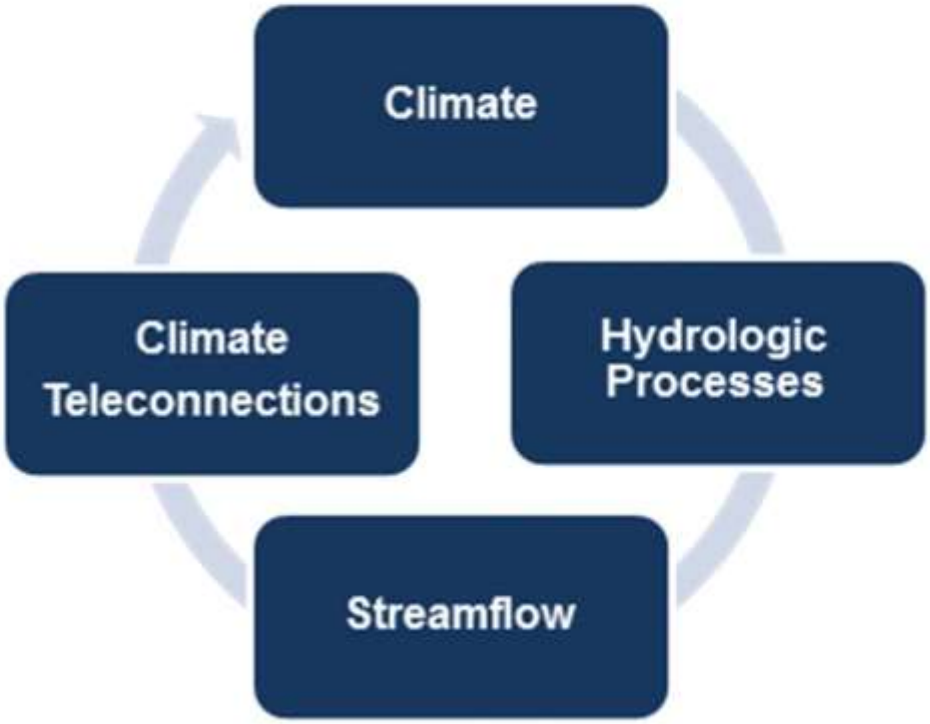


Figure 3-1. Types of water supply indicators used in the study.

3.1.1. Assessment of Historical Supply

3.1.1.1. Climate and Trends

The recent historical observed climate datasets from Livneh et al. (2013) were analyzed to evaluate trends in the historical climate. These datasets extend work from Maurer et al. (2002) and incorporate the longer historical time period represented in the Hamlet and Lettenmaier (2005) dataset. Additional details of this methodology is described in Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections*. The Livneh update contains historical gridded climate forcing data over the period 1915-2011. It was used to assess spatial and temporal trends in precipitation and temperature over the 1981-2010 period that NOAA has defined as the current climate normal. Monthly, seasonal, and annual statistics were computed for temperature and precipitation and for each grid cell for the period of 1981-2010 to facilitate comparisons to future climate. The seasons were defined as follows:

- Fall: October, November, and December (OND)
- Winter: January, February, and March (JFM)
- Spring: April, May, and June (AMJ)
- Summer: July, August, and September (JAS)

The use of this recently updated data set allowed for an improved and consistent assessment of multi-year drought periods of large-scale extent since 1900 (i.e., 1918-1920, 1923-1926, 1928-1935, 1947-1950, 1959-1962, 1976-1977, 1987-1992, 2000-2002, and 2007-2009).

Precipitation in most of California is dominated by extreme variability, both spatially and temporally. The northern part of the Central Valley receives greater precipitation than the semi-desert southern part (Figure 3-2). Average temperatures vary considerably by location and elevation. Warmest temperatures in the Central Valley are seen in the low-latitude desert near Bakersfield.

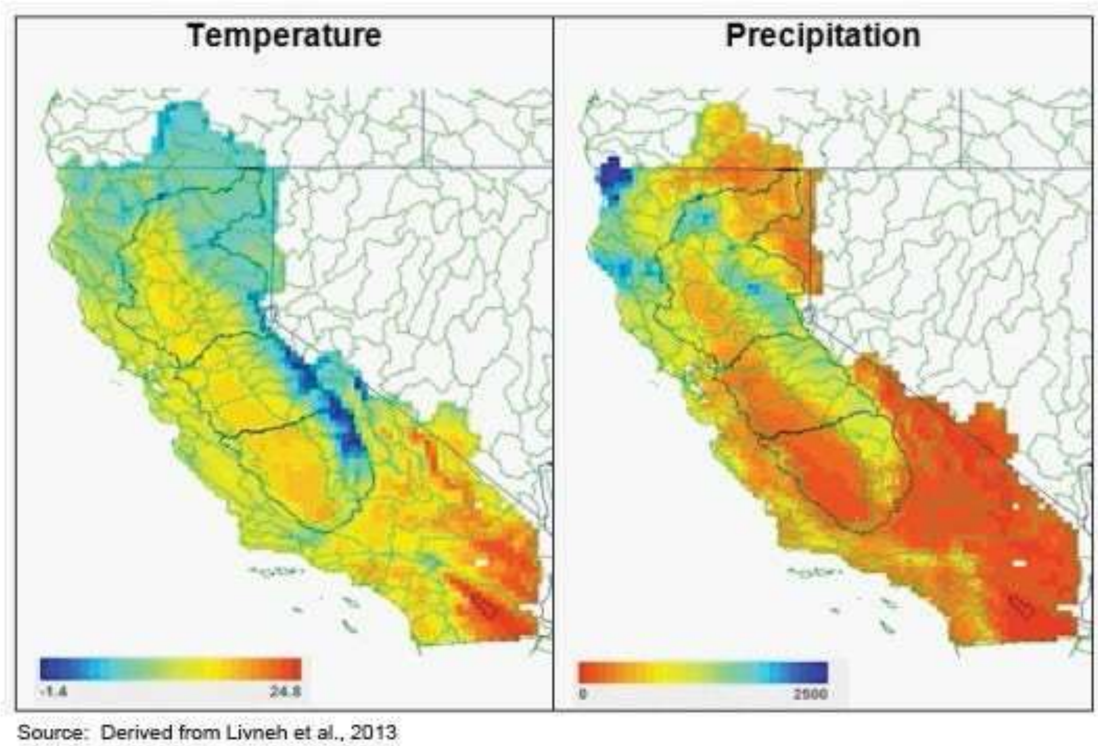


Figure 3-2. Average annual temperature (°C) and average annual precipitation for 1981 to 2010 (in millimeters) Derived from Livneh et al. 2013.

The water year annual average temperature departure and precipitation totals for California from 1896 to 2012 are shown on Figure 3-3. A significant increase in temperature is apparent beginning from about 1975, although periods of cooling have occurred historically. Most important is the warming trend that has occurred since the late 1970s. This warming trend also has been observed in North American and global trends. Observed climate and hydrologic records indicate that more substantial warming has occurred since the 1970s, and that this observation is likely a response to the increases in greenhouse gas (GHG) during this time.

Figure 3-3. California's historical temperature and precipitation.

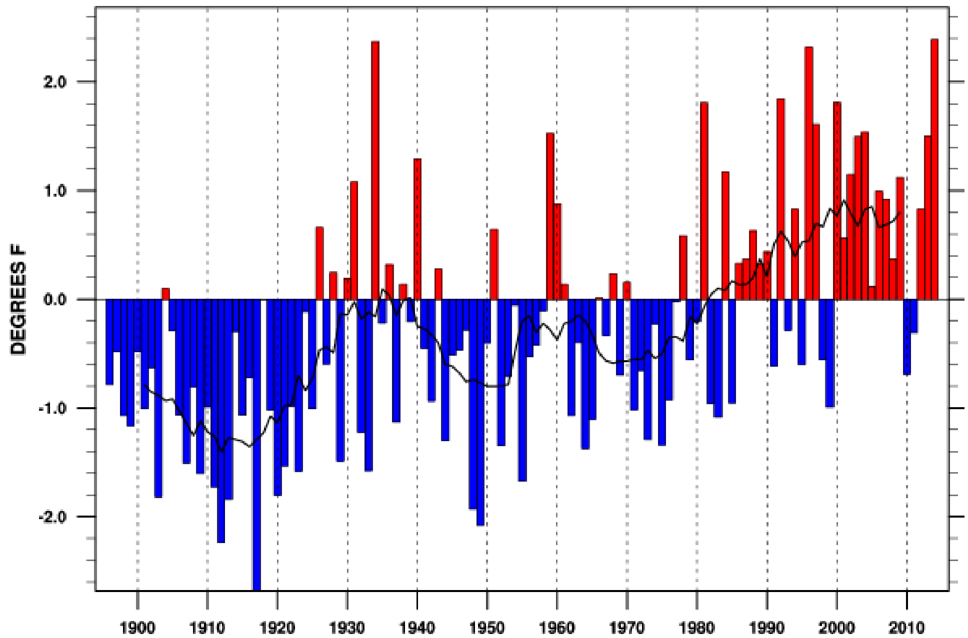


Figure 3-3a. California statewide mean **temperature** departure (Oct-Sep). Notes: Departure of annual water year average surface air temperature for the entire state, 1896-2014. Departure for temperature is computed for 1949-2005 base period. Bars: annual values; solid line: 11-year running mean.
Source: Western Regional Climate Center 2015

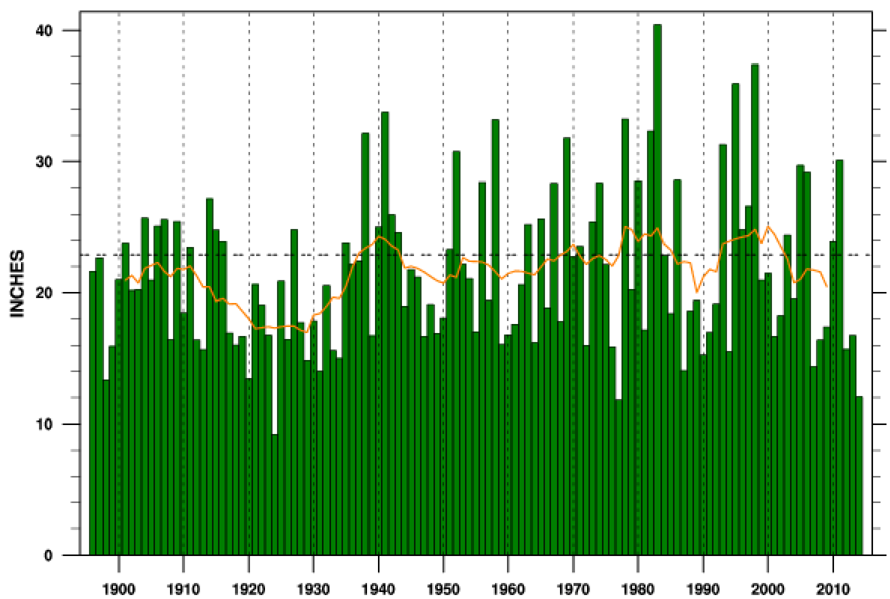
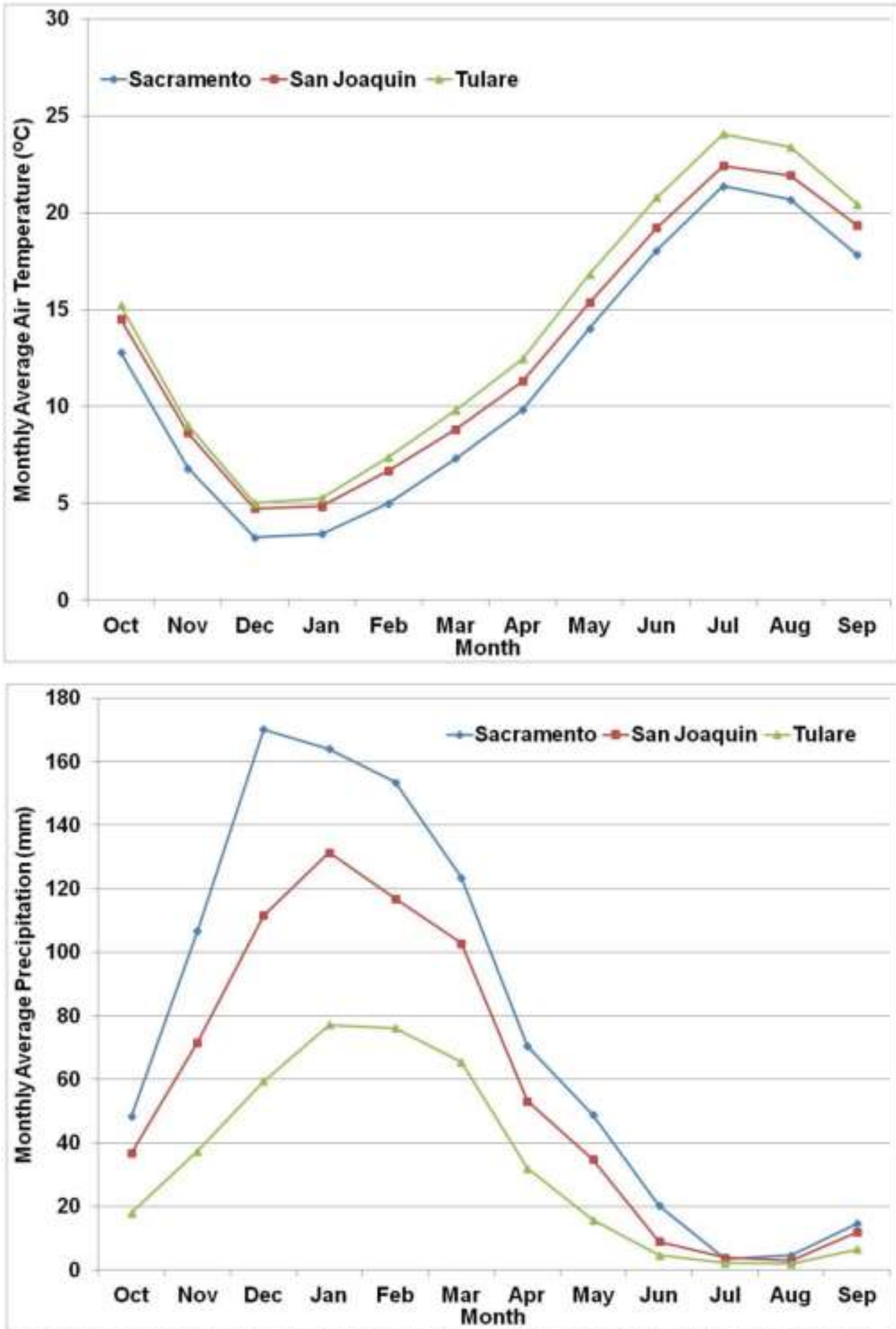


Figure 3-3b. California statewide **precipitation** (Oct-Sep). Notes: Annual water year average precipitation for the entire state, 1896-2014. Bars: annual values; solid line: 11-year running mean. Source: Western Regional Climate Center 2015.

Annual precipitation shows substantial variability and periods of dry and wet spells. Most notable in the precipitation record is the lack of a significant long term annual trend, yet the annual variability appears to be increasing.

The climate of the Central Valley basins exhibits important spatial and seasonal variability. To illustrate this variability, Figure 3-4 shows average monthly temperature and precipitation as averages for the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. The warmest temperatures are seen in July and coolest temperatures are seen in December (Figure 3-4). The monthly temperature varies by about 2 degrees Celsius (°C) among the three regions, and by about 16°C between the cooler and warmer seasons. Cool winter temperatures at the higher elevation portions of the basins cause much of the precipitation to fall in the form of snow. At lower elevations, warmer conditions exist and rainfall is the dominant form. For most regions, most of the precipitation occurs in the cool season (fall and winter). Warmer temperatures in the spring and summer induce snowmelt at the higher elevations. The summer precipitation does not contribute a significant portion of the annual basin totals.



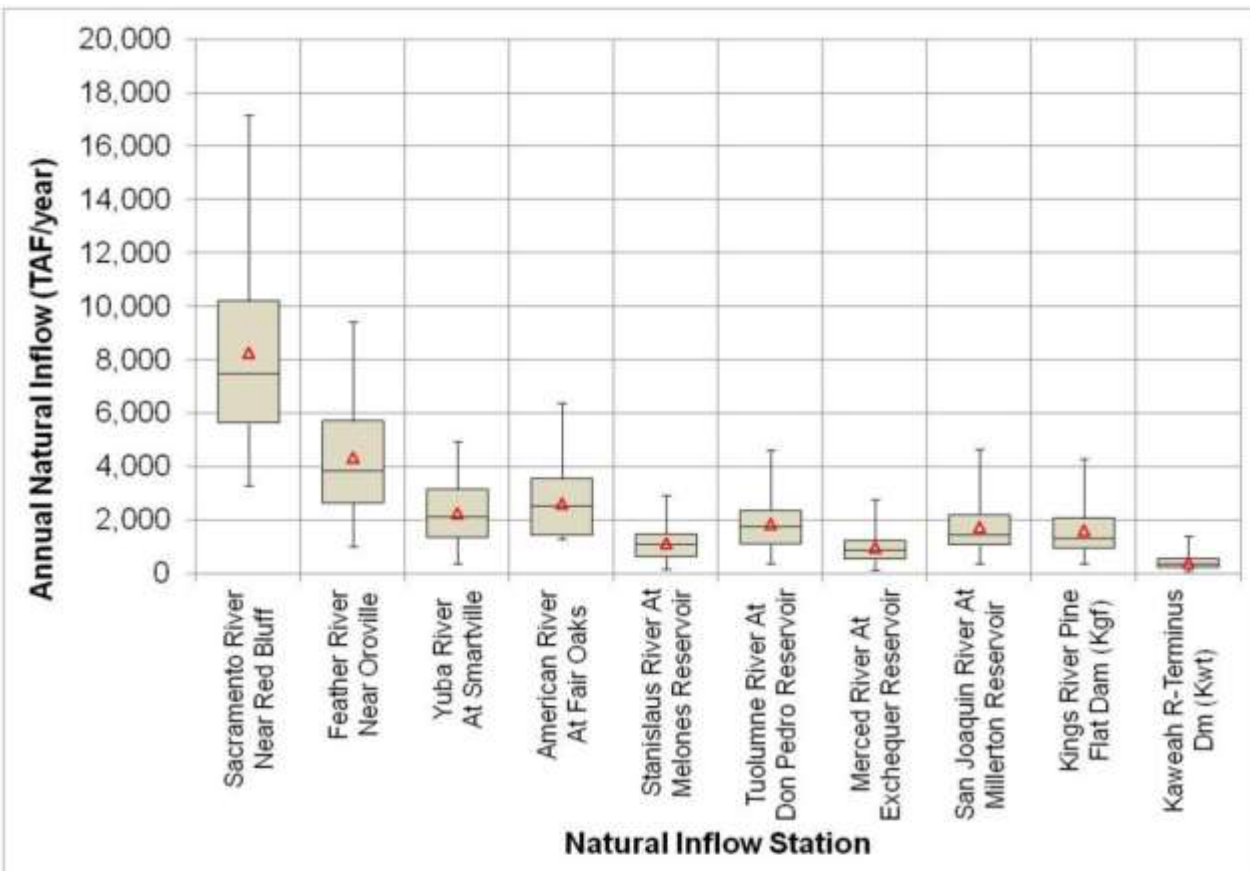
Note: Derived from daily gridded observed meteorology (Livneh et al., 2013) and averaged for Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions over the period 1981-2010.

Figure 3-4. Monthly average temperature (above) and precipitation (below) in the Sacramento River system, the San Joaquin River system, and the Tulare Lake region. Derived from Livneh et al. 2013.

3.1.1.2. Streamflow and Trends

Streamflow assessments provide an understanding of the cumulative effect of various climatic-hydrologic processes. Monthly and annual observed natural (termed "unimpaired") streamflows from the major tributary watersheds in the Central Valley (Sacramento, San Joaquin, and Tulare River basins) were assessed. The historical observed data were collected from different sources, including naturalized flow data from the California Data Exchange Center (CDEC) and unimpaired flow datasets prepared by DWR for use in Central Valley hydrologic studies (CDEC 2015 [website] at http://cdec.water.ca.gov) Historical observed streamflows were used to assess the extent of seasonal shifts in runoff due to climate warming and earlier snowmelt.

The mean annual flows from water year 1922 (October 1, 1922 to September 30, 1923) to water year 2010 at each of the major natural flow locations are shown on Figure 3-5. Also shown is the variability of annual flows as "box-whisker" ranges. Additionally, Table 3-1 presents the mean annual flows at the ten major flow locations used in this assessment.



Notes: Black line represents median, box represents the 25th and 75th percentiles; whiskers represent the maximum (max) and minimum (min), and triangle represents the mean flow. Streamflow derived from the observed period (1922–2010). TAF/yr = thousand acre-feet per year

Figure 3-5. Average annual total natural flows for major locations.

Table 3-1. Mean Annual Flows at Major Locations

Location	Mean Annual Flow
Sacramento River near Red Bluff (location 1)	8.2 MAF (ranging from 3.3 to 17.2 MAF)
Feather River near Oroville (location 2)	4.3 MAF (ranging from 1.0 to 9.4 MAF)
Yuba River at Smartville (location 3)	2.3 MAF (ranging from 0.4 to 4.9 MAF)
American River at Fair Oaks (location 4)	2.6 MAF (ranging from 0.4 to 6.4 MAF)
Stanislaus River Inflow to New Melones Lake (location 5)	1.1 MAF (ranging from 0.2 to 3.0 MAF)
Tuolumne River Inflow to New Don Pedro Reservoir (location 6)	1.9 MAF (ranging from 0.4 to 4.6 MAF)
Merced River Inflow to Lake McClure (location 7)	1.0 MAF (ranging from 0.15 to 2.8 MAF)
San Joaquin River Inflow to Millerton Lake (location 8)	1.7 MAF (ranging from 0.4 to 4.6 MAF)
Kings River Inflow to Pine Flat Dam (location 9)	1.6 MAF (ranging from 0.4 to 4.3 MAF)
Kaweah River Inflow to Terminus Dam (location 10)	0.4 MAF (ranging from 0.1 to 1.4 MAF)

MAF = million acre-feet

The Sacramento-San Joaquin 8 Index is the sum of all of the rivers included in the Sacramento and San Joaquin 4 Rivers Indices:

- The Sacramento 4 River Index is the sum of four streamflows including:
  - the Sacramento River above Bend Bridge
  - Feather River inflow to Lake Oroville
  - Yuba River at Smartville
  - American River inflow to Folsom Lake

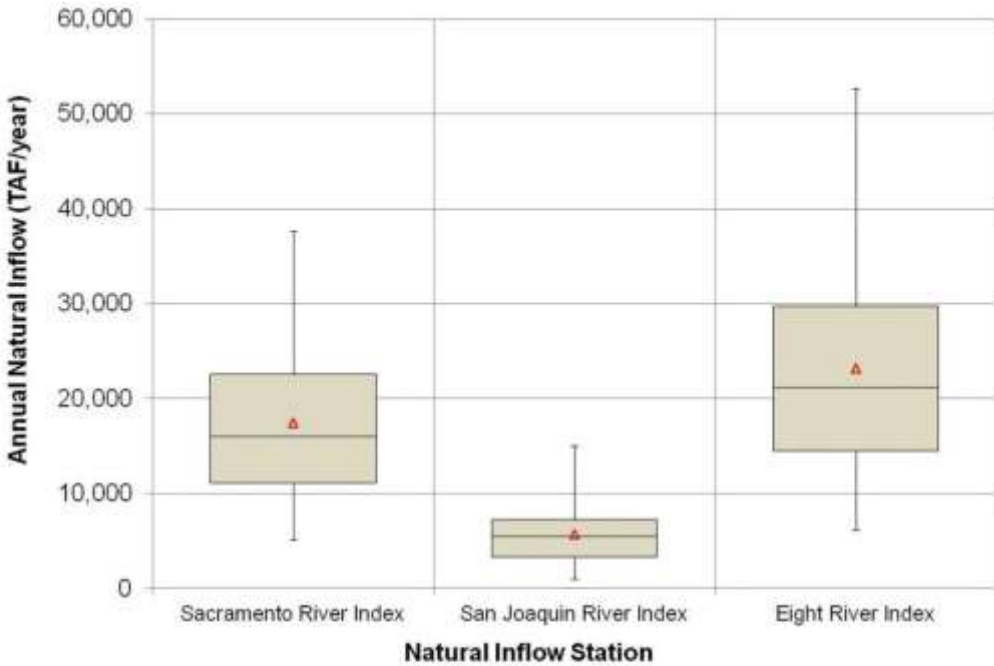
- The San Joaquin 4 River Index is the sum of four streamflows including:
  - the Stanislaus River inflow to New Melones Lake
  - Tuolumne River inflow to New Don Pedro Reservoir
  - Merced River inflow to Lake McClure
  - San Joaquin River inflow to Millerton Lake

The annual flow statistics for the Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index, and Sacramento-San Joaquin 8 River Index for the period of water years from 1922 to 2010 are shown in Figure 3-6.

- The mean annual flow of the Sacramento 4 Rivers Index is about 17.5 MAF, but ranged from 5.1 MAF (1977) to 37.7 MAF (1983) over the analysis period.

- The mean annual flow of the San Joaquin 4 Rivers Index is about 5.7 MAF, but ranged from 1.1 MAF (1977) to 15.0 MAF (1983).

- The mean annual flow of the Sacramento and San Joaquin 8 River Index is about 23.1 MAF, but ranged from 6.2 MAF (1977) to 52.7 MAF (1983) over the period of water years from 1922 to 2010.



Notes:
Black line represents median, box represents the 25th, and 75th percentiles, whiskers represent the maximum (max) and minimum (min), and triangle represents the mean flow. Streamflow derived from the observed period (1922–2010).
TAF/yr = thousand acre-feet per year

Figure 3-6. Average annual total natural flows for Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index and the Sacramento and San Joaquin 8 River Index in thousand acre-feet (TAF) per year.

3.1.1.3. Drought Analysis

Drought has played an important role in shaping California's water supply history. Multiple large-scale drought sequences in California since 1900 include: 1918-1920, 1923-1926, 1928-1935, 1947-1950, 1959-1962, 1976-1977, 1987-1992, 2000-2002, 2007-2010, and 2012-present. These periods of significant drought provide a historical perspective on hydrologic variability. There are multiple ways and indices that can be used to define drought. In general, droughts are defined as periods of prolonged dryness. In this study, droughts were evaluated using streamflow-based indices.

The drought period length and magnitude were evaluated for each drought period. As part of the analysis, different averaging periods for determining and measuring drought were considered using the naturalized flow data for the major watersheds obtained from the CDEC (CDEC2015 [website]). Data from the CDEC were used because of the longer period data availability.

The inter-annual variability of climate and hydrology within the Central Valley basins produces frequent periods when the mean flow during that period is below the long-term mean. These occurrences are referred to as periods of streamflow deficit or deficits for the purpose of this report. As part of the analysis conducted for this report, different averaging periods for determining and measuring deficits were considered. The use of a 1-year averaging period was adopted based on the reservoir storage capacity and mean annual flow considerations. The use of a 1-year averaging period implies that it may take a single above-normal year to end a deficit. The definition of “deficit” used in the remainder of this report is the following: a deficit occurs whenever the annual flow falls below the long-term mean annual flow of the 1906 to 2014 period. The deficit is defined as the 1-year mean below long-term mean.

Figure 3-7 presents the drought summaries for the:

- Sacramento and San Joaquin 8 River Index
- Sacramento 4 Rivers Index
- San Joaquin 4 Rivers Index
- Tulare 2 Rivers Index, which is the sum of streamflows of Kings River inflow to Pine Flat and Kaweah River inflow to Terminus Dam.

Applying the definition of “deficit,” Figure 3-7 presents the severity of deficits in the observed record for the Sacramento and San Joaquin 8 River Index. For each year of the 1906 to 2014 period, the difference between the annual flow and the long-term mean annual flow was computed. If the difference was negative, it was labeled “deficit” and the volumes were accumulated until the difference was once again positive. The deficit length and cumulative amount were recorded for each year. The figure shows significant deficit spells that occurred in the observed period:

- Beginning in 1928 (8-year deficit). 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.

- 1944 (7-year deficit)

- 1976 (2-year deficit). The 1976-1977 drought was the most severe 2-year period in the observed record.

- 1987 (6-year deficit)

- 2007 (4-year deficit). The recent drought period that began in 2007 extended for 4 years and accumulated a deficit of about 28 MAF.

- The current on-going drought that began in 2012. The current on-going drought accumulated a deficit of more than 31 MAF over the period 2012-2014. This accumulated deficit is almost equal to the 2-year (1976-77) drought deficit.

Figure 3-7. Streamflow deficits

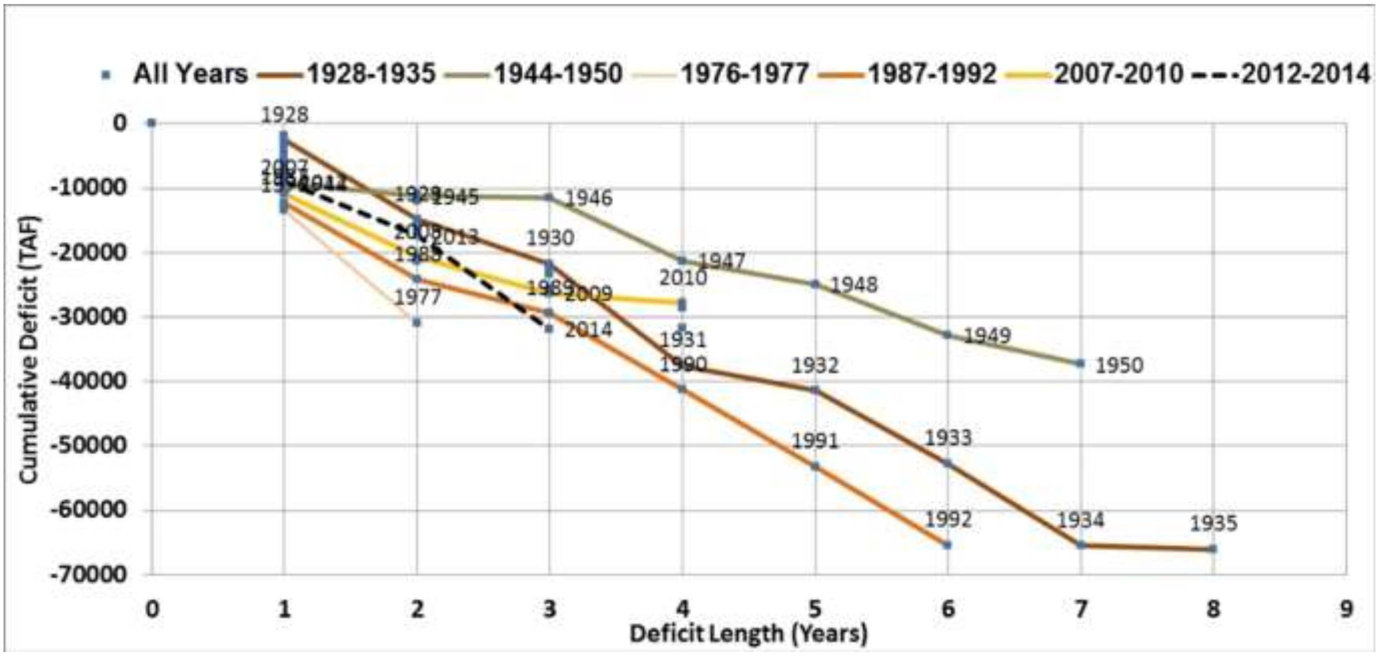


Figure 3-7a. Cumulative Streamflow Deficits in Observed Natural Flow Records for the **Sacramento and San Joaquin 8 River Index** (1906-2014)

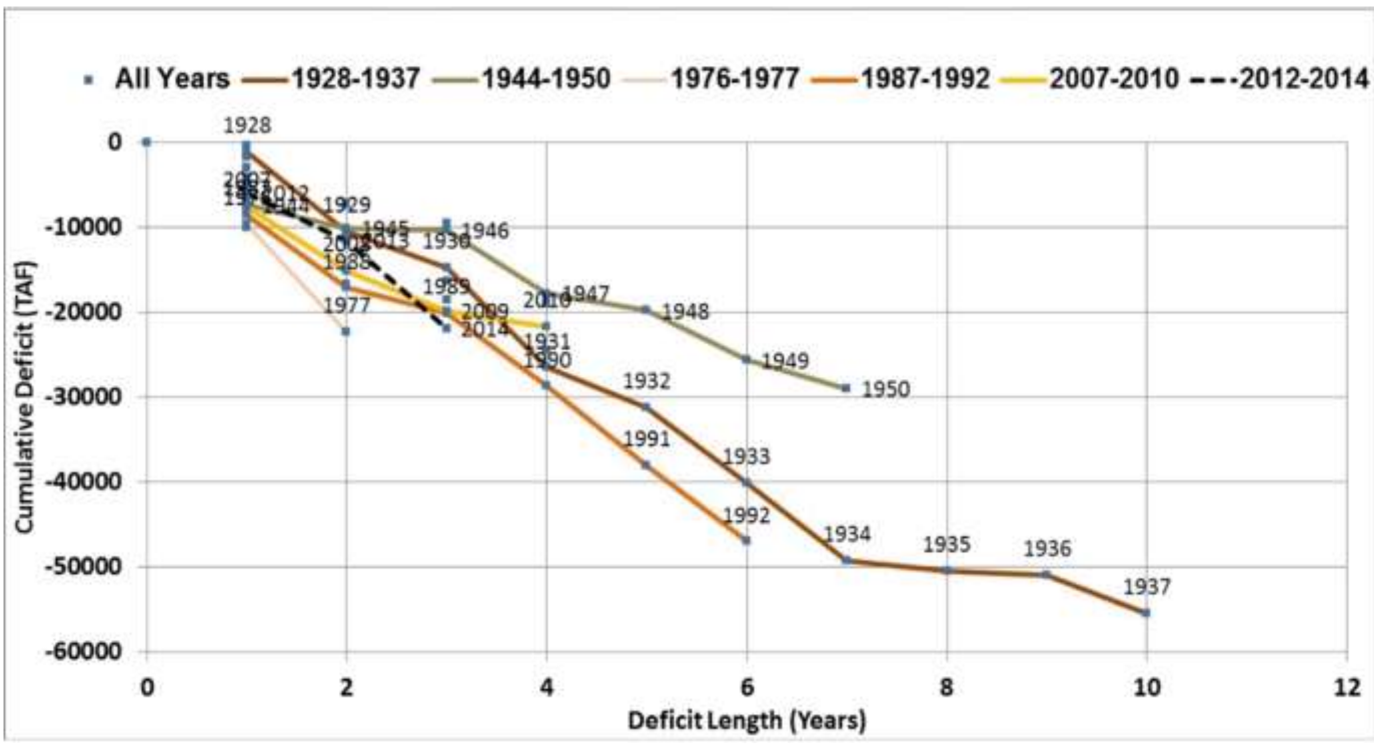


Figure 3-7b. Cumulative Streamflow Deficits in Observed Natural Flow Records for the **Sacramento 4 Rivers Index** (1906-2014)

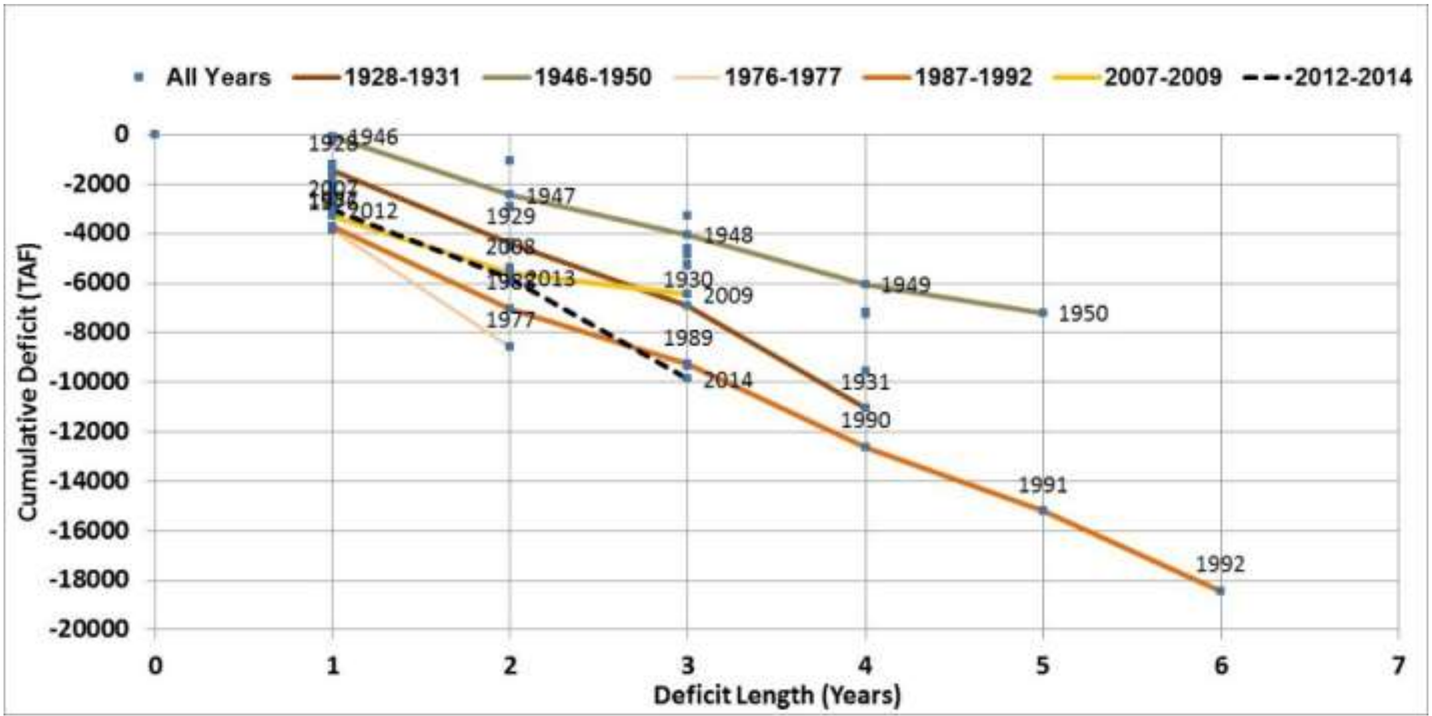


Figure 3-7c. Cumulative Streamflow Deficits in Observed Natural Flow Records for the San Joaquin 4 Rivers Index (1906-2014)

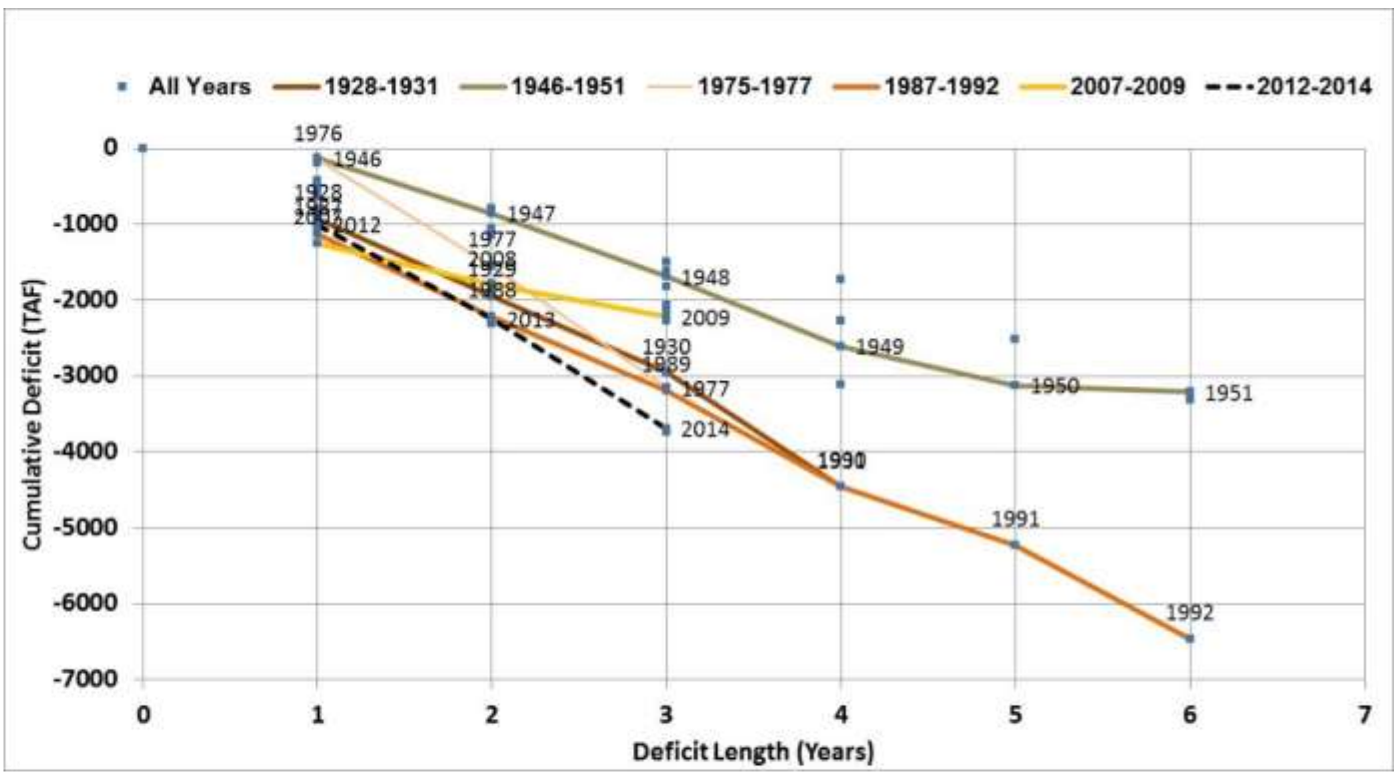


Figure 3-7d. Cumulative Streamflow Deficits in Observed Natural Flow Records for the Tulare 2 Rivers Index (1906-2014)

3.1.1.4. Paleo Reconstruction of Streamflow

Paleoclimate information is useful in understanding longer time horizons of natural variability (droughts, floods, alternative sequences of wet-dry periods). The paleo-reconstructed streamflow data were collected from the recently released Meko et al. (2014) study, which contains reconstructions for Sacramento, San Joaquin, and Klamath River streamflows. A time series of the Sacramento and San Joaquin 8 River Index from the paleo-reconstructed 900 to 2012 period is shown in Figure 3-8.

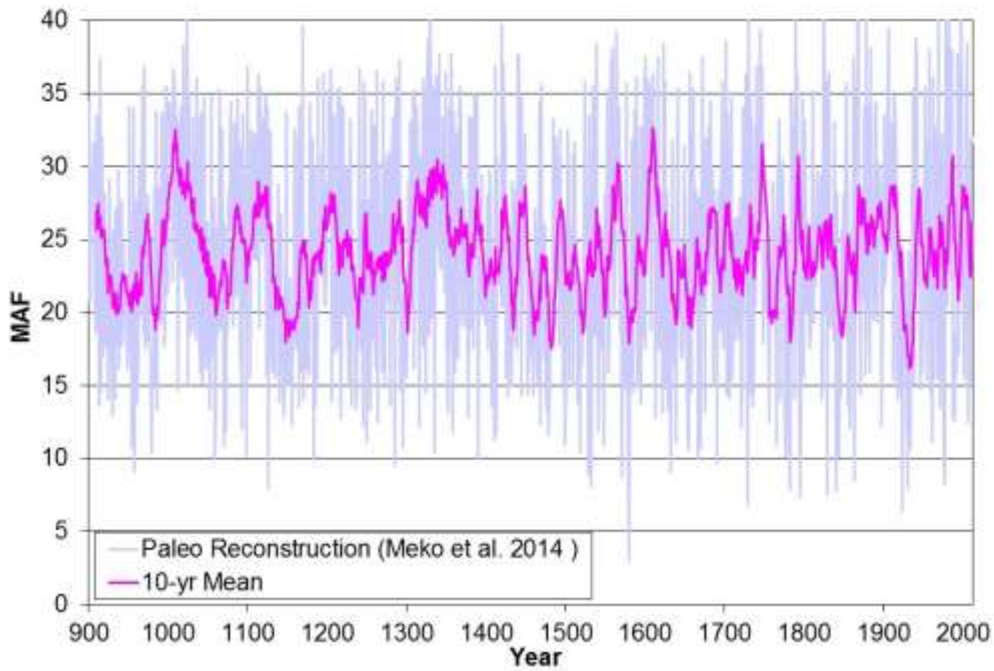


Figure 3-8. Reconstructed streamflows for the Sacramento and San Joaquin 8 River Index (900-2012)

Streamflow deficits using the same methods as described in the previous section were similarly computed for the 900 to 2012 period to improve the understanding of the severity of paleo droughts. Figure 3-9 presents the magnitude and severity of deficits from the paleo reconstructed period for the Sacramento and San Joaquin 8 River Index. According to this reconstructed record, significant prolonged drought periods occurred for the following periods: 975-981, 1292-1301, 1395-1400, 1475-1483, 1578-1582, 1924-1931, 1975-1977, 1987-1992, and 2007-2010.

Two important findings can be drawn from this analysis of the 8-River Index. First, paleo droughts have been identified that demonstrate greater short-term severity than those in the observed streamflow record. Second, multiple droughts extending beyond 8 years have been identified in the paleo record and indicate that droughts of this length are not unique to the 1930s. However, the observed short-term 1975-1977 drought and the long-term 1924-1931 drought are among the most severe in both the paleo and observed records.

Figure 3-9 depicts the prolonged dry periods for the Sacramento River Basin and San Joaquin River Basin, respectively. Differences in dry periods can be seen in comparing these two figures. For example, the 1924-1935 represents the most severe prolonged dry period for the Sacramento River Basin, while the period of 1471-1483 represents the most significantly dry period in the San Joaquin River Basin. However, in both river basins, the period of 1578-1582 represents the most severe short-term dry period and is similar in severity to that observed in the 1970s.

Figure 3-9. Deficits in the paleo reconstructed period.

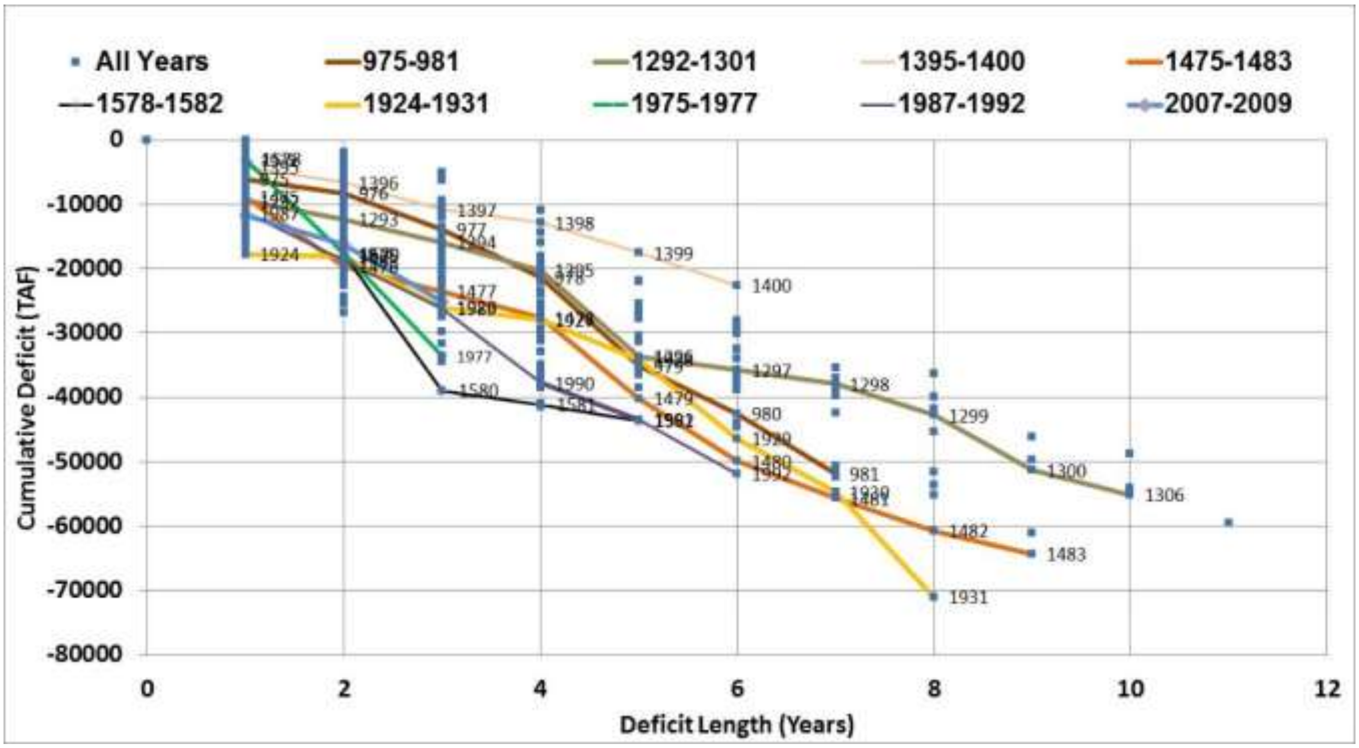


Figure 3-9a. Cumulative streamflow deficits in paleo reconstruction of streamflow for the **Sacramento and San Joaquin 8 River Index** (900-2012).

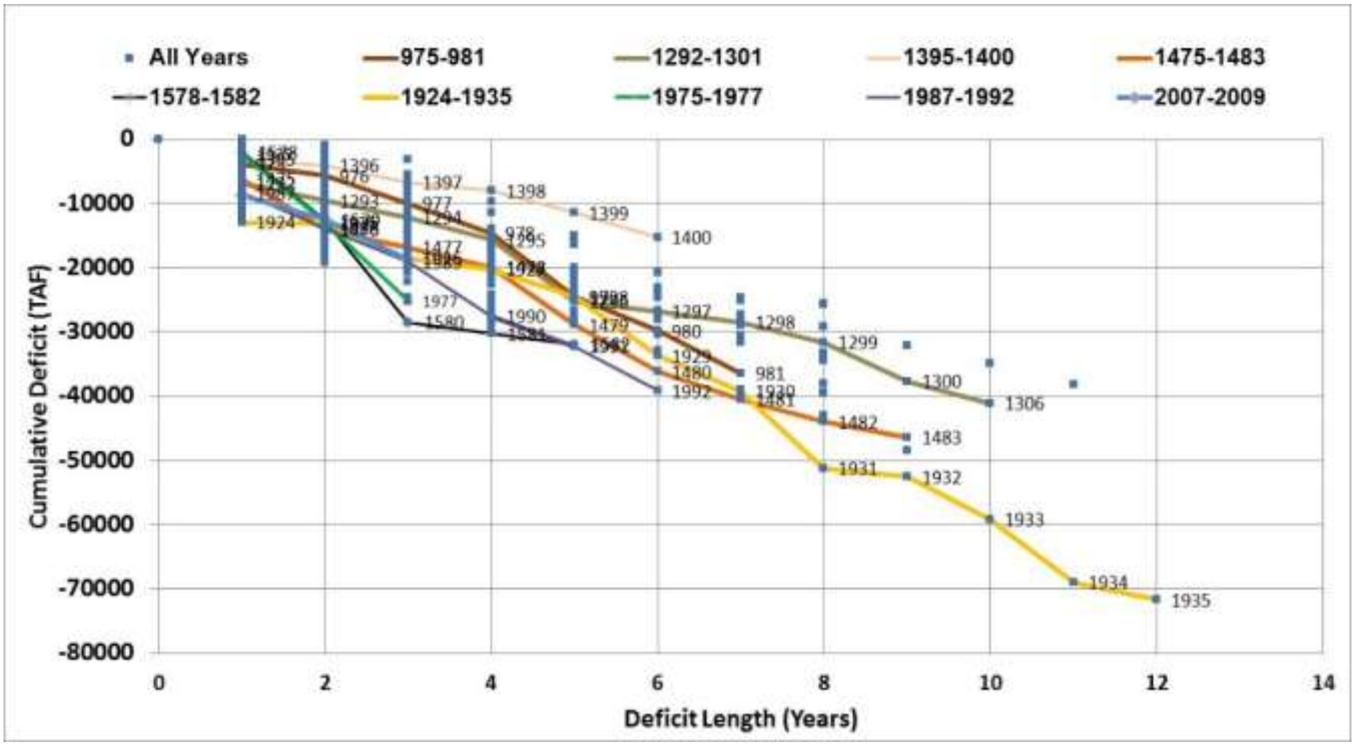


Figure 3-9b. Cumulative streamflow deficits in paleo reconstruction of streamflow for the **Sacramento 4 River Index** (900-2012).

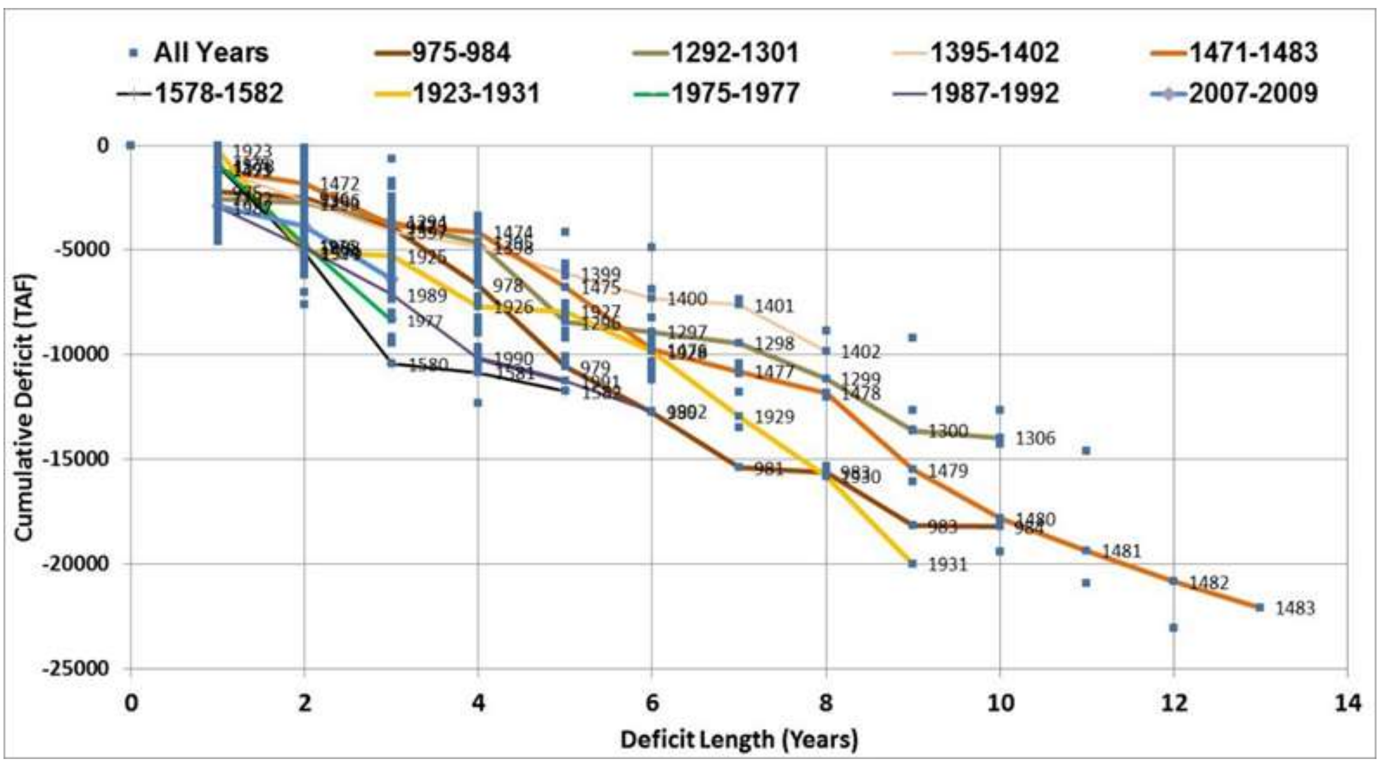


Figure 3-9. Cumulative streamflow deficits in paleo reconstruction of streamflow for the **San Joaquin 4 River Index (**900-2012).

3.1.1.5. Other Hydrologic Processes and Trends

Dynamic hydrologic modeling is used to derive the hydrologic responses from climate, land cover, and soil conditions because historical observations of these processes are often limited. The hydrologic processes that describe the interaction between climate and the watershed landscape are critically important in determining water availability and the manner in which the response may change under future climate. For this study, multiple hydrologic process indicators were analyzed including runoff, ET, SWE, and soil moisture. Annual ET and runoff, and April SWE were computed over the period 1981-2010. These indicators were developed using results from the Variable Infiltration Capacity (VIC) model simulations under historical climate, which allowed both catchment and more refined spatial scale assessments. This use of the VIC model also allowed comparisons with previous Reclamation studies using the VIC model (Reclamation 2011 [SWA report]).

The VIC model (Liang et al. 1994, Liang et al. 1996, Nijssen et al. 1997) is a spatially distributed macro-scale hydrologic model that solves the water balance at each model grid cell. The VIC model is populated with the historical temperature and precipitation data to simulate historical hydrologic parameters. The simulated hydrologic parameters include ET, runoff (surface runoff), baseflow (subsurface runoff), and SWE. Representative statistics describing these parameters were generated on monthly, seasonal, and annual bases. The statistical analysis was conducted on both grid cell and watershed bases. The results of the grid cell analysis produced the most informative map graphics and clearly show spatial variation at the greatest resolution possible.

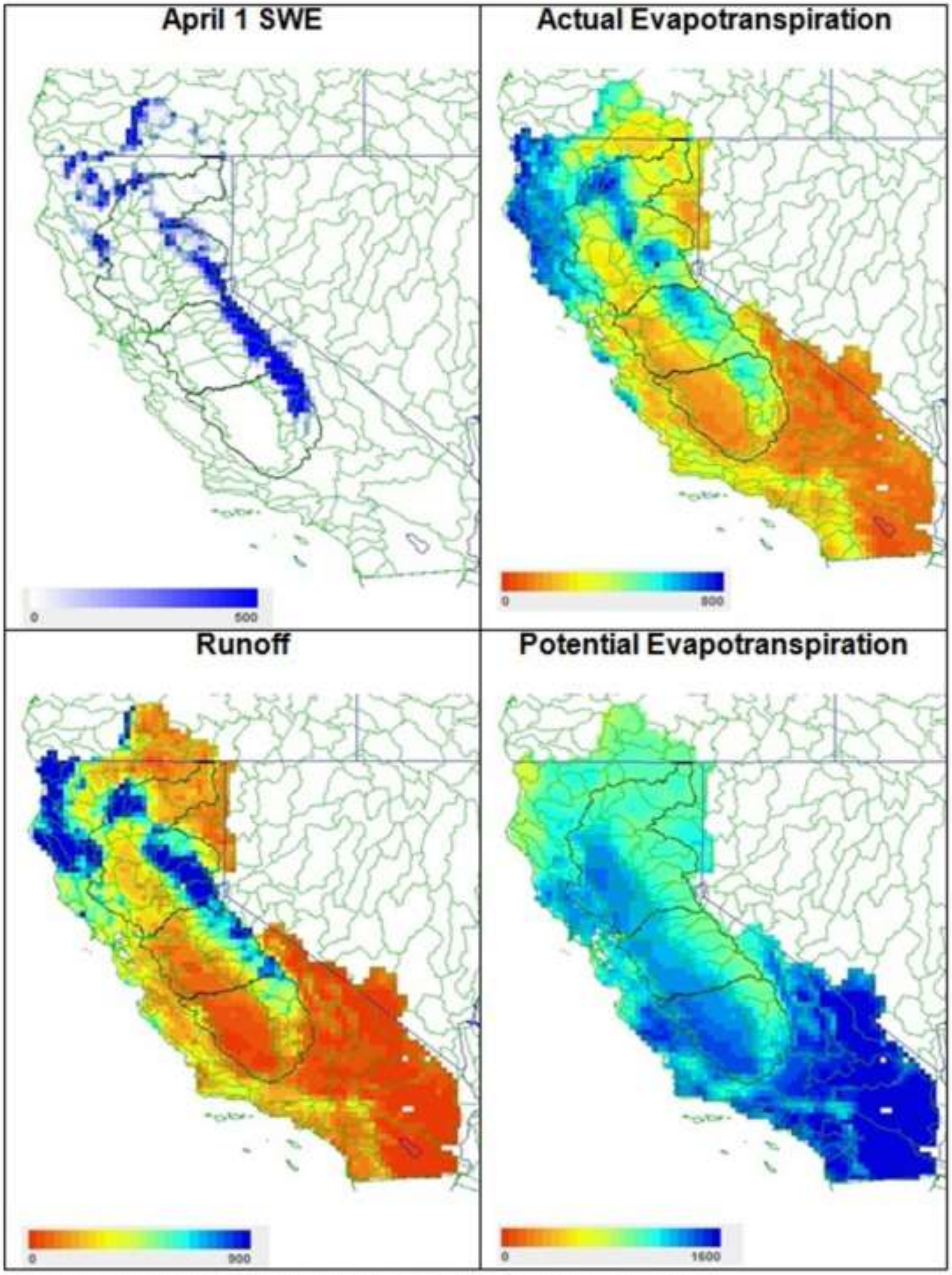
Figure 3-10 provides an estimate of the average spatially distributed April 1 SWE, actual and potential ET, and runoff for the period 1981 to 2010 derived from a historical simulation using the VIC hydrology model. ET is the sum of evaporation from the land surface and plant transpiration. There is considerable spatial variability in runoff, with higher values in the high elevation Sierra and northern coastal areas. The southern portion of the dry region produces small runoff annually. ET is the dominant hydrologic flux on the annual scale, consuming more than 50 percent of the precipitation supply. As shown on Figure 3-15, actual ET (AET) is highest in regions with greatest precipitation. This is not to say that the potential ET (PET) demand is highest in these regions, but rather that actual ET tends to be supply-limited in the southern part of the Central Valley where PET is actually higher. In the warmer climate of the southern part of the Central Valley, potential water supply in the form of snowpack and soil moisture is less than PET resulting in less runoff than in the northern part of the Central Valley.

Water retained in the snowpack from winter storms forms an important part of the hydrological cycle and water supply in California. Previously published research was used to assess observed snowpack trends in the Central Valley. Research by Cayan et al. (2001), Mote (2003), Mote et al. (2008), Pierce et al. (2008), Stoelinga et al. (2010), Pederson et al. (2011), and Garfin et al.

(2013: Chapter 5, Fig. 5.6) indicate a general decline in April 1 SWE for Pacific Northwest and northern Sierra locations, and increases in parts of the southern Sierra (Figure 3-11).

Widespread decreases in springtime snowpack are observed with consistent results across the lower elevation northern latitudes of the western United States. To assess the vertical characteristics of SWE, Mote (2003) plotted April 1 SWE trends (1950 to 2000) against elevation of snow course (Figure 3-11). Losses of SWE tend to be largest at low elevations and strongly suggest a temperature-related effect.

Mote et al. (2008) used the VIC model to simulate SWE accumulation and depletion for western U.S. basins. From this analysis, it was clear that changes in SWE are not simply linear, but 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 declined since mid-century.



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

Figure 3-10. Estimated Average April 1 SWE, Average Annual ET, and Runoff (1981 to 2010, in millimeters [mm]).

Figure 3-11. Snow water equivalents.

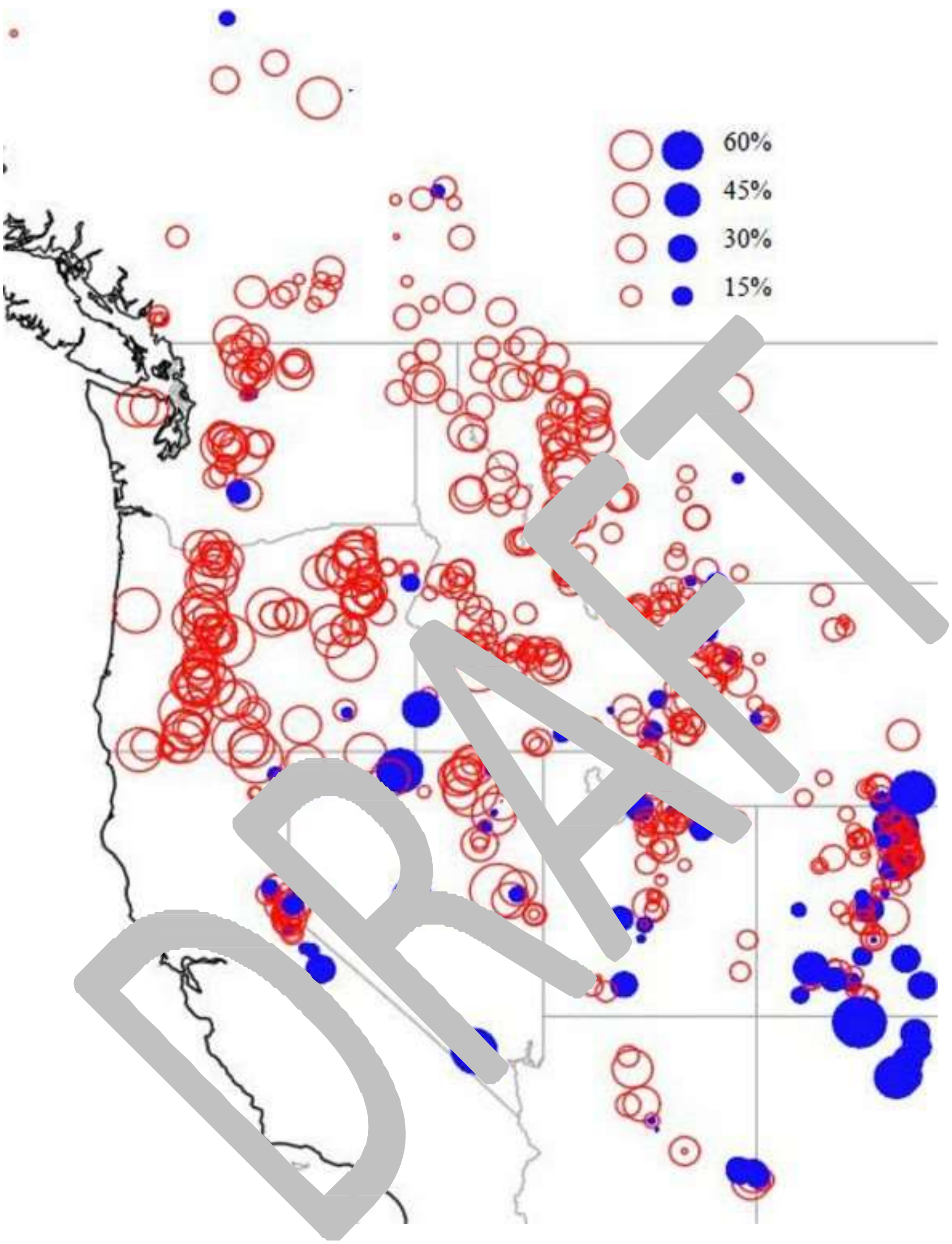
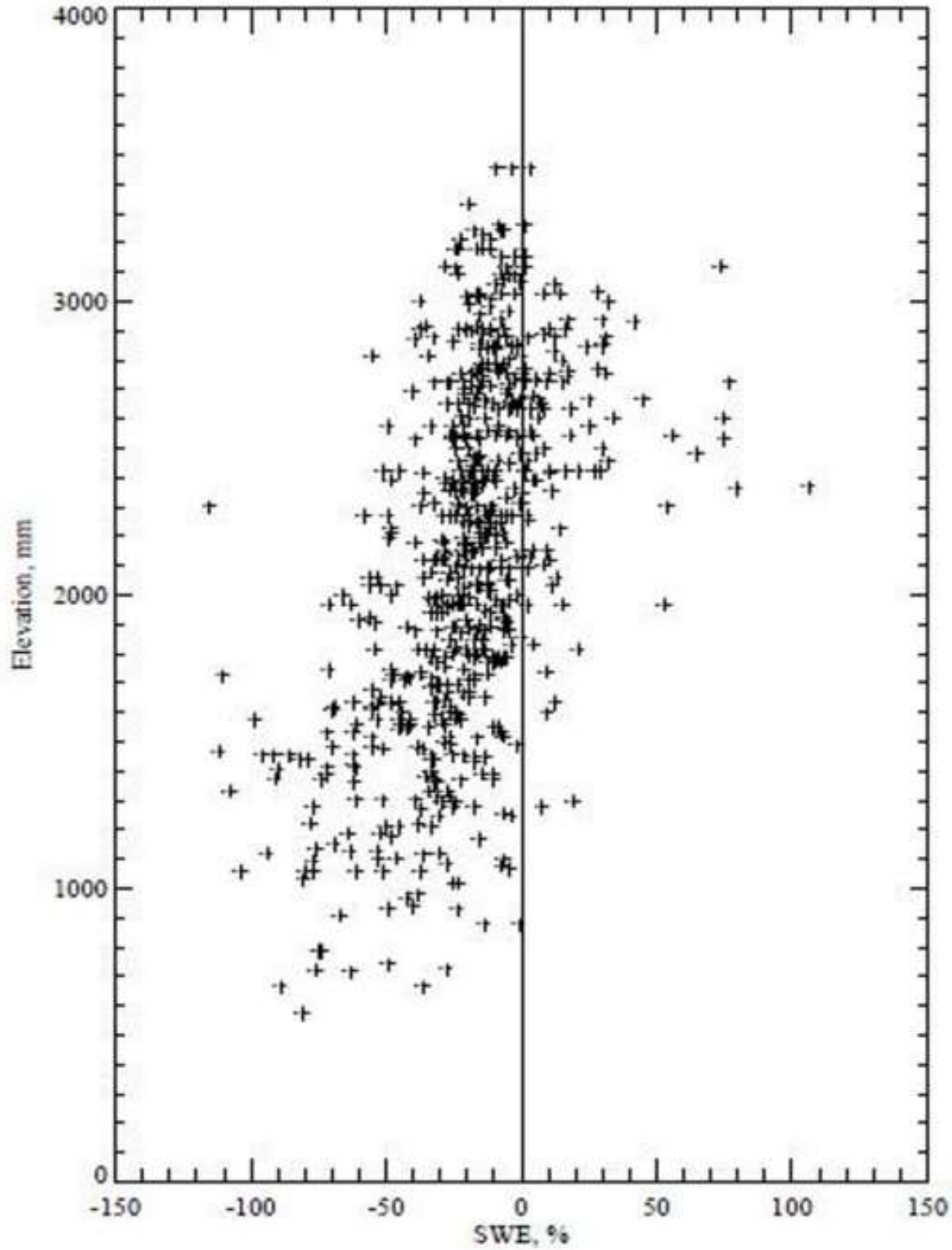


Figure 3-11a. Linear trends in **April 1 SWE at 594 locations** in the Western United States and Canada (1950 to 2000). Note: Negative trends are shown by open red circles, positive by solid blue circles (Mote et al. 2008).



Source: Mote et al. 2008

Figure 3-11b. **April 1 SWE trends plotted against elevation of snow course** (1950 to 2000) (Mote et al. 2008).

3.1.1.6. Teleconnection Analysis and Trends

Research indicates a relationship between Pacific Ocean climate indices and streamflows in the Southwest. Climate teleconnections were analyzed first by selecting indices that could have potential influence in streamflow changes in the Sacramento, San Joaquin, and Tulare Lake River basins. Based on published research, the ENSO and the PDO indices are known to have correlations with precipitation and runoff in these basins (see Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections*). Other teleconnections, such as the AMO and the Madden-Julian Oscillation, were investigated based on current published research for skill in predicting long-term or seasonal precipitation trends. For ENSO, data were collected for the ocean component (sea surface temperature anomalies) and the atmospheric component (atmospheric pressure anomalies). The two components are highly correlated. Combined, they describe ENSO.

3.1.2. Assessment of Future Water Supply

3.1.2.1. Projected Climate and Trends

Future projections of climate are typically drawn from GCMs forced by a range of plausible atmospheric conditions. The climate scenarios used in this study were based on the CMIP5 archives developed by Reclamation and others (Reclamation 2013 [CVP IRP] and 2014 [Climate]) and include the 5 ensemble scenarios and the 12 individual downscaled GCM projections (2 scenarios for each of the 6 CCTAG GCMs). Future climate scenarios based on the CMIP5 climate simulations has been developed to ensure that this Basins Study uses the most current science available at the time of its release. A brief comparison between CMIP3 and CMIP5 has been described in Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections*.

The ensemble scenarios were developed using statistical techniques similar to those used to develop climate scenarios for the BDCP and CVP IRP. These techniques considered the 175 bias-corrected spatially downscaled climate projections (Reclamation 2013 [CVP IRP]) to develop the five statistically representative climate scenarios employed in this study. These 175 climate projections used in the IPCC's AR5 and the WCRP CMIP5 have been bias-corrected and spatially downscaled (Reclamation 2013 [CVP IRP] and 2014 [Climate]) and were obtained from the Lawrence Livermore National Laboratory archive. These five sequences were developed using a multi-model hybrid delta ensemble approach in which the ensemble of future climate change scenarios was broken into regions representing future climate uncertainties: (Warm-Dry) drier, less warming; (Hot-Dry) drier, more warming; (Hot-Wet) wetter, more warming; and (Warm-Wet) wetter, less warming scenarios than captured by the ensemble median (Central Tendency). Refer to Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections* for additional information.

These regions are labeled Warm-Dry (WD), Hot-Dry (HD), Hot-Wet (HW), and Warm-Wet (WW) on figures and tables. The ensemble "consensus" region (Central Tendency [CEN]) samples from inner quartiles (25th to 75th percentile) of the ensemble represented the central tendency of projected climate changes. In each of the five regions, a subset of climate change scenarios, consisting of those bounded by the region were identified. For the Central Tendency climate scenario, all of the projections in the bounded region were included. For the Warm-Dry, Hot-Dry, Hot-Wet and Warm-Wet climate scenarios, the subset consisted of the 10 nearest neighbors to the 10–90 percentile points (Figure 3-12). In this figure, the Central Tendency scenario is bounded by the 25th and 75th percentile joint temperature-precipitation change. Scenarios Warm-Dry-Warm-Wet are selected to reflect the results of the 10 projections nearest each of 10th and 90th joint temperature-precipitation change bounds. The representative gridcell at American River Basin used as an example employing the 10 NN Method. This approach was employed to sample the range of climate projection uncertainty present in the large ensemble of the 175 projections, but to allow a smaller representative set of scenarios to be included in the analysis.

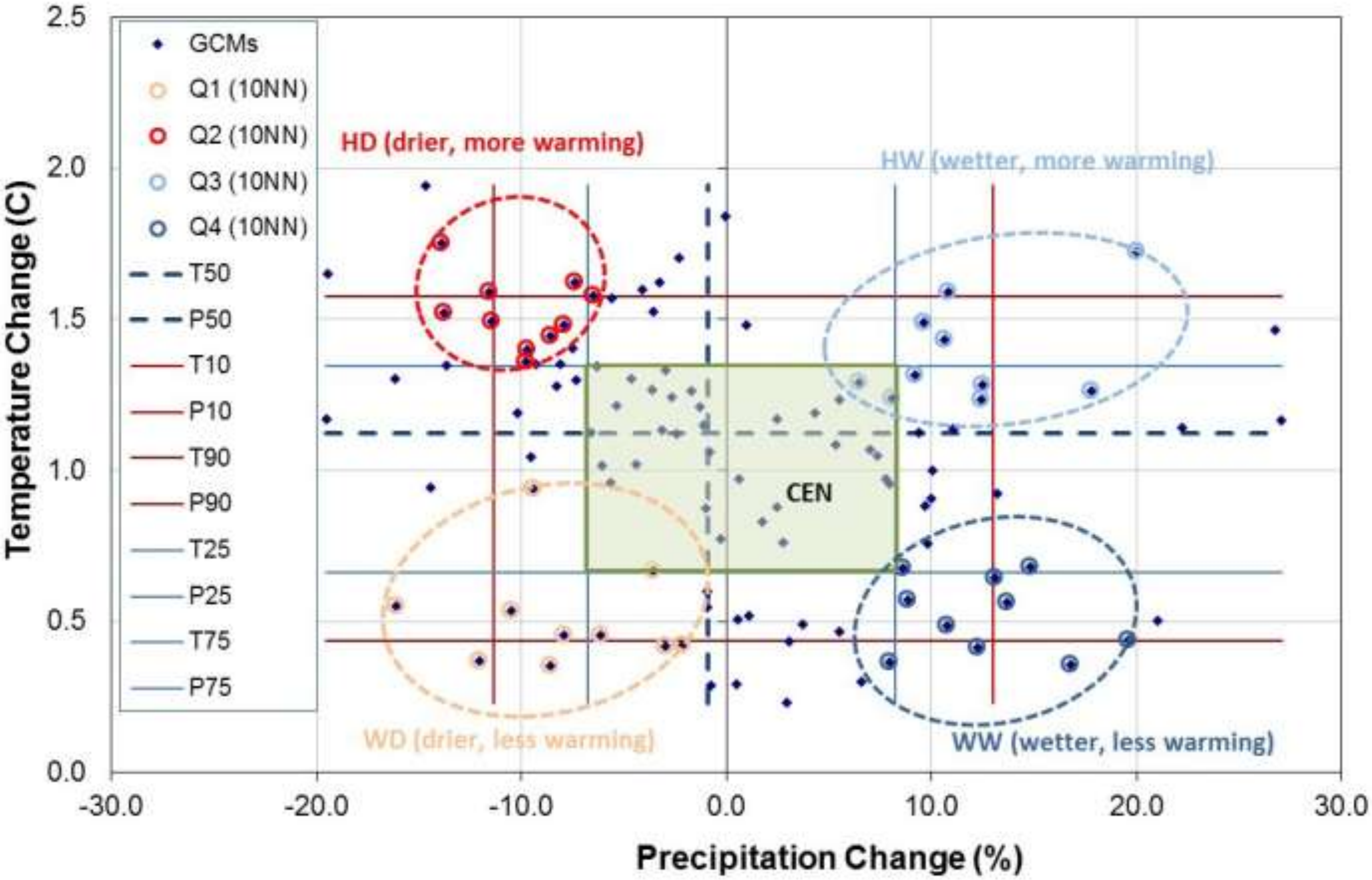


Figure 3-12. Example of the relationship between the ensemble climate scenarios and individual climate projections. These are not the actual projections used in the scenarios.

In the transient climate change scenario approach used in this water supply assessment, the climate change as projected to occur through the GCM simulations of temperature and precipitation is mapped to a historical time series developed based on monthly PRISM (Daly et al. 1994) and daily Livneh et al. (2013). The historical cumulative distribution function (CDF) was developed using a 30-year period centered around 1995 (1981-2010). In addition, three future CDFs were developed using 30-year periods centered around 2025 (2011-2040), 2055 (2041-2070), and 2084 (2070-2099). The method uses the quantile map developed for each of these periods to redevelop a monthly time series of temperature and precipitation reflecting the observed natural variability sequence (1922-2010) and the projected changes in climate. The method applies the change for each year by interpolating from the two CDFs that bracket the simulation year. This process adjusts the historical observed climate records by the climate shifts projected to occur in the future. Because the sequence of future climate variability (wet/dry periods) is unknown, the transient ensemble informed method could be applied with any sequence of an observational, paleo-reconstructed, or synthetic "stationary" climate record. An automated process was used to identify ensemble members and generate the five transient projection sequences at locations within the Central Valley watershed (see Appendix 3A. *CMIP3 and CMIP5 Downscaled Climate Model Projections*).

To help understand how climate change will vary regionally within California and on a monthly time step within the year, the following additional information is provided for the Central Tendency climate scenario, as discussed in Section 2.1.2.*Socioeconomic and Climate Scenarios.* Figure 3-13 shows the annual mean temperature and precipitation changes for California and Nevada derived from the central quadrant (Central Tendency climate scenario). Projected changes for the future periods 2011-2040 (2025), 2041-2070 (2055), and 2070-2099 (2084) are compared to the historical climatological period of 1981-2010. The current suite of GCMs, when simulated under potential, future GHG emission pathways and current atmospheric GHGs, exhibits warming globally and regionally over California. The Central Tendency climate scenario indicates substantial warming by 2050. Warming is projected to be generally higher farther away from the coast, reflecting a continued ocean cooling influence.

In addition to the ensemble scenarios, twelve individual downscaled GCM projections[3] were selected from six GCMs coupled under two emission scenarios (RCP4.5 and RCP8.5). These six GCMs were chosen from the 10 GCMs selected by the DWR CCTAG[4] for California climate and water resources assessments. Figure 3-14 shows projected changes in future annual temperature for the Sacramento Region using the 10 GCMs selected by DWR CCTAG. The projected

[3] GCMs selected for this Basins Study: CCSM4, CESM1-BGC, CNRM-CM5, GFDL-CM3, HadGEM2-ES, MIROC5

[4] GCMs selected by CCTAG: ACCESS-1.0, CCSM4, CESM1-BGC, CMCC-CMS, CNRM-CM5, CanESM2, GFDL-CM3, HadGEM2-CC, HadGEM2-ES, MIROC5

changes are computed with respect to model simulated 1981-2010 period mean. The plot has been produced using the downscaled BCSD data. Changes are shown from two representative RCPs (RCP4.5 and RCP8.5).

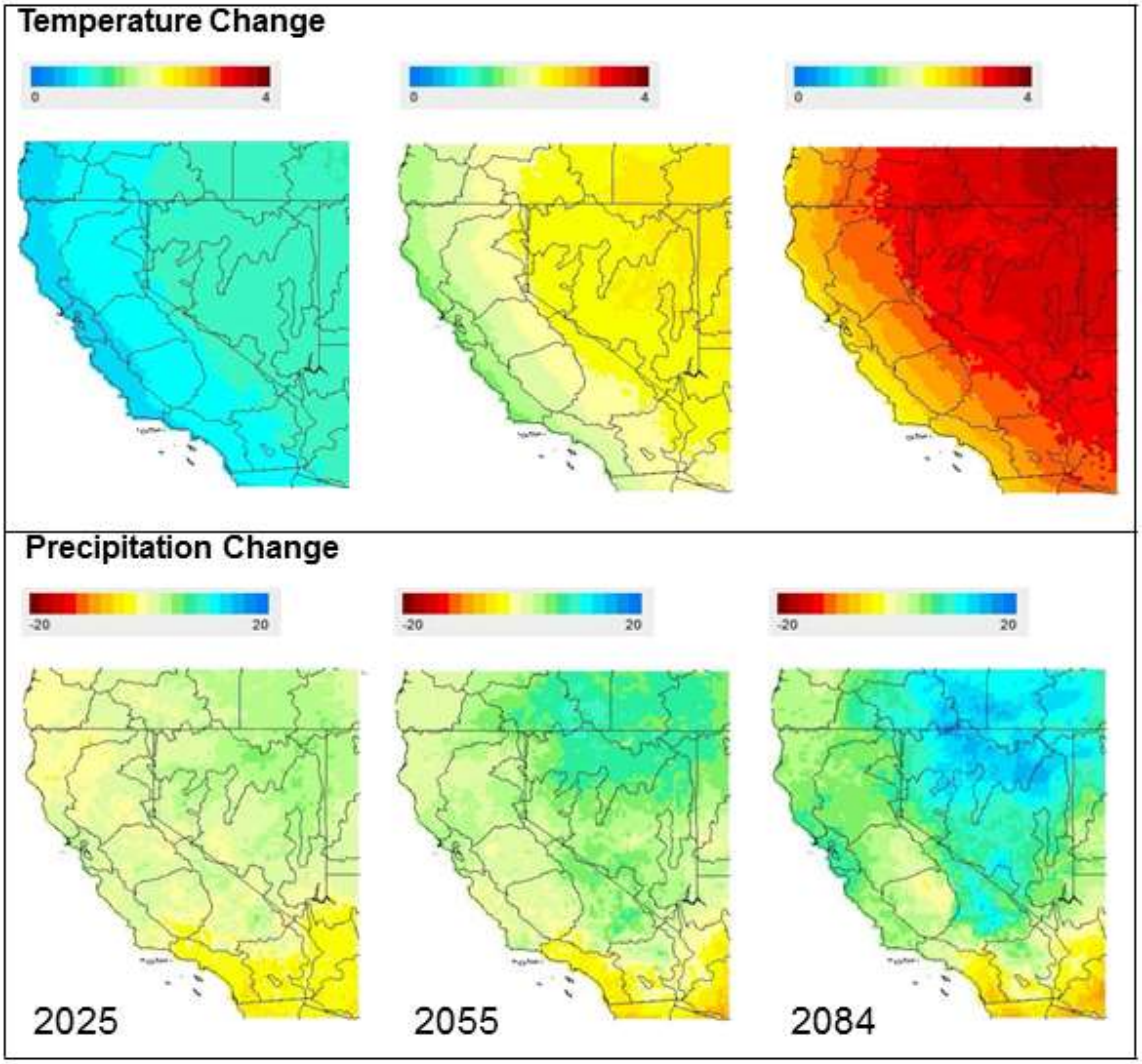


Figure 3-13. Projected changes in annual mean temperature and precipitation for 2011-2040 (2025), 2041-2070 (2055) and 2070-2099 (2084).

In the early part of the twenty-first century, the amount of warming produced by the higher emission RCP8.5 scenario is not very different from the lower emission RCP4.5 scenario, but becomes increasingly larger through the middle and especially the latter part of the century. The GCMs selected by the CCTAG project a mid-century temperature increase of about 1.4°C to 3.4°C and an end-of-century increase from about 1.6°C to 5.4°C.

Projections of future precipitation are much more uncertain than those for temperature. Statewide trends in annual precipitation are not as apparent as those for temperature. Regional trends are more pronounced for the upper Sacramento Valley which may experience equal or greater precipitation, the San Joaquin Valley may experience equal or drier conditions, the Tulare Lake hydrologic region may experience drier conditions. Southern California exhibits projections of future drier conditions. The north-south transition of precipitation change may be attributable to a more northerly push of storm tracks caused in part by increased sea level pressure blocking systems under future climate conditions (Cayan et al. 2009).

The GCMs selected by the CCTAG project a mid-century precipitation change of about-11% to 29% and an end-of-century change of about-11% to 40% (Figure 3-14). The projected changes are computed with respect to model simulated 1981-2010 period mean. Bars with outline show changes from 6 GCMs selected for the SSJBS. The results have been produced using the BCSD downscaled data. Future changes are shown from two representative RCPs (RCP4.5 and RCP8.5).

Figure 3-14. Change in temperature and precipitation for CCTAG climate scenarios.

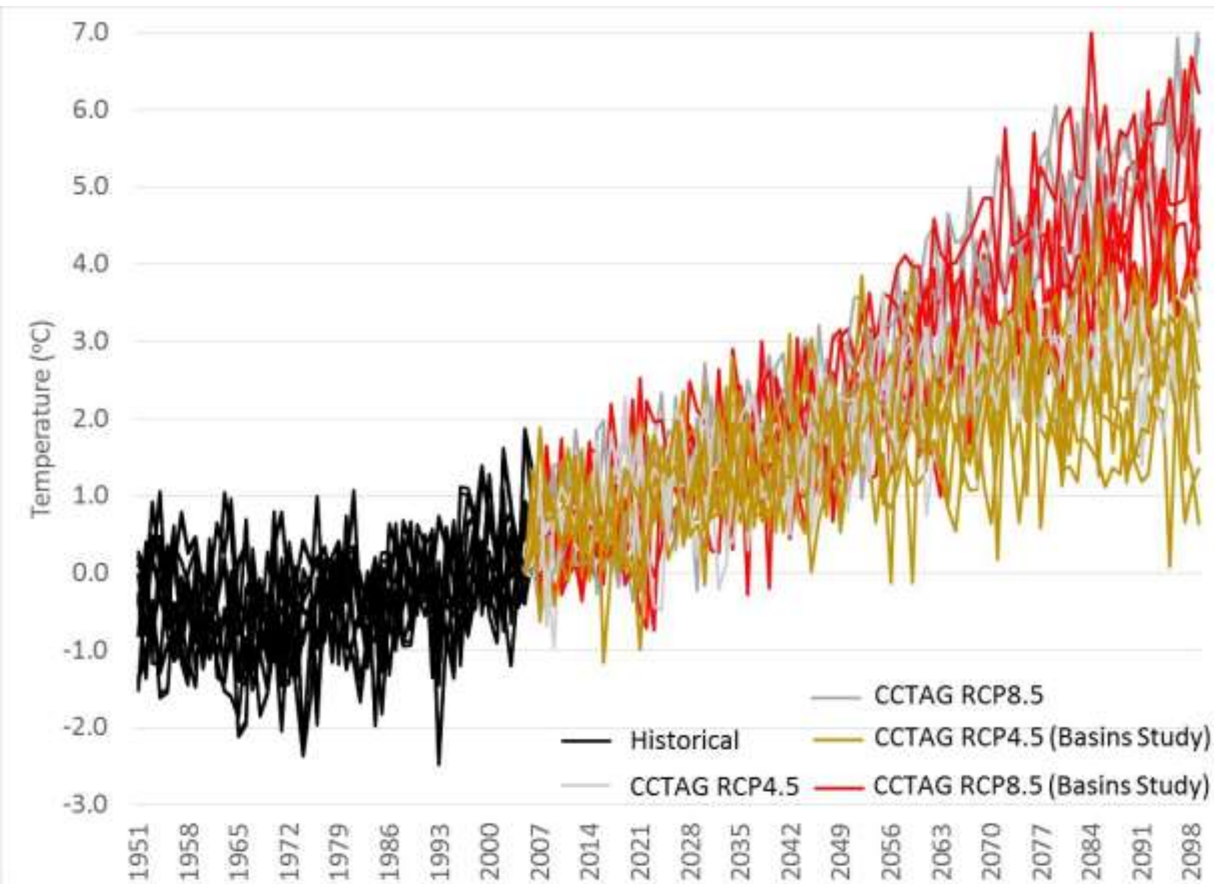


Figure 3-14a. Change in simulated future annual **temperature** projections. (Departure from Model Simulated 1981-2010 Period Mean) for the Sacramento Region using CCTAG Climate Model Projections for RCP4.5 and RCP8.5 Gray colors show climate model projections from all 10 GCMs selected by CCTAG, darker colors show climate model selections from 6 GCMs selected for this Basins Study.

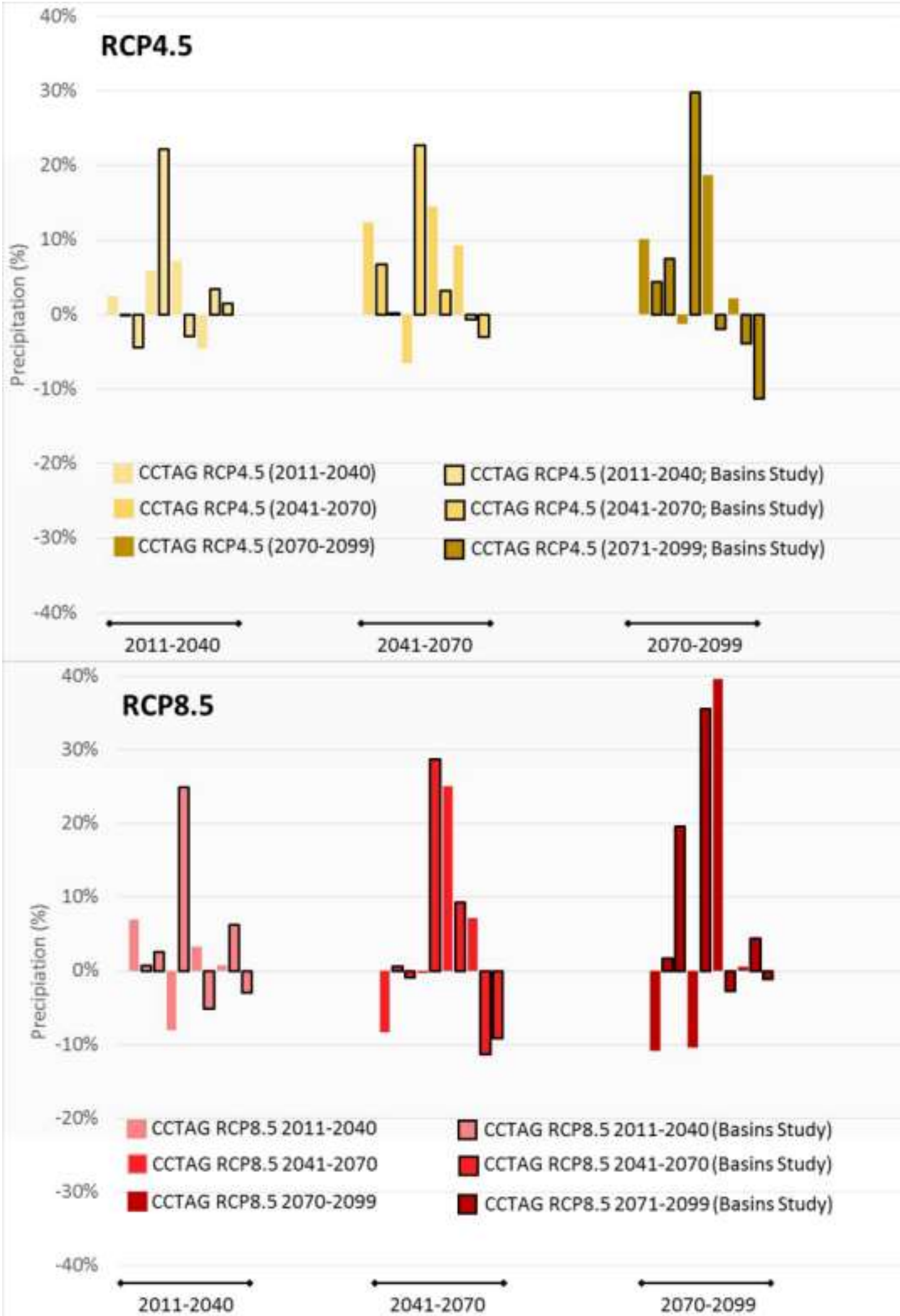


Figure 3-14b. Simulated Future Percentage Change in Annual **Precipitation** for the Sacramento Region Using CCTAG Climate Model Projections for RCP4.5 and RCP8.5

A set of graphs and tables were prepared to illustrate the projected temperature and precipitation changes in each of the 17 climate scenarios. Figure 3-15 shows the annual average temperature and annual total precipitation in the Sacramento River, San Joaquin River, and the Tulare Lake hydrologic regions for each of the climate scenarios over the period of water years from 2012 through 2099. These figures show the projected transient climate departures during the 21st century. All projections are consistent in the direction of the temperature change, but vary in terms of climate sensitivity. Trends in precipitation projections are less steady because of naturally occurring decadal and multi-decadal precipitation variations. The ensemble transient climate scenarios capture most of the considerable range of future uncertainty represented by the 12 CCTAG climate scenarios.

Figure 3-15. Average annual temperature and precipitation changes.

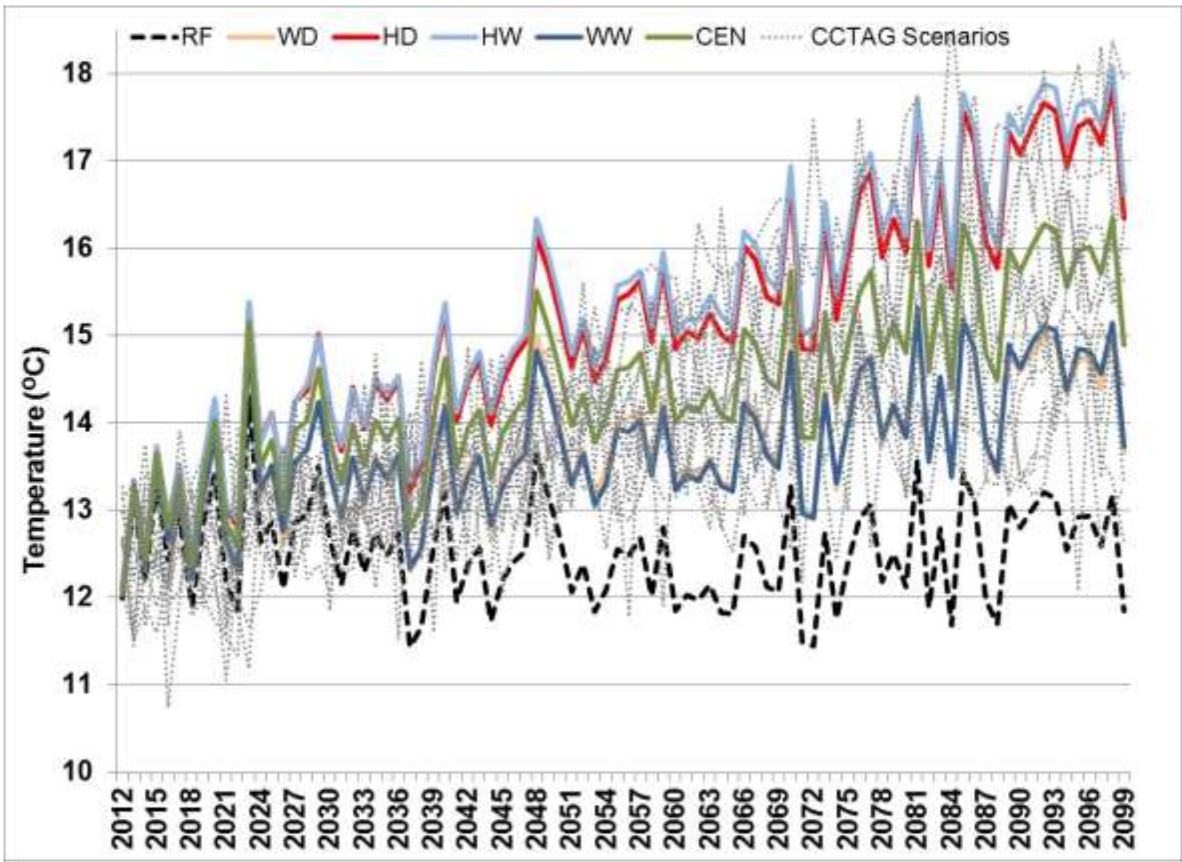


Figure 3-15a. Annual average **temperature for the Sacramento River** hydrologic region in each climate scenario.

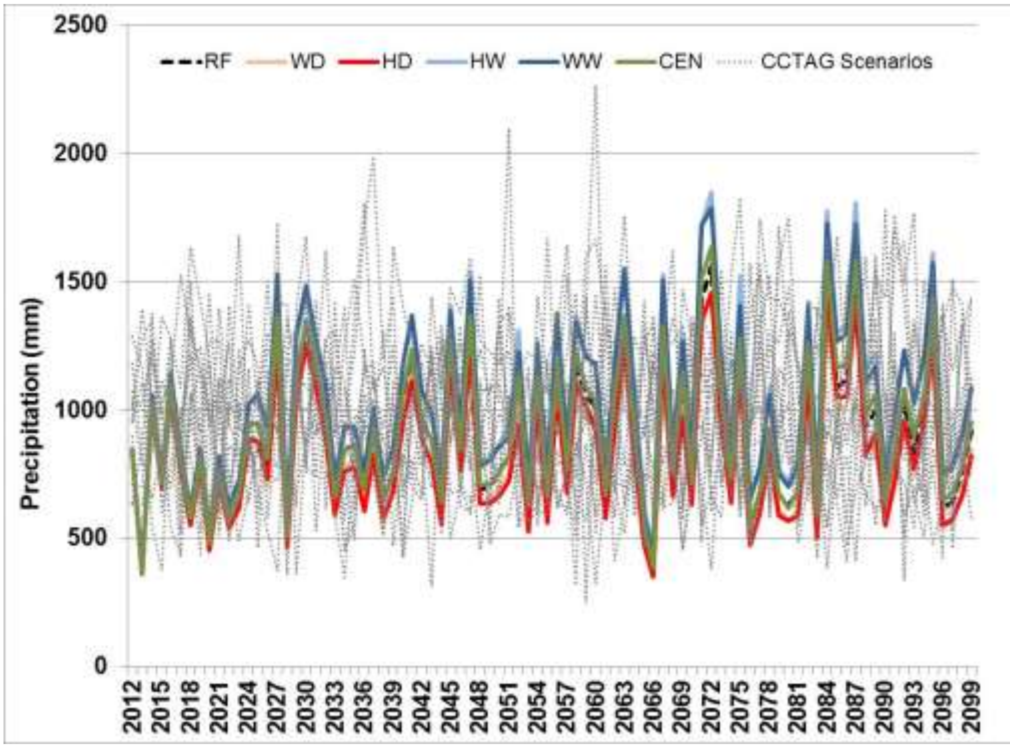


Figure 3-15b. Annual total **precipitation for the Sacramento River** hydrologic region in each climate scenario.

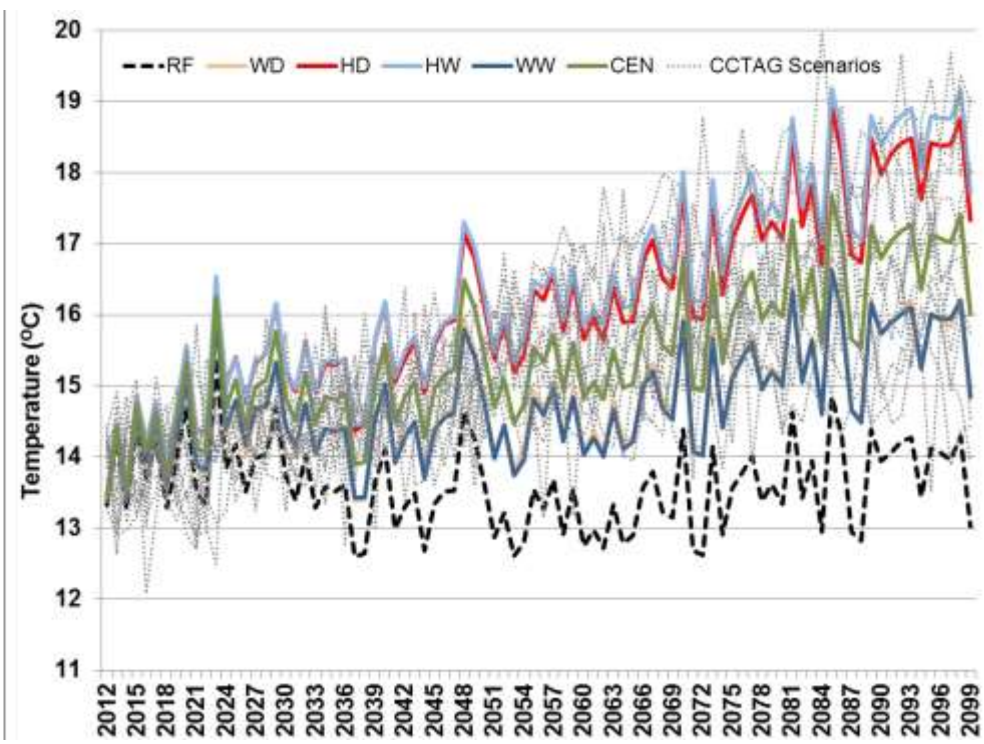


Figure 3-15c. . Annual average **temperature for the San Joaquin River** hydrologic region in each climate scenario.

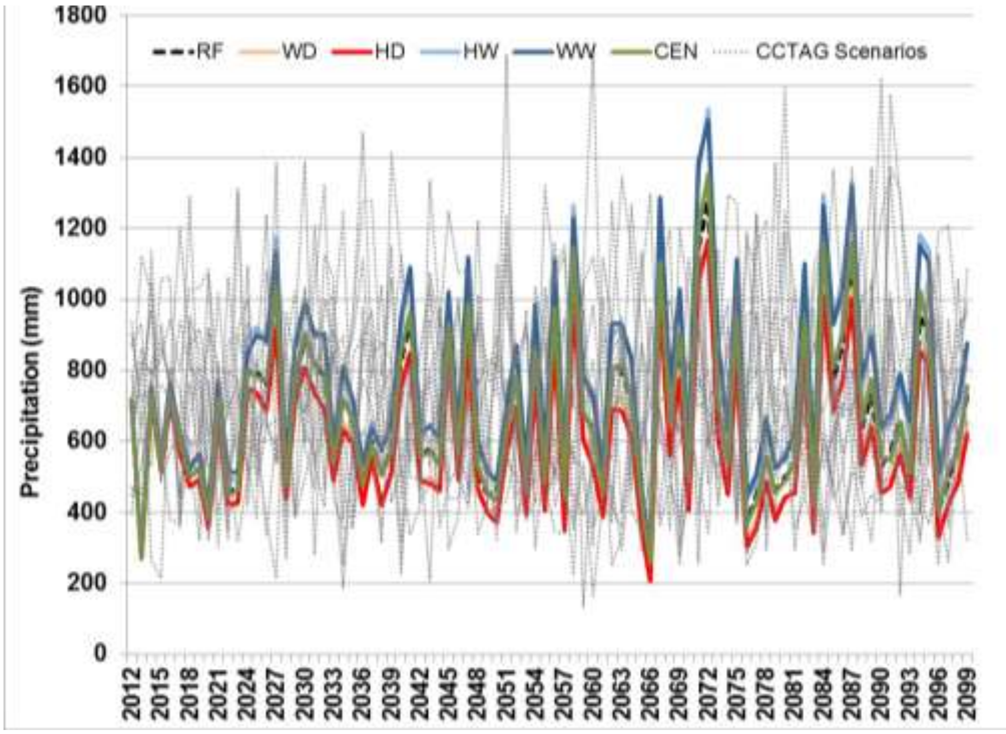


Figure 3-15d. Annual total **precipitation for the San Joaquin River** hydrologic region in each climate scenario.

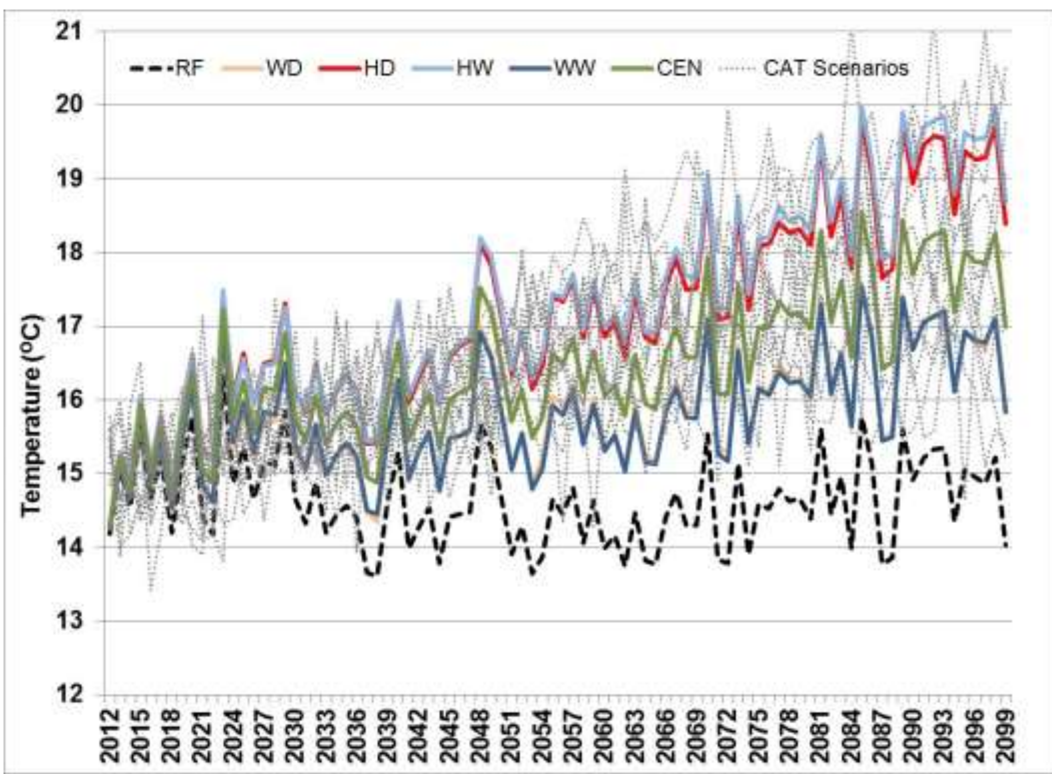


Figure 3-15e. Annual average **temperature for the Tulare Lake** hydrologic region in each climate scenario.

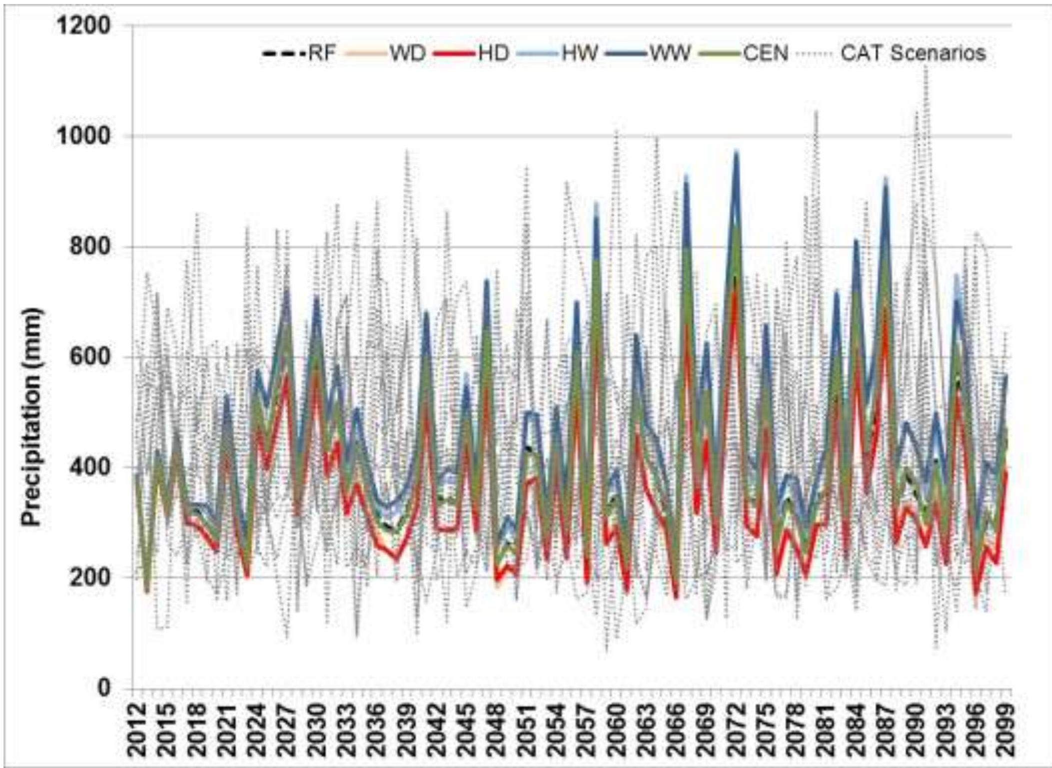


Figure 3-15f. Annual total **precipitation for the Tulare Lake** hydrologic region in each climate scenario.

Projected changes in annual precipitation and temperature were computed for three periods (2015-2039, 2040-2069, and 2070-2099) relative to the Reference-No-Climate-Change climate scenario developed based on Livneh et al. (2013)'s historical observed climate data. All scenarios are consistent in the direction of the temperature change, but vary in terms of climate sensitivity. Annual precipitation trends are not apparent.

The central tendency of projected temperature change in the Sacramento River hydrologic region ranges from 0.3°C (12 CCTAG mean) to 1.0°C (Central Tendency climate scenario), with projections ranging from 0.1 to 1.3°C during the period of 2015-2039, from 1.7 (12 CCTAG mean) to 2.0°C (Central Tendency climate scenario), with projections ranging from 1.0°C to 2.9°C during the period of 2040-2069 and from 2.6°C (12 CCTAG mean) to 2.8°C (Central Tendency climate scenario), with projections ranging from 1.0°C to 4.5°C during the period of 2070-2099. The projected temperature changes are similar in the San Joaquin River and Tulare Lake hydrologic regions with slightly higher projected warming.

The range of projections indicates considerable uncertainty around these mean values. Projected precipitation change ranges from:

- Sacramento River hydrologic region: +0.1% (Central Tendency climate scenario) to +15.4% (12 CCTAG mean):

    - 2015-2039: 7.9% to +34.5%
    - 2040-2069: from +2.1% (Central) to +3.7% (12 CCTAG mean),with projections ranging from-10.6% to +22.6%
    - 2070-2090: +3.9% (Central Tendency Climate climate scenario) to +5.2% (12 CCTAG mean), with projections ranging from-13.7% to +28.6%

- San Joaquin River hydrologic region:
    - 2015-2039:-0.2% (Central Tendency climate scenario) to +11.7% (12 CCTAG mean)
    - 2040-2069: +0.8% (Central Tendency climate scenario) to +1.4% (12 CCTAG mean)
    - 2070-2099: +4.8% (Central Tendency climate scenario) to +2.5% (12 CCTAG mean)
- Tulare Lake hydrologic region:-0.3% (Central Tendency climate scenario) to +9.4% (12 CCTAG mean):
    - 2015-2039:-11.4%% to +28.6%
    - 2040-2069:-0.4%% (Central Tendency climate scenario) to +0.3% (12 CCTAG mean), with projections ranging from -20.6% to +18.4%
    - 2070-2099 +1.5% (Central Tendency climate scenario) to +2.2% (12 CCTAG mean), with projections ranging from-19.7% to +26.9%

In all regions, the 12 CCTAG scenarios represent wetter conditions than those represented in the Central Tendency scenario, reflecting a wet bias in the 12 CCTAG scenarios.

Table 3-2 summarizes projected changes in mean annual temperature and precipitation in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions (basins) in each climate scenario.

Table 3-2. Temperature and Precipitation Changes

Table 3-2 a. Annual **Temperature** Change (in °C) for the Reference-No-Climate-Change and Ensemble Climate Scenarios and in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions in Each Climate Scenario.

	Ensemble-Informed Scenarios					
	RF Average	WD	HD	HW	WW	CEN
Sacramento River Hydrologic Region						
2015-2039	12.6	0.6	1.3	1.3	0.6	1.0
2040-2069	12.3	1.3	2.7	2.9	1.3	2.0
2070-2099	12.6	1.7	4.0	4.3	1.7	2.8
San Joaquin River Hydrologic Region						
2015-2039	13.8	0.6	1.3	1.3	0.6	0.9
2040-2069	13.3	1.3	2.7	2.8	1.2	1.9
2070-2099	13.7	1.7	3.9	4.2	1.7	2.7
Tulare Lake Hydrologic Region						
2015-2039	14.8	0.5	1.3	1.3	0.6	0.9
2040-2069	14.4	1.3	2.6	2.7	1.2	1.9
2070-2099	14.7	1.7	3.9	4.1	1.7	2.7

	CCTAG Scenarios											
	RCP4.5_CCSM4	RCP4.5_CESM1-BGC	RCP4.5_CNRM-CM5	RCP4.5_GFDL-CM3	RCP4.5_HadGEM2-ES	RCP4.5_MIROC5	RCP8.5_CCSM4	RCP8.5_CESM1-BGC	RCP8.5_CNRM-CM5	RCP8.5_GFDL-CM3	RCP8.5_HadGEM2-ES	RCP8.5_MIROC5
Sacramento River Hydrologic Region												
2015-2039	0.4	0.4	0.2	0.4	0.3	0.1	0.3	0.3	0.4	0.6	0.7	0.3
2040-2069	1.0	1.1	1.3	1.8	1.8	1.1	1.5	1.8	2.0	2.4	2.6	1.7
2070-2099	1.2	1.0	1.8	2.1	2.4	1.6	3.0	3.0	3.7	3.8	4.5	2.8
San Joaquin River Hydrologic Region												
2015-2039	0.5	0.5	0.3	0.6	0.4	0.3	0.3	0.4	0.5	0.7	0.8	0.5
2040-2069	1.3	1.4	1.7	2.2	2.1	1.6	1.8	2.1	2.4	2.7	3.0	2.2
2070-2099	1.4	1.2	2.0	2.3	2.5	1.9	3.0	3.0	3.8	4.1	4.5	3.1
Tulare Lake Hydrologic Region												
2015-2039	0.7	0.6	0.5	0.8	0.6	0.5	0.5	0.6	0.5	0.9	0.9	0.7
2040-2069	1.4	1.5	1.6	2.3	2.2	1.8	1.9	2.2	2.4	2.8	3.1	2.3
2070-2099	1.5	1.3	2.0	2.5	2.7	2.1	3.2	3.1	3.7	4.4	4.6	3.4

Note: Changes are computed with respect to the Reference-No-Climate-Change climate scenario (RF)scenario.

Table 3-2b. Annual **Precipitation** (in mm) for the Reference-No-Climate-Change Scenario and Percent Change in Each Ensemble Climate Scenario in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions (2015–2039, 2040–2069, and 2070-2099)

	Ensemble-Informed Scenarios					
	RF Average	**WD**	**HD**	**HW**	**WW**	**CEN**
Sacramento Hydrologic Region						
2015-2039	843	-7.9	-7.5	8.0	9.7	0.1
2040-2069	925	-8.4	-8.9	15.0	13.9	2.1
2070-2099	946	-8.2	-8.3	19.4	16.8	3.9
San Joaquin Hydrologic Region						
2015-2039	646	-9.2	-8.9	10.0	9.4	-0.2
2040-2069	681	-11.4	-12.4	12.6	14.3	0.8
2070-2099	695	-10.9	-12.8	19.0	19.7	2.5
Tulare Hydrologic Region						
2015-2039	397	-11.4	-10.5	9.7	11.7	-0.3
2040-2069	406	-14.5	-14.2	12.3	14.5	-0.4
2070-2099	418	-12.4	-14.8	18.9	21.0	1.5

	CCTAG Scenarios											
	RCP4.5_CCSM4	**RCP4.5_CESM1-BGC**	**RCP4.5_CNRM-CM5**	**RCP4.5_GFDL-CM3**	**RCP4.5_HadGEM2-ES**	**RCP4.5_MIROC5**	**RCP8.5_CCSM4**	**RCP8.5_CESM1-BGC**	**RCP8.5_CNRM-CM5**	**RCP8.5_GFDL-CM3**	**RCP8.5_HadGEM2-ES**	**RCP8.5_MIROC5**
Sacramento Hydrologic Region												
2015-2039	10.1	11.7	34.5	10.8	10.8	12.8	19.0	18.6	34.3	3.5	16.2	2.1
2040-2069	5.5	4.6	18.4	4.8	-5.3	-3.3	2.1	5.2	22.6	9.4	-10.6	-8.7
2070-2099	1.2	10.2	24.9	-1.1	-7.7	-13.7	3.4	22.7	28.6	-3.5	0.7	-3.8
San Joaquin Hydrologic Region												
2015-2039	2.6	15.1	29.1	4.2	7.3	8.8	18.0	16.6	32.4	-1.8	10.6	-1.7
2040-2069	4.6	9.9	17.8	1.8	-2.8	-10.0	-4.7	7.0	16.1	5.4	-13.4	-14.8
2070-2099	4.2	12.0	20.5	-3.1	-5.0	-17.6	8.2	29.5	27.1	-9.6	1.2	-10.2
Tulare Hydrologic Region												
2015-2039	-2.7	18.4	26.8	2.8	4.1	4.6	12.5	14.5	28.6	-2.8	7.6	-1.7
2040-2069	3.9	15.8	18.4	-0.1	-1.6	-14.5	-4.3	11.3	12.0	3.6	-20.0	-20.6
2070-2099	2.2	13.8	16.0	-3.8	-8.6	-19.7	4.4	26.9	26.3	-12.1	-1.1	-17.6

Note: Changes are computed with respect to the Reference-No-Climate-Change climate scenario (RF) scenario.

3.1.2.2. Projected Hydrologic Processes and Trends

Consistent with the evaluation of the historical hydrologic process, hydrologic process indicators of runoff, ET, snowpack accumulation (SWE), and soil moisture were analyzed for future climate projections. Projected changes in monthly, seasonal, and annual hydrologic process indicators were computed for each grid cell and for the major watersheds over three future 30-year periods centered on 2025, 2055, and 2084. These indicators were developed using results from both WEAP-CV catchment and VIC grid model simulations under future climate conditions.

3.1.2.3. Projected Streamflow

The water supply scenarios span perspectives of the past, present, and future hydroclimate. The following scenarios were evaluated:

- **Observed Scenario**, including simulations of hydrologic conditions under historical climate.

- **Future Climate–Ensemble-Informed Scenarios,** using ensemble scenarios based on downscaled GCM projections included in the CMIP5 archives.

- **Future Climate–CCTAG Climate Scenarios,** using 12 specific GCM projections (12 CCTAG) that are being used in the CWP.

The precipitation and average temperature from the ensemble and 12 CCTAG climate scenarios described above were used in the WEAP-CV hydrology model for each of the future periods. The WEAP model obtains these climate data at the discrete nodes shown on Figure 3-16.

The WEAP-CV model was used to develop climate-based watershed runoff for the main watersheds of the Bay-Delta, the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions. The model includes rainfall-runoff modules of the source watersheds in the Central Valley water system that can be computed directly from climatic inputs. The WEAP-CV model was run one time for each of the climate scenarios under the Current Trends socioeconomic projection for water years 2012 through 2099. Each scenario was analyzed for this period using a transient approach in which the climate and socioeconomic factors gradually change as the simulation progresses through time.

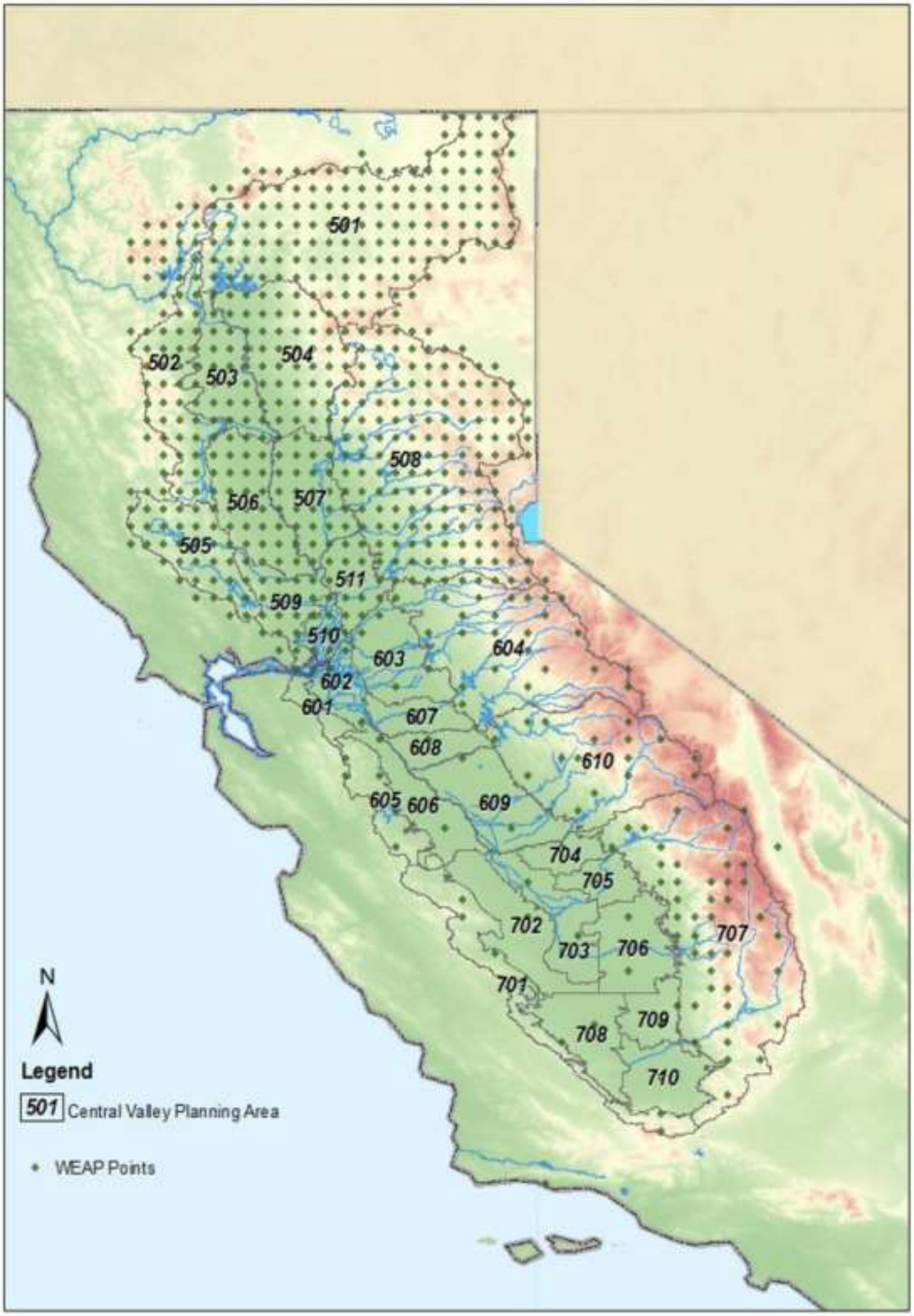


Figure 3-16. Climate input locations used in the WEAP-CV hydrologic modeling.

Based on the assessment of the historical WEAP-CV simulated streamflows for each upper watershed, a statistical bias-correction method, developed for the CVP IRP study (Reclamation 2013 [CVP IRP]), was applied to better reflect the statistics of the observed streamflow in the historical simulation period and to remove similar biases which likely exist in future period simulations. The study applied the statistical bias-correction method to:

- Seventeen major river locations in the upper watersheds using the results of the historical WEAP-CV simulation from 1970-2003.

- The Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios and each of the seventeen socioeconomic-climate scenarios from 2012 to 2099.

The result of the streamflow bias correction is that the historical bias-corrected flows at each location have the same statistical characteristics as those occurring in the observed flows. The bias-corrected streamflows were used as inputs to the CalLite-CV model to perform the impact, system risk, and reliability assessments presented in the subsequent sections of this report.

3.2. Summary of Results

3.2.1. Historical Water Supply

Streamflow analysis summaries (snapshots) were prepared for selected major natural flow locations in the Central Valley to evaluate the trends and variability of flows (See Section 3.1.1.2 *Streamflow and Trends*). Four snapshot summaries are presented in this report for the Sacramento and San Joaquin 8 River Index, Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index, and Tulare 2 Rivers Index.[5]

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[5] The Sacramento-San Joaquin 8 Index is the sum of all of the rivers included in the Sacramento and San Joaquin 4 Rivers Indices:

- The Sacramento 4 River Index is the sum of four streamflows including:
  - the Sacramento River above Bend Bridge
  - Feather River inflow to Lake Oroville
  - Yuba River at Smartville
  - American River inflow to Folsom Lake

- The San Joaquin 4 River Index is the sum of four streamflows including:
  - the Stanislaus River inflow to New Melones Lake
  - Tuolumne River inflow to New Don Pedro Reservoir
  - Merced River inflow to Lake McClure
  - San Joaquin River inflow to Millerton Lake

- Tulare 2 Rivers Index is the sum of streamflows of Kings River inflow to Pine Flat and Kaweah River inflow to Terminus Dam

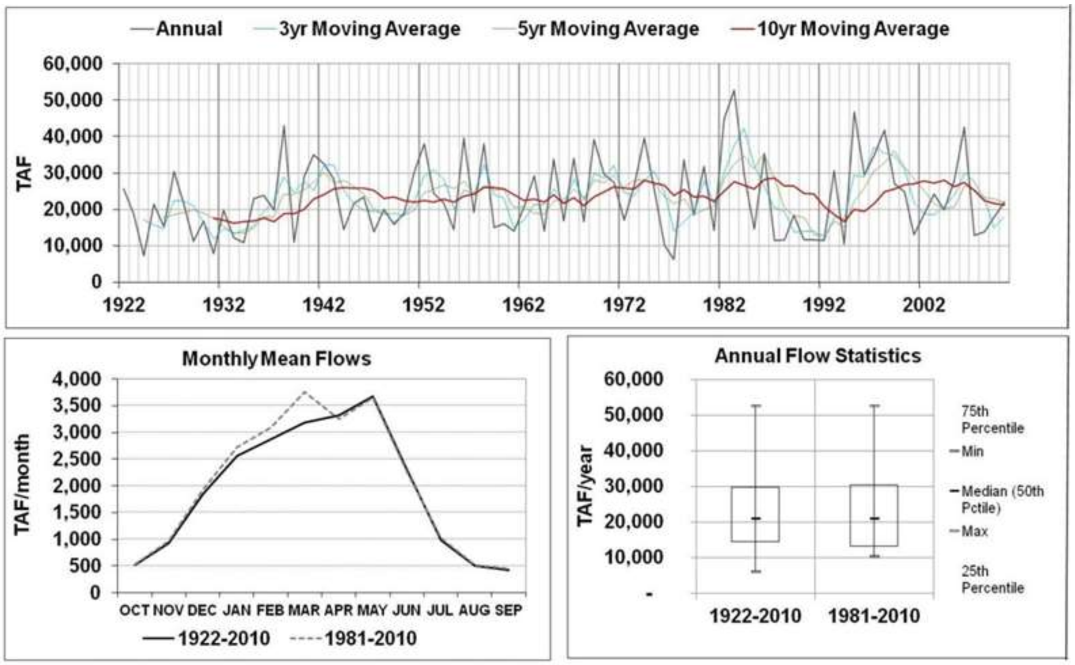
The snapshot results were developed from the natural flows dataset using data for water years 1922 to 2010 (Figure 3-17). The top plot in each figure shows the annual flow volumes and the moving averages for 3, 5, and 10 years. This plot provides a visual assessment of streamflow variability, minimum and maximum flows, and long-term trends.

For most locations, greater variability and more frequent events of greater magnitude are observed 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.

The bottom left plot shows a two-period comparison of monthly average streamflow. The first period spans 1922 to 2010, and the second period captures the more recent 30-year period (1981 to 2010). For 1981 to 2010, all selected locations exhibit slight increases in winter streamflows when compared to the long-term (1922 to 2010) averages. Annual variability, based on the inter-quartile (25th to 75th percentile) range of flows, was higher during the 1981-2010 period for most of the selected locations.

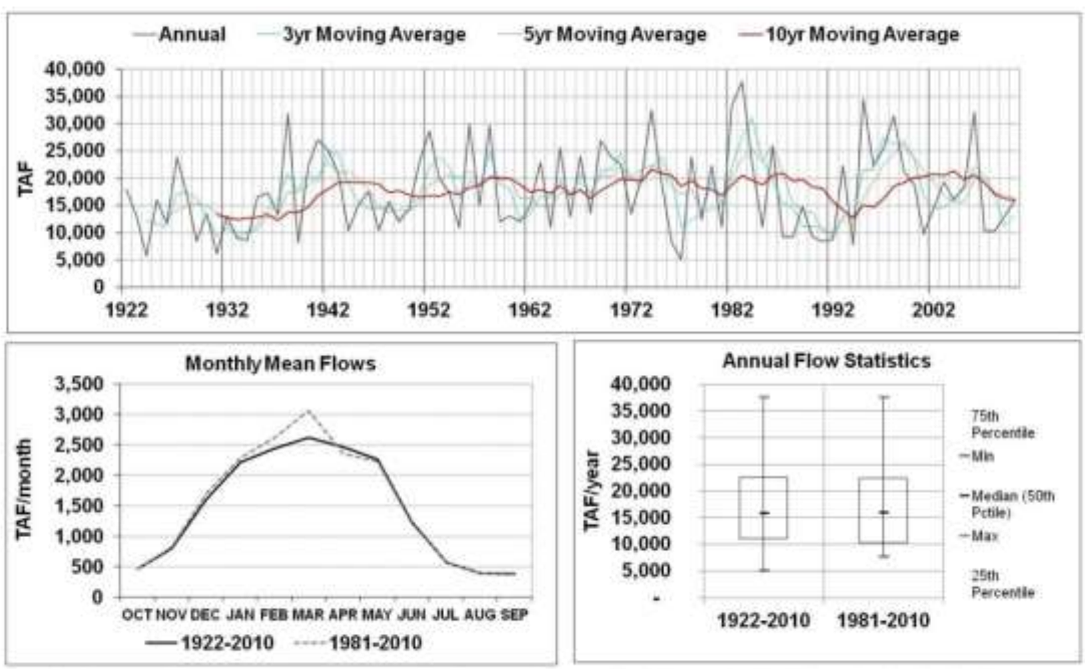
As an example, the Sacramento and San Joaquin 8 Rivers Index plot (Figure 3-17) shows a period of generally below-average streamflow and a period of moderate variability for the period 1930 to 1976. Beginning in 1977, streamflow amplitude and variability increased, with a decrease in streamflows in the most recent two decades. These recent changes in streamflow are attributed, in part, to shifts in the atmospheric-oceanic conditions as represented by PDO and ENSO and hydrologic response to recent warming. The mean annual flow for the 1981 to 2010 period is 24.2 MAF—about 4.8 percent higher than the 1922 to 2010 period mean annual flow of 23.1 MAF. The two periods show similar maximums and minimums for the 1-, 3-, and 5-year averages, with the exception of the very low 1-year average that occurred in the critically dry year of 1977.

Figure 3-17. Streamflow snapshot analysis



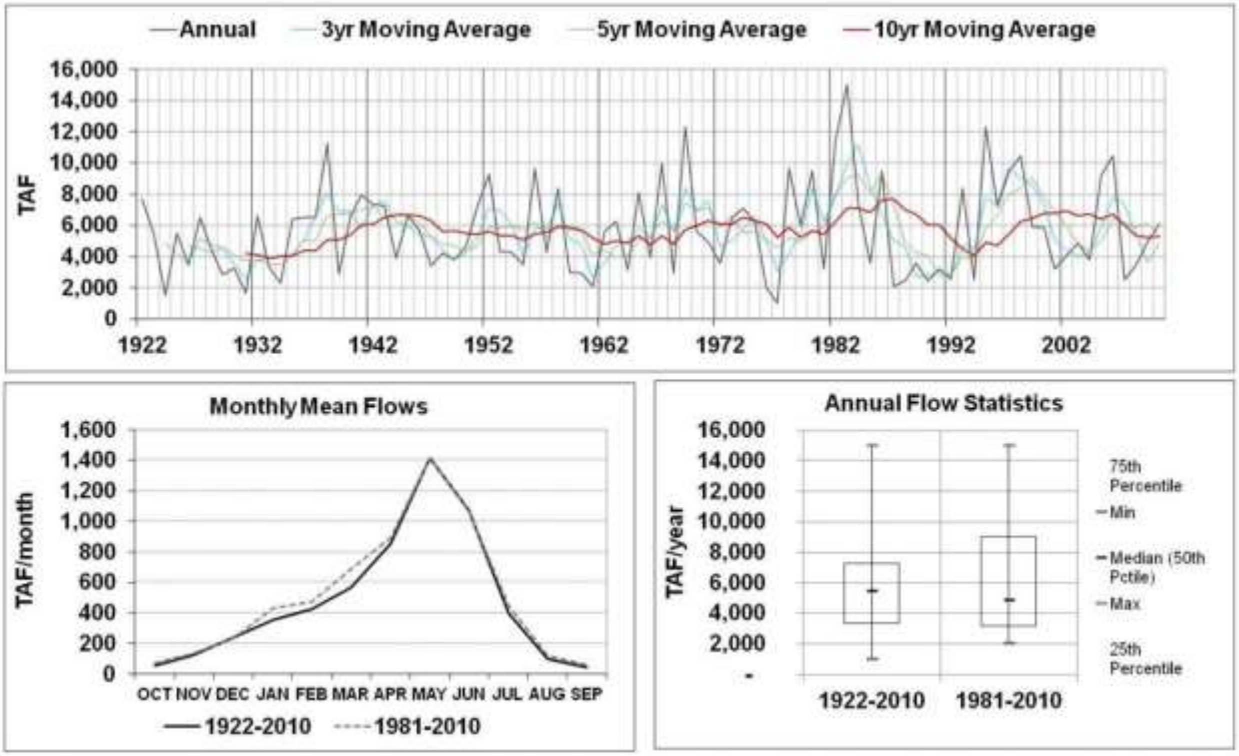
Note: The Sacramento and San Joaquin 8 River Index is the sum of streamflows of Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro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

Figure 3-17a**. Sacramento and San Joaquin 8 River Index** natural streamflow snapshot analysis.



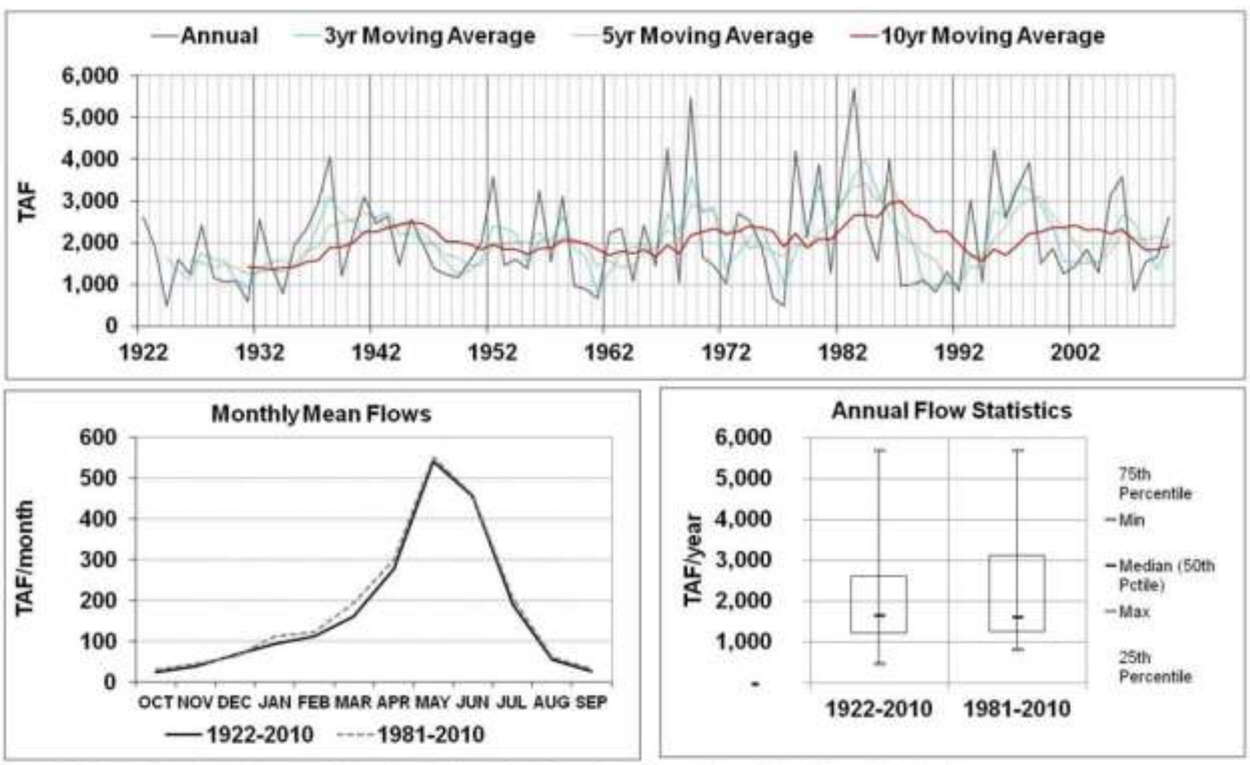
Note: The Sacramento 4 River Index is the sum of streamflows of the Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake

Figure 3-17b. **Sacramento 4 River Index** natural streamflow snapshot analysis.



Note: The San Joaquin 4 Rivers Index is the sum of streamflows of 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 3-17c. **San Joaquin 4 Rivers Index** natural streamflow snapshot analysis.



Note: The Tulare 2 Rivers Index is the sum of streamflows of Kings River inflow to Pine Flat and Kaweah River inflow to Terminus Dam.

Figure 3-17d. **Tulare 2 Rivers Index** natural streamflow snapshot analysis.

Table 3-3 summarizes the key statistics of the annual flow volumes and the moving averages for 3, 5, and 10 years and provides a tabular presentation of the information shown on the figures.

Table 3-3. Key Statistics for Natural Flows in the Sacramento and San Joaquin Eight Rivers Index, Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index, and Tulare 2 Rivers Index

	Sacramento & San Joaquin 8 Rivers Index	Sacramento 4 Rivers Index	San Joaquin 4 Rivers Index	Tulare 2 Rivers Index
Annual (mean, min, max in TAF)				
Mean	23,141	17,478	5,663	2,048
75th percentile	29,669	22,572	7,253	2,611
Min	6,174	5,125	1,050	480
Median (50th percentile)	21,128	15,993	5,506	1,658
Max	52,691	37,679	15,011	5,689
25th Percentile	14,483	11,098	3,341	1,209
Moving Averages (min and max in TAF)				
1 Water Year Min	6,174 (1977)	5,125 (1977)	1,050 (1977)	480 (1977)
1 Water Year Max	52,691 (1983)	37,679 (1983)	15,011 (1983)	5,689 (1983)
3 Water Year Min	11,606 (1992)	8,858 (1992)	2,585 (1931)	843 (1961)
3 Water Year Max	42,333 (1984)	31,147 (1984)	11,187 (1984)	3,988 (1984)
5 Water Year Min	12,963 (1991)	10,013 (1933)	2,758 (1991)	1,021 (1992)
5 Water Year Max	36,045 (1999)	26,968 (1999)	9,332 (1986)	3,508 (1986)
10 Water Year Min	16,324 (1933)	12,273 (1937)	3,908 (1933)	1,367 (1933)
10 Water Year Max	28,639 (1987)	21,587 (1974)	7,706 (1987)	2,996 (1987)
Monthly (Mean in TAF)				
Oct	523	470	53	24
Nov	925	800	125	39
Dec	1,849	1,609	241	68
Jan	2,568	2,212	356	94
Feb	2,870	2,444	426	113
Mar	3,190	2,622	569	161
Apr	3,316	2,462	855	279
May	3,676	2,260	1,416	541
Jun	2,318	1,243	1,075	455
Jul	976	578	399	189
Aug	502	400	102	56
Sep	428	380	47	27
Jul	976	578	399	189
Seasonal (Mean in TAF)				
OND	3,297	2,878	419	131
JFM	8,628	7,277	1,351	368
AMJ	9,310	5,965	3,345	1,275
JAS	1,906	1,358	548	273
JFM	8,628	7,277	1,351	368
AMJ	9,310	5,965	3,345	1,275
JAS	1,906	1,358	548	273

3.2.2. Future Projected Water Supply

This section describes future water supply projections that were developed for the eighteen climate scenarios described above, with Current Trends socioeconomic projections assumed along with each climate scenario.

Under the Reference-No-Climate-Change/Current Trends scenarios, average annual streamflow was about 33,364 TAF/year:

- Sacramento River system: 21,649 TAF/year
- East Side streams and the Delta system: 886 TAF/year
- San Joaquin River system: 6,112 TAF/year
- Tulare Lake region: 3,625 TAF/year

3.2.2.1. Sacramento River System

Under the Current Trends socioeconomic scenario, the projected average annual streamflow in the Sacramento River system ranged from a low of 22,282 TAF/year (under the Central Tendency climate scenario) to a high of 25,121 TAF/year (under the mean of the 12 CCTAG climate scenarios). The range over all 18 projected scenarios was 18,190 to 33,717 TAF/year over the simulation period of water years 2015 through 2099:

- The Central Tendency climate scenario had an average annual streamflow about 2.9% higher than the Reference-No-Climate-Change climate scenario.

- The drier climate scenarios (Warm-Dry and Hot-Dry) had average annual streamflow that were substantially lower (ranging from-15 to-16 percent) than the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

- The wetter climate scenarios (Hot-Wet and Warm-Wet) had average streamflow that were substantially higher (about 26 percent higher) than the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

Across the range of all climate scenarios, average annual streamflow ranged from:

- 2015-2039: 15,979 to 32,613 TAF/year
- 2040-2069:18,258 to 32,439 TAF/year
- 2070-2099: 18,572 to 36,409 TAF/year

3.2.2.2. East Side Streams and the Delta System

Under the Current Trends socioeconomic scenario, the projected average annual streamflow in the East Side streams and the Delta River system ranged from a low of 937 TAF/year (Central Tendency climate scenario) to a high of 1,199 TAF/year (under the mean of the 12 CCTAG climate scenarios). The range over all 18 projected scenarios was 669 to 1,764 TAF/year over the simulation period of water years 2015 through 2099:

- The Central Tendency climate scenario had an average annual streamflow about 2.8% higher than the Reference-No-Climate-Change climate scenario.

- The drier climate scenarios (Warm-Dry and Hot-Dry) had average annual streamflow that were substantially lower (ranging from-26 to -27 percent) than the Reference-No-Climate-Change climate scenario.

- The wetter climate scenarios (Hot-Wet and Warm-Wet) had average streamflow that were substantially higher (ranging from +44 to +50 percent) than the Reference-No-Climate-Change climate scenario.

Across the range of all climate scenarios, average annual streamflow ranged from:

- 2015-2039: 601 to 1,788 TAF/year
- 2040-2069: 667 to 1,580 TAF/year
- 2070-2099: 669 to 1,927 TAF/year

3.2.2.3. San Joaquin River System

Under the Current Trends socioeconomic scenario, the projected central tendencies of average annual streamflow in the San Joaquin River system ranged from a low of 6,394 (Central Tendency climate scenario) to a high of 7,016 TAF/year (under the mean of the 12 CCTAG climate scenarios). The range over all 18 projected scenarios was 4,924 to 9,441 TAF/year over the simulation period of water years 2015 through 2099:

- The Central Tendency climate scenario had an average annual streamflow about 0.2 percent lower than the Reference-No-Climate-Change climate scenario.

- The drier climate scenarios (Warm-Dry and Hot-Dry) had average annual streamflow that was substantially lower (ranging from-20 to-23 percent) than the Reference-No-Climate-Change climate scenario.

- The wetter climate scenarios (Hot-Wet and Warm-Wet) had average streamflow that was substantially higher (ranging from +26 to +30 percent) than the Reference-No-Climate-Change climate scenario.

Across the range of all climate scenarios, average annual streamflow ranged from:

- 2015-2039: 4,983 to 9,408 TAF/year
- 2040-2069: 4,714 to 8,688 TAF/year
- 2070-2099: 4,653 to 10,428 TAF/year

3.2.2.4. Tulare Lake Region

Under the Current Trends socioeconomic scenario, the projected central tendencies of average annual streamflow in the Tulare Lake system ranged from a low of 3,352 TAF/year (Central Tendency climate scenario) to a high of 4,330 TAF/year (under the mean of the 12 CCTAG climate scenarios). The range over all 18 socioeconomic and ensemble climate scenarios was 2,452 to 5,862 TAF/year over the simulation period of water years 2015 through 2099:

- The Central Tendency climate scenario had an average annual streamflow about 4.3 percent lower than the Reference-No-Climate-Change climate scenario.

- The drier climate scenarios (Warm-Dry and Hot-Dry) had average annual streamflow that was substantially lower (ranging from-26 to-30 percent) than the Reference-No-Climate-Change climate scenario

- The wetter climate scenarios (Hot-Wet and Warm-Wet) had average streamflow that was substantially higher (ranging from 23 to 31 percent) than the Reference-No-Climate-Change climate scenario.

3.2.2.5. Average Annual Streamflow

Under the Current Trends socioeconomic scenario, across the range of all climate scenarios, average annual streamflow ranged from:

- 2015-2039: 2,488 to 6,091 TAF/year
- 2040-2069: 2,456 to 5,501 TAF/year
- 2070-2099: 2,419 to 6,576 TAF/year

Figure 3-18 shows the average annual streamflow in the Sacramento River system upstream of Hood, the East Side streams and the Delta, the San Joaquin River system upstream of Vernalis, and the Tulare Lake region for each of the socioeconomic-climate scenarios over the simulation period of water years 2015 through 2099.

Figure 3-18. Average annual streamflow

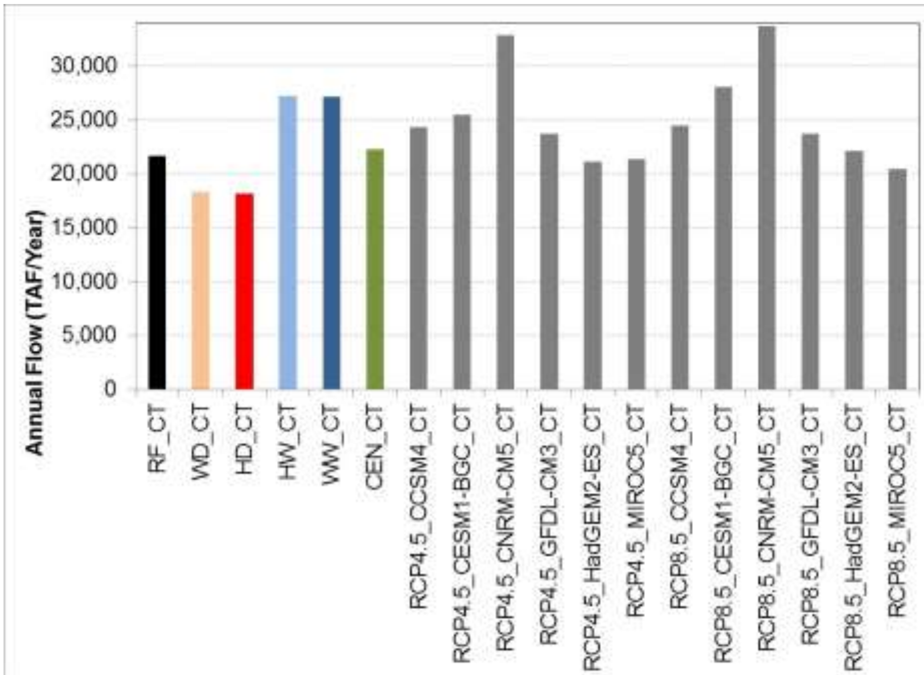


Figure 3-18a. Projected average annual streamflow in the **Sacramento River System** in each scenario (water years 2015 – 2099)

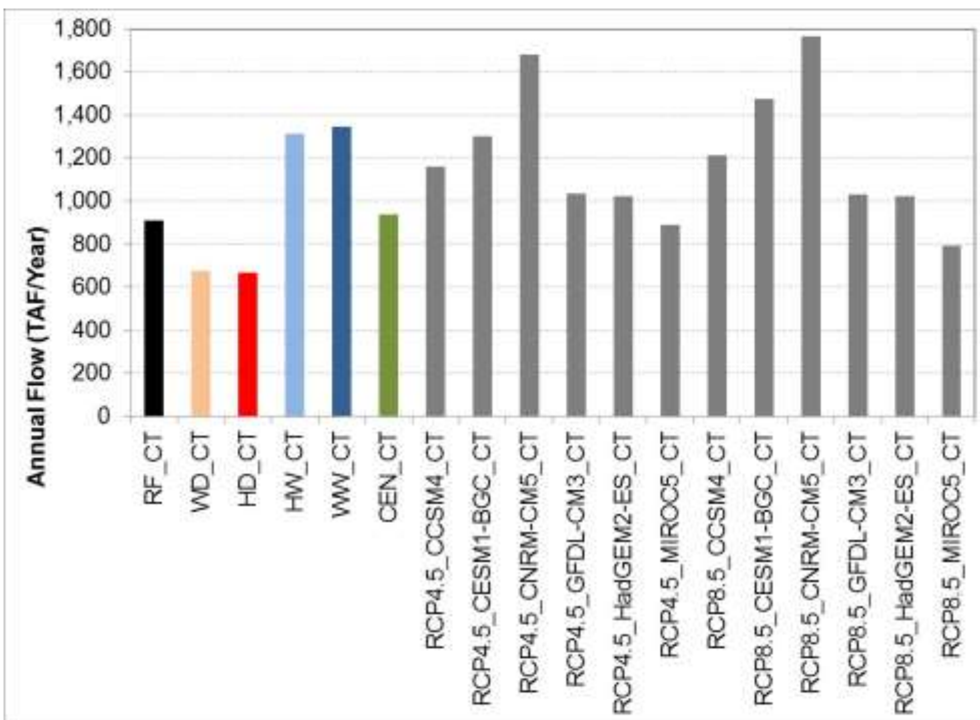


Figure 3-18b. Projected average annual streamflow in the **East Side Streams and Delta** in each scenario (water years 2015 – 2099)

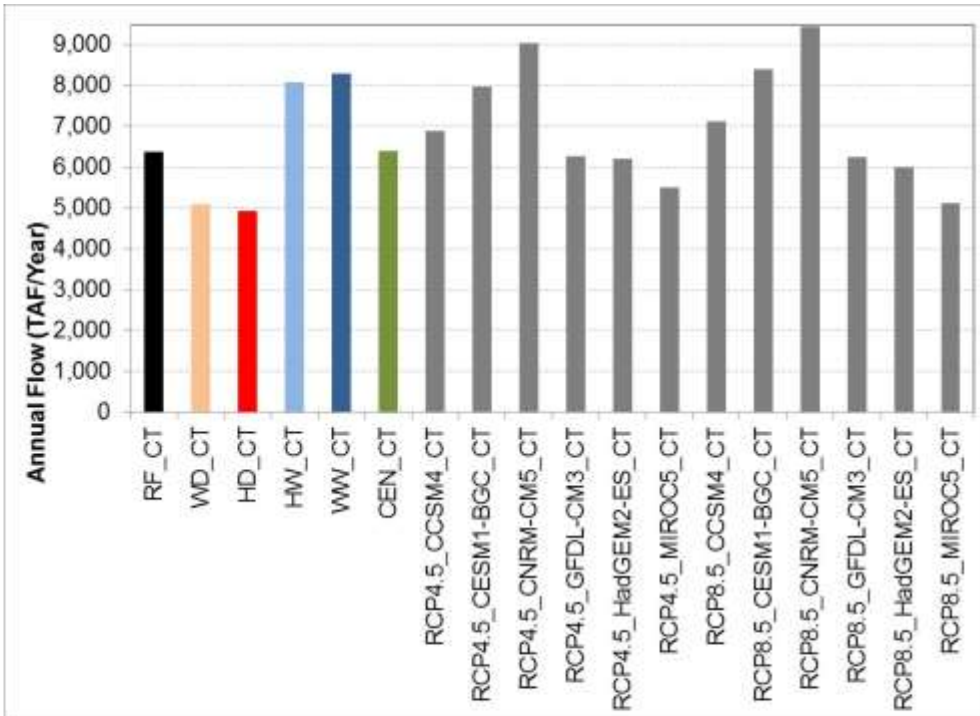


Figure 3-18c. Projected average annual streamflow in the **San Joaquin River System** in each scenario (water years 2015 – 2099)

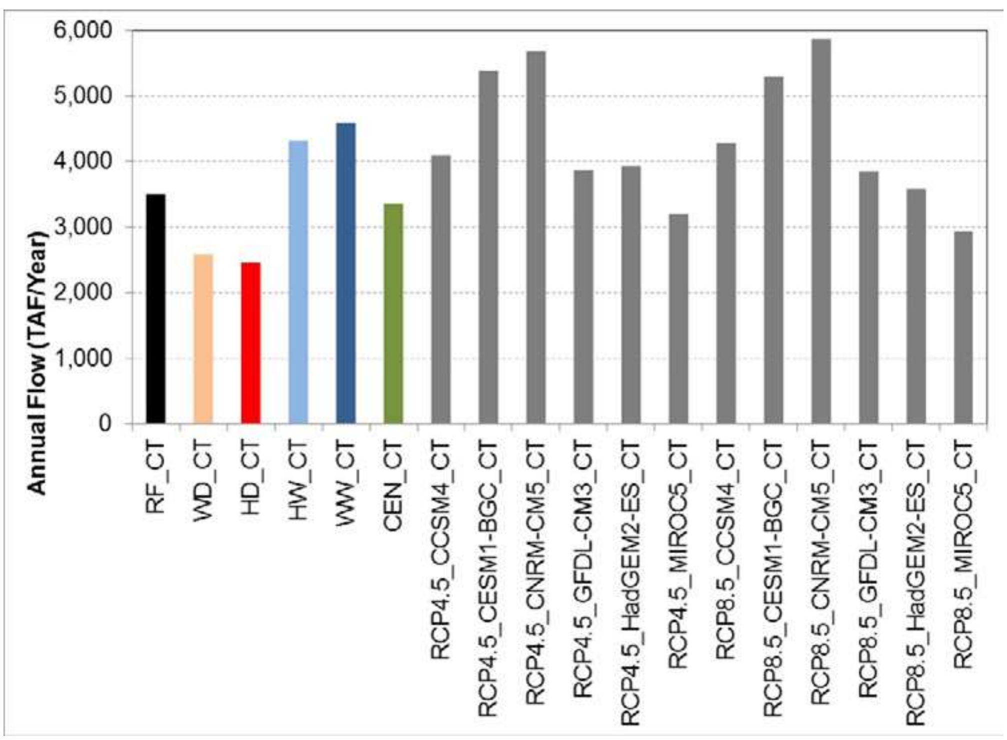


Figure 3-18d. Projected average annual streamflow in the **Tulare Lake Region** in each scenario (water years 2015 – 2099)

Table 3-4 summarizes period average annual streamflow (in TAF/year) for the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios and projected changes in mean annual streamflow in the Sacramento, San Joaquin, Eastside Streams and Delta, and Tulare regions for each of the climate scenarios simulated by WEAP-CV. Projected changes in annual streamflow were computed over four periods (2015-2039, 2040-2069, 2070-2099, and 2015-2099).

Table 3-4. Annual Streamflow

Table 3-4a. Summary of Annual Streamflow (in TAF/year) and Changes (%) in the Sacramento River System, Eastside Streams and Delta, San Joaquin River System, and Tulare Lake Region for the **Ensemble Climate Scenarios** under the Current Trends Socioeconomic Scenario.

Period	Reference _CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_ CT	Warm-Wet_CT	Central_CT
Sacramento River System						
2015-2039	18,535	-13.8	-13.7	15.2	18.9	-0.3
2040-2069	22,617	-16.4	-16.7	26.4	26.2	3.1
2070-2099	23,277	-15.8	-16.9	32.3	29.6	4.9
2015-2099	21,649	-15.5	-16.0	25.8	25.6	2.9
Eastside Streams and Delta						
2015-2039	789	-23.8	-23.6	32.8	28.7	-1.7
2040-2069	920	-27.4	-25.5	42.3	47.9	2.6
2070-2099	1,005	-26.3	-29.6	53.5	60.3	6.0
2015-2099	911	-26.0	-26.6	44.2	47.9	2.8
San Joaquin River System						
2015-2039	5,883	-14.7	-15.3	21.4	19.7	0.1
2040-2069	6,471	-23.1	-25.8	22.1	28.2	-0.9
2070-2099	6,700	-21.3	-25.4	35.0	38.8	1.4
2015-2099	6,379	-20.2	-22.8	26.7	29.8	0.2
Tulare Lake Region						
2015-2039	3,211	-22.4	-22.5	16.8	23.5	-3.7
2040-2069	3,562	-28.3	-31.1	19.2	27.0	-5.8
2070-2099	3,689	-27.0	-34.4	31.8	40.5	-3.3
2015-2099	3,504	-26.2	-30.0	23.2	31.1	-4.3

Table 3-4b. Summary of Annual Streamflow (in TAF/year) and Changes (%) in the Sacramento River System, Eastside Streams and Delta, San Joaquin River System, and Tulare Lake Region (2015–2039, 2040–2069, 2070-2099, and 2015–2099) for the **CCTAG RCP 4.5** Climate Scenarios under the Current Trends Socioeconomic Scenario.

Period	RCP4.5_CCSM4 _CT	RCP4.5_CESM1-BGC_CT	RCP4.5_CNRM-CM5_CT	RCP4.5_GFDL-CM3_CT	RCP4.5_HadGEM2 -ES_CT	RCP4.5_MIROC5 _CT
Sacramento River System						
2015-2039	28.5	24.9	76.0	23.6	25.8	29.2
2040-2069	12.5	7.4	37.1	8.5	-9.1	-2.6
2070-2099	1.5	22.6	49.9	1.4	-14.4	-20.2
2015-2099	12.4	17.6	51.7	9.6	-2.3	-1.3
Eastside Streams and Delta						
2015-2039	42.3	55.2	123.2	25.1	43.4	50.6
2040-2069	32.7	28.2	71.7	16.4	6.3	-6.7
2070-2099	13.0	48.3	71.0	3.8	-3.2	-33.4
2015-2099	27.5	42.9	84.5	13.7	12.0	-2.5
San Joaquin River System						
2015-2039	4.7	29.1	59.4	4.9	12.6	14.3
2040-2069	11.1	19.4	34.3	-1.7	-4.6	-17.2
2070-2099	7.1	27.0	36.2	-6.4	-11.7	-30.6
2015-2099	7.9	24.8	41.8	-1.7	-2.6	-13.6
Tulare Lake Region						
2015-2039	9.1	63.9	89.7	24.9	34.3	24.3
2040-2069	20.4	48.3	54.4	4.0	12.6	-15.0
2070-2099	18.9	51.1	50.0	5.3	-4.5	-25.7
2015-2099	16.8	53.6	62.3	10.1	12.1	-8.4

Note: Changes are computed with respect to Reference-No-Climate-Change-Current Trends scenario

Table 3-4c. Summary of Annual Streamflow (in TAF/year) and Changes (%) in the Sacramento River System, Eastside Streams and Delta, San Joaquin River System, and Tulare Lake Region (2015–2039, 2040–2069, 2070-2099, and 2015–2099) for the **CCTAG RCP 8.5** Climate Scenarios under the Current Trends Socioeconomic Scenario

Period	RCP8.5_CCSM 4_CT	RCP8.5_CESM1	RCP8.5_CNRM-CM5_CT	RCP8.5_GFDL-CM3_CT	RCP8.5_HadGEM2-ES_CT	RCP8.5_MIROC5_CT
Sacramento River System						
2015-2039	40.2	35.1	72.8	14.2	34.7	8.2
2040-2069	2.7	13.0	43.4	17.6	-19.3	-14.4
2070-2099	5.0	42.4	56.4	-1.1	1.4	-5.9
2015-2099	13.0	29.7	55.7	9.6	2.1	-5.5
Eastside Streams and Delta						
2015-2039	74.9	61.2	126.7	20.9	54.7	3.8
2040-2069	3.6	33.3	71.8	31.0	-16.1	-22.7
2070-2099	32.2	88.3	91.9	-8.1	10.4	-15.1
2015-2099	32.9	61.8	93.6	13.2	12.2	-13.0
San Joaquin River System						
2015-2039	33.9	24.7	59.9	0.2	16.4	-8.1
2040-2069	-11.2	13.4	31.1	10.6	-26.5	-27.2
2070-2099	17.7	54.2	55.6	-16.0	-3.1	-21.3
2015-2099	11.8	31.6	48.0	-2.1	-6.2	-19.8
Tulare Lake Region						
2015-2039	47.9	48.1	86.9	21.9	36.6	11.4
2040-2069	0.6	37.6	41.2	18.8	-28.4	-27.3
2070-2099	24.4	66.4	78.3	-7.5	6.8	-25.7
2015-2099	22.2	51.1	67.3	9.9	2.2	-16.2

Note: Changes are computed with respect to Reference-No-Climate-Change-Current Trends scenario.

Figure 3-19 shows the projected monthly pattern of inflow to the major reservoirs in the study area for the 2015-2039, 2040-2069 and 2070-2099 periods. Each basin has a different monthly pattern, reflecting differences in hydroclimate and watershed characteristics within the basin. In each basin, the climate scenarios exhibited a similar pattern to the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, but with a shift in streamflow from the spring months to the winter months. This projected shift occurs because higher temperatures during winter cause earlier snowmelt runoff. This seasonal shift is greater in basins where the elevations of the historical snowpack areas are lower and, therefore, more susceptible to warming induced changes in precipitation from snow to rain.

Figure 3-19. Average monthly streamflow.

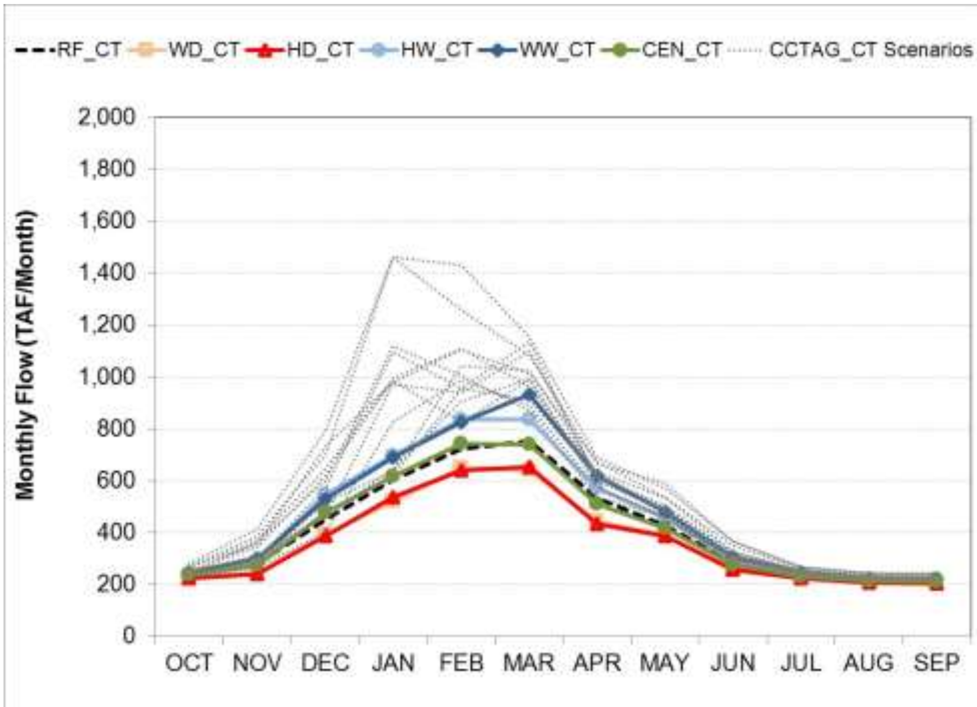


Figure 3-19a. Projected average streamflow in each month into **Lake Shasta** in each climate scenario (long-term average over water years **2015 through 2039**).

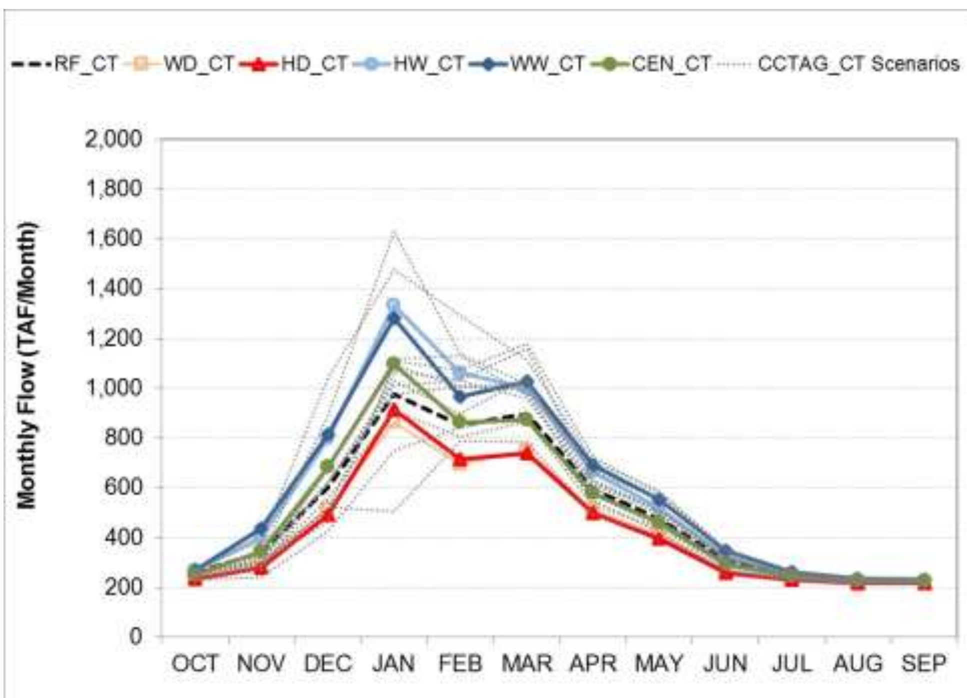


Figure 3-19b. Projected average streamflow in each month into **Lake Shasta** in each climate scenario (long-term average over water years **2040 through 2069**).

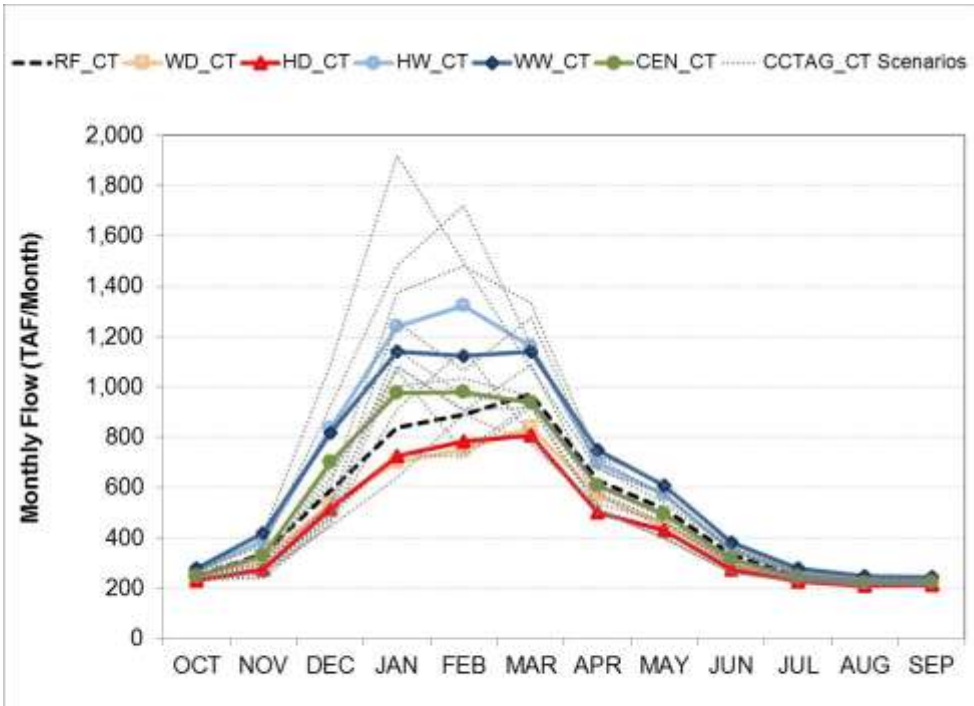


Figure 3-19c. Projected average streamflow in each month into **Lake Shasta** in each climate scenario (long-term average over water years **2070 through 2099**).

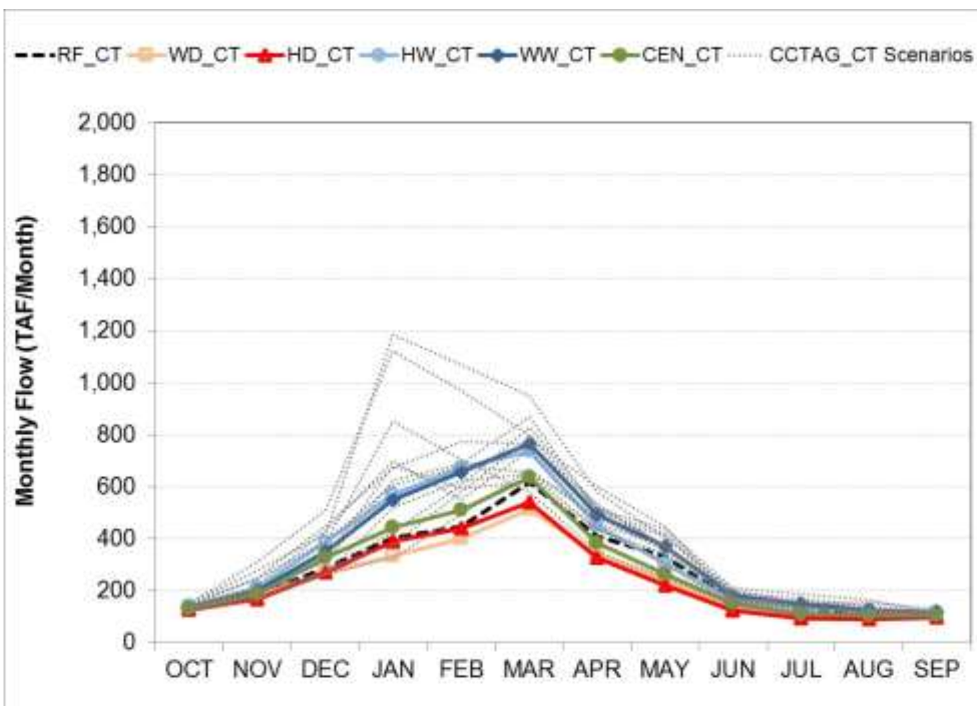


Figure 3-19d. Projected average streamflow in each month into **Lake Oroville** in each climate scenario (long-term average over water years **2015 through 2039**).

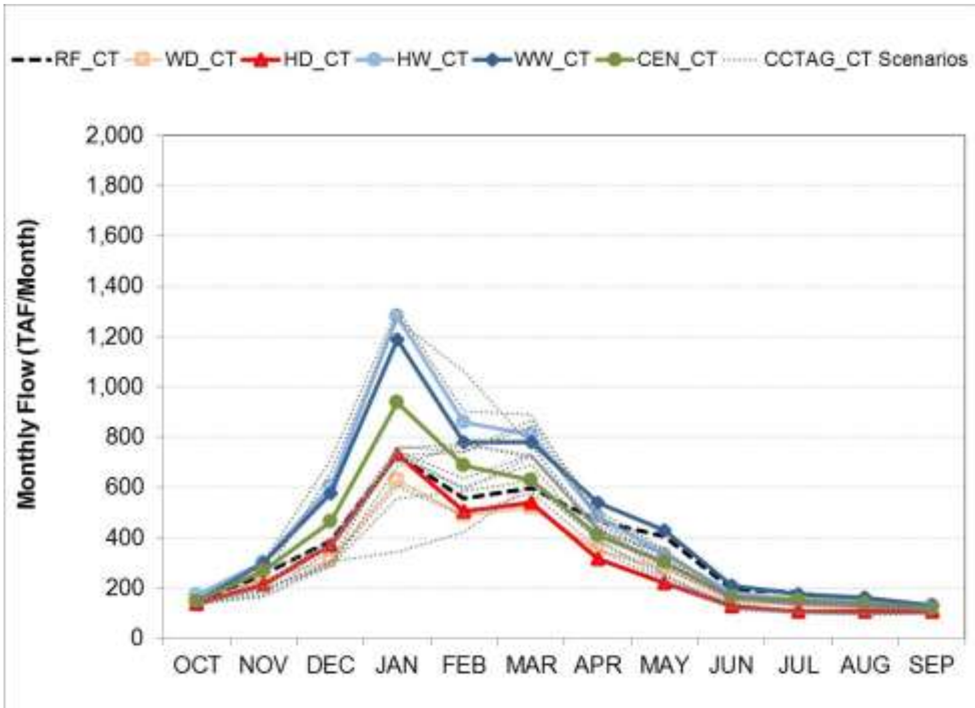


Figure 3-19e. Projected average streamflow in each month into **Lake Oroville** in each climate scenario (long-term average over water years **2040 through 2069**).

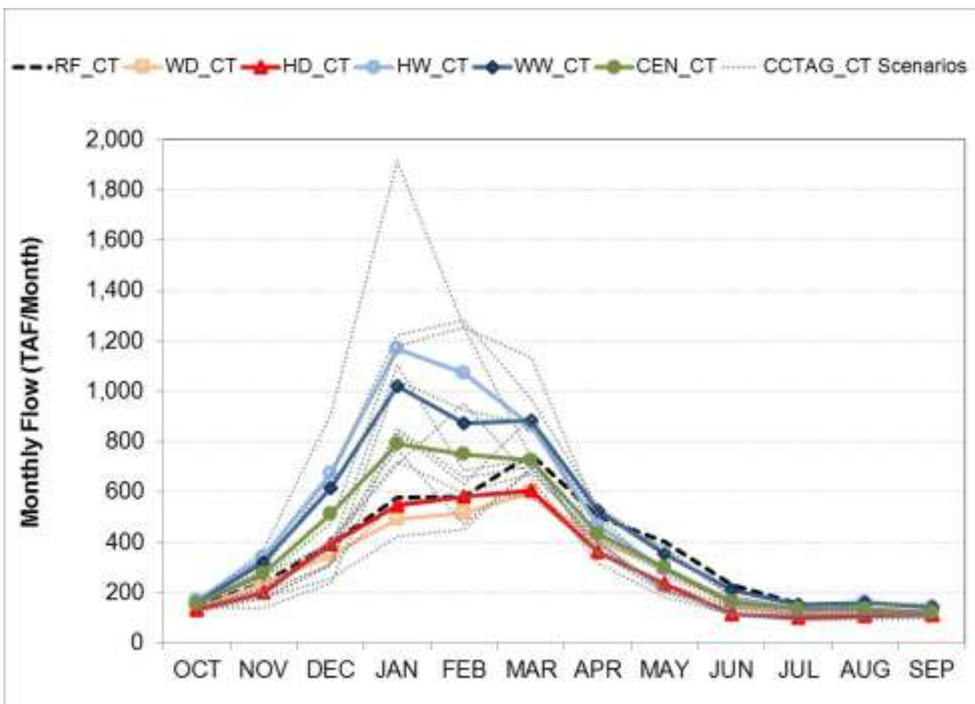


Figure 3-19f. Projected average streamflow in each month into **Lake Oroville** in each climate scenario (long-term average over water years **2070 through 2099**).

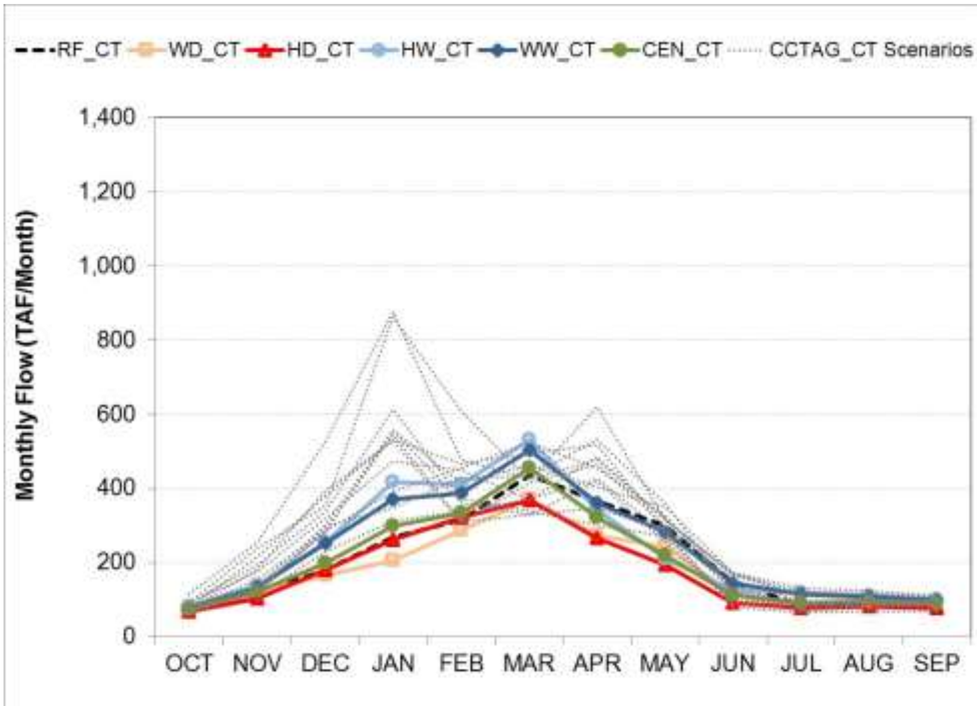


Figure 3-19g. Projected average streamflow in each month into **Folsom Lake** in each climate scenario (long-term average over water years **2015 through 2039**).

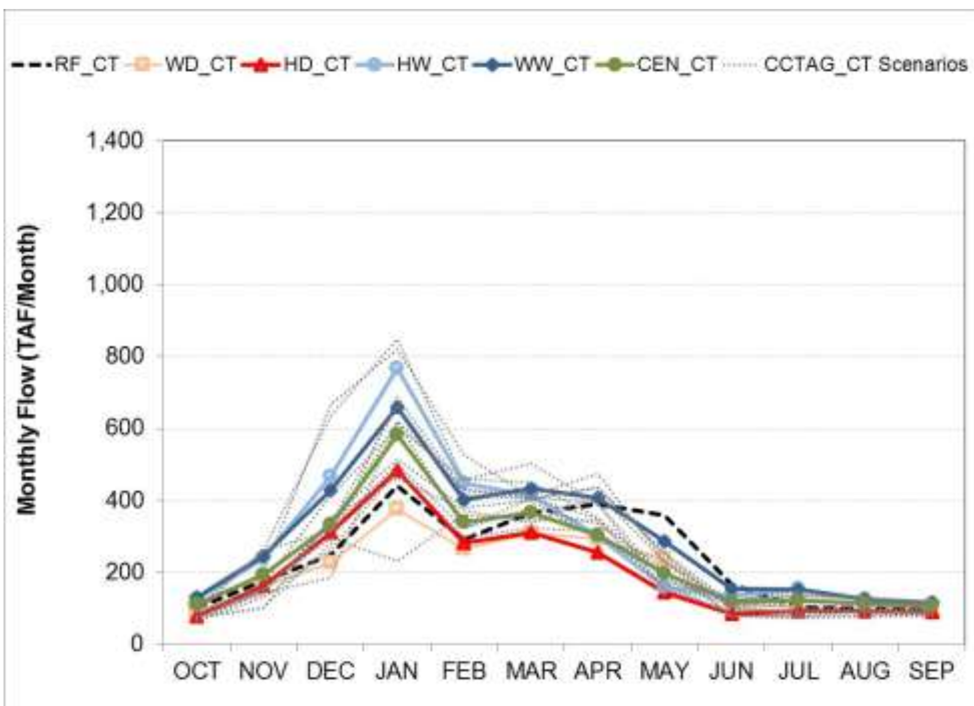


Figure 3-19h. Projected average streamflow in each month into **Folsom Lake** in each climate scenario (long-term average over water years **2040 through 2069**).

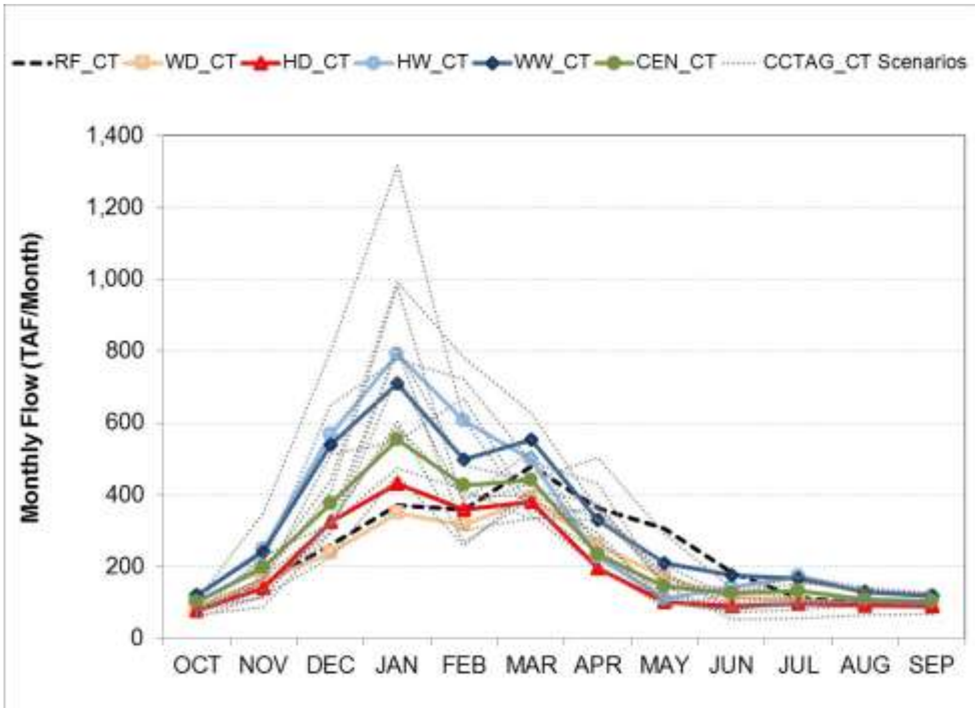


Figure 3-19i. Projected average streamflow in each month into **Folsom Lake** in each climate scenario (long-term average over water years **2070 through 2099**).

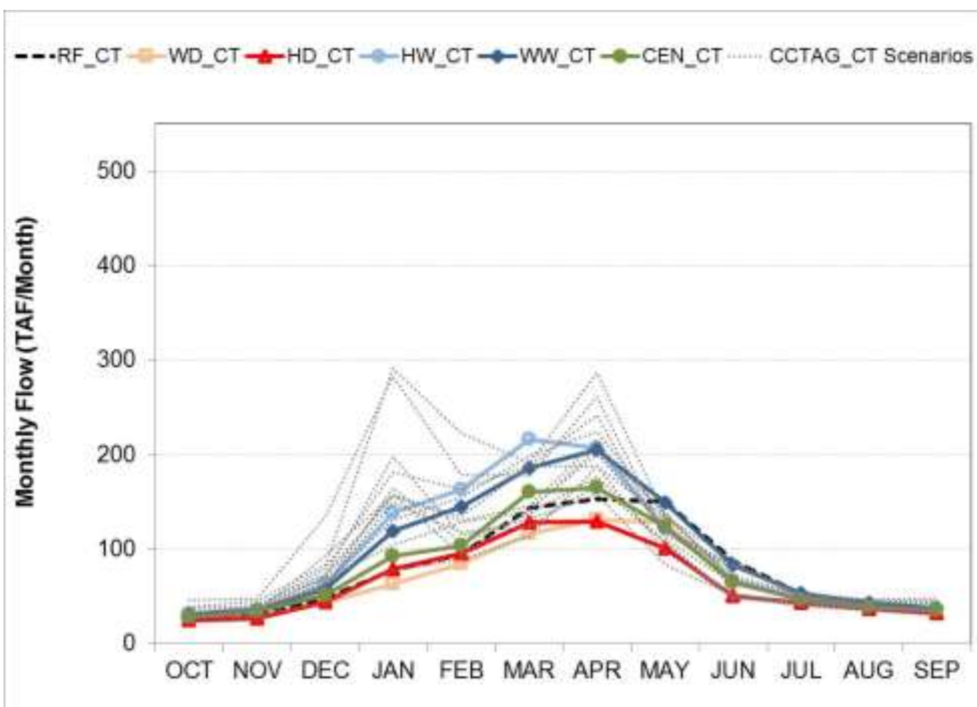


Figure 3-19j. Projected average streamflow in each month into **New Melones Reservoir** in each climate scenario (long-term average over water years **2015 through 2039**).

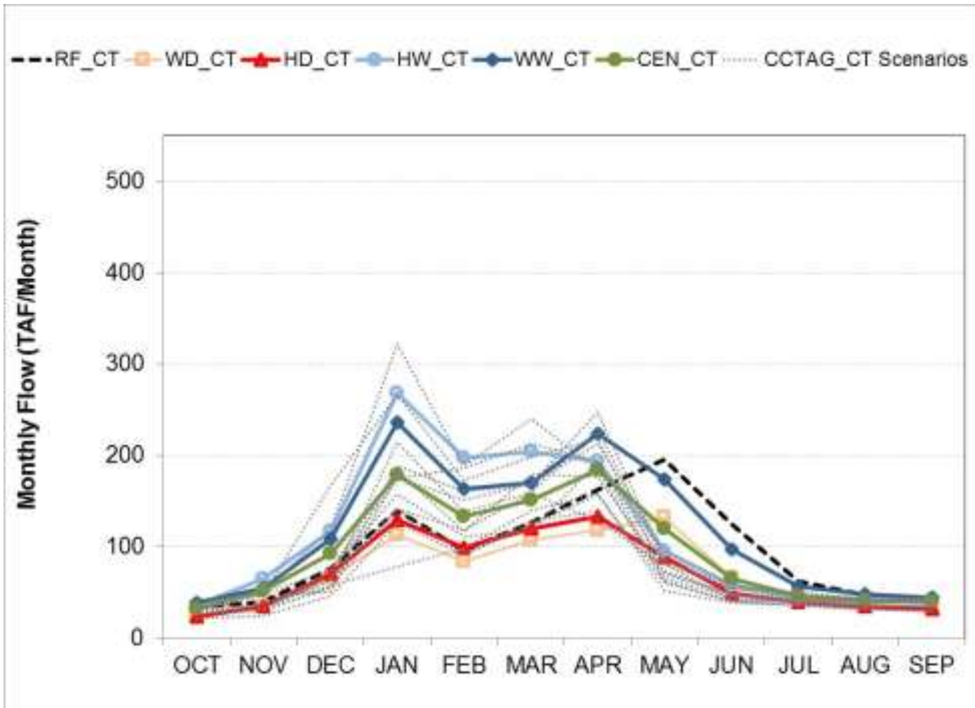


Figure 3-19k. Projected average streamflow in each month into **New Melones Reservoir** in each climate scenario (long-term average over water years **2040-2069**).

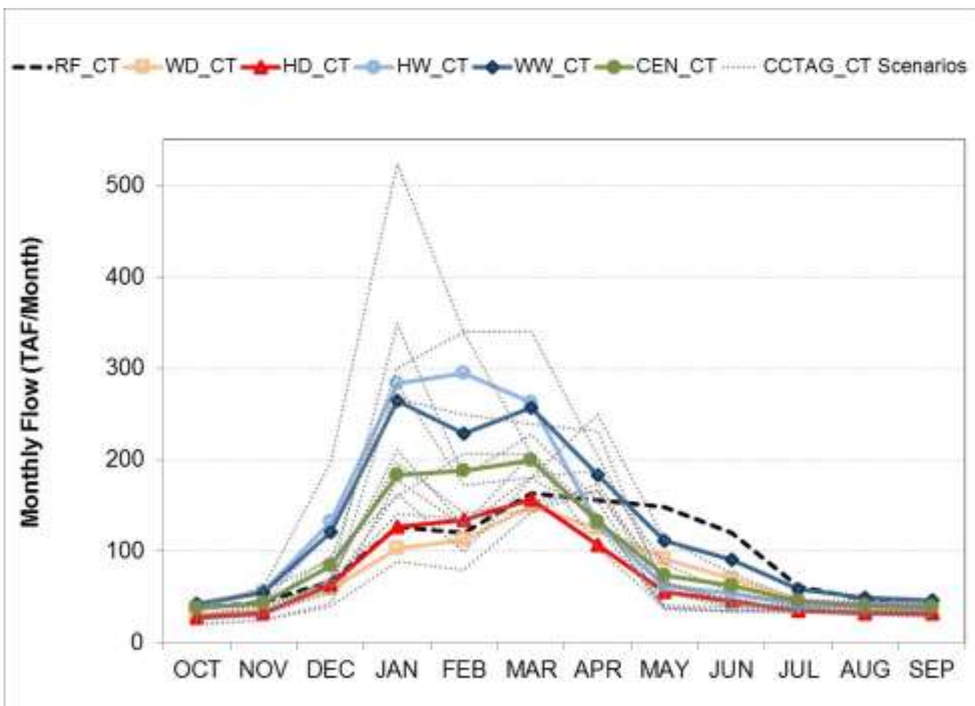


Figure 3-19l. Projected average streamflow in each month into **New Melones Reservoir** in each climate scenario (long-term average over water years **2070-2099**).

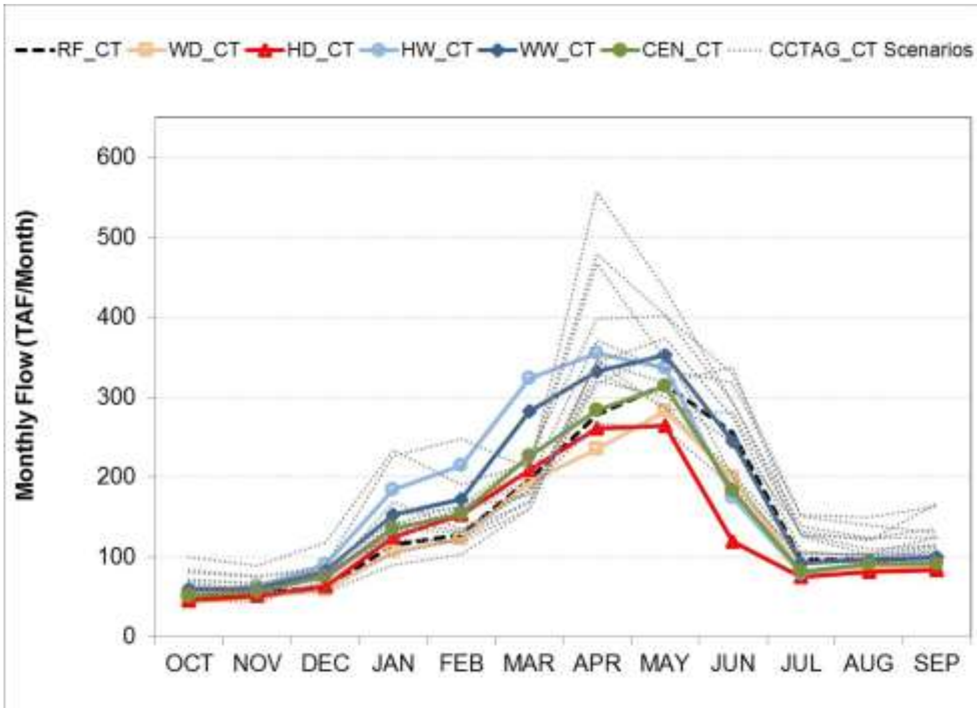


Figure 3-19m. Projected average streamflow in each month into **Millerton Lake** in each climate scenario (long-term average over water years **2015-2039**).

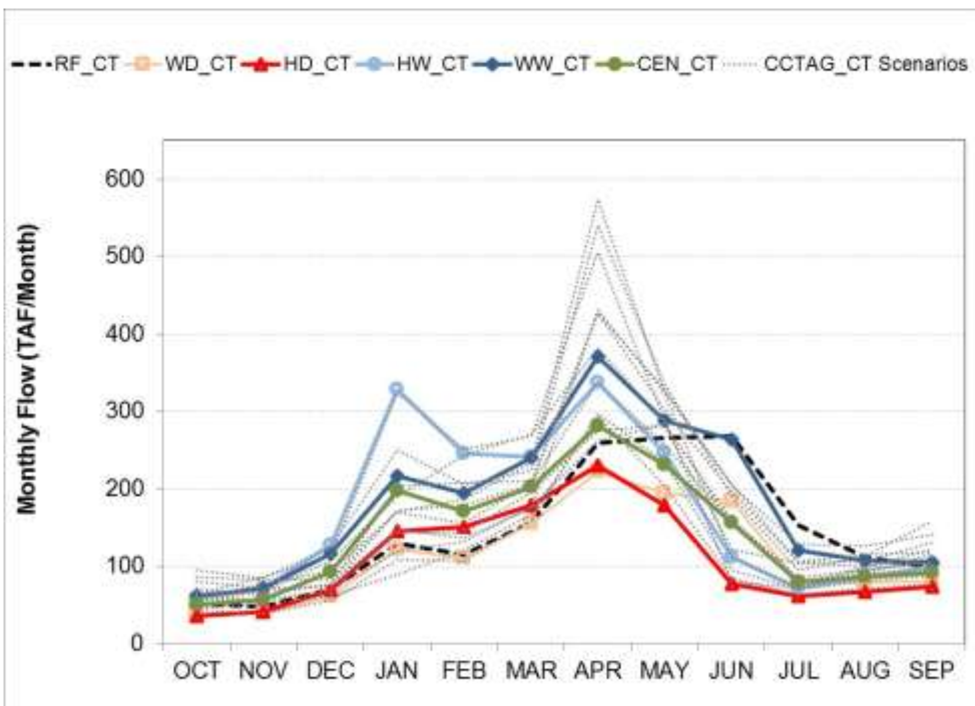


Figure 3-19n. Projected average streamflow in each month into **Millerton Lake** in each climate scenario (long-term average over water years **2040-2069**)

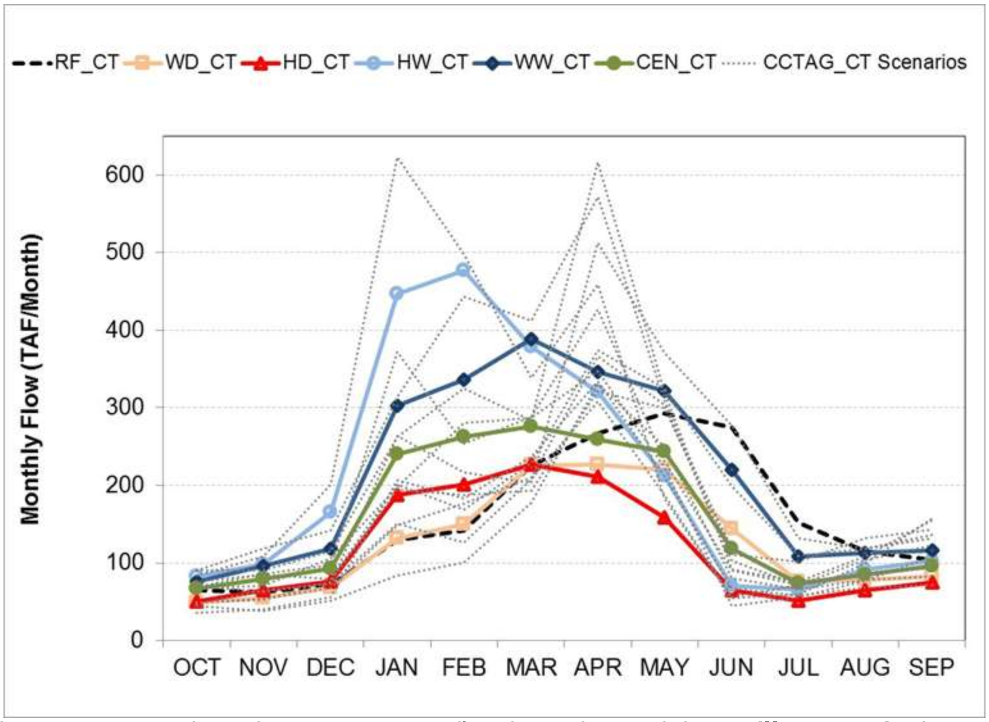


Figure 3-19o. Projected average streamflow in each month into **Millerton Lake** in each climate scenario (long-term average over water years **2070-2099**).

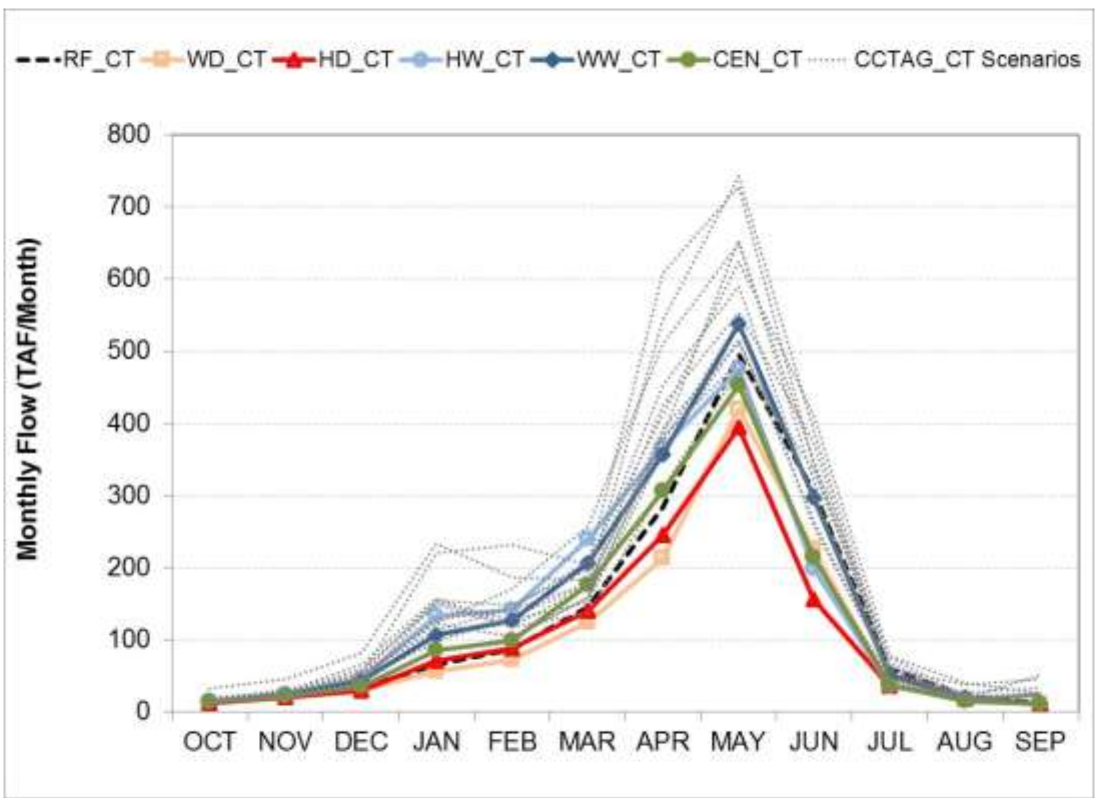


Figure 3-19p.Projected average streamflow in each month into **Pine Flat** in each climate scenario (long-term average over water years **2015-2039**).

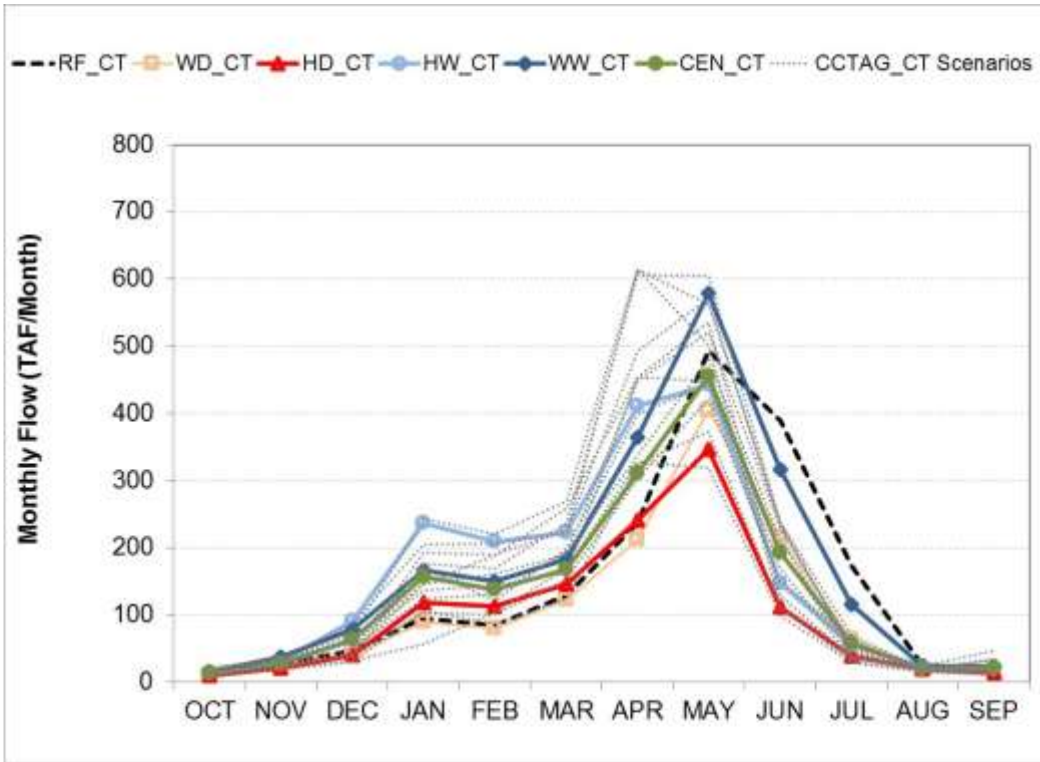


Figure 3-19q. Projected average streamflow in each month into **Pine Flat** in each climate scenario (long-term average over water years **2040-2069**).

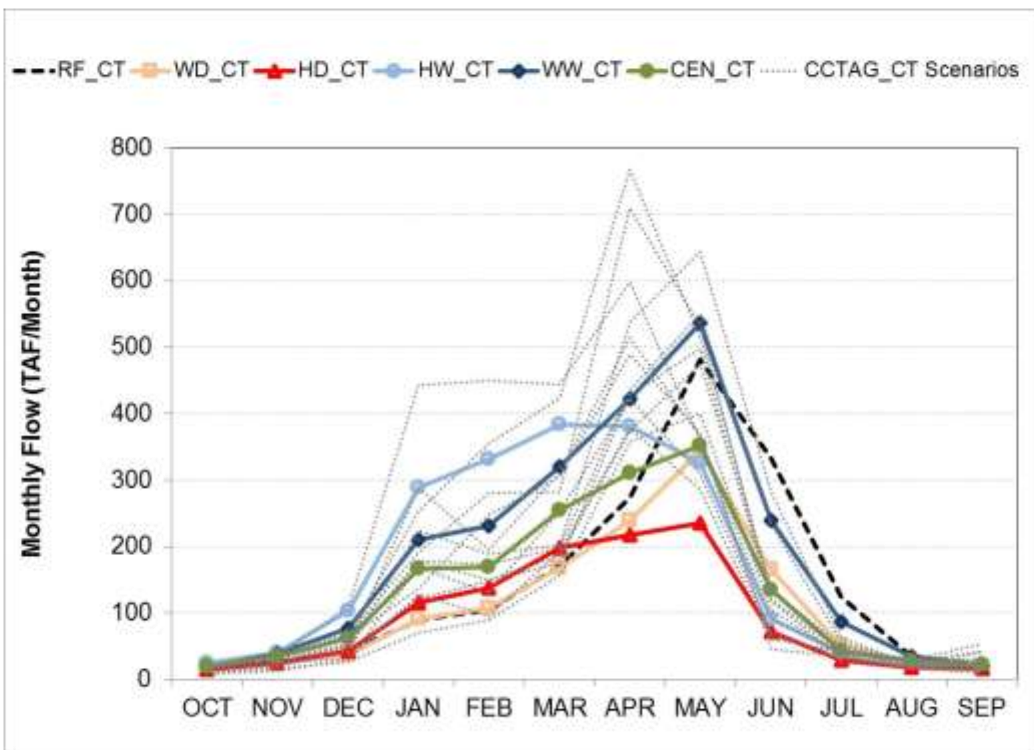


Figure 3-19r. Projected average streamflow in each month into **Pine Flat** in each climate scenario (long-term average over water years **2070-2099**).

The time series projections in the ensemble scenarios reflect the same inter-annual sequence as the historical period because of the methodology used in developing the projections, with extended drought periods of lower streamflow values from 2018 to 2023 (corresponding to the 1929-1934 dry period) and from 2076 to 2081 (corresponding to the 1987-1992 drought), and a very substantial dry period from 2065 to 2066 (corresponding to the 1976-1977 low precipitation years). However, as shown on the figures, the magnitude of the events differs from historical conditions. For the 12 CCTAG climate scenarios, the inter-annual variability is not constrained by the historic climate variability. For these projections individual GCM simulations used:

- Climate variability results from the representation of physical characteristics of the land surface, ocean and atmospheric processes and initial conditions
  ,
- RCP emissions scenarios
- Computational methods

Figure 3-20 shows the projected annual time series of streamflow in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region in water years 2015 through 2099 for each climate scenario in the Current Trends socioeconomic scenario.

Figure 3-20. Streamflow time series

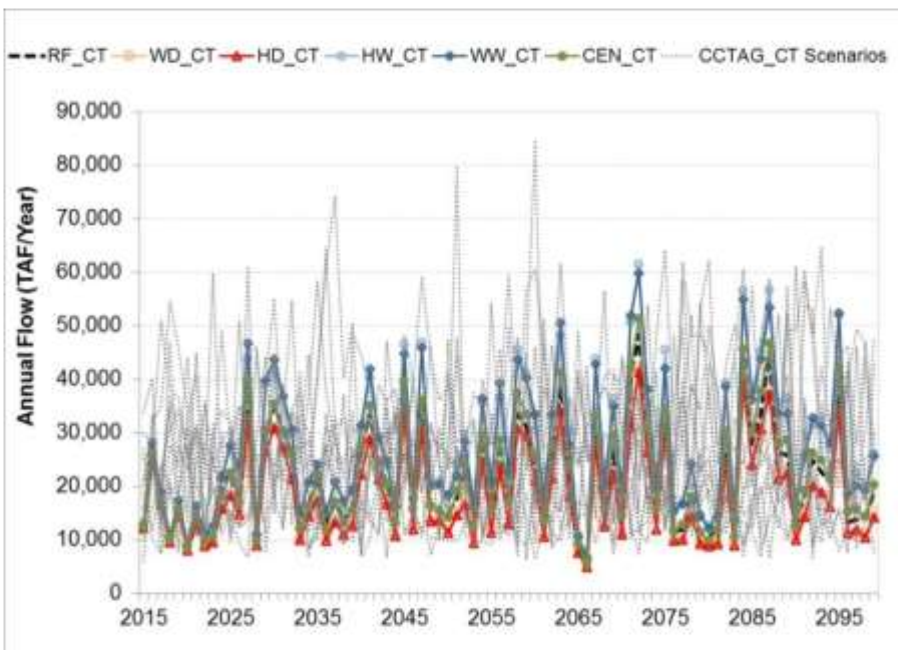


Figure 3-20a. Annual time series of streamflow in **Sacramento River system** in each climate scenario.

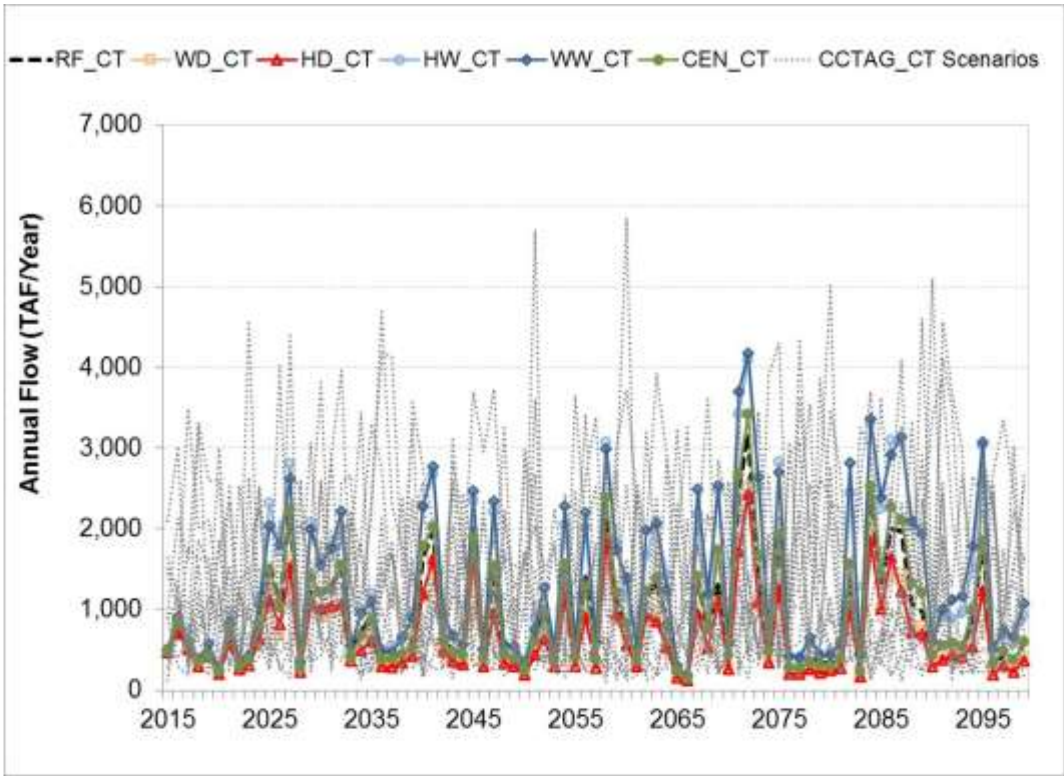


Figure 3-20b. Projected annual time series of streamflow in the **East Side streams and Delta** in each climate scenario.

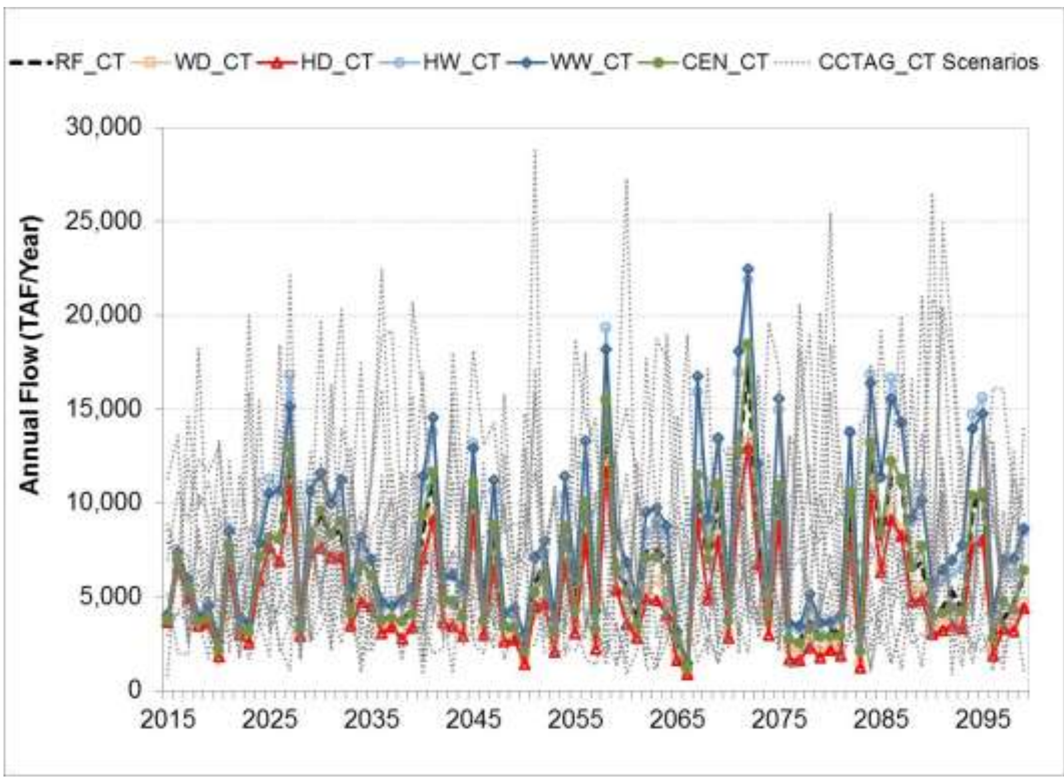


Figure 3-20c. Projected annual time series of streamflow in the **San Joaquin River system** in each climate scenario.

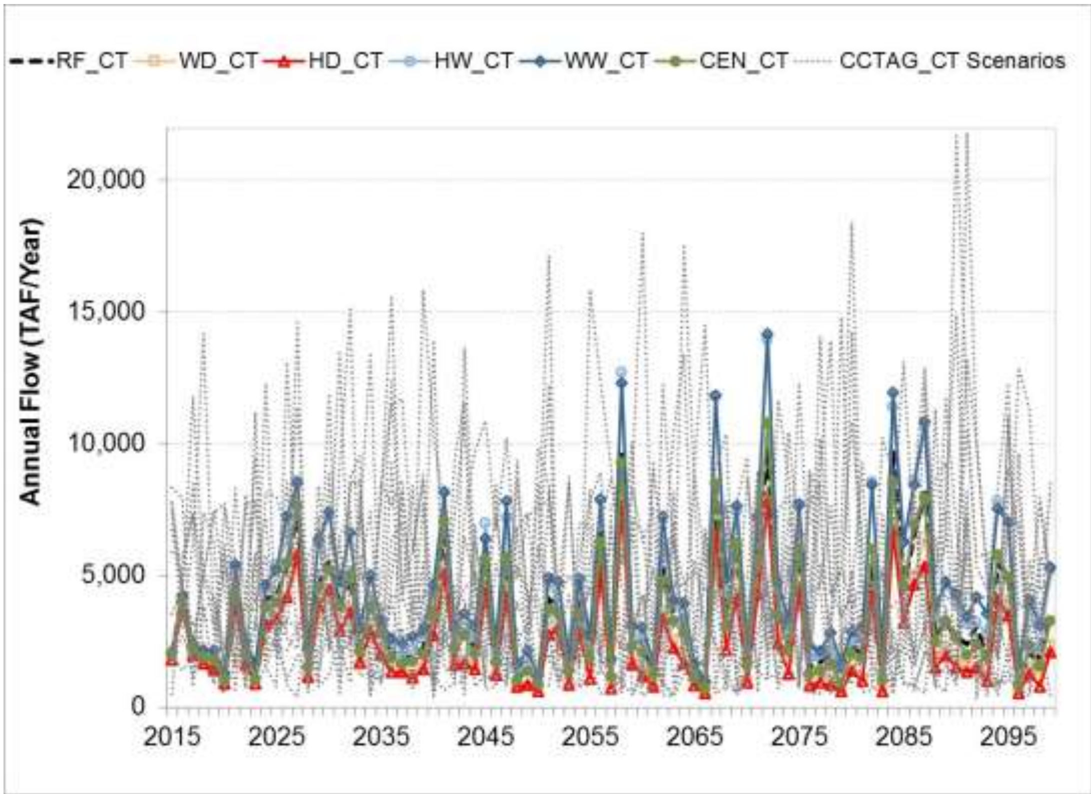


Figure 3-20d. Projected annual time series of streamflow in the **Tulare Lake Region** in each climate scenario.

4. Water Demand Assessment

The water demand assessment was performed for the socioeconomic-climate scenarios developed using the scenario planning approach described in Section 2. *Socioeconomic-Climate Futures.* This section provides a quantitative evaluation of recent historical and projected future agricultural and urban demands in each of the Central Valley basins.

4.1. Objective and Approach

4.1.1. Assessment of Recent Historical Demand

Recent historical water demand information for the Sacramento-San Joaquin Basins was obtained from the water use information developed by the CWP for 1998 through 2010. For this Basins Study, the crop evapotranspiration rates (ET) computed in the WEAP-CV Plant Growth Model (PGM) were updated by calibrating to results calculated by DWR's CUP crop water use model under recent climatic conditions. The resulting overall Central Valley agricultural water use requirements compared favorably with values used in the CWP. Additionally, historical water use and trends, geographic and sector-based demand trends, and trends in water use efficiency and urban and agricultural footprints were evaluated and are reported below.

4.1.2. Assessment of Future Demand

Uncertainty related to future conditions exists in numerous areas, adding additional complexity to assessing future water demand conditions. Key areas of uncertainty related to water demand projections:

- Future land uses and agricultural practices
- Conservation and efficiency achievement
- Assumed population growth rates
- Potential impact of climate change on water demands, reservoir evaporation, and vegetation demands
- Potential future in-stream flow requirements (beyond those already reflected in existing regulatory requirements)
- Degree to which regions outside of the Central Valley depend on Central Valley water supplies

Scenarios that reasonably bracket a range of potential future water demands had been developed in previous planning studies. As described in Section 2, water demand scenarios for this Basins Study were developed for three scenarios that DWR developed for the CWP (DWR 2014 [Water Plan]):

- **Expansive Growth,** which assumes projections of high population growth and low urban density.

- **Current Trends**, which assumes current trends projections of population growth and urban density.

- **Slow Growth**, which assumes projections of low population growth and high urban density.

Each of these socioeconomic scenarios were combined with the Reference-No-Climate-Change and five ensemble future climate projections to develop a suite of 18 future scenarios. In addition, the Current Trends socioeconomic projection was combined with 12 CCTAG climate scenarios as a fair test to compare how climate change may impact the resource system under different modeling approaches. This results in a total of 30 future socioeconomic-climate scenarios to characterize a plausible range of potential future water demands:

(3 total scenarios) Reference-No-Climate-Change scenario with three socioeconimc scenarios

(15 total scenarios) 5 ensemble climate scenarios with three socioeconimc scenarios

(12 total scenarios) 12 CCTAG climate scenarios with the Current Trends socioeconomic scenario

The WEAP-CV model was used to develop climate-based agricultural and urban water demand estimates for the Bay-Delta, Sacramento, San Joaquin, and Tulare Lake hydrologic regions. In addition to temperature and precipitation, WEAP-CV requires additional climate inputs to simulate the effects of changes in solar radiation, atmospheric humidity, wind speed and carbon dioxide (CO_2) on agricultural water use. These climate inputs were developed from the same climate projections used to estimate future water supply changes described in Section 3. *Water Supply Assessment* to have a consistent climate based water supply and demand assessment. The methods used to develop the additional projected climate inputs are described in 4B. *Climate Inputs for the WEAP-CV Agricultural Demands.*

The PGM employs a variety climatic inputs as well as crop specific parameters to compute crop water use and yields. An important reason for including the PGM in WEAP-CV is its ability to simulate the effects of carbon dioxide (CO_2) on crop growth (carbon fertilization) and water use efficiency (amount of water transpired per unit of biomass produced). As CO_2 increases, plants are generally able to transpire less water for a given amount of growth. Counterbalancing this effect is the fact many plants respond to higher CO_2 by growing more. These effects have been well documented in the scientific literature (Ainsworth and Long 2005).

Another important aspect of the PGM is that it simulates the effects of atmospheric vapor pressure deficit (VPD) on crop ET. The VPD is a measure of humidity of the air. As temperature increases VPD increases proportionately and generally a corresponding increase in crop ET occurs. However, when VPD increases beyond certain limits, plants respond in varying degrees by reducing their transpiration to prevent excessive loss of cell fluids (Ocheltree et al 2014). The balance between these processes along with other factors determines whether increasing temperature, CO2 and VPD will result more or less crop water use.

The WEAP-CV PGM was employed to simulate each of the socioeconomic-climate scenarios for water years 2015 through 2099. Each scenario was simulated using a transient approach in which the climate, population and irrigated land areas gradually change as the simulation progresses through time. As previously described in Section 1. *Technical Approach*, the climate-based demand results produced by WEAP-CV were used as inputs to the CalLite-CV model to perform the system risk and reliability assessment presented in Section 5. *System Risk and Reliability Assessment.*

4.2. Summary of Results

4.2.1. Recent Historical Demand

Table 4-1 presents the total historical agricultural and urban applied water use in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions as well as for the entire Central Valley from 1998 to 2010. In the Central Valley, agricultural demand ranged from 18,752 to 27,269 TAF/year during this period, while urban demand ranged from 1,794 TAF/year to 2,461 TAF/year. The differences in agricultural and applied water use in each year are caused by changes in many factors, including: population, land use, conservation measures, precipitation, temperature, and water availability.

Table 4-1. Historical Applied Water Use in the Central Valley (in TAF/year). Source: DWR, 2014

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Sacramento River Hydrologic Region													
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 Hydrologic Region													
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 Hydrologic Region													
Agricultural	7,831	10,138	10,006	9,976	10,514	9,969	10,659	9,298	9,919	10,743	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	10,65	11,535	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	23,76	26,847	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	26,09	29,233	29,730	29,086	25,975

Source: DWR, 2014

To gain some additional insights into historical water demands over a longer period of time, a historical reference climate scenario (Reference-No-Climate-Change) combined with a reference socioeconomic scenario (2006 Historic Demands) (RF-RF) were employed. These scenarios assumed that the historical climate that occurred between 1923 and 2010 would apply to the future climate, 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 2010 (Figure 4-1). The simulation provides a reference point for comparisons with the other projected socioeconomic-climate scenarios presented in the following sections.

Figure 4-1 provides annual time series projections for agricultural and urban applied water demands for the CVP, SWP, and non-project water users in the Central Valley, Sacramento River system, East Side streams and the Delta, San Joaquin River system and Tulare Lake regions from 2015 through 2099. Because population and land use do not change over time in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF), the year-to-year variability in demand was due to changes in annual temperature, precipitation, and other meteorological conditions affecting evapotranspiration (ET) in the historical period climate. In all the regions, urban demands were fairly consistent across all years of the simulation.

Agricultural demands varied according to the historical climate, with higher demands in drier years and lower demands in wetter years. The slight decline in agricultural water demands over the simulation period is largely related to the slight increase in precipitation in the later part of simulated historical period (See Section 3. *Water Supply Assessment*). The total Central Valley agricultural demand ranged from 18,561 TAF/year to 38,765 TAF/year, reflecting year-to-year variability in precipitation and temperature during the historical period. The total Central Valley urban demand ranged from 1,518 TAF/year to 1,908 TAF/year.

Table 4-2 shows the simulated average annual agricultural and urban demands in the Central Valley and hydrologic regions under the Reference-No-Climate-Change climate scenario/2006 Historic Demands socioeconomic scenarios (RF_RF).

Figure 4-1. Agricultural and urban water demand time series.

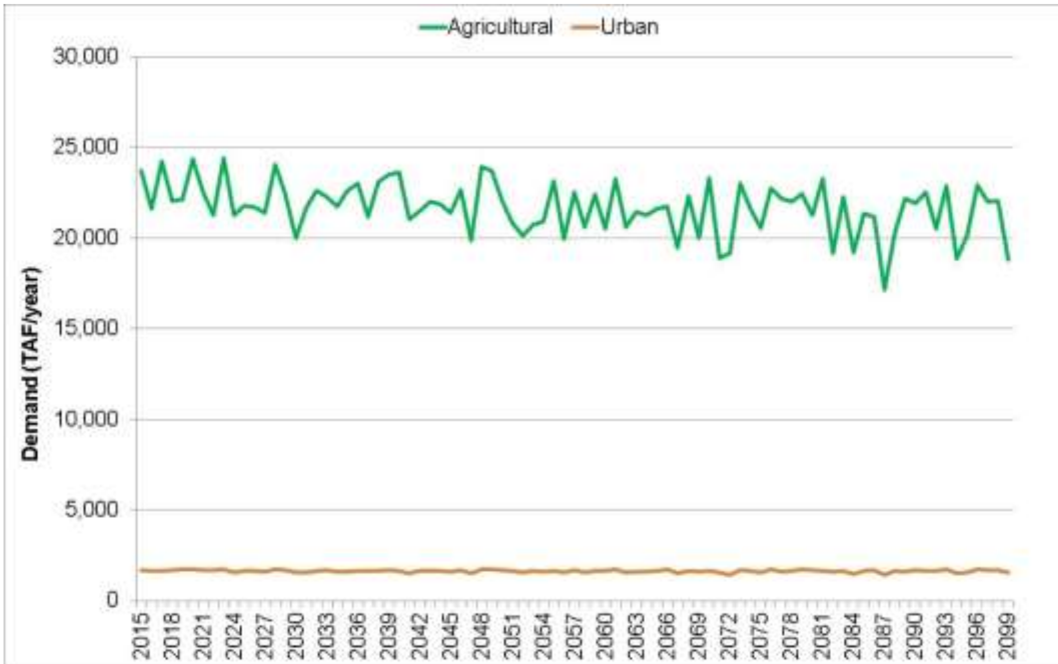


Figure 4-1a. Annual time series of simulated recent historical agricultural and urban applied water demand with historical climate and hydrology in the **Central Valley.**

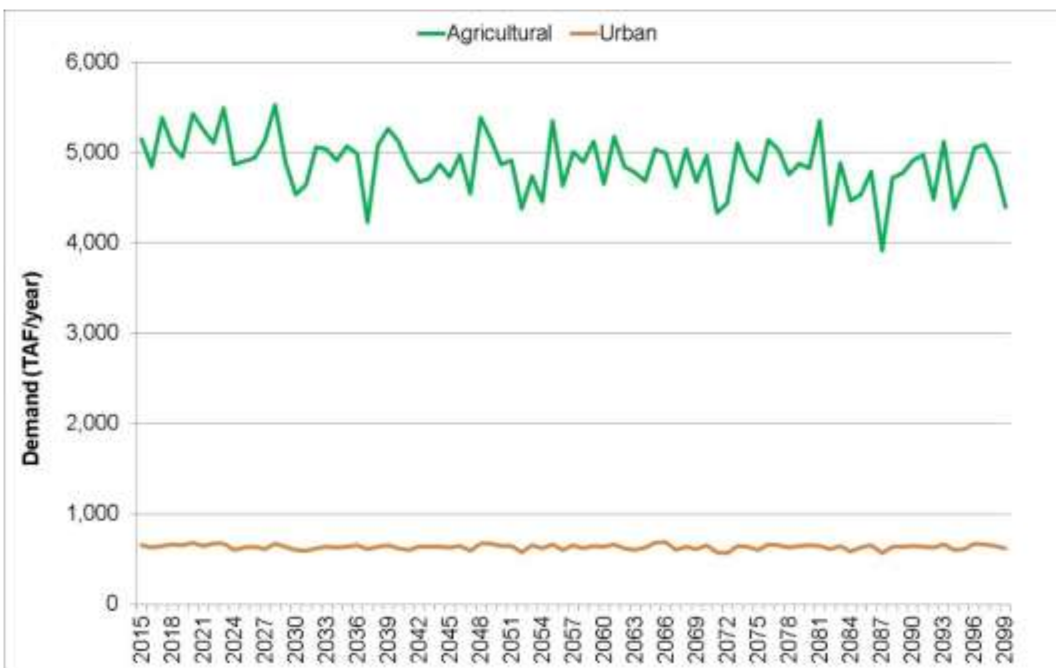


Figure 4-1b. Annual time series of simulated recent historical agricultural and urban applied water demand with historical climate and hydrology in the **Sacramento River system.**

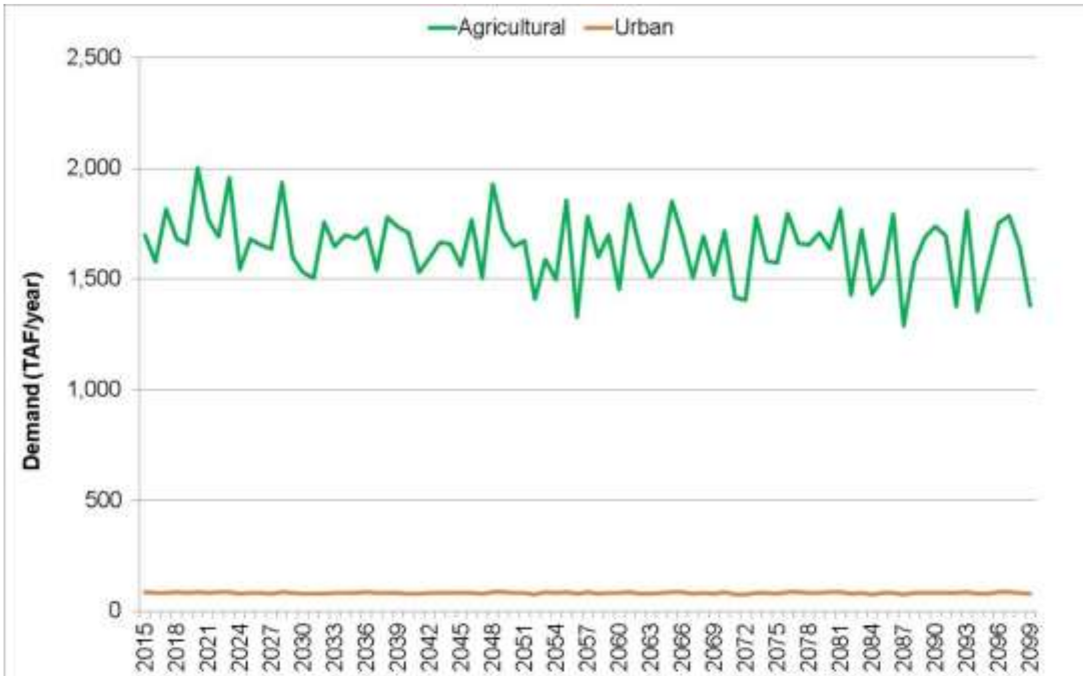


Figure 4-1c.Annual time series of simulated recent historical agricultural and urban applied water demand with historical climate and hydrology in the **San Joaquin River System.**

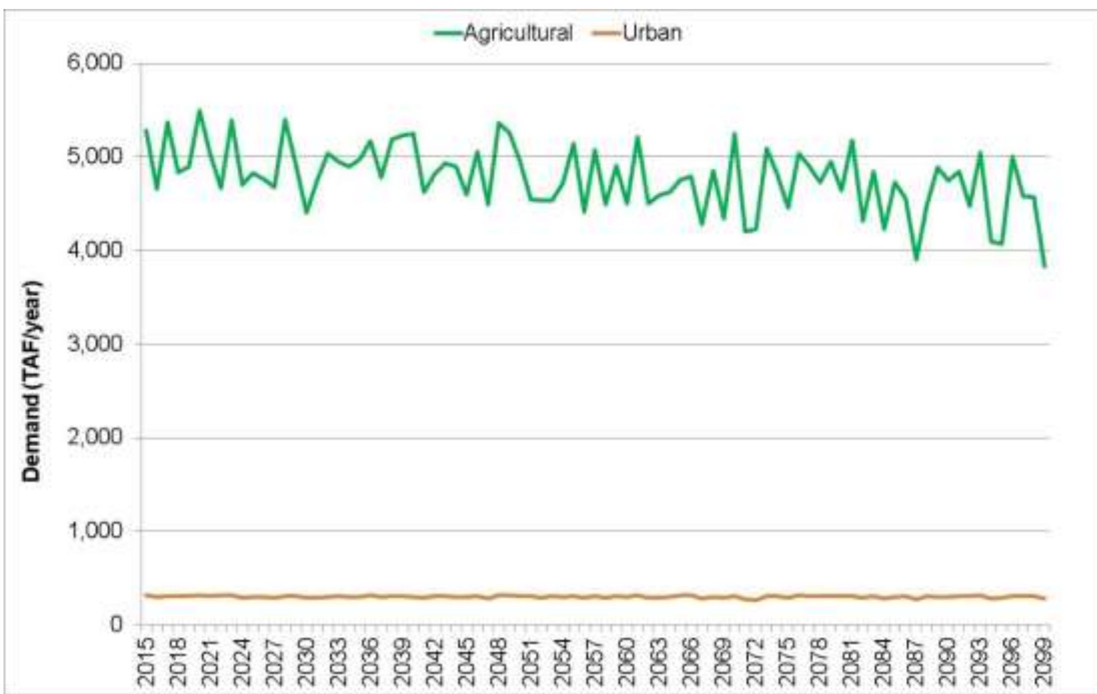


Figure 4-1d. Annual time series of simulated recent historical agricultural and urban applied water demand with historical climate and hydrology in the **Tulare Lake Region.**

Table 4-2. Average Annual Agricultural and Urban Applied Water Historical Demand (in TAF/year) in Each Scenario

	Agricultural	Urban	Total
Total Central Valley	21,683	1,631	23,314
Sacramento River System	4,876	634	5,510
Delta and Eastside Streams	1,645	82	1,727
San Joaquin River System	4,778	302	5,080
Tulare Lake region	10,385	613	10,997

4.2.2. Future Projected Demand

Using multiple scenarios to capture the effects of future uncertainties in population, land use and climate is an important aspect of projecting future water demands. As described in Section 2. *Socioeconomic-Climate Future Scenarios*, three socioeconomic scenarios were used to represent three potential levels of future changes in population with the Slow Growth, Current Trends, and Expanded Growth representing increasing levels of population with decreasing urban land use density.

This approach recognizes that as population increases, agricultural land area typically is also reduced to varying degrees. This land use change assumption is based on observations that as urban population increases some adjacent agricultural land is often incorporated into urban areas. The magnitude of the reduction in agricultural land typically occurs proportionately to population growth. Consequently, projected agricultural water demands would tend to decline over time with fewer acres of future irrigated lands, and, correspondingly, future urban demands may be anticipated to most likely increase with increasing population. Even though irrigated acreages were simulated as declining, the amount of contracted water supply available to the agricultural and urban contractors was not reduced.

4.2.2.1. Future Projected Agricultural Demand

In addition to land use assumptions, other aspects of the simulations influence the results presented here. These factors include the types of crops and their "growing season." There are many different crops grown in the Central Valley and it is not possible to precisely simulate all of them. Consequently, the crop types used by DWR in the CWP and other studies (see Appendix 4C. *WEAP-CV Calibration of PGM*) were employed because these categories have been typically used in studies and are widely accepted and familiar to the participants. Table 4-3 provides a listing of these representative categories.

Table 4-3. Central Valley Crop Types, Growth Period and Projected Acreages in the Current Trends Socio-Economic Scenario during 21st Century

Crop Type Category	Length of Growth Period	Start of Growth Period	End of Growth Period	Crop Acreage (Acres)	Period Average		
	Days	Date	Date	2012	2012-2039	2040-2069	2070-2099
Alfalfa	365	1-Jan	31-Dec	670,002	651,179	537,777	544,460
Almond/Pistachio	229	1-Mar	15-Oct	777,531	775,071	753,178	757,052
Other Deciduous	229	1-Apr	15-Nov	565,300	557,187	516,135	462,809
Pasture	365	1-Jan	31-Dec	259,635	258,678	209,569	142,557
Subtropical	365	1-Jan	31-Dec	247,333	246,980	224,105	243,875
Vineyards	215	1-Apr	1-Nov	591,866	587,760	529,984	484,574
Corn	153	1-May	15-Aug	654,120	623,784	509,202	426,455
Cotton	154	15-May	31-Aug	665,770	661,580	596,587	638,042
Cucurbits	123	15-May	15-Sep	91,414	91,303	87,087	90,639
Dry Beans	108	15-Jun	30-Sep	60,746	59,294	51,574	37,819
Grain	212	1-Nov	31-May	360,558	364,500	304,440	296,034
Onion + Garlic	215	1-Mar	1-Oct	44,925	44,768	39,709	43,677
Other Field	107	1-May	15-Aug	412,383	378,927	269,827	165,864
Other Truck-Cucumber[1]	93	15-May	31-Aug	215,886	207,971	180,453	198,905
Other Truck-Lettuce[2]	73	25-Aug	5-Nov				
Potatoes	123	15-Apr	15-Aug	25,879	24,834	24,755	24,656
Rice	139	15-May	30-Sep	496,146	546,137	522,968	487,804
Safflower	122	1-Apr	31-Jul	50,213	48,936	44,838	38,556
Sugar Beets	200	15-Mar	30-Sep	27,306	21,026	20,016	20,136
Tomatoes	153	1-Apr	31-Aug	340,921	340,600	331,928	337,863
Total Perennial Crop Acreage				3,111,667	3,076,855	2,770,748	2,635,326
Total Annual Crop Acreage				3,446,266	3,413,660	2,983,383	2,806,449
Total Central Valley Crop Acreage				6,557,933	6,490,515	5,754,131	5,441,775

Notes: 1. Sacramento Valley only. 2. San Joaquin and Tulare Lake Basins only.

Using a "growing season" length based on the recent historical growth period was another important assumption made in this study. This choice may seem at odds with the phenomena of global warming which, at first blush, would appear to lengthen the growing season by allowing crops to be begin growing earlier in the spring and continue growing later in the fall. While this lengthening of the overall growing season occurs with warming, the result of warmer temperatures effects individual crops differently and depends on the magnitude of warming. However, it is important to recognize that planting dates which may or may not occur before the start of the growth period are not solely based on temperature. Other factors are often considered. First, management considerations are important. For example, the effects of precipitation on the preparation of fields for planting in the spring and soil conditions during harvesting in the fall are major considerations. Moreover, warmer temperatures result in more rapid crop growth which counteracts the extension of the potential growing season by reducing the growth period. Thus, a temperature driven reduction in growth period may actually result in less rather than more total crop ET. This phenomenon affects most annual crops and some perennials. As can be noted from Table 4-3, annual crops make up slightly more than half of the Central Valley crops and some perennial crops including alfalfa, pasture and subtropicals (mainly citrus) were simulated throughout the entire year.

It is also worth noting that, a reduction in a crop's growth period is not desirable because it generally reduces the crop's yield and its economic value. Therefore, it is likely that growers will adapt to warming temperatures by seeking more heat tolerant cultivars that grow more slowly. Thus, using the current growth period as presented in Table 4-3 to simulate future water demand is a conservative assumption to maximize agricultural water demand as the model uses longer simulated growth periods than would have been otherwise simulated based solely on higher temperatures. Furthermore, for perennial crops with growth periods of less than 365 days (vineyards and other deciduous), as most of their water use would still occur within their current relatively long growth periods (see Table 4-3), their crop water demands should not be significantly underestimated. Therefore, the lengths of growth period used in this study are defined as the elapsed time in days between the historical period dates specified in Table 4-3.

Table 4-4 shows the average annual agricultural applied water demands (including CVP, SWP, and non-project water users) in the Central Valley, Sacramento River, East Side streams and the Delta, San Joaquin River, and Tulare Lake regions for each of the reference climate and ensemble-informed socioeconomic-climate scenarios.

As can be observed from the table, total agricultural water demands varied with the socioeconomic-climate scenarios. In all basins, agricultural demands showed a strong relationship to the climate scenarios with the less warming, wetter scenarios having less agricultural water demand than the hotter, drier ones. As expected, the climate scenarios under the Slow Growth socioeconomic scenario which have the largest irrigated areas had the highest agricultural water demands, while the climate scenarios under the Current Trends and Expanded Growth socioeconomic scenarios had progressively lower demands.

Table 4-4. Agricultural Applied Water Demand

Table 4-4a. Average Annual Agricultural Applied Water Demand in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_EG	Warm-Dry_EG	Hot-Dry_EG	Hot-Wet_EG	Warm-Wet_EG	Central_EG
Total Central Valley	2015-2039	21,389	21,389	22,112	21,644	21,089	21,611
	2040-2069	19,456	19,456	19,542	18,948	18,726	19,324
	2070-2099	17,935	17,935	14,978	14,469	16,838	16,658
	2015-2099	**19,488**	**19,488**	**18,687**	**18,160**	**18,755**	**19,056**
Sacramento River System	2015-2039	4,653	4,653	4,801	4,753	4,633	4,734
	2040-2069	4,155	4,155	4,221	4,156	4,075	4,189
	2070-2099	3,788	3,788	3,371	3,325	3,676	3,655
	2015-2099	**4,172**	**4,172**	**4,092**	**4,038**	**4,098**	**4,161**
Delta and Eastside Streams	2015-2039	1,632	1,632	1,687	1,656	1,613	1,659
	2040-2069	1,468	1,468	1,456	1,407	1,398	1,444
	2070-2099	1,315	1,315	989	961	1,225	1,182
	2015-2099	**1,462**	**1,462**	**1,359**	**1,323**	**1,400**	**1,415**
San Joaquin River System	2015-2039	4,789	4,789	4,971	4,849	4,719	4,839
	2040-2069	4,362	4,362	4,403	4,248	4,160	4,329
	2070-2099	3,902	3,902	3,157	3,048	3,626	3,577
	2015-2099	**4,325**	**4,325**	**4,130**	**4,001**	**4,136**	**4,214**
Tulare Lake Region	2015-2039	10,315	10,315	10,652	10,387	10,124	10,378
	2040-2069	9,471	9,471	9,462	9,136	9,093	9,362
	2070-2099	8,930	8,930	7,461	7,135	8,311	8,244
	2015-2099	9,528	9,528	9,106	8,798	9,120	9,266

Table 4-4b. Average Annual Agricultural Applied Water Demand in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	21,722	21,964	22,456	21,979	21,416	21,946
	2040-2069	20,135	19,919	20,211	19,594	19,373	19,990
	2070-2099	19,081	18,537	15,864	15,326	17,905	17,695
	2015-2099	**20,230**	**20,033**	**19,337**	**18,789**	**19,456**	**19,756**
Sacramento River System	2015-2039	4,746	4,804	4,896	4,846	4,724	4,828
	2040-2069	4,339	4,304	4,404	4,334	4,253	4,372
	2070-2099	4,107	4,030	3,627	3,575	3,980	3,951
	2015-2099	**4,377**	**4,354**	**4,275**	**4,217**	**4,295**	**4,357**
Delta and Eastside Streams	2015-2039	1,655	1,674	1,712	1,680	1,637	1,683
	2040-2069	1,523	1,481	1,508	1,458	1,448	1,497
	2070-2099	1,438	1,373	1,075	1,044	1,339	1,290
	2015-2099	**1,532**	**1,500**	**1,415**	**1,377**	**1,465**	**1,479**

Location	Period	Reference_ CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_ CT
San Joaquin River System	2015-2039	4,880	4,937	5,065	4,940	4,807	4,930
	2040-2069	4,553	4,493	4,591	4,429	4,341	4,516
	2070-2099	4,247	4,112	3,414	3,297	3,945	3,884
	2015-2099	**4,541**	**4,489**	**4,315**	**4,180**	**4,338**	**4,415**
Tulare Lake Region	2015-2039	10,442	10,549	10,783	10,514	10,248	10,506
	2040-2069	9,720	9,642	9,708	9,373	9,330	9,606
	2070-2099	9,289	9,021	7,748	7,410	8,641	8,569
	2015-2099	**9,780**	**9,690**	**9,333**	**9,016**	**9,357**	**9,505**

Table 4-4c. Average Annual Agricultural Applied Water Demand in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Trends Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_ SG	Warm-Dry_SG	Hot-Dry_SG	Hot-Wet_SG	Warm-Wet_SG	Central_S G
Total Central Valley	2015-2039	21,966	22,210	22,707	22,224	21,655	22,192
	2040-2069	20,688	20,452	20,743	20,104	19,893	20,525
	2070-2099	19,887	19,296	16,444	15,876	18,634	18,399
	2015-2099	**20,781**	**20,561**	**19,803**	**19,235**	**19,967**	**20,265**
Sacramento River System	2015-2039	4,794	4,853	4,946	4,894	4,771	4,877
	2040-2069	4,440	4,400	4,501	4,427	4,348	4,469
	2070-2099	4,199	4,115	3,687	3,632	4,063	4,030
	2015-2099	**4,459**	**4,433**	**4,345**	**4,284**	**4,372**	**4,434**
Delta and Eastside Streams	2015-2039	1,664	1,683	1,721	1,689	1,646	1,692
	2040-2069	1,550	1,507	1,534	1,482	1,473	1,523
	2070-2099	1,489	1,422	1,110	1,078	1,385	1,335
	2015-2099	**1,562**	**1,529**	**1,440**	**1,400**	**1,493**	**1,506**
San Joaquin River System	2015-2039	4,949	5,007	5,135	5,009	4,875	5,000
	2040-2069	4,708	4,641	4,738	4,572	4,485	4,665
	2070-2099	4,481	4,332	3,577	3,452	4,157	4,088
	2015-2099	**4,699**	**4,640**	**4,445**	**4,305**	**4,484**	**4,560**
Tulare Lake Region	2015-2039	10,559	10,66	10,90	10,632	10,36	10,62
	2040-2069	9,990	9,904	9,969	9,623	9,586	9,868
	2070-2099	9,718	9,426	8,071	7,714	9,028	8,946
	2015-2099	**10,062**	**9,960**	**9,574**	**9,246**	**9,618**	**9,765**

In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the average annual total Central Valley agricultural demand was 20,230 TAF/year from 2015 to 2099 and had period averages:

- 2015 to 2039: 21,722 TAF/year
- 2040 to 2069: 20,135 TAF/year
- 2070 to 2099:19,081 TAF/year

Across the range of all of the socioeconomic-climate scenarios, average annual agricultural demand in the Central Valley was 19,547 TAF/year and ranged from:

- 2015 to 2099: 18,160 to 20,781 TAF/year
- 2015-2039: 21,089 to 22,707 TAF/year
- 2040-2069: 18,726 to 20,743 TAF/year
- 2070-2099: 14,469 to19,887 TAF/year

As discussed above, the plant growth models simulation of the effects of CO_2 and VPD on stomatal conductance revealed the important these effects on crop water use. As these biophysical processes are not accounted for in some ET algorithms, the results presented differ from some of the other studies (Reclamation 2014 [Climate]). However, it is important to note that there are studies that have found similar results similar to those presented here. Details of these studies are provided in Appendix 4D. *Agricultural Water Demand Simulations with WEAP-CV PGM*. In general, the agricultural demand differences are most significant in later part of the 21st century when increases in CO2 and VPD are greatest. These effects are most evident in the HD and HW climate projections in which CO2 concentrations exceeding 600 parts per million (ppm) and VPD greater than 1.3 kilo Pascals (kPa) occur in the late 21st century (see Appendix 4B. *Agricultural Water Demand Simulations with WEAP-CV PGM*).

Short-term variability and longer-term trends both exist in agricultural water demands. The short-term demand 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. Overall agricultural demands were projected to remain relatively constant in the early twenty-first century and begin to decline in the mid-century period primarily because of increasing temperature and VPD.

The longer-term trends show the combined effects of decreasing irrigated lands and climate changes. Overall, agricultural demands were projected to remain relatively constant in the early 21st century and begin to decline more significantly in the mid and late-century periods. In the early and mid-century period, the climate scenarios with less warming (Warm-Wet and Warm-Dry) have lower water demands than corresponding scenarios with more warming (Hot-Wet and Hot-Dry). However, this relationship changes in the late century period. This change is due primarily to two climate related factors, CO_2 and VPD:

- **CO_2.** The increase in the mid-century CO_2 from approximately 550 ppm to nearly 800 ppm by late century in the Hot-Wet and Hot-Dry climate scenarios is substantially more than the increase from approximately 500 to 550 ppm in the corresponding Warm-Wet and Warm-Dry cliamte scenarios (see Appendix 4B. *Agricultural Water Demand Simulations with WEAP-CV PGM*).

- **VPD.** The increase in VPD from approximately 1.3 kPa at mid-century to 1.4 kPa in the Hot-Wet and Hot-Dry climate scenarios during the late century is much more significant than the change in the Warm-Wet and Warm-Dry climate scenarios, which remain relatively constant at about 1.25 kPa (see Appendix 4B. *Agricultural Water Demand Simulations with WEAP-CV PGM*). In previous studies using a standard Penman-Monteith model (Reclamation 2014 [Irrigation]), increasing VPD results in higher crop transpiration. The results presented here reflect the WEAP-CV PGM's biologically based algorithms that simulate how crops respond to high VPD by reducing their transpiration when VPD exceeds crop specific threshold values (see Appendix 4C. *WEAP-CV Calibration of the PGM*).

Taken together, the effects of high CO_2 and VPD account for the larger reductions in agricultural water demands in the Hot-Wet and Hot-Dry scenarios relative to their corresponding Warm-Wet and Warm-Dry scenarios in the latter part of the 21st century.

Figure 4-2 presents annual time series from 2015 to 2099 of projected total agricultural and urban demands in the Central Valley as well as for the Sacramento River, East Side streams and Delta, San Joaquin River and Tulare Lake regions for each of the thirty socioeconomic-climate scenarios.

Figure 4-2. Time series of agricultural applied water demands.

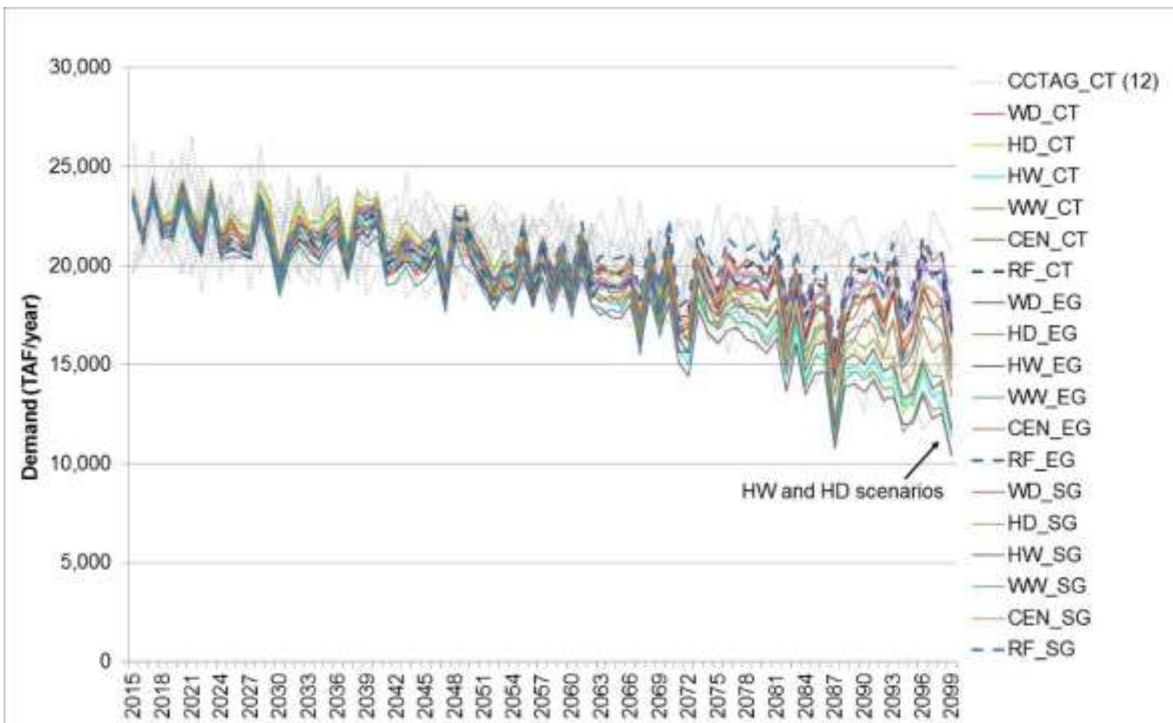


Figure 4-2a. Annual time series of agricultural applied water demand in the **Central Valley** in each scenario.

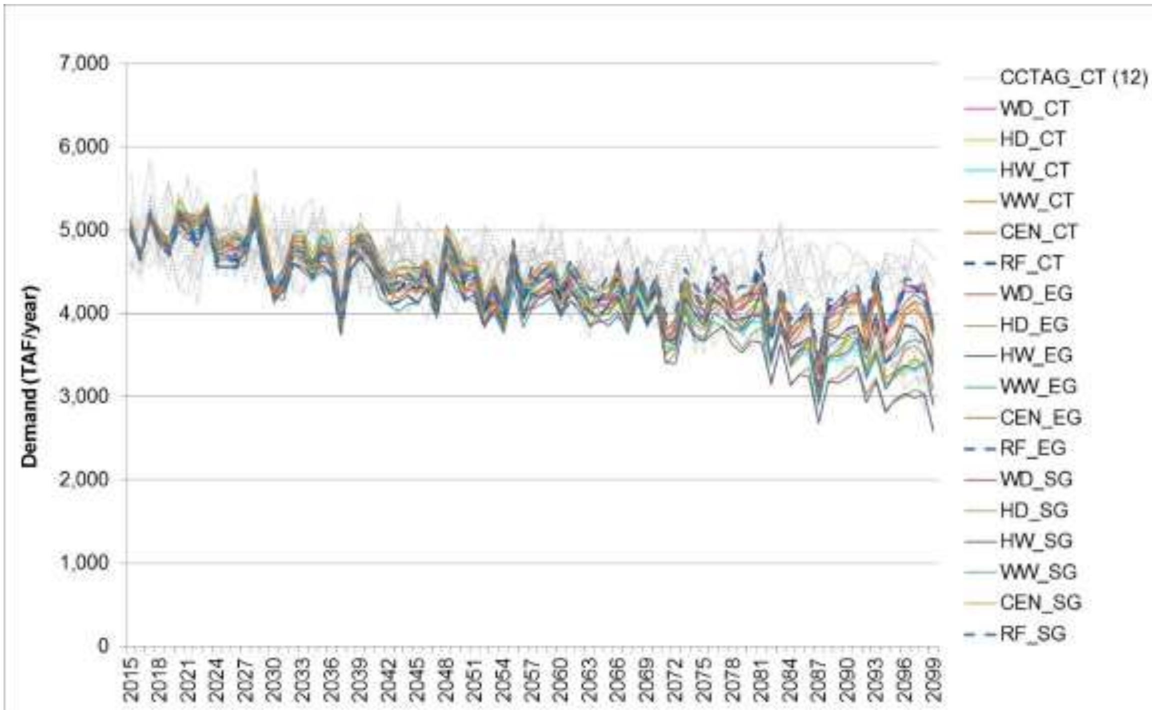


Figure 4-2b. Annual time series of agricultural applied water demand in the **Sacramento River system in** each scenario.

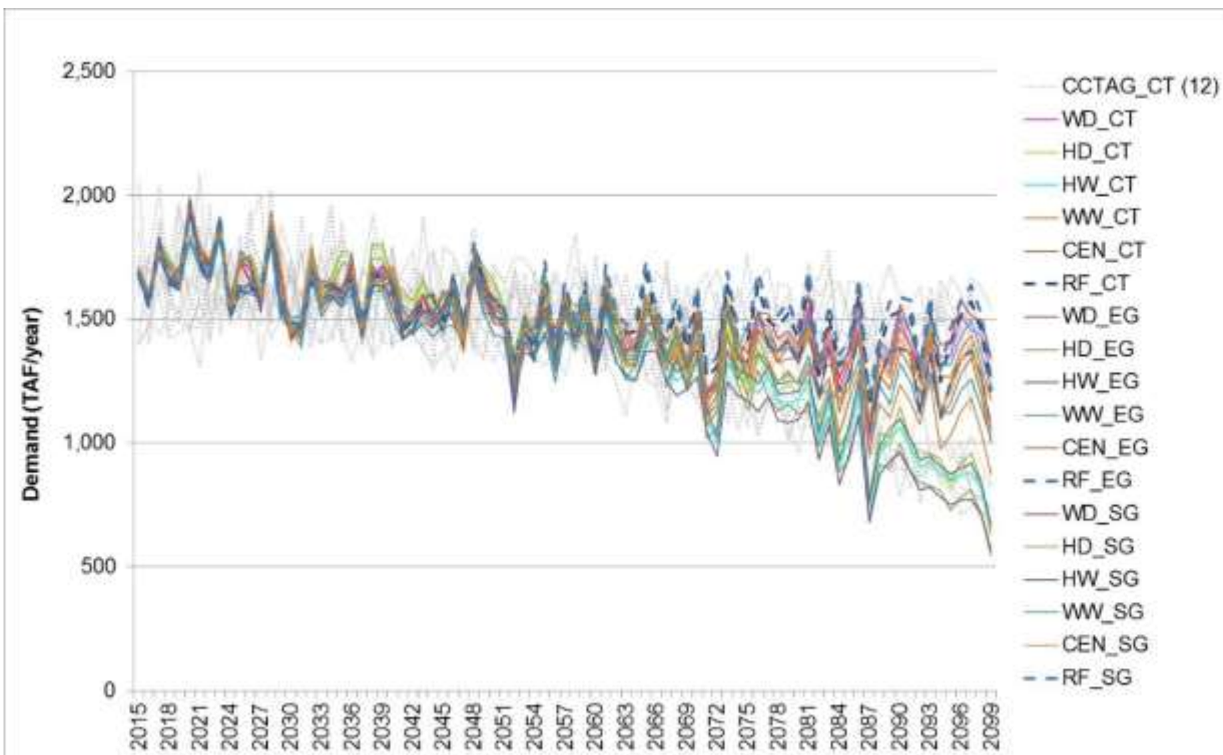


Figure 4-2c. Annual time series of agricultural applied water demand in the **East Side Streams and Delta** in each scenario.

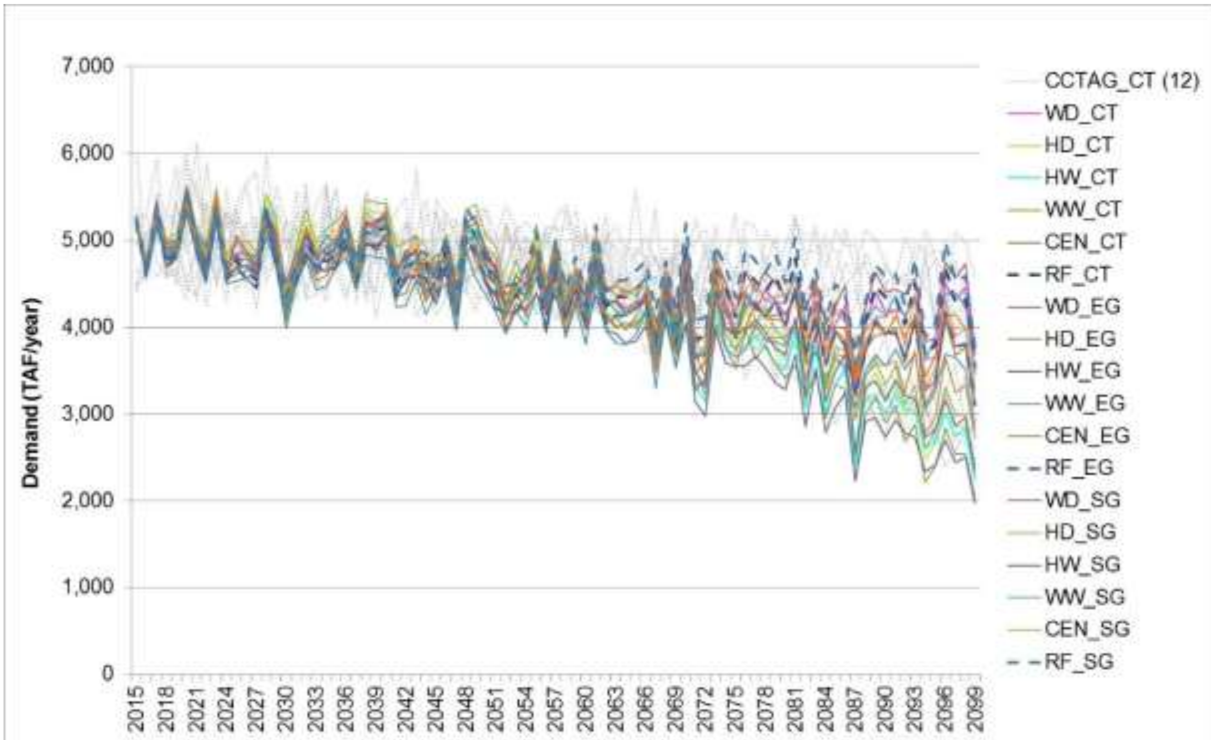


Figure 4-2d. Annual time series of agricultural applied water demand in the **San Joaquin River system** in each scenario.

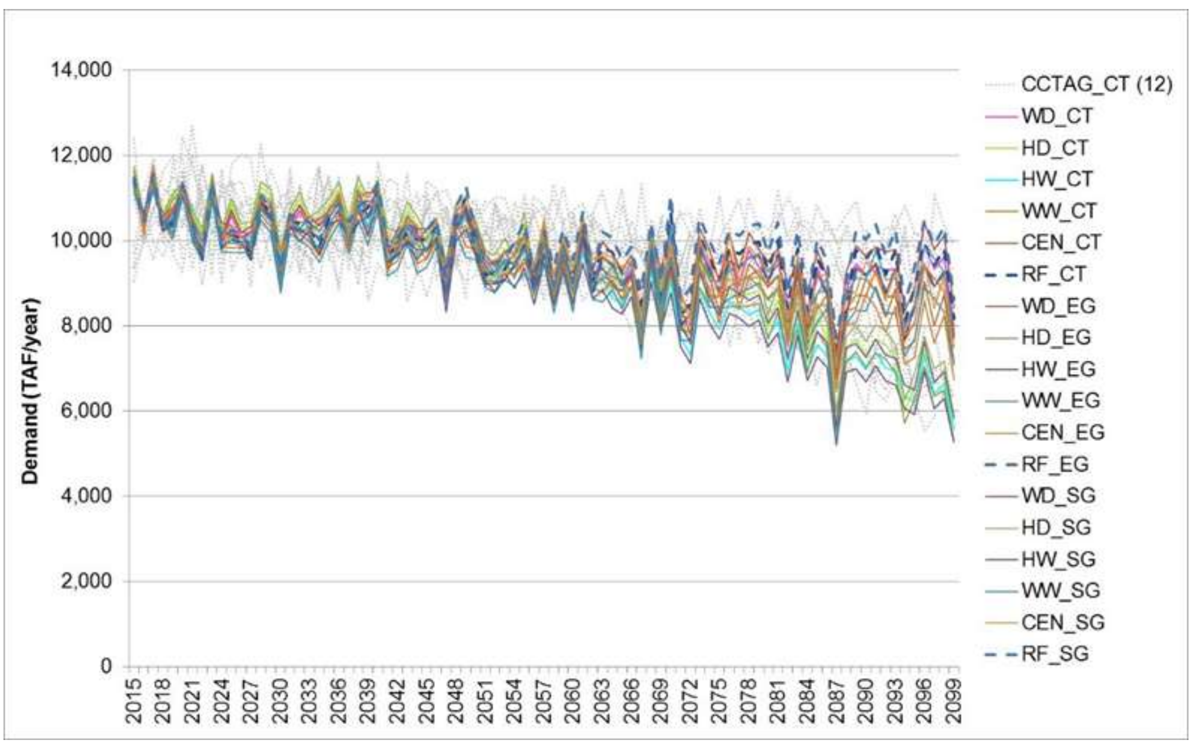


Figure 4-2e. Annual time series of agricultural applied water demand in the **Tulare Lake region** in each scenario.

4.2.2.2. Future Projected Urban Demand

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 contrast with agricultural demands, the urban demands do not show significant sensitivity to the climate scenarios. This result occurs because much of the urban demand is for indoor use, which was assumed to be less sensitive to precipitation variability. Furthermore, outdoor urban demands were not computed using the WEAP-CV PGM and therefore do not account for the effects of CO_2 and VPD on outdoor urban demands.

In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the total Central Valley urban demand averaged 2,970 TAF/year from 2015 to 2099 and had period averages:

- 2015 to 2039: 2,152 TAF/year
- 2040 to 2069: 2,920 TAF/year
- 2070 to 2099: 3,701 TAF/year

Across the range of all the socioeconomic-climate scenarios, the average annual total urban demand in the Central Valley was 3,244 TAF/year and ranged from:

- 2015 to 2099; 2,518 to 4,242 TAF/year
- 2015-2039: 2,035 to 2,470 TAF/year
- 2040-2070: 2,482 to 3,914 TAF/year
- 2070-2099: 2,957 to 6,048 TAF/year

Short-term variability and longer-term trends both exist in urban water demands. Although markedly reduced with respect agricultural demands, short-term demand variability in urban demand is correlated with the variability in annual precipitation. The longer term trends clearly reflect the assumptions expressed in the three socioeconomic scenarios with highest demands occurring in the Expanded Growth socioeconomic scenario and correspondingly reduced demands in the Current Trends and Slow Growth socioeconomic growth scenarios.

Table 4-5 shows the average annual urban water demands (including CVP, SWP, and non-project water users) in the Central Valley, Sacramento River, East Side streams and the Delta, San Joaquin River, and Tulare Lake regions for the Reference-No-Climate-Change and ensemble-informed climate scenarios over the projected period of water years from 2015 through 2099 and for the multi-decadal periods of 2015-2039, 2040-2069, and 2070-2099.

Figure 4-3 presents annual time series from 2015 to 2099 of projected total urban demands in the Central Valley, Sacramento River, East Side streams and Delta, San Joaquin River and Tulare Lake regions for the eighteen socioeconomic-climate scenarios and twelve CCTAG scenarios.

Table 4-5. Urban Applied Water Demands

Table 4-5a. Average Annual Urban Applied Water Demand in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario (in TAF/year)

Location	Period	Reference_EG	Warm-Dry_EG	Hot-Dry_EG	Hot-Wet_EG	Warm-Wet_EG	Central_EG
Total Central Valley	2015-2039	2,406	2,406	2,470	2,424	2,406	2,434
	2040-2069	3,778	3,778	3,914	3,841	3,789	3,852
	2070-2099	5,859	5,859	6,048	5,928	5,860	5,944
	2015-2099	**4,109**	**4,109**	**4,242**	**4,161**	**4,113**	**4,174**
Sacramento River System	2015-2039	848	848	867	852	847	857
	2040-2069	1,286	1,286	1,326	1,300	1,286	1,305
	2070-2099	1,966	1,966	2,026	1,990	1,967	1,994
	2015-2099	**1,397**	**1,397**	**1,438**	**1,411**	**1,398**	**1,416**
Delta and Eastside Streams	2015-2039	146	146	150	147	146	148
	2040-2069	226	226	234	228	225	230
	2070-2099	330	330	343	335	330	336
	2015-2099	**239**	**239**	**248**	**242**	**239**	**243**
San Joaquin River System	2015-2039	516	516	530	519	515	522
	2040-2069	844	844	876	857	844	860
	2070-2099	1,320	1,320	1,374	1,343	1,319	1,344
	2015-2099	**916**	**916**	**950**	**929**	**915**	**932**
Tulare Lake Region	2015-2039	894	894	923	906	897	906
	2040-2069	1,422	1,422	1,477	1,456	1,433	1,459
	2070-2099	2,243	2,243	2,304	2,260	2,244	2,270
	2015-2099	**1,557**	**1,557**	**1,606**	**1,578**	**1,562**	**1,583**

Table 4-5b. Average Annual Urban Applied Water Demand in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year)

Location	Period	Reference_CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	2,152	2,186	2,211	169	2,153	2,178
	2040-2069	2,920	2,995	3,036	2,977	2,933	2,986
	2070-2099	3,701	3,793	3,851	3,758	3,705	3,769
	2015-2099	**2,970**	**3,039**	**3,081**	**3,015**	**2,976**	**3,025**
Sacramento River System	2015-2039	744	757	761	747	743	753
	2040-2069	946	964	979	957	946	961
	2070-2099	1,116	1,140	1,162	1,134	1,117	1,137
	2015-2099	**947**	**965**	**980**	**958**	**947**	**962**
Delta and Eastside Streams	2015-2039	127	130	131	128	127	129
	2040-2069	171	175	177	173	171	174
	2070-2099	208	213	218	212	208	212
	2015-2099	**171**	**175**	**178**	**173**	**171**	**174**

Location	Period	Reference_CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_CT
San Joaquin River System	2015-2039	447	455	458	449	445	452
	2040-2069	621	636	646	631	620	633
	2070-2099	781	802	820	797	780	798
	2015-2099	**626**	**641**	**652**	**636**	**625**	**638**
Tulare Lake Region	2015-2039	833	845	861	845	837	845
	2040-2069	1,183	1,221	1,234	1,216	1,195	1,217
	2070-2099	1,597	1,639	1,651	1,614	1,601	1,622
	2015-2099	**1,226**	**1,258**	**1,271**	**1,248**	**1,233**	**1,250**

Table 4-5c. Average Annual Urban Applied Water Demand in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the **Slow Growth** Socioeconomic Scenario (in TAF/year)

Location	Period	Reference_SG	Warm-Dry_SG	Hot-Dry_SG	Hot-Wet_SG	Warm-Wet_SG	Central_SG
Total Central Valley	2015-2039	2,035	2,066	2,090	2,051	2,036	2,059
	2040-2069	2,482	2,550	2,587	2,537	2,496	2,542
	2070-2099	2,957	3,038	3,088	3,013	2,965	3,018
	2015-2099	**2,518**	**2,580**	**2,618**	**2,562**	**2,526**	**2,568**
Sacramento River System	2015-2039	687	698	703	690	686	694
	2040-2069	764	780	794	774	764	778
	2070-2099	820	841	861	836	821	839
	2015-2099	**761**	**778**	**791**	**771**	**761**	**775**
Delta and Eastside Streams	2015-2039	124	126	127	124	124	125
	2040-2069	161	164	166	162	160	163
	2070-2099	202	206	210	205	202	205
	2015-2099	**164**	**168**	**170**	**166**	**164**	**167**
San Joaquin River System	2015-2039	431	439	442	433	430	436
	2040-2069	572	585	594	581	572	583
	2070-2099	733	751	766	747	733	748
	2015-2099	**588**	**601**	**610**	**596**	**587**	**598**
Tulare Lake Region	2015-2039	793	803	819	804	797	803
	2040-2069	985	1,021	1,033	1,020	999	1,018
	2070-2099	1,201	1,240	1,250	1,224	1,210	1,225
	2015-2099	**1,005**	**1,034**	**1,047**	**1,028**	**1,014**	**1,028**

Figure 4-3. Time series of urban applied water demands

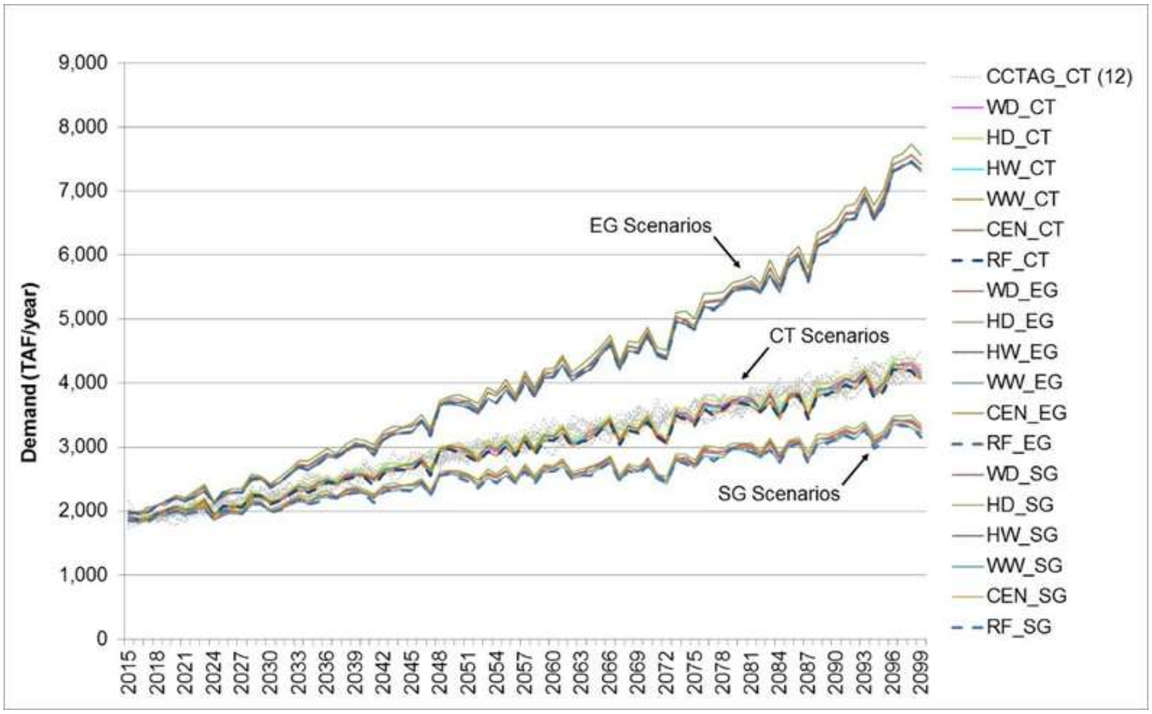


Figure 4-3a. Annual time series of total urban applied water demand in the **Central Valley** in each scenario.

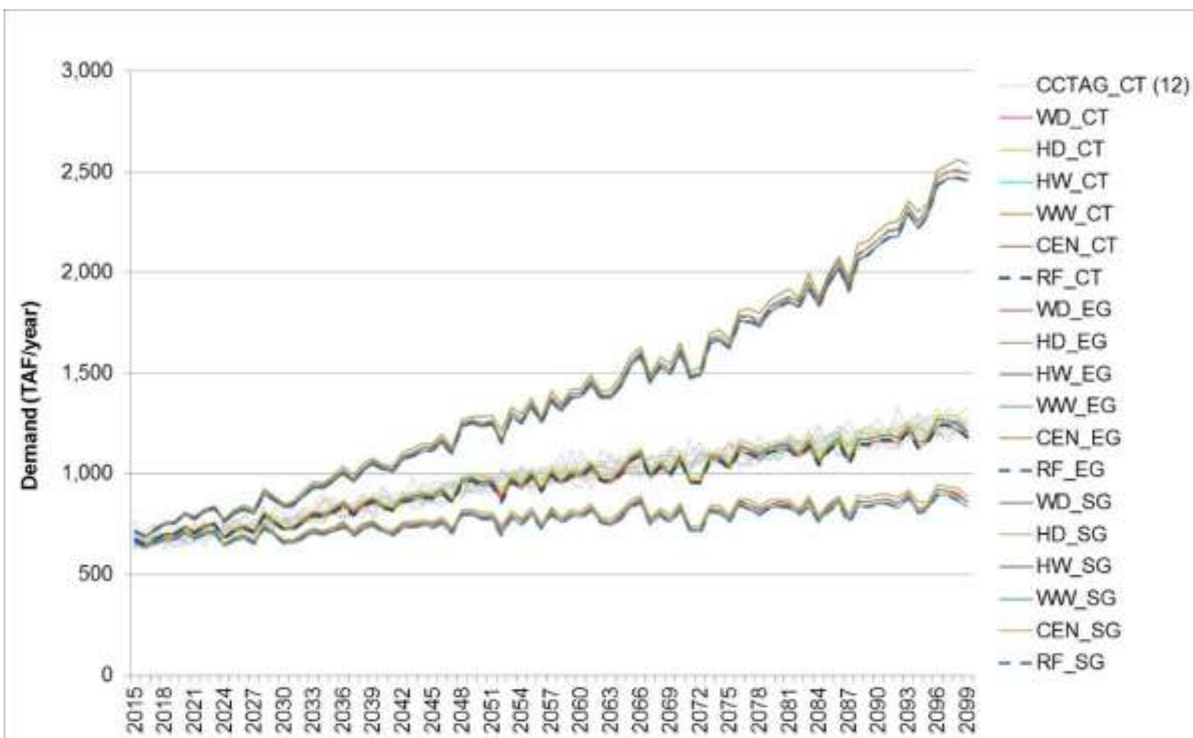


Figure 4-3b. Annual time series of urban applied water demand in the **Sacramento River system** in each scenario.

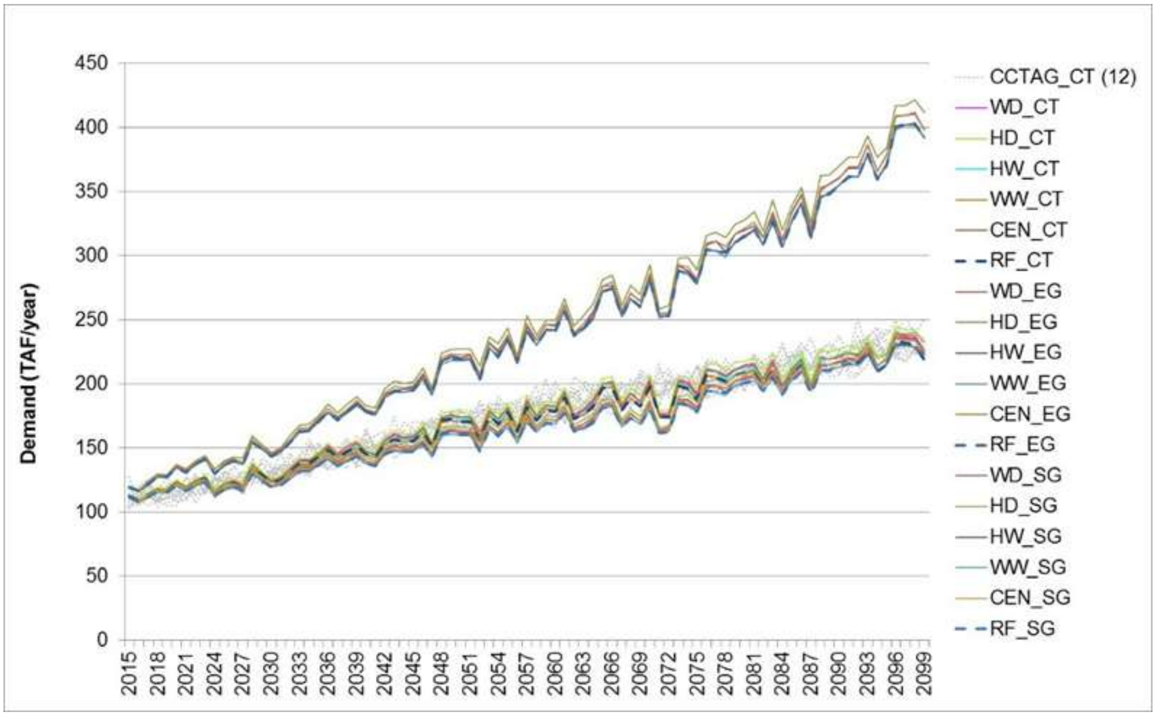


Figure 4-3c. Annual time series of urban applied water demand in the **East Side Streams and Delta in** each scenario.

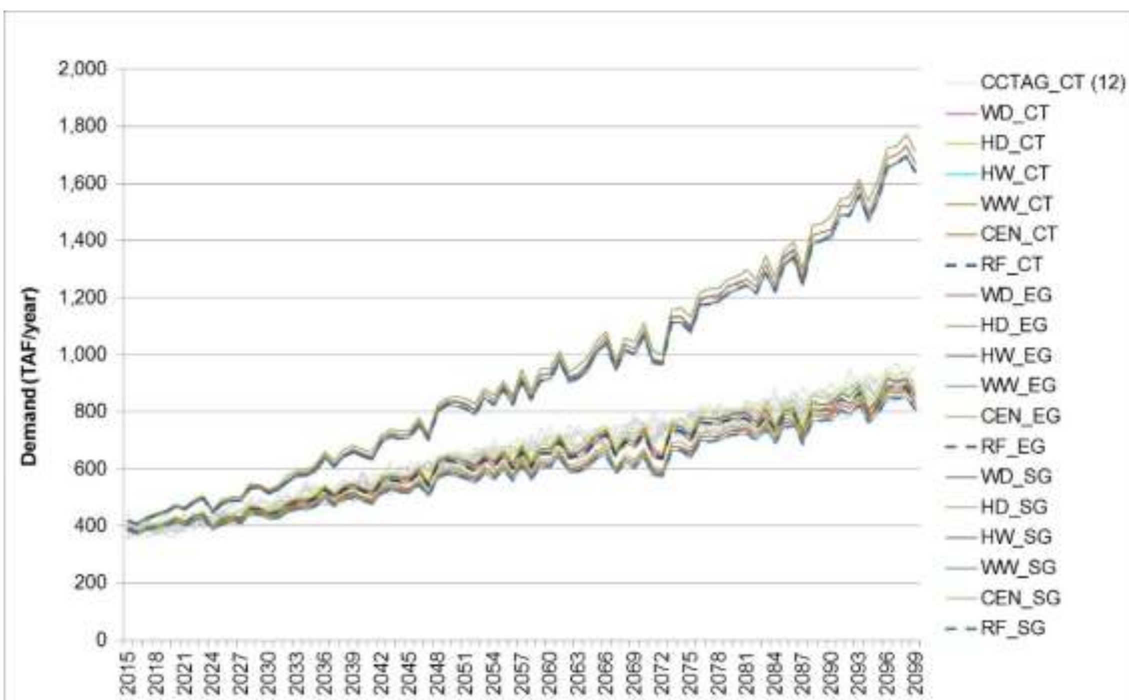


Figure 4-3d. Annual time series of urban applied water demand in the **San Joaquin River** system in each scenario.

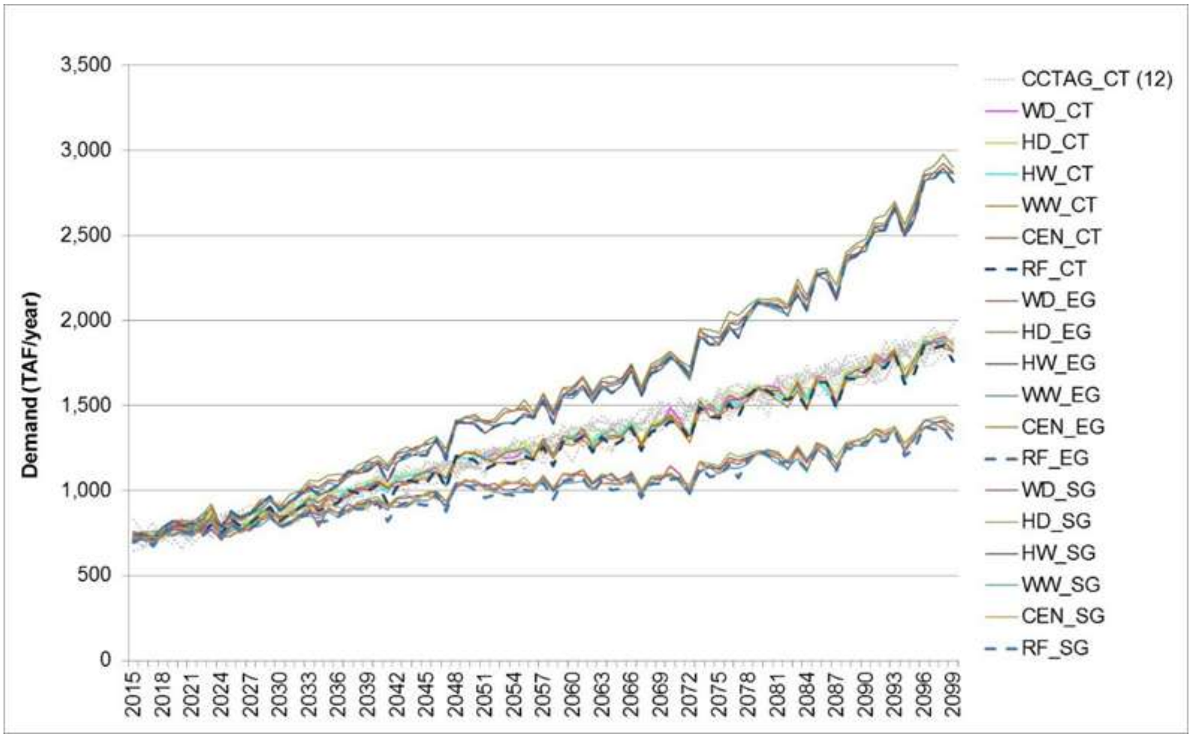


Figure 4-3e. Annual time series of urban applied water demand in the **Tulare Lake region** in each scenario.

5. System Risk and Reliability Assessment

This section describes impacts under the No Action alternative. See Section 7. *Adaptation Portfolios Evaluation* for a parallel discussion of impacts under adaptation portfolios.

5.1. Indicators and Summary of Results

5.1.1. Indicators

System reliability metrics are performance measures that indicate the ability of the current water management system to meet Central Valley water and related resource needs. These metrics were used to measure the potential impacts of future water supply changes on seven major resource categories. The following resource categories were selected to generally correspond with resource categories identified in Section 9503 of the SECURE Water Act.

- Delivery Reliability
- Water Quality
- Hydropower and GHG emissions
- Flood Control
- Recreational Use
- Ecological Resources

Indicators are used in this Basins Study to illustrate how changes 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 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 (discussed in this section)

- Determine which adaptation portfolios performed well for the resources in question (See Section 6. *Water Management Actions and Adaptation Portfolios*)

- Help demonstrate how different resources were sensitive to changes in supply or demand, both independently and together (Discussed in this section for the No Action alternative and in Section 7. *Adaptation Portfolios Evaluation* for the adaptation portfolios).

The metrics were evaluated in either a quantitative or qualitative fashion. A metric was evaluated quantitatively if: (a) direct evaluation was possible using output from the model package or results from post-processing of modeling output data were usable, or (b) an indirect measure of the attribute of interest at the specified location could be developed, based on modeling output or from post-processing of modeling results.

5.1.2. Summary of Results

Figure 5-1 provides a comparison between the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios and Central Tendency climate/Current Trends socioeconomic scenarios. 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 5-1 provides the impacts shown in Figure 5-1 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 this report for further analysis of these impacts under the No Action alternative.)

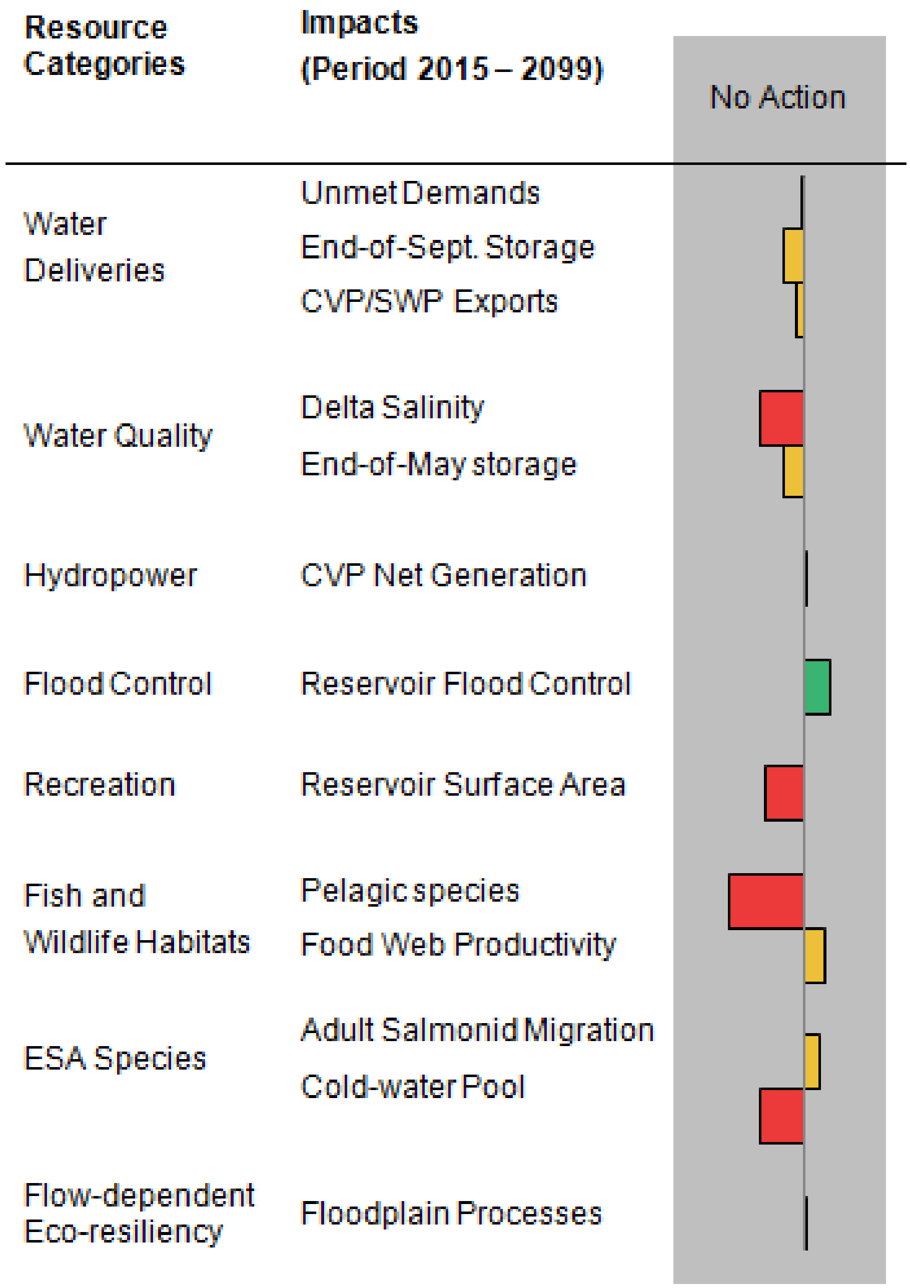


Figure 5-1. Climate impacts under the No Action alternative. (Changes from the Reference-No-Climate-Change to the Central Tendency climate scenario—both under the Current Trends socioeconomic scenario)[6]

[6] 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.

Table 5-1. 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.

5.2. System Risk and Reliability Assessment

The SECURE Water Act mandates the analysis of impacts that changes in water supply may have on eight specific resource categories. This analysis could only be performed at fairly broad spatial and temporal scales. It is important to recognize that there are limitations to the interpretation of the impacts presented in this section. First, the resource impacts represent overall 21st century and other period average conditions. However, considerable variability exists during these time periods. Second, other limitations exist because of uncertainties in the socioeconomic-climate scenarios, the use of performance-based change metrics, and in the models employed for the impact evaluations.

5.2.1. Objective and Approach

The system risk and reliability was evaluated using the future socioeconomic-climate scenarios using the methods and models described in the previous sections. For the system risk and reliability assessment, the overall 21st century projected impacts were evaluated by changes in performance metrics assuming that current CVP/SWP operations, infrastructure and regulatory requirements remain in effect throughout the twenty-first century. Potential strategies to address the issues identified by the system risk and reliability assessment are described in Section 6. *Water Management Actions and Adaptation Portfolios* and analyzed in Section 7. *Adaptation Portfolio Evaluation*.

In some cases, the future scenarios are evaluated against the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) that assumed current socioeconomic conditions and no climate change as described in Section.4.2.1. *Recent Historical Demand.* In other cases, the future scenarios are evaluated against the climate change and socioeconomic scenarios described in Section 2.1.2. *Socioeconomic and Climate Scenarios.*

This Sacramento-San Joaquin Basins Study used the same set of tools used for the CVP IRP and Sacramento and San Joaquin Basins Climate Impact Assessment (Reclamation 2014 [Climate]) with some additional tools and analyses required to quantify the performance metrics used in this study. Table 5-2 shows the models used to simulate the performance metrics associated with various resource categories. These analytical approaches are described in greater detail in Appendix 5E. *Economics Performance Assessment Tools*.

Table 5-2. Models Used for Resource Category Assessments

Resource Category	Models	Metrics
Water Delivery	CalLite-CV	Unmet demands, CVP & SWP Delta exports, exports, Surface reservoir storage, & Change in groundwater storage
Economics	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

5.2.2. 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.

5.2.2.1. 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.

Indicator:
Unmet demands represent the difference between total applied agricultural and urban water needs and the supply available from surface water sources, groundwater pumping, and water recycling.

Measured:
TAF of unmet demands at Sacramento River, San Joaquin River, Delta, and Tulare Lake regions.
Decreases in the unmet demand indicator would imply that water delivery reliability is increasing.

The highest unmet demands in all climate and socioeconomic scenarios were in the Tulare Lake region. The Sacramento River region had lower unmet demands in all scenarios than the Tulare Lake and San Joaquin regions, while the East Side streams and Delta had virtually no unmet demands in any scenario.

Under the Current Trends socioeconomic scenario, the drier climate scenarios (Hot-Dry and Wet-Dry) had the largest unmet demands while the wetter climate scenarios (Hot-Wet and Wet-Wet) had the lowest unmet demands. Within each of these pairs of scenarios, the demands are highest in the hotter scenario (Hot-Dry and Hot-Wet) during the early and mid-century periods, but in the late century period the demands in the hotter scenarios go down and are lower than their corresponding warmer scenario. This occurs because the agricultural demands in the late century (discussed in Section 4. *Water Demand Assessment*) are heavily influenced by carbon dioxide concentrations (discussed as in Section 2.1. *Scenario Development*), which are higher in the hotter scenarios and therefore result in lower demands and unmet demands in the late century.

5.2.2.1.1. Year-to-Year Variability

All climate scenarios showed similar year-to-year variability, with demands increasing and surface water supplies decreasing during dry periods, and the opposite occurring in wetter years. Under the Current Trends socioeconomic scenario:

- The Reference-No-Climate-Change climate scenario’s projected unmet demands ranged from a low of about 3,240 TAF/year to a high of about 12,397 TAF/year over the course of the simulation period.

- The Central Tendency climate scenario showed only modest changes in demand and supply relative to the Reference-No-Climate-Change climate scenario, with unmet demands ranging from 3,192 to 13,082 TAF/year.

- The drier (Hot-Dry and Warm-Dry) climate scenarios had much greater increases in demand and reductions in supply from the Reference-No-Climate-Change scenario, with unmet demands ranging from 3,138 to 14,980 TAF/year for Hot-Dry and from 3,557 to 14,497 TAF/year for Warm-Dry.

- Conversely, the wetter (Hot-Wet and Warm-Wet) climate scenarios had lower demands, higher supplies, and—consequently— lower unmet demands than the Reference-No-Climate-Change climate scenario, with unmet demands ranging from 2,529 to 11,522 TAF/year for Hot-Wet climate scenario and from 2,016 to 11,949 TAF/year for the Warm-Wet climate scenario.

Figure 5-2 presents annual time series for groundwater, surface water, and unmet demand for the Central Valley.

Figure 5-2. Water supply and unmet demands

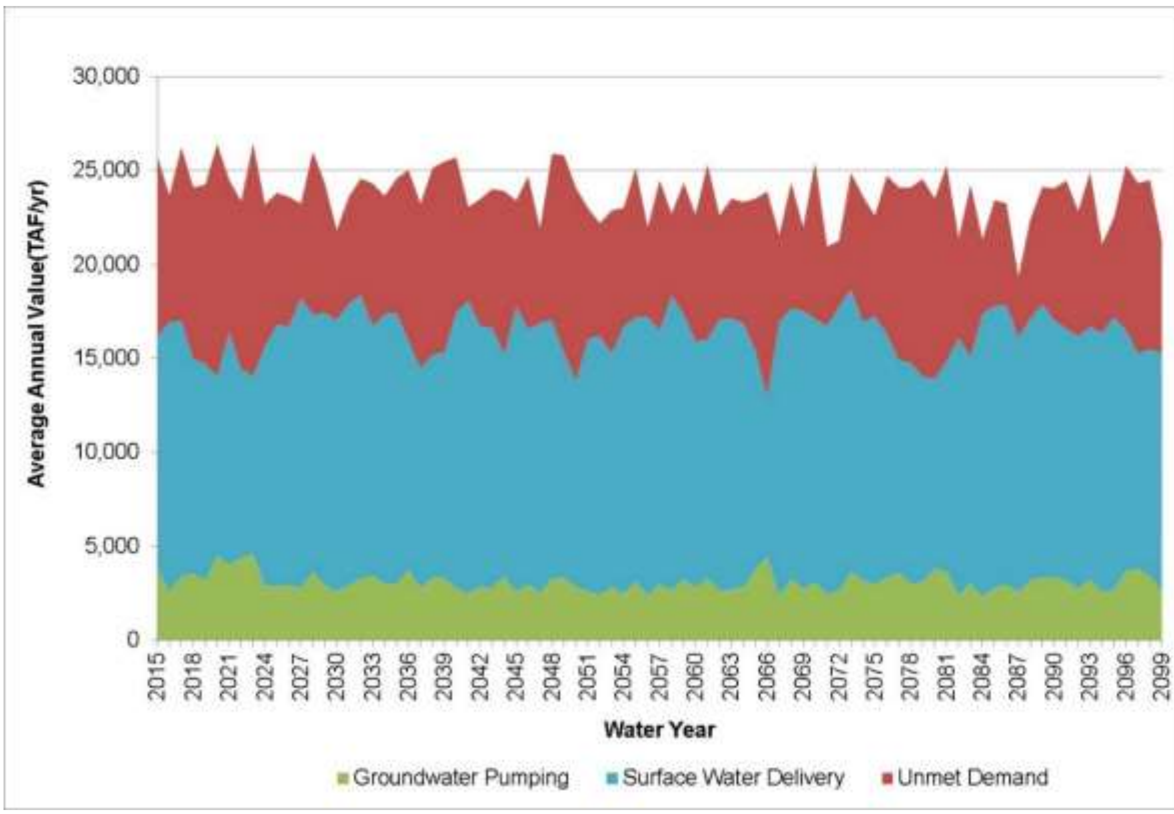


Figure 5-2a. Annual time series of supplies and unmet demand in the Central Valley in the **Reference-No-Climate-Change climate**/Current Trends socioeconomic scenarios.

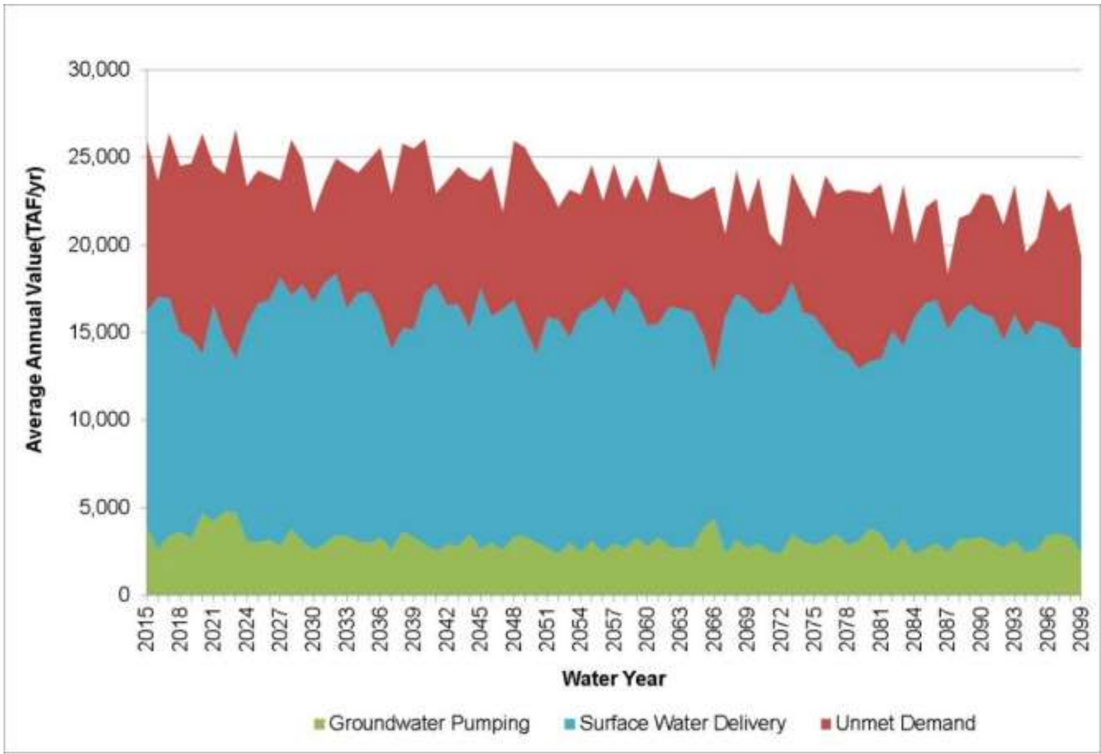


Figure 5-2b. Annual time series of supplies and unmet demand in the Central Valley in the **Central Tendency climate**/Current Trends socioeconomic scenarios.

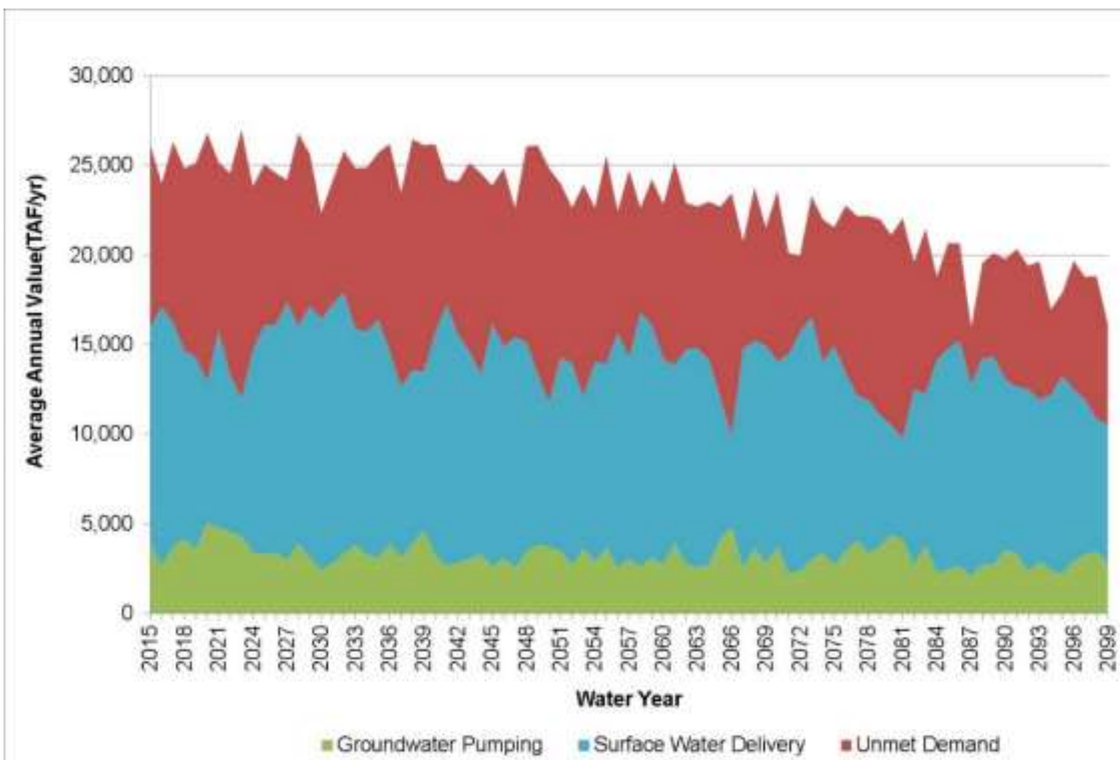


Figure 5-2c. Annual time series of supplies and unmet demand in the Central Valley in the **Hot-Dry climate**/Current Trends socioeconomic scenarios.

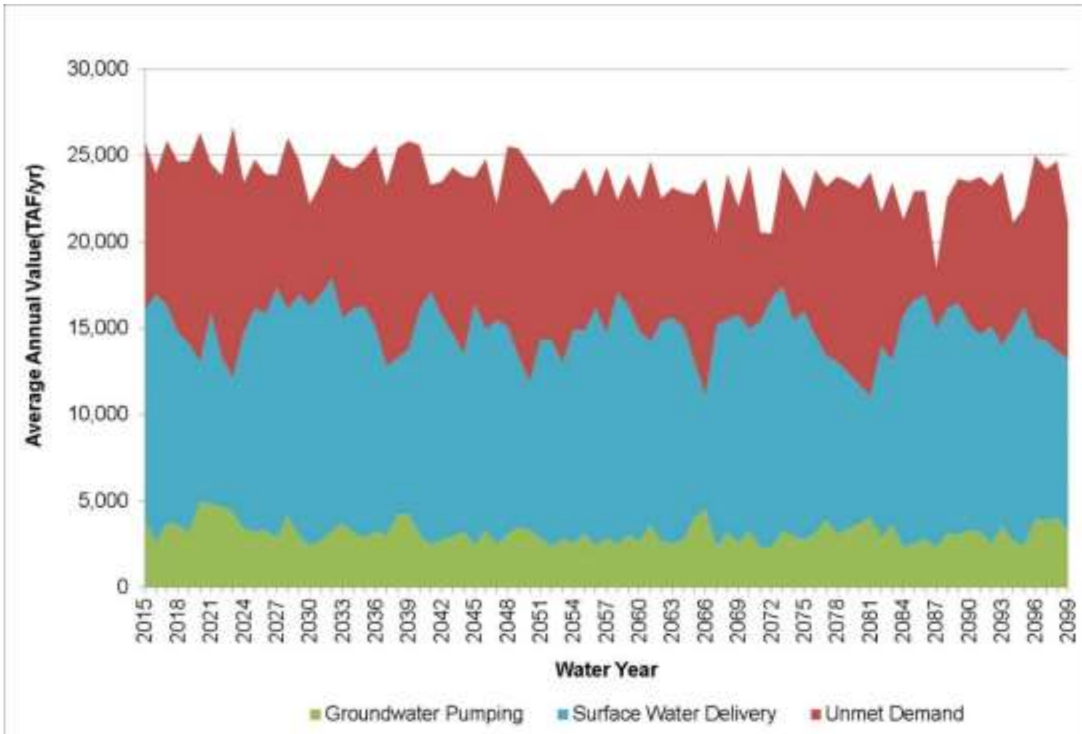


Figure 5-2d. Annual time series of supplies and unmet demand in the Central Valley in the **Warm-Dry climate**/Current Trends socioeconomic scenarios.

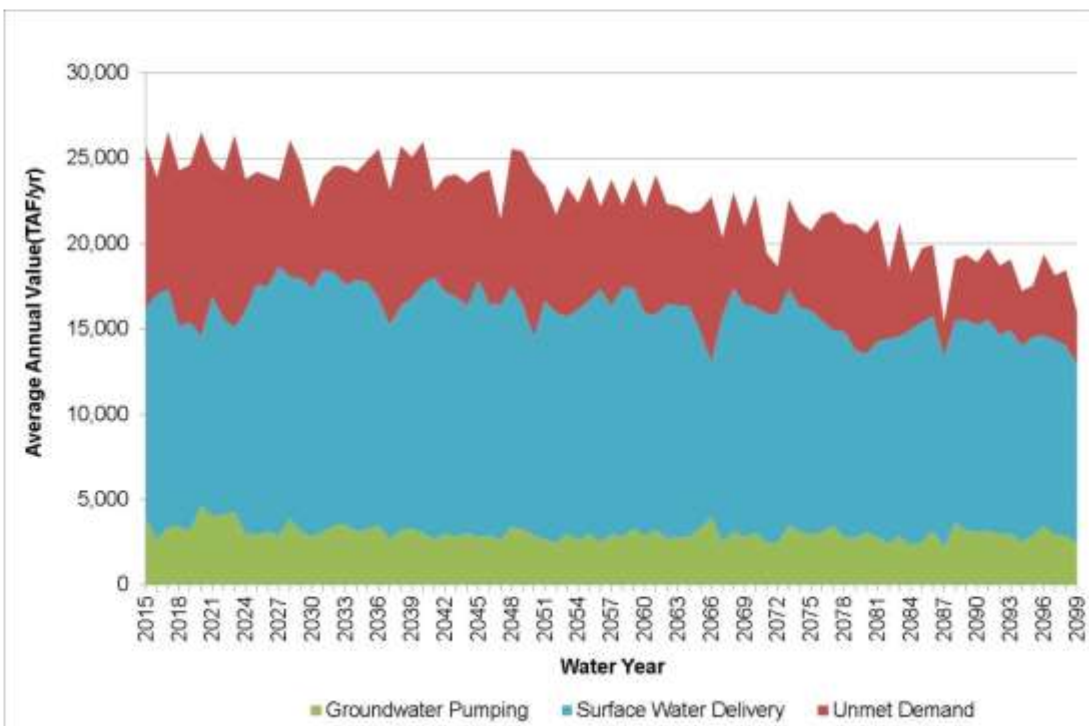


Figure 5-2e. Annual time series of supplies and unmet demand in the Central Valley in the **Hot-Wet climate**/Current Trends socioeconomic scenarios.

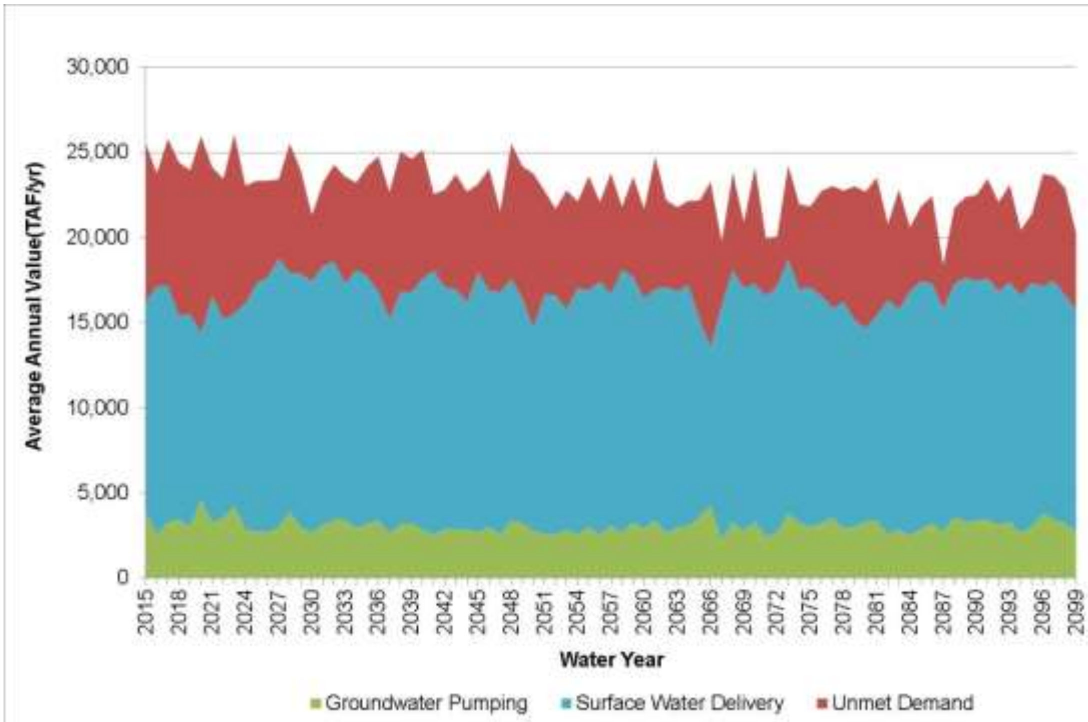


Figure 5-2f. Annual time series of supplies and unmet demand in the Central Valley in the **Warm-Wet climate/**Current Trends socioeconomic scenarios.

5.2.2.1.2. Average Annual Unmet Demand

In Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Central Valley average annual unmet demand was 7,353 TAF/year from 2015 to 2099 and had period averages of:

- 2015-2039: 7,092 TAF/year
- 2040-2069: 6,953 TAF/year
- 2070-2099: 7,353 TAF/year

Across the range of all socioeconomic-climate scenarios, the average annual unmet demand in the Central Valley was 7,505 TAF/year, an increase of 2.1% compared to the Reference-No-Climate-Change/Current Trends scenario and ranged from:

- 2014-2039: 5,473 to 9,971 TAF/year
- 2040-2069: 6.042 to 9,721 TAF/year
- 2070-2099: 4,201 to 10,090 TAF/year

Table 5-3 shows the average annual unmet demands in the Central Valley and in the Sacramento River, East Side streams and Delta, San Joaquin River and the Tulare Lake regions.

Table 5-3. Average Annual Unmet Demands

Table 5-3a. Average Annual Unmet Demands in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_EG	Warm-Dry_EG	Hot-Dry_EG	Hot-Wet_EG	Warm-Wet_EG	Central_EG
Total Central Valley	2015-2039	8,053	9,116	9,763	7,729	7,131	8,390
	2040-2069	7,073	8,682	9,357	6,673	6,042	7,423
	2070-2099	7,242	8,858	7,764	5,058	5,715	7,032
	2015-2099	**7,421**	**8,872**	**8,914**	**6,414**	**6,247**	**7,570**
Sacramento River System	2015-2039	23	79	124	16	2	41
	2040-2069	8	18	56	4	4	6
	2070-2099	12	133	121	2	0	11
	2015-2099	**14**	**77**	**99**	**7**	**2**	**18**
Delta and Eastside Streams	2015-2039	0	0	0	0	0	0
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**0**	**0**	**0**	**0**	**0**
San Joaquin River System	2015-2039	1,624	1,867	2,039	1,547	1,437	1,675
	2040-2069	1,470	1,821	2,000	1,355	1,238	1,488
	2070-2099	1,514	1,849	1,545	973	1,158	1,406
	2015-2099	**1,531**	**1,845**	**1,851**	**1,277**	**1,268**	**1,514**
Tulare Lake Region	2015-2039	6,406	7,169	7,600	6,165	5,691	6,674
	2040-2069	5,595	6,842	7,301	5,315	4,800	5,930
	2070-2099	5,716	6,875	6,098	4,083	4,557	5,615
	2015-2099	**5,876**	**6,950**	**6,965**	**5,130**	**4,976**	**6,038**

Table 5-3b. Average Annual Unmet Demands in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	8,146	9,350	9,853	7,81	7,221	8,478
	2040-2069	7,092	8,620	9,364	6,67	6,064	7,434
	2070-2099	6,953	8,141	7,225	4,64	5,396	6,666
	2015-2099	**7,353**	**8,666**	**8,753**	**6,29**	**6,168**	**7,470**
Sacramento River System	2015-2039	24	96	122	17	3	42
	2040-2069	6	9	42	1	3	4
	2070-2099	0	44	44	0	0	0
	2015-2099	**9**	**47**	**66**	**5**	**2**	**14**
Delta and Eastside Streams	2015-2039	0	0	0	0	0	0
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**0**	**0**	**0**	**0**	**0**

Location	Period	Reference _CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_ CT	Warm-Wet_CT	Central_CT
San Joaquin River System	2015-2039	1,655	1,923	2,071	1,57	1,463	1,707
	2040-2069	1,488	1,795	2,007	1,37	1,257	1,499
	2070-2099	1,462	1,711	1,409	881	1,098	1,328
	2015-2099	**1,528**	**1,803**	**1,815**	**1,25**	**1,261**	**1,500**
Tulare Lake Region	2015-2039	6,468	7,331	7,660	6,22	5,755	6,729
	2040-2069	5,599	6,816	7,315	5,30	4,804	5,932
	2070-2099	5,490	6,386	5,772	3,75	4,298	5,338
	2015-2099	**5,816**	**6,816**	**6,872**	**5,03**	**4,905**	**5,957**

Table 5-3c. Average Annual Unmet Demands in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrmcm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
Total Central Valley	2015-2039	8,407	6,810	6,267	8,027	7,701	7,702
	2040-2069	7,660	6,901	6,308	8,208	8,784	9,253
	2070-2099	7,356	6,715	6,355	8,702	9,369	10,090
	2015-2099	**7,773**	**6,809**	**6,313**	**8,329**	**8,672**	**9,092**
Sacramento River System	2015-2039	5	0	0	0	13	0
	2040-2069	0	4	0	0	51	5
	2070-2099	4	0	0	27	154	84
	2015-2099	**3**	**1**	**0**	**9**	**76**	**31**
Delta and Eastside Streams	2015-2039	0	0	0	0	0	0
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**0**	**0**	**0**	**0**	**0**
San Joaquin River System	2015-2039	1,939	1,512	1,404	1,808	1,741	1,753
	2040-2069	1,756	1,544	1,466	1,818	2,127	2,224
	2070-2099	1,620	1,530	1,392	1,973	2,138	2,405
	2015-2099	**1,762**	**1,530**	**1,421**	**1,870**	**2,017**	**2,149**
Tulare Lake Region	2015-2039	6,464	5,298	4,864	6,219	5,947	5,949
	2040-2069	5,905	5,353	4,842	6,390	6,607	7,024
	2070-2099	5,732	5,185	4,964	6,702	7,077	7,601
	2015-2099	**6,008**	**5,277**	**4,891**	**6,450**	**6,579**	**6,912**

Table 5-3d. Average Annual Unmet Demands in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_Gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Total Central Valley	2015-2039	6,967	6,803	5,473	9,063	7,915	8,652
	2040-2069	7,524	6,643	6,510	7,861	9,721	9,346
	2070-2099	5,638	4,201	4,562	7,036	6,809	7,064
	2015-2099	**6,694**	**5,828**	**5,517**	**7,923**	**8,162**	**8,337**
Sacramento River System	2015-2039	0	0	0	9	2	56
	2040-2069	7	5	0	0	50	38
	2070-2099	0	0	0	8	11	16
	2015-2099	**2**	**2**	**0**	**6**	**22**	**36**
Delta and Eastside Streams	2015-2039	0	0	0	0	0	0
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**0**	**0**	**0**	**0**	**0**
San Joaquin River System	2015-2039	1,469	1,494	1,216	2,099	1,871	1,980
	2040-2069	1,729	1,494	1,407	1,747	2,302	2,185
	2070-2099	1,045	811	896	1,366	1,390	1,402
	2015-2099	**1,411**	**1,253**	**1,170**	**1,716**	**1,853**	**1,848**
Tulare Lake Region	2015-2039	5,498	5,309	4,257	6,954	6,042	6,617
	2040-2069	5,787	5,144	5,103	6,114	7,369	7,124
	2070-2099	4,593	3,390	3,666	5,662	5,408	5,645
	2015-2099	**5,281**	**4,574**	**4,347**	**6,201**	**6,287**	**6,453**

Table 5-3e. Average Annual Unmet Demands in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference_SG	Warm-Dry_SG	Hot-Dry_SG	Hot-Wet_SG	Warm-Wet_SG	Central_SG
Total Central Valley	2015-2039	8,252	9,463	9,971	7,927	7,325	8,589
	2040-2069	7,243	8,739	9,500	6,782	6,174	7,554
	2070-2099	7,123	8,223	7,208	4,633	5,502	6,741
	2015-2099	7,497	8,770	8,830	6,360	6,275	7,572
Sacramento River System	2015-2039	19	96	122	17	4	42
	2040-2069	5	7	32	0	2	2
	2070-2099	0	18	26	0	0	0
	2015-2099	**7**	**37**	**57**	**5**	**2**	**13**
Delta and Eastside Streams	2015-2039	0	0	0	0	0	0
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**0**	**0**	**0**	**0**	**0**

Location	Period	Reference_SG	Warm-Dry_SG	Hot-Dry_SG	Hot-Wet_SG	Warm-Wet_SG	Central_SG
San Joaquin River System	2015-2039	1,694	1,962	2,111	1,612	1,501	1,746
	2040-2069	1,563	1,871	2,094	1,433	1,322	1,573
	2070-2099	1,598	1,839	1,488	948	1,210	1,431
	2015-2099	**1,614**	**1,886**	**1,885**	**1,315**	**1,335**	**1,574**
Tulare Lake Region	2015-2039	6,539	7,405	7,737	6,297	5,820	6,802
	2040-2069	5,676	6,862	7,375	5,349	4,850	5,978
	2070-2099	5,525	6,367	5,694	3,685	4,292	5,311
	2015-2099	**5,876**	**6,847**	**6,888**	**5,040**	**4,938**	**5,985**

Figure 5-3 presents the 10-year running average of unmet demands in the Central Valley and in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region for the Reference-No-Climate-Change, each of the 5 ensemble and 12 CCTAG climate scenarios under the Current Trends socioeconomic scenario over water years from 2015 to 2099. The 10-year running average of unmet demand in the Delta and Eastside Streams in each climate scenario under the Current Trends socioeconomic scenario is zero in all years and thus is not shown on a figure.

Figure 5-3. Unmet Demands: 10-year running average

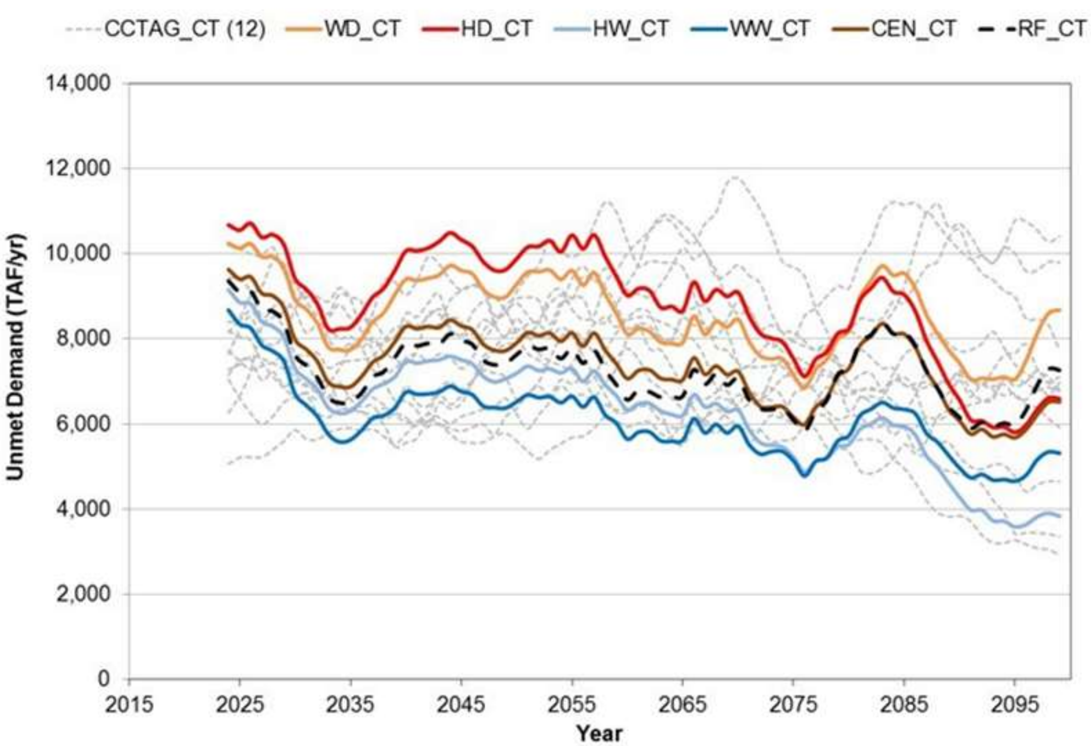


Figure 5-3a. 10-year running average of unmet demand in the **Central Valley** in each climate scenario under the Current Trends socioeconomic scenario.

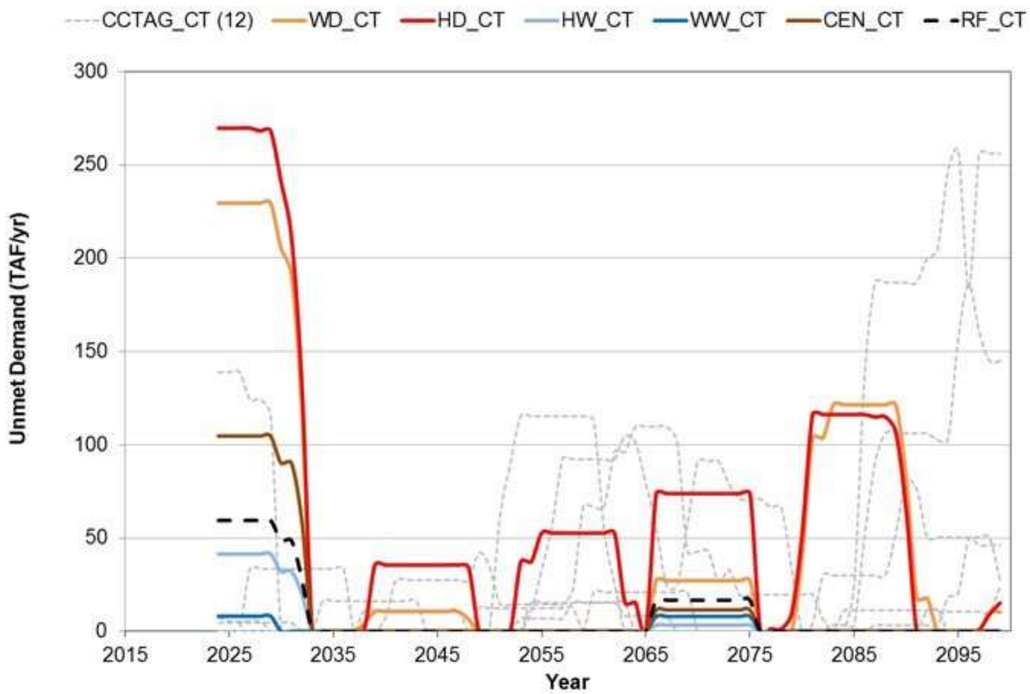


Figure 5-3b. 10-year running average of unmet demand in the **Sacramento River System** in each climate scenario under the Current Trends socioeconomic scenario.

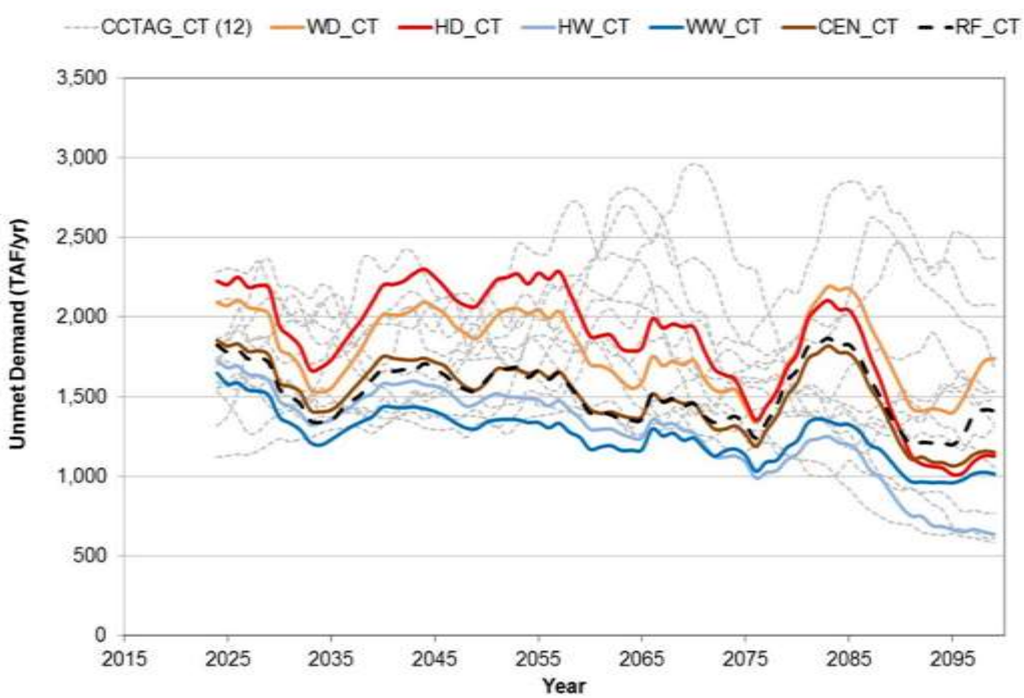


Figure 5-3c. 10-year running average of unmet demand in the **San Joaquin River System** in each climate scenario under the Current Trends socioeconomic scenario.

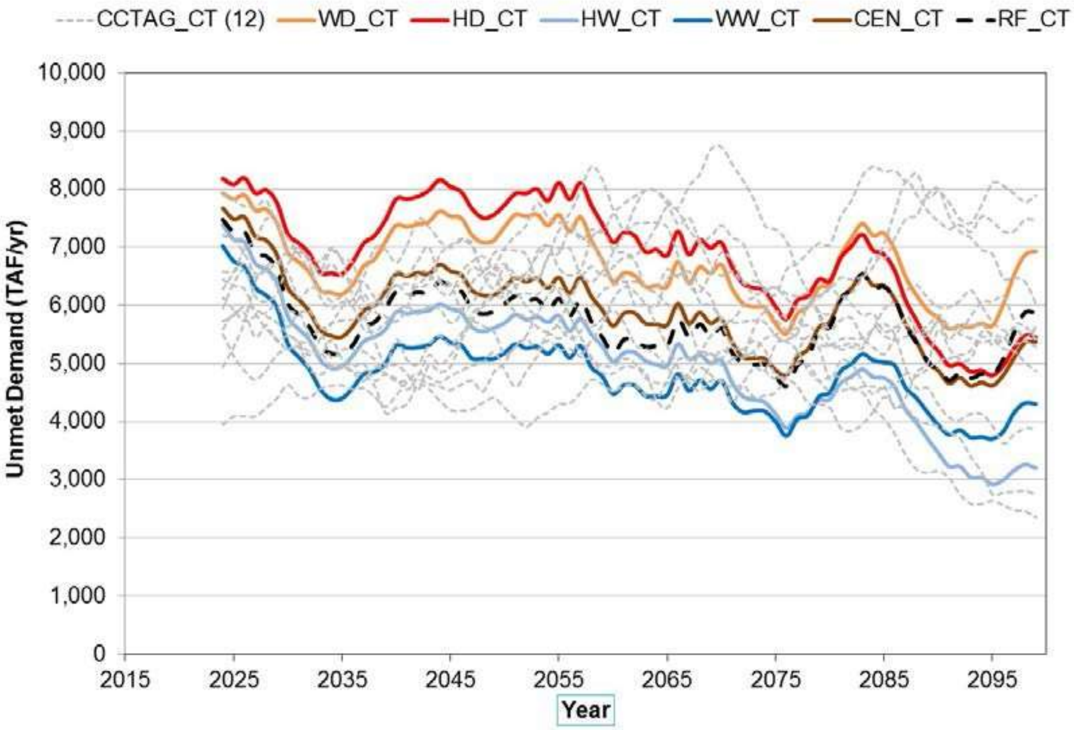


Figure 5-3d. 10-year running average of unmet demand in the **Tulare Lake Region** in each climate scenario under the Current Trends socioeconomic scenario.

5.2.2.2. End-of-September System 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).

> **Indicator:**
> End of September storage indicates relative risk for future deliveries, particularly during extended droughts.
>
> **Measures:**
> 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)1 scenario in Shasta, Folsom, Oroville, New Melones, and San Luis reservoirs. Surface storage totals for Sacramento Valley, San Joaquin Valley, and Tulare Lake Region. *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.*

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.

The 50 percent probability of exceedance may be interpreted as the median storage volume over the entire twenty-first century period.

In some of the drier climate scenarios (Warm-Dry and Hot-Dry), reservoir storage reached a minimum volume (dead pool) below which releases cannot be made. Typically, the CVP and SWP systems are operated to maintain sufficient carryover storage to meet demand requirements during drought periods of several years. In the model simulations, the reservoir operating rules have not been adjusted to account for the projected hydrologic conditions under climate change. Therefore, the dead pool results presented in these figures do not reflect how the CVP and SWP systems would actually be operated under future changes in climate but, rather, may be viewed as indicators of the potential need for adaptation under some of the projected future climates should such conditions actually occur. . In this study, the target storage is the percentage of years that Sacramento Valley storage is less than the 10th percentile of historical end-of-September storage represented by the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic (RF_RF) scenarios.[1]

Under the Current Trends socioeconomic scenario:

- The median climate scenario (Central Tendency) had storage levels very close to the Reference No-Climate-Change climate scenario in Lake Oroville and New Melones Reservoir and a moderate amount lower than the Reference-No-Climate-Change climate scenario in Shasta and Folsom reservoirs.

- In all the upstream reservoirs, the storage was higher under the wetter climate scenarios (Hot-Wet and Warm-Wet) than under the Reference-No-Climate-Change climate scenario, with the highest storage levels in the wetter, less warming scenario (Warm-Wet).

- Conversely, the storage levels in September were lower under the drier climate scenarios (Warm-Dry and Hot-Dry) than under the Reference-No-Climate-Change climate/Current Trends socioeconomic scenario, with the lowest storage levels in the drier, more warming climate scenario (Hot-Dry).

- Shasta, Folsom, and New Melones reservoirs were all at dead storage in some proportion of years at the end of September under the Hot-Dry climate scenario, with Lake Shasta the most likely to be at dead storage in about 25% of all years.

- In each of these reservoirs, dead storage conditions also occurred in the Warm-Dry and Central Tendency Climate scenarios, but less frequently than under the Hot-Dry climate scenario.

Although the storage trends for the five ensemble climate scenarios were very similar in the first few years of the simulation, the variability among scenarios grew greater as the transient simulation moved toward the latter part of the century. In addition, the 12 CCTAG climate scenarios show significant variability across the twenty-first century in all three regions.

In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the percentage of years that the end-of-September reservoir storages were less than the 10th percentile storage value in 2015-2099 period ranged from:

- 2015-2039: 8 to 32%
- 2040-2069: 0 to 17%
- 2070-2099: 0 to 13%

Across the range of all socioeconomic-climate scenarios, the overall average end-of-September storages over the course of the 21st century were below the 10th percentile storage value from 2015-2099:

- Sacramento Valley: 0-53% of the years
- San Joaquin Valley: 1-44% of the years
- Tulare Lake region: 4-42% of the years

In each reservoir, the drier climate scenarios (e.g. Hot-Dry and Warm-Dry) were more likely to have low storage results, while the wetter climate scenarios (e.g. Hot-Wet and Warm-Wet) were less likely to have low storage results.

Figure 5-4 shows exceedance plots of storage at the end of September in Shasta, Folsom, Oroville, New Melones and San Luis reservoirs and for total Central Valley, the Sacramento Valley (including Shasta, New Bullards Bar, Oroville, and Folsom reservoirs), San Joaquin Valley (including New Don Pedro, McClure, New Melones, and Millerton reservoirs) and Tulare Lake region (including Pine Flat, Kaweah, Success, and Isabella reservoirs) for each of the climate scenarios with the Current Trends socioeconomic scenario.

Figure 5-5 shows the 10-year moving average of end-of-September storage in each scenario in the total Central Valley, Sacramento Valley, San Joaquin Valley, and Tulare Lake region.

Table 5-4 presents the percentage of time that end-of-September storage is less than the 10th percentile storage value occurring in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF) during the 21st century in all of the climate scenarios under the Current Trends socioeconomic scenario. Storage metrics are presented for Shasta, Folsom, Oroville, New Melones, and San Luis reservoirs and for the total storage in the Sacramento Valley, San Joaquin Valley, and Tulare Lake regions for each of the socioeconomic-climate scenarios in the water years 2015 through 2099 and for the periods from 2015-2039, 2040-2069, and 2070-2099.

Figure 5-4. End-of-September storage: exceedence plots

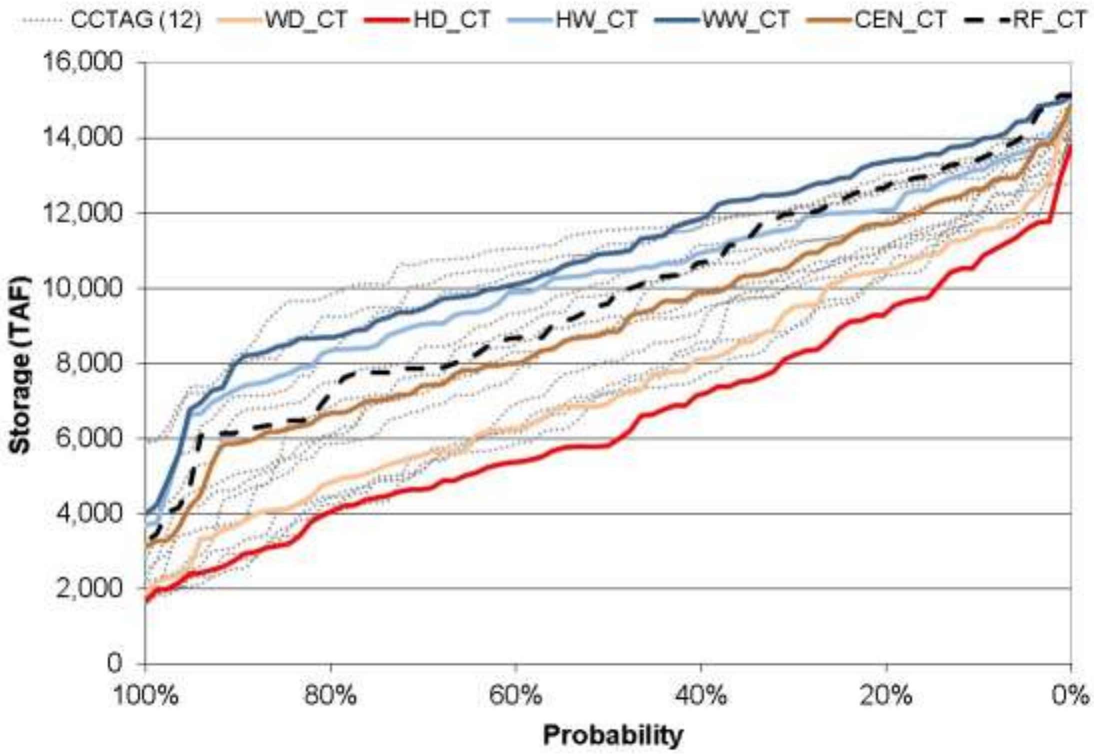


Figure 5-4a. Exceedance plot of total **Central Valley** end-of-September storage for each scenario.

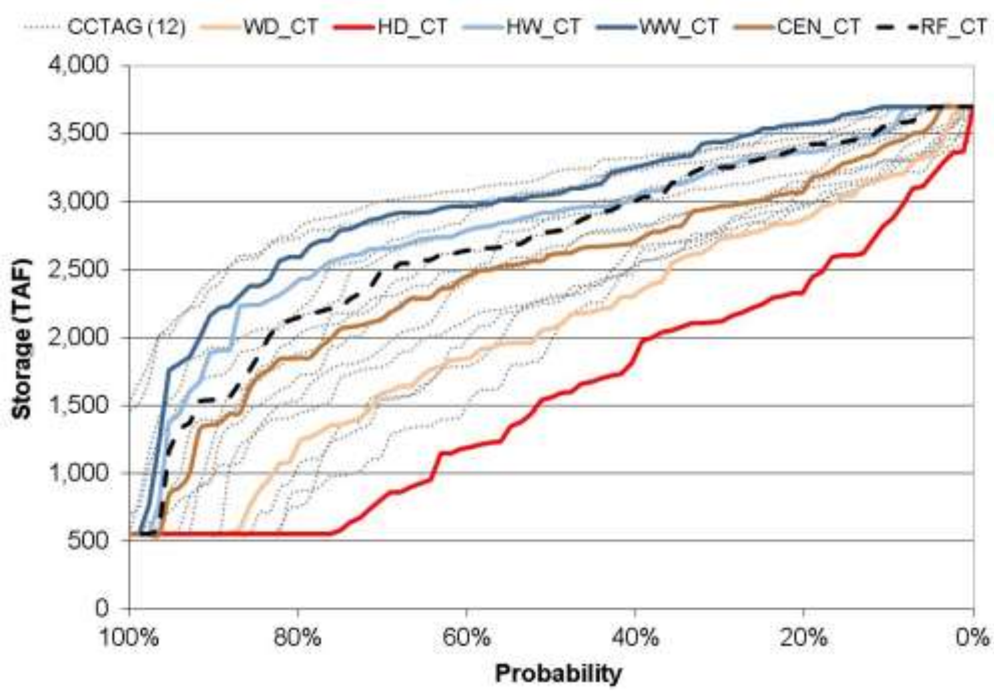


Figure 5-4b. Exceedance plot of **Lake Shasta** end-of-September storage for each scenario.

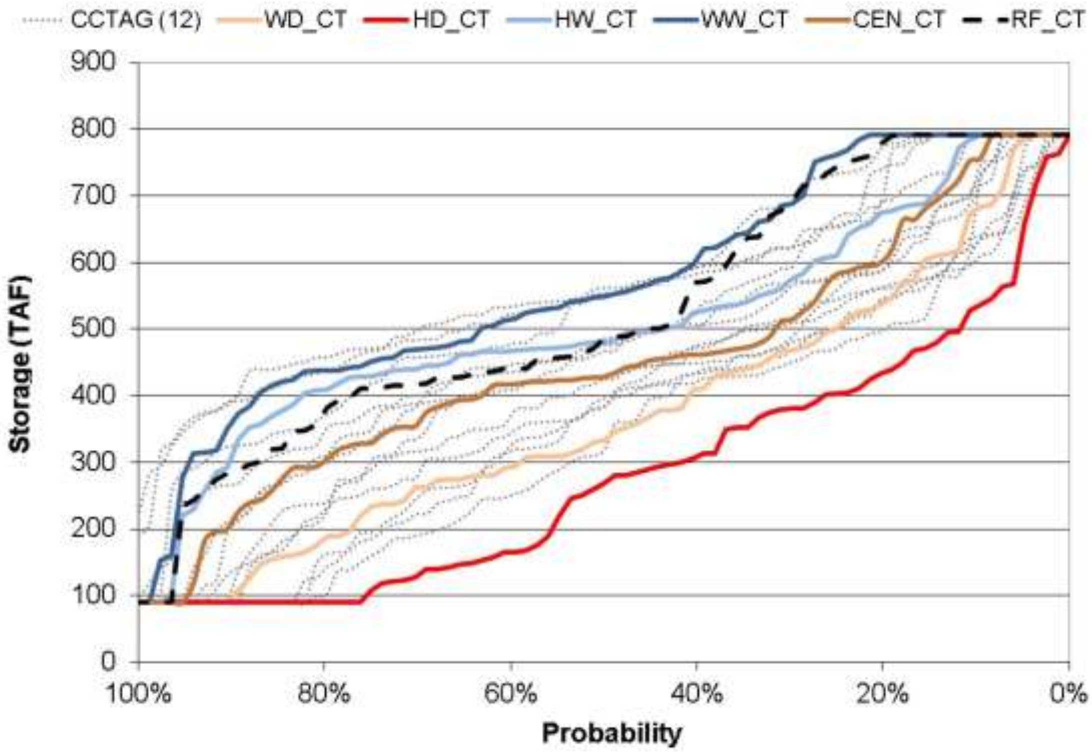


Figure 5-4c. Exceedance plot of **Folsom Lake** end-of-September storage for each scenario.

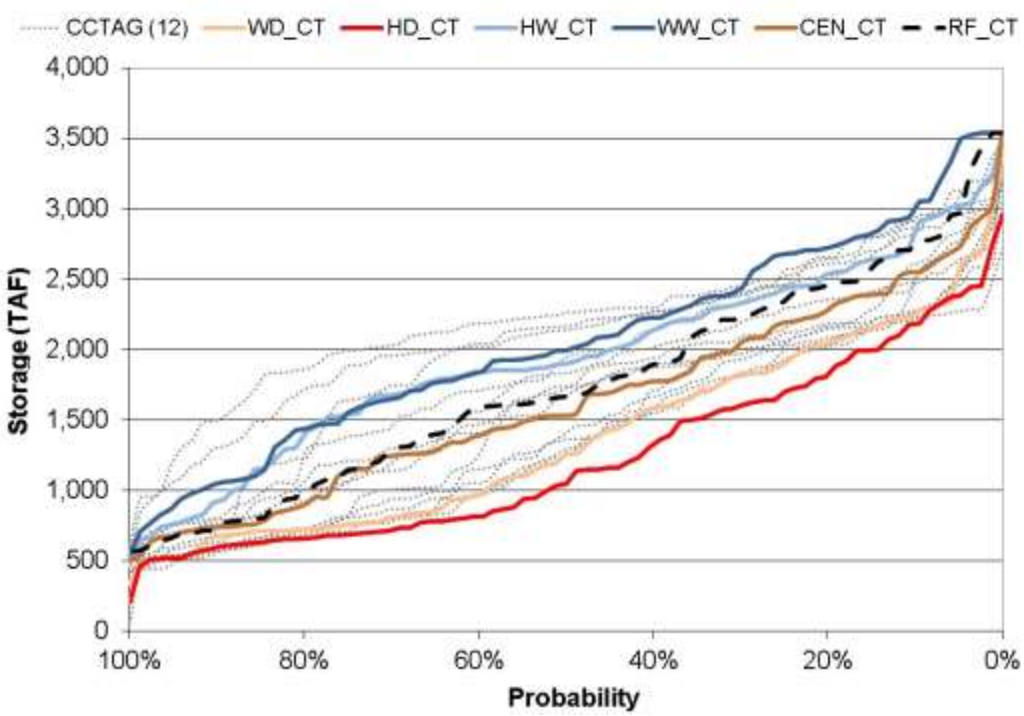


Figure 5-4d. Exceedance plot of **Lake Oroville** end-of-September storage for each scenario.

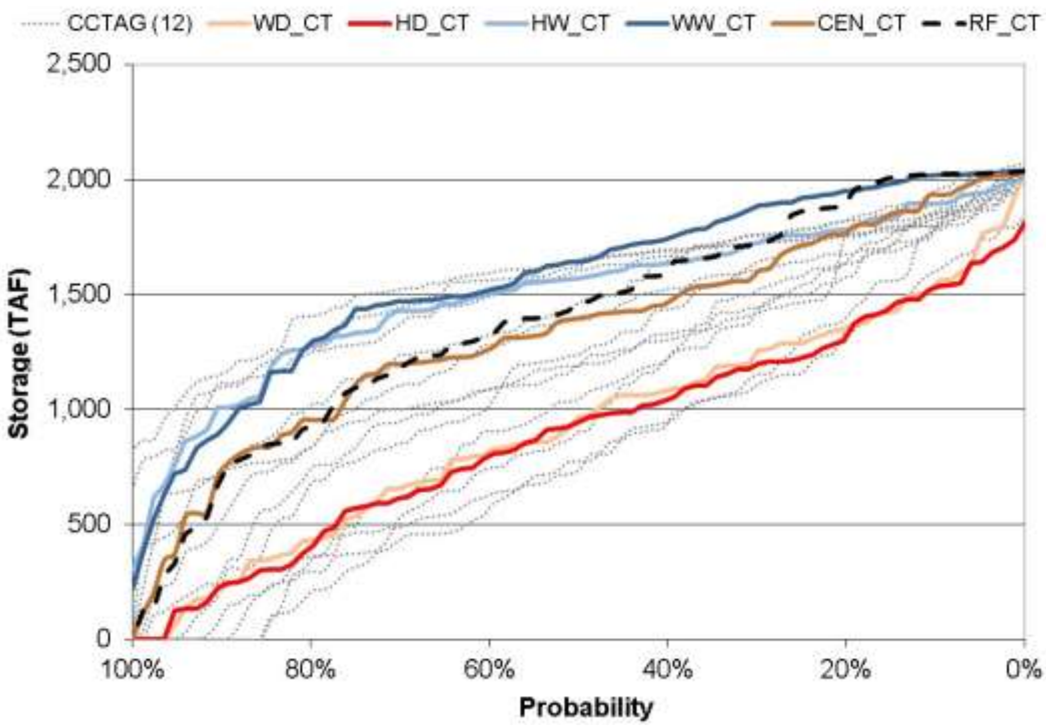


Figure 5-4e. Exceedance plot of **New Melones Reservoir** end-of-September storage for each scenario.

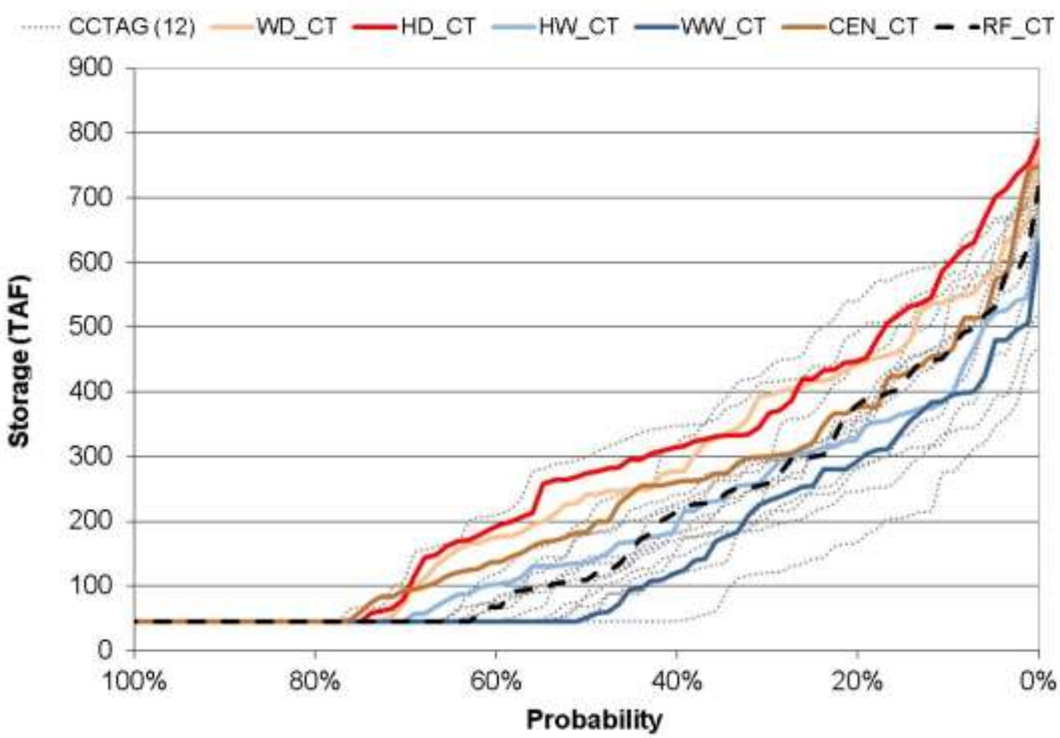


Figure 5-4f. Exceedance plot of **CVP San Luis Reservoir** end-of-September storage for each scenario.

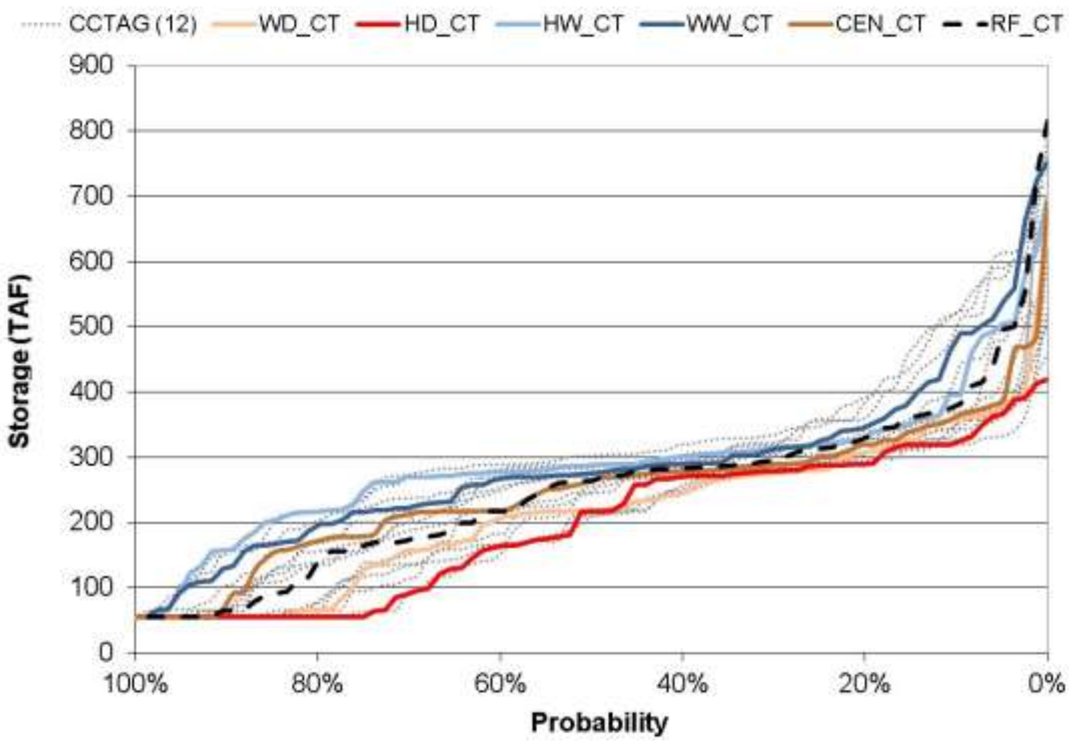


Figure 5-4g. Exceedance plot of **SWP San Luis Reservoir** end-of-September storage for each scenario.

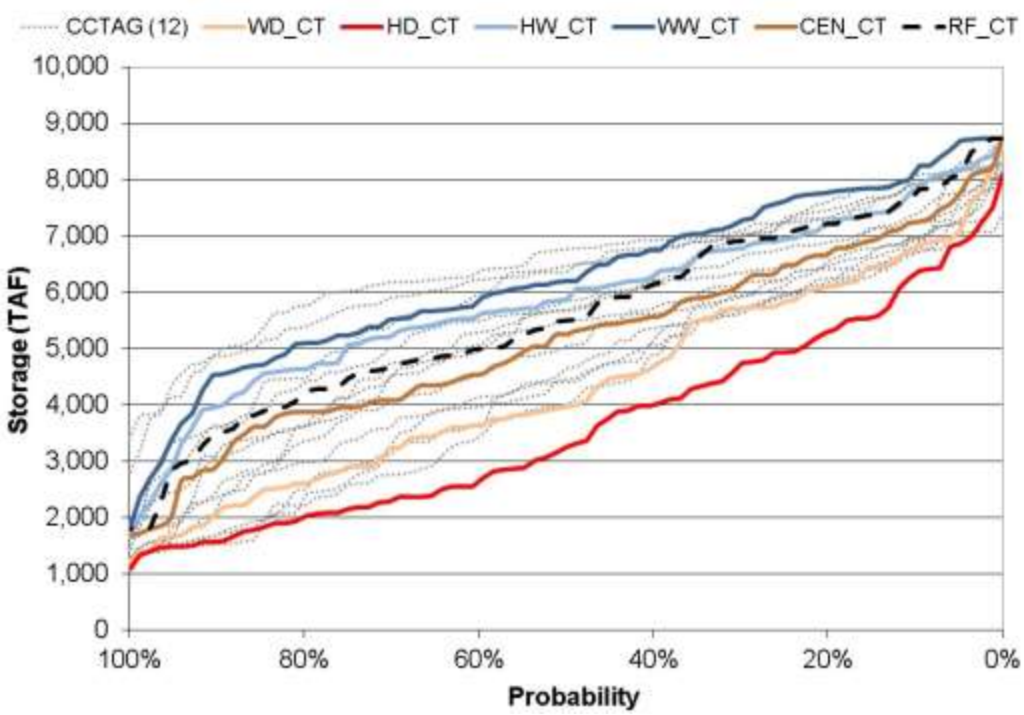


Figure 5-4h. Exceedance plot of **Sacramento Valley** end-of-September storage for each scenario.

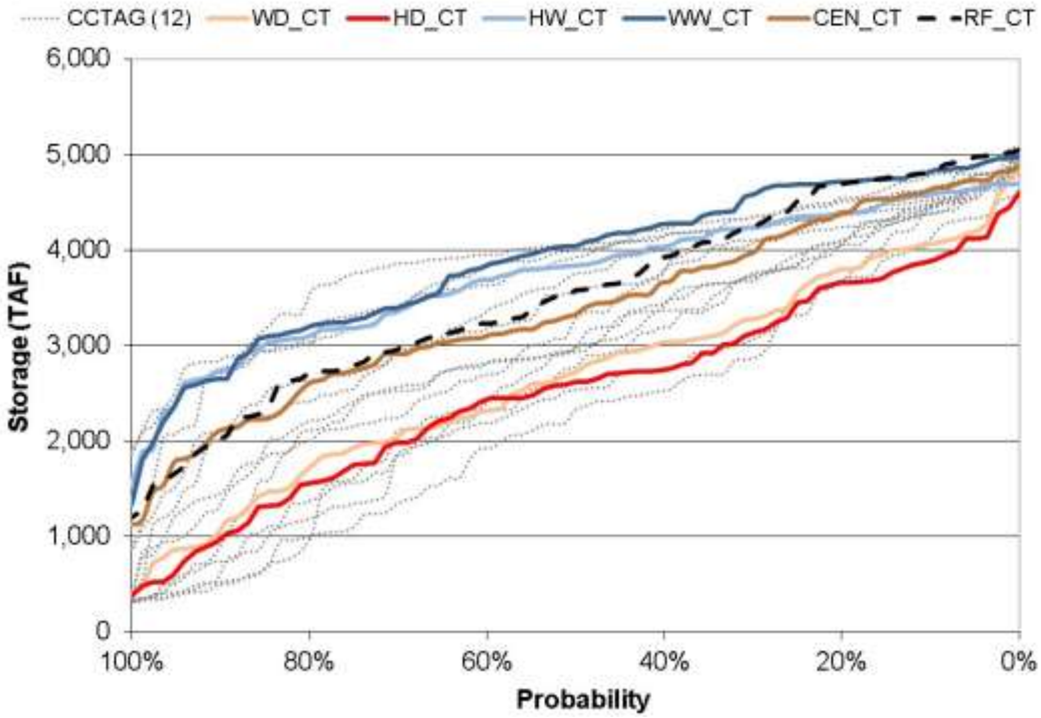


Figure 5-4i. Exceedance plot of **San Joaquin Valley** end-of-September storage for each scenario.

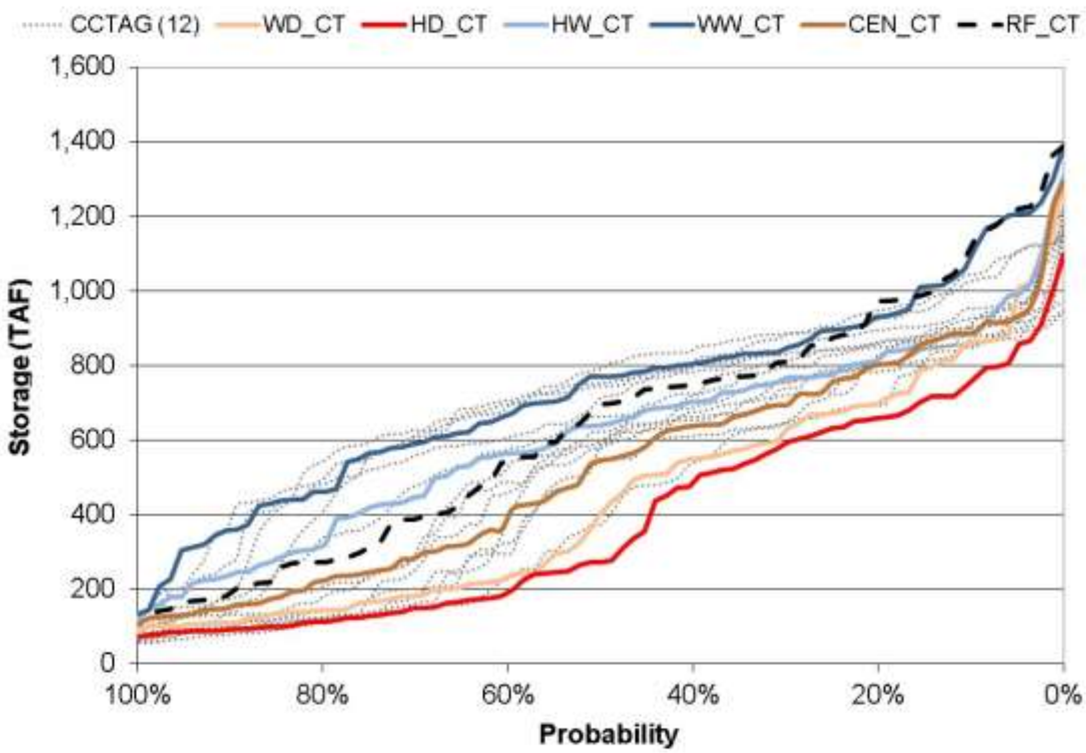


Figure 5-4j. Exceedance plot of **Tulare Lake Region** end-of-September storage for each scenario.

Figure 5-5. End-of-September storage: 10-year moving average

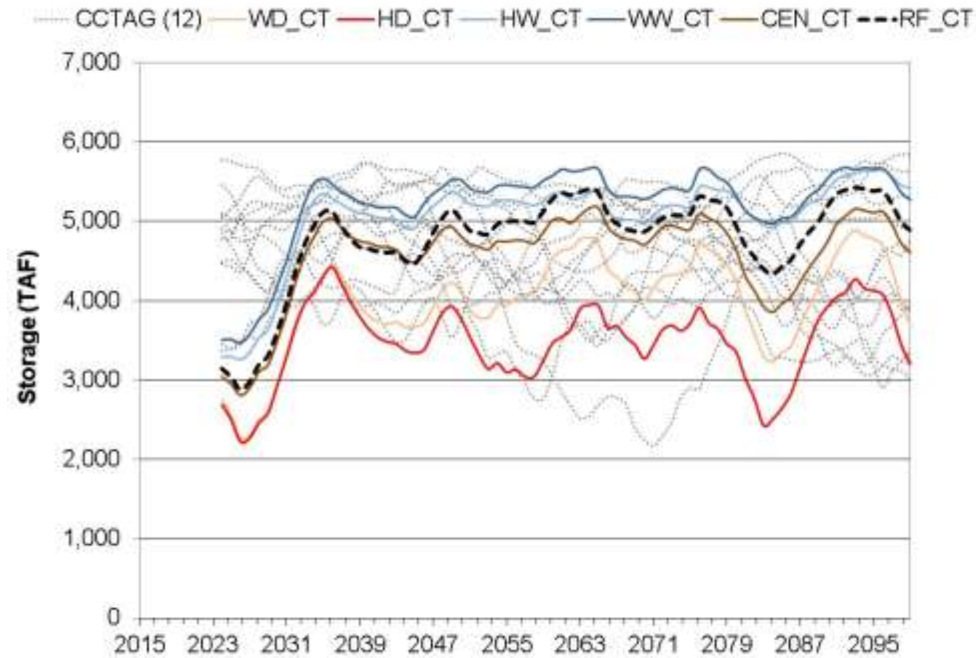


Figure 5-5a. 10-year moving average of total annual storage in the **Central Valley** in each scenario.

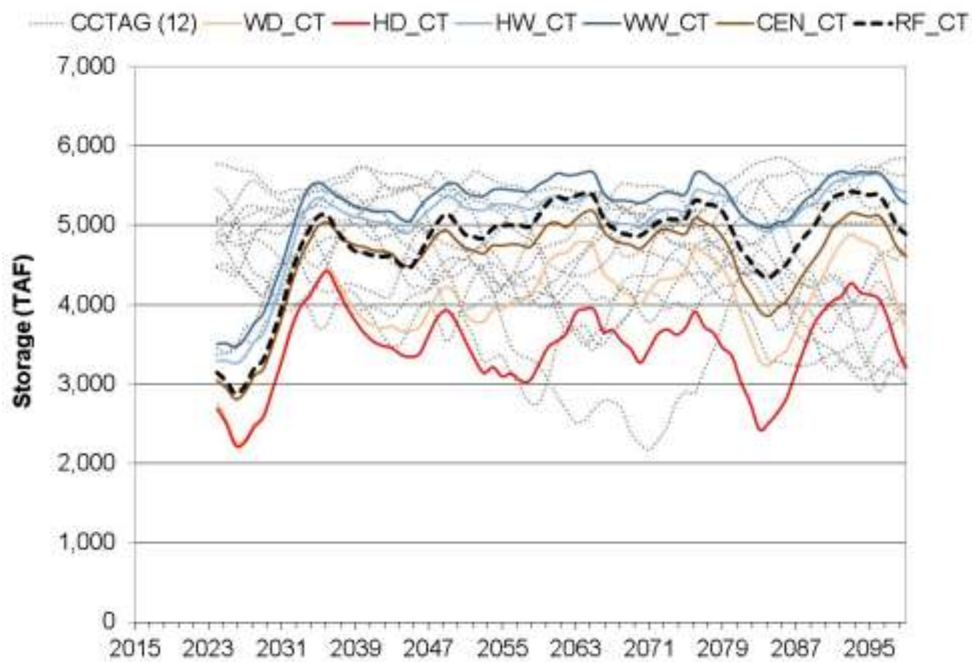


Figure 5-5 b. 10-year moving average of total annual storage in the **Sacramento Valley** in each scenario.

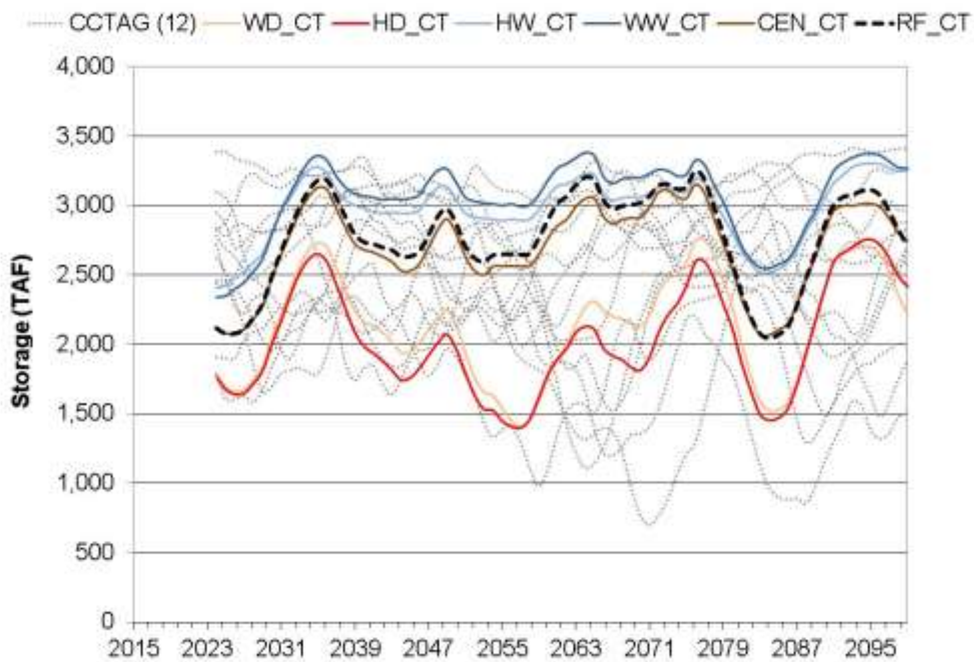


Figure 5-5 c. 10-year moving average of total annual storage in the **San Joaquin Valley** in each scenario.

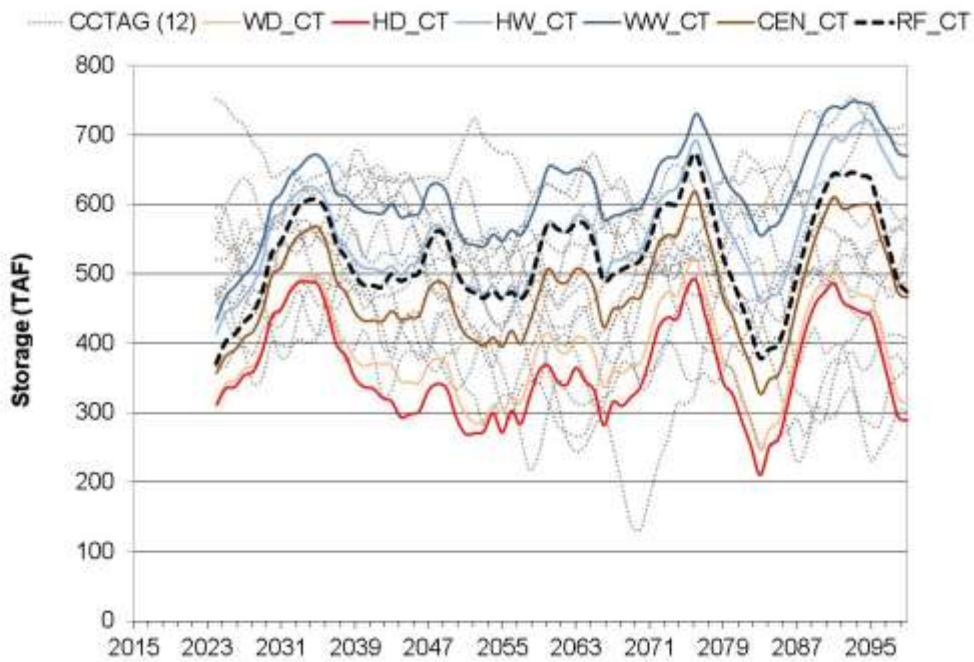


Figure 5-5d. 10-year moving average of total annual storage in the **Tulare Lake Region** in each scenario.

Table 5-4. End-of-September Storage: Percentage of Years Less than Historic Values

Table 5-4a. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF) for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Shasta	2015-2039	28%	52%	56%	24%	16%	32%
	2040-2069	3%	17%	43%	0%	0%	3%
	2070-2099	0%	17%	47%	0%	0%	3%
	2015-2099	**9%**	**27%**	**48%**	**7%**	**5%**	**12%**
Folsom	2015-2039	20%	48%	52%	20%	12%	36%
	2040-2069	3%	23%	40%	3%	3%	3%
	2070-2099	0%	23%	50%	0%	0%	7%
	2015-2099	**7%**	**31%**	**47%**	**7%**	**5%**	**14%**
Oroville	2015-2039	24%	24%	32%	8%	8%	16%
	2040-2069	7%	27%	30%	3%	3%	10%
	2070-2099	3%	20%	40%	0%	0%	3%
	2015-2099	**11%**	**24%**	**34%**	**4%**	**4%**	**9%**
New Melones	2015-2039	24%	40%	48%	16%	16%	24%
	2040-2069	0%	37%	43%	0%	0%	0%
	2070-2099	13%	30%	23%	3%	3%	10%
	2015-2099	**12%**	**35%**	**38%**	**6%**	**6%**	**11%**
San Luis CVP	2015-2039	8%	24%	16%	0%	0%	0%
	2040-2069	3%	10%	17%	0%	0%	3%
	2070-2099	0%	10%	13%	0%	0%	3%
	2015-2099	**4%**	**14%**	**15%**	**0%**	**0%**	**2%**
San Luis SWP	2015-2039	24%	32%	28%	8%	8%	20%
	2040-2069	7%	17%	30%	3%	3%	3%
	2070-2099	0%	30%	40%	0%	0%	3%
	2015-2099	**9%**	**26%**	**33%**	**4%**	**4%**	**8%**
Sacramento Valley	2015-2039	28%	52%	56%	20%	16%	24%
	2040-2069	3%	27%	47%	3%	3%	3%
	2070-2099	0%	23%	47%	0%	0%	7%
	2015-2099	**9%**	**33%**	**49%**	**7%**	**6%**	**11%**
San Joaquin Valley	2015-2039	12%	32%	40%	8%	8%	12%
	2040-2069	7%	33%	40%	3%	3%	7%
	2070-2099	13%	33%	20%	0%	3%	20%
	2015-2099	**11%**	**33%**	**33%**	**4%**	**5%**	**13%**
Tulare Lake	2015-2039	8%	28%	28%	8%	4%	8%
	2040-2069	17%	43%	43%	7%	7%	23%
	2070-2099	7%	40%	50%	0%	0%	23%

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
	2015-2099	**11%**	**38%**	**41%**	**5%**	**4%**	**19%**

Table 5-4b. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Shasta	2015-2039	32%	52%	56%	24%	16%	32%
	2040-2069	3%	17%	43%	3%	0%	3%
	2070-2099	0%	23%	47%	0%	0%	10%
	2015-2099	**11%**	**29%**	**48%**	**8%**	**5%**	**14%**
Folsom	2015-2039	32%	52%	56%	20%	12%	32%
	2040-2069	3%	17%	43%	3%	3%	3%
	2070-2099	0%	27%	47%	0%	0%	10%
	2015-2099	**11%**	**31%**	**48%**	**7%**	**5%**	**14%**
Oroville	2015-2039	24%	24%	24%	8%	4%	16%
	2040-2069	7%	20%	27%	3%	3%	7%
	2070-2099	3%	27%	47%	0%	0%	13%
	2015-2099	**11%**	**24%**	**33%**	**4%**	**2%**	**12%**
New Melones	2015-2039	24%	44%	48%	16%	16%	24%
	2040-2069	0%	37%	40%	0%	0%	0%
	2070-2099	10%	27%	20%	0%	0%	10%
	2015-2099	**11%**	**35%**	**35%**	**5%**	**5%**	**11%**
San Luis CVP	2015-2039	8%	12%	16%	0%	0%	4%
	2040-2069	7%	20%	20%	0%	0%	3%
	2070-2099	7%	17%	17%	3%	0%	3%
	2015-2099	**7%**	**16%**	**18%**	**1%**	**0%**	**4%**
San Luis SWP	2015-2039	24%	24%	28%	8%	8%	20%
	2040-2069	7%	23%	33%	0%	3%	3%
	2070-2099	7%	30%	43%	3%	0%	3%
	2015-2099	**12%**	**26%**	**35%**	**4%**	**4%**	**8%**
Sacramento Valley	2015-2039	28%	52%	56%	20%	16%	24%
	2040-2069	3%	20%	47%	3%	3%	3%
	2070-2099	3%	33%	50%	0%	0%	10%
	2015-2099	**11%**	**34%**	**51%**	**7%**	**6%**	**12%**
San Joaquin Valley	2015-2039	12%	36%	40%	8%	8%	12%
	2040-2069	7%	33%	40%	3%	3%	7%
	2070-2099	13%	27%	20%	0%	0%	10%
	2015-2099	**11%**	**32%**	**33%**	**4%**	**4%**	**9%**
Tulare Lake	2015-2039	8%	8%	28%	8%	4%	8%
	2040-2069	17%	17%	47%	7%	7%	23%
	2070-2099	7%	7%	50%	0%	0%	23%
	2015-2099	**11%**	**11%**	**42%**	**5%**	**4%**	**19%**

Table 5-4c. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) for the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year)

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_Gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
Shasta	2015-2039	12%	4%	4%	8%	12%	4%
	2040-2069	7%	13%	0%	3%	30%	20%
	2070-2099	13%	3%	0%	27%	50%	47%
	2015-2099	**11%**	**7%**	**1%**	**13%**	**32%**	**25%**
Folsom	2015-2039	16%	12%	8%	12%	24%	8%
	2040-2069	17%	7%	0%	7%	33%	23%
	2070-2099	13%	10%	0%	27%	47%	43%
	2015-2099	**15%**	**9%**	**2%**	**15%**	**35%**	**26%**
Oroville	2015-2039	16%	4%	4%	4%	16%	4%
	2040-2069	10%	7%	0%	13%	20%	23%
	2070-2099	7%	3%	0%	7%	30%	40%
	2015-2099	**11%**	**5%**	**1%**	**8%**	**22%**	**24%**
New Melones	2015-2039	20%	0%	4%	20%	16%	16%
	2040-2069	23%	10%	0%	10%	40%	57%
	2070-2099	20%	10%	0%	30%	40%	67%
	2015-2099	**21%**	**7%**	**1%**	**20%**	**33%**	**48%**
San Luis CVP	2015-2039	4%	4%	4%	8%	4%	8%
	2040-2069	0%	7%	0%	7%	3%	27%
	2070-2099	10%	7%	0%	10%	10%	20%
	2015-2099	**5%**	**6%**	**1%**	**8%**	**6%**	**19%**
San Luis SWP	2015-2039	12%	4%	4%	8%	12%	8%
	2040-2069	3%	7%	0%	7%	13%	27%
	2070-2099	10%	10%	0%	7%	20%	40%
	2015-2099	**8%**	**7%**	**1%**	**7%**	**15%**	**26%**
Sacramento Valley	2015-2039	16%	4%	8%	12%	20%	8%
	2040-2069	17%	10%	0%	13%	30%	23%
	2070-2099	13%	10%	0%	23%	43%	43%
	2015-2099	**15%**	**8%**	**2%**	**16%**	**32%**	**26%**
San Joaquin Valley	2015-2039	28%	0%	4%	12%	16%	24%
	2040-2069	23%	10%	3%	17%	33%	50%
	2070-2099	13%	17%	0%	27%	37%	53%
	2015-2099	**21%**	**9%**	**2%**	**19%**	**29%**	**44%**
Tulare Lake	2015-2039	12%	8%	4%	16%	24%	24%
	2040-2069	27%	13%	7%	23%	23%	40%
	2070-2099	17%	20%	0%	33%	33%	43%
	2015-2099	**19%**	**14%**	**4%**	**25%**	**27%**	**36%**

Table 5-4d. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) for the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/year)

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_Gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Shasta	2015-2039	4%	0%	0%	36%	8%	28%
	2040-2069	13%	13%	0%	7%	60%	37%
	2070-2099	30%	0%	0%	17%	50%	30%
	2015-2099	**16%**	**5%**	**0%**	**19%**	**41%**	**32%**
Folsom	2015-2039	16%	0%	0%	48%	12%	32%
	2040-2069	17%	13%	0%	7%	60%	40%
	2070-2099	37%	0%	3%	20%	43%	23%
	2015-2099	**24%**	**5%**	**1%**	**24%**	**40%**	**32%**
Oroville	2015-2039	4%	0%	0%	24%	12%	28%
	2040-2069	10%	10%	3%	13%	40%	33%
	2070-2099	17%	3%	0%	23%	13%	17%
	2015-2099	**11%**	**5%**	**1%**	**20%**	**22%**	**26%**
New Melones	2015-2039	0%	8%	0%	32%	24%	48%
	2040-2069	20%	7%	0%	10%	43%	57%
	2070-2099	7%	0%	0%	0%	43%	30%
	2015-2099	**9%**	**5%**	**0%**	**13%**	**38%**	**45%**
San Luis CVP	2015-2039	4%	16%	0%	24%	4%	20%
	2040-2069	3%	7%	3%	13%	7%	27%
	2070-2099	7%	0%	0%	13%	13%	23%
	2015-2099	**5%**	**7%**	**1%**	**16%**	**8%**	**24%**
San Luis SWP	2015-2039	4%	16%	0%	20%	8%	28%
	2040-2069	10%	10%	3%	13%	33%	40%
	2070-2099	10%	0%	0%	20%	17%	23%
	2015-2099	**8%**	**8%**	**1%**	**18%**	**20%**	**31%**
Sacramento Valley	2015-2039	8%	0%	0%	36%	12%	28%
	2040-2069	13%	13%	0%	10%	57%	43%
	2070-2099	33%	3%	0%	23%	43%	27%
	2015-2099	**19%**	**6%**	**0%**	**22%**	**39%**	**33%**
San Joaquin Valley	2015-2039	4%	4%	0%	40%	28%	28%
	2040-2069	20%	7%	3%	10%	53%	50%
	2070-2099	7%	0%	0%	10%	23%	30%
	2015-2099	**11%**	**4%**	**1%**	**19%**	**35%**	**36%**
Tulare Lake	2015-2039	8%	4%	0%	32%	20%	4%
	2040-2069	20%	13%	23%	30%	53%	47%
	2070-2099	13%	0%	10%	33%	20%	43%
	2015-2099	**14%**	**6%**	**12%**	**32%**	**32%**	**33%**

Table 5-4e. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Shasta	2015-2039	36%	52%	56%	24%	16%	32%
	2040-2069	3%	20%	47%	3%	0%	3%
	2070-2099	3%	20%	47%	0%	0%	10%
	2015-2099	**13%**	**29%**	**49%**	**8%**	**5%**	**14%**
Folsom	2015-2039	32%	52%	56%	20%	12%	32%
	2040-2069	3%	27%	43%	3%	3%	3%
	2070-2099	0%	27%	47%	0%	0%	10%
	2015-2099	**11%**	**34%**	**48%**	**7%**	**5%**	**14%**
Oroville	2015-2039	24%	24%	24%	8%	8%	16%
	2040-2069	10%	20%	27%	3%	3%	13%
	2070-2099	3%	27%	37%	0%	0%	10%
	2015-2099	**12%**	**24%**	**29%**	**4%**	**4%**	**13%**
New Melones	2015-2039	24%	44%	48%	16%	16%	24%
	2040-2069	0%	30%	43%	0%	0%	0%
	2070-2099	10%	27%	20%	0%	3%	10%
	2015-2099	**11%**	**33%**	**36%**	**5%**	**6%**	**11%**
San Luis CVP	2015-2039	8%	12%	16%	0%	0%	4%
	2040-2069	7%	20%	20%	0%	0%	3%
	2070-2099	7%	17%	17%	3%	0%	3%
	2015-2099	**7%**	**16%**	**18%**	**1%**	**0%**	**4%**
San Luis SWP	2015-2039	24%	24%	28%	8%	8%	20%
	2040-2069	7%	23%	33%	0%	3%	3%
	2070-2099	7%	33%	43%	0%	0%	3%
	2015-2099	**12%**	**27%**	**35%**	**2%**	**4%**	**8%**
Sacramento Valley	2015-2039	28%	52%	56%	20%	16%	24%
	2040-2069	3%	20%	50%	3%	3%	3%
	2070-2099	3%	33%	53%	0%	0%	10%
	2015-2099	**11%**	**34%**	**53%**	**7%**	**6%**	**12%**
San Joaquin Valley	2015-2039	12%	36%	40%	8%	8%	12%
	2040-2069	7%	33%	37%	3%	3%	7%
	2070-2099	13%	30%	20%	0%	3%	13%
	2015-2099	**11%**	**33%**	**32%**	**4%**	**5%**	**11%**
Tulare Lake	2015-2039	8%	28%	28%	8%	4%	8%
	2040-2069	17%	43%	47%	10%	7%	23%
	2070-2099	7%	40%	50%	0%	0%	23%
	2015-2099	**11%**	**38%**	**42%**	**6%**	**4%**	**19%**

5.2.2.3. CVP and SWP 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 three 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, providing most of the Delta's freshwater, while the San Joaquin River arrives from the south.

Indicator
As the CVP and SWP Delta exports are a significant portion of the water supply available to San Joaquin Valley, Tulare Lake Basin, and out-of-basin water users, exports indicate overall water supply reliability.

Measure:
Amount of Delta exports in cfs/yr by the CVP and SWP. *Increases in Delta exports would imply that water delivery reliability is increasing.*

The CVP exports water from the C.W. "Bill" Jones Pumping Plant (PP) and SWP exports from the Harvey O. Banks PP. Both pumping plants are in the southern part of the Delta.

Although the trends for the five ensemble climate scenarios were very similar in the first few years of the simulation, the variability among all the climate scenarios grew greater as the transient simulation moved toward the latter part of the 21st century.

Under the Current Trends socioeconomic scenario:

- The total Delta export results differed significantly among the different climate scenarios. The 12 CCTAG scenarios reflected a range of results similar to the ensemble scenarios for total Delta exports and for CVP and SWP exports.

- Jones PP (CVP) and Banks PP (SWP) pumping were all lower under the Central, Warm-Dry, and Hot-Dry climate scenarios than under the Reference-No-Climate-Change climate scenario, with the lowest flows among the ensemble scenarios occurring in the warmer-drier Hot-Dry climate scenario. Conversely, the annual flows at both locations were greater under the Warm-Wet and Hot-Wet climate scenarios than under the Reference-No-Climate-Change climate scenario, with the highest flows among the ensemble climate scenarios occurring in the Warm-Wet climate scenario.

- The drier climate scenarios (Warm-Dry-and Hot-Dry) showed a greater difference in Delta exports relative to the Reference-No-Climate-Change climate scenarios than did the wetter climate scenarios (Hot-Wet and Warm-Wet) because exports in the wetter climate scenarios were frequently limited by CVP-SWP conveyance capacities and Delta regulatory requirements.

In Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the total average annual export was 5,252 TAF/year from 2015 to 2099 and had period averages of:

- 2015-2039: 4,472 TAF/year
- 2040-2069: 5,522 TAF/year
- 2070-2099: 5,466 TAF/year

Across the range of all socioeconomic-climate scenarios, the average annual total export was 5,121 TAF/year, a decrease of approximately 2.5% compared to the Reference-No-Climate-Change climate scenario. Export pumping ranged from:

- 2015-2039: 4,557 to 6,219 TAF/year
- 2040-2069: 4,265 to 6,066 TAF/year
- 2070-2099: 4,634 to 6,172 TAF/year

Figure 5-6 shows annual exceedance of CVP and SWP exports at Jones PP, Banks PP, and total Delta exports for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic scenario.

Figure 5-7 shows box plots showing these annual exports in TAF at Banks PP (CVP), Jones PP (SWP), and the total Delta exports for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic scenario.

Figure 5-8 shows 10-year moving average time series of average annual Delta exports in each year in each ensemble and CCTAG climate scenario for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic scenario.

Table 5-5 shows the average annual exports from each pumping facility as well as total average annual exports.

Figure 5-6. Delta exports: exceedence plots

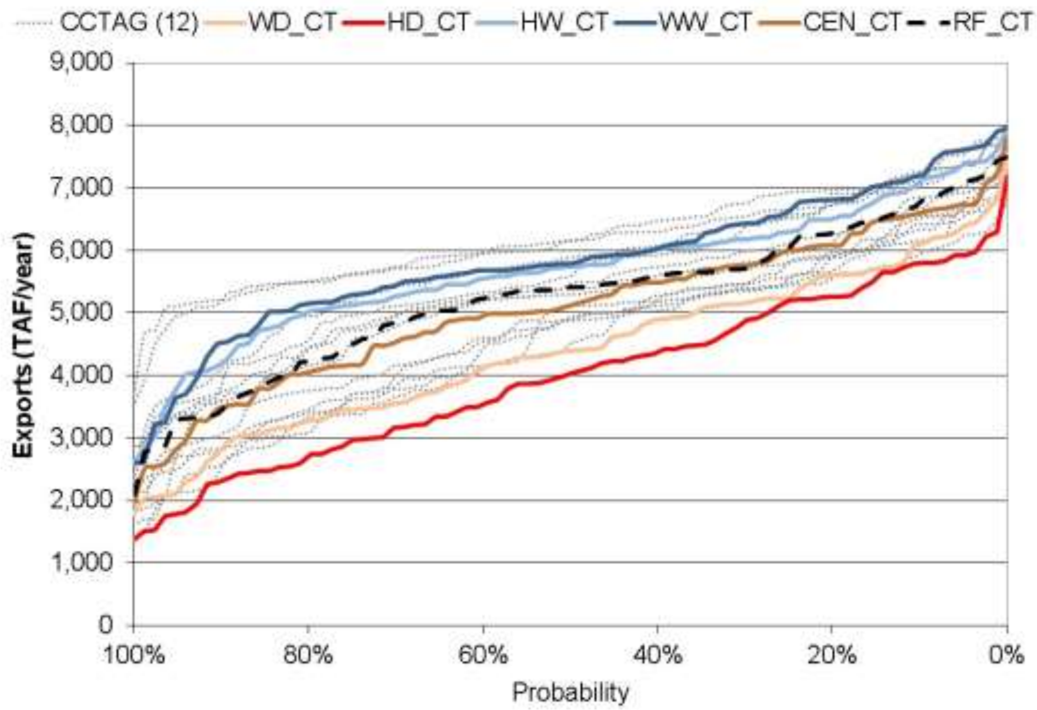


Figure 5-6a. Annual exceedance plot of **total Delta exports** for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic

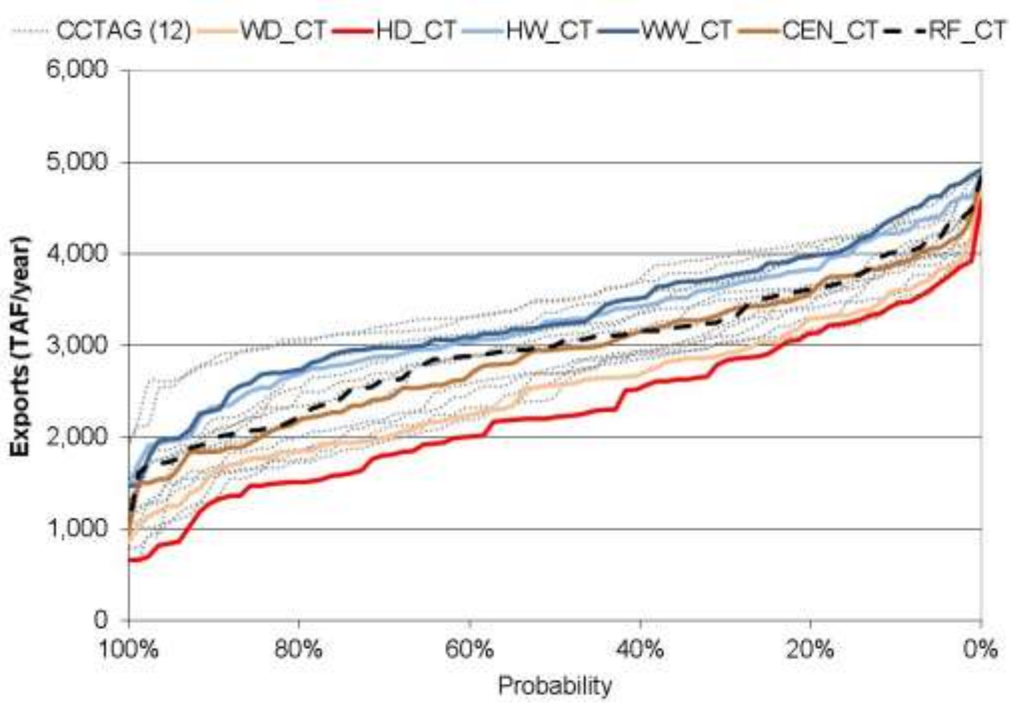


Figure 5-6b. Annual exceedance plot of **Banks PP pumping (CVP)** for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic scenario.

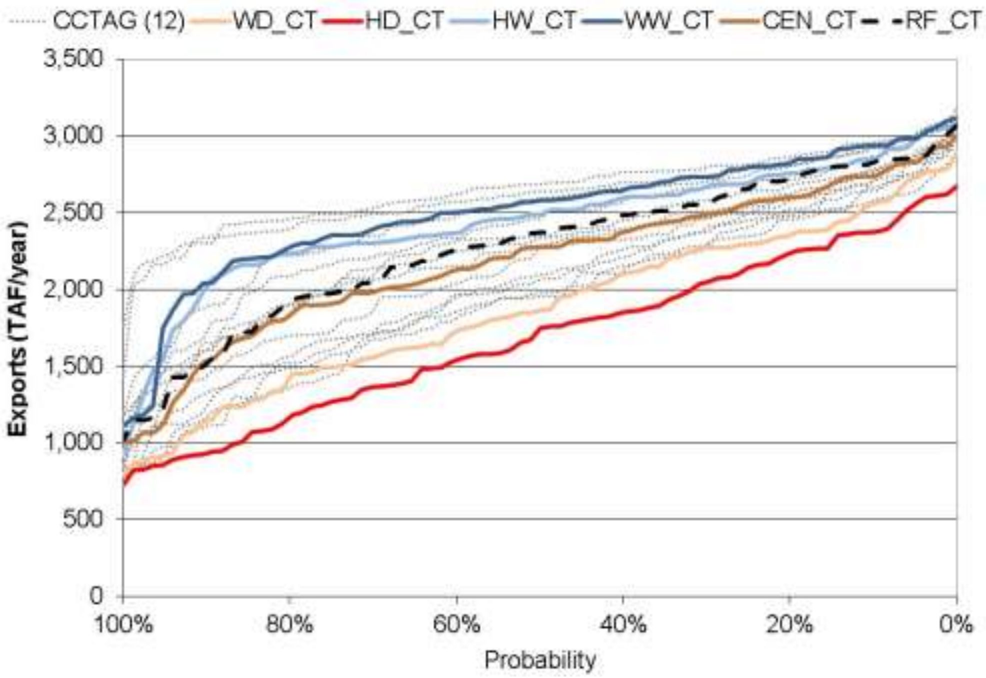


Figure 5-6c. Annual exceedance plot of **Jones PP pumping (SWP)** for the Reference-No-Climate-Change and ensemble climate scenarios with the Current Trends socioeconomic scenario.

Figure 5-7. Delta exports: box plots

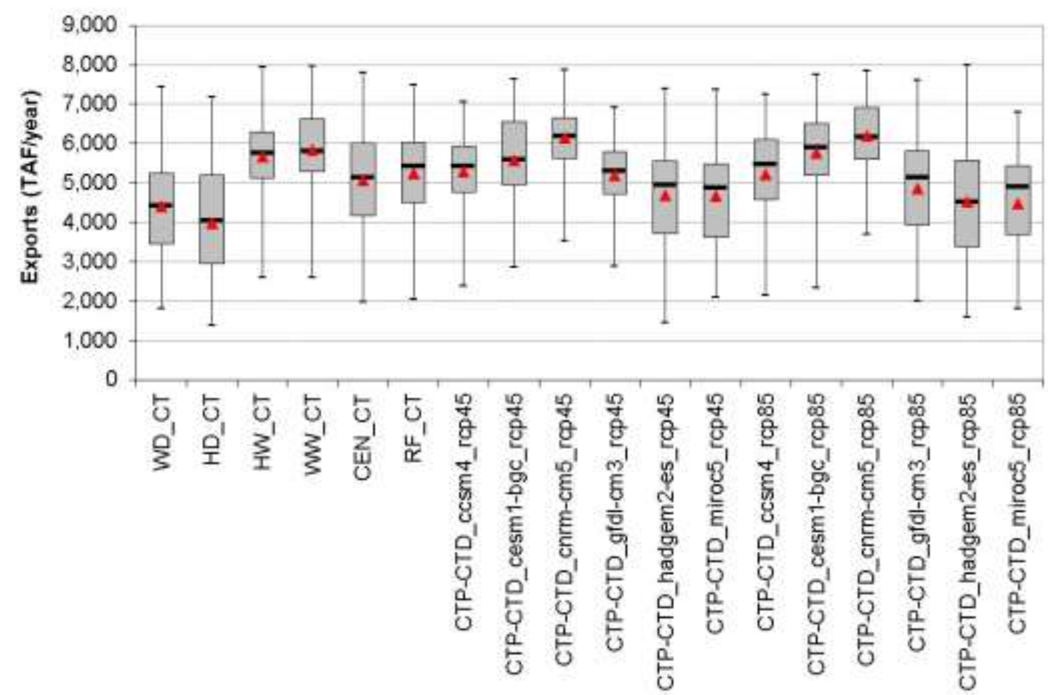


Figure 5-7a. Box plot of average annual **total Delta exports** for each climate scenario under the Current Trends socioeconomic scenario (TAF/year).

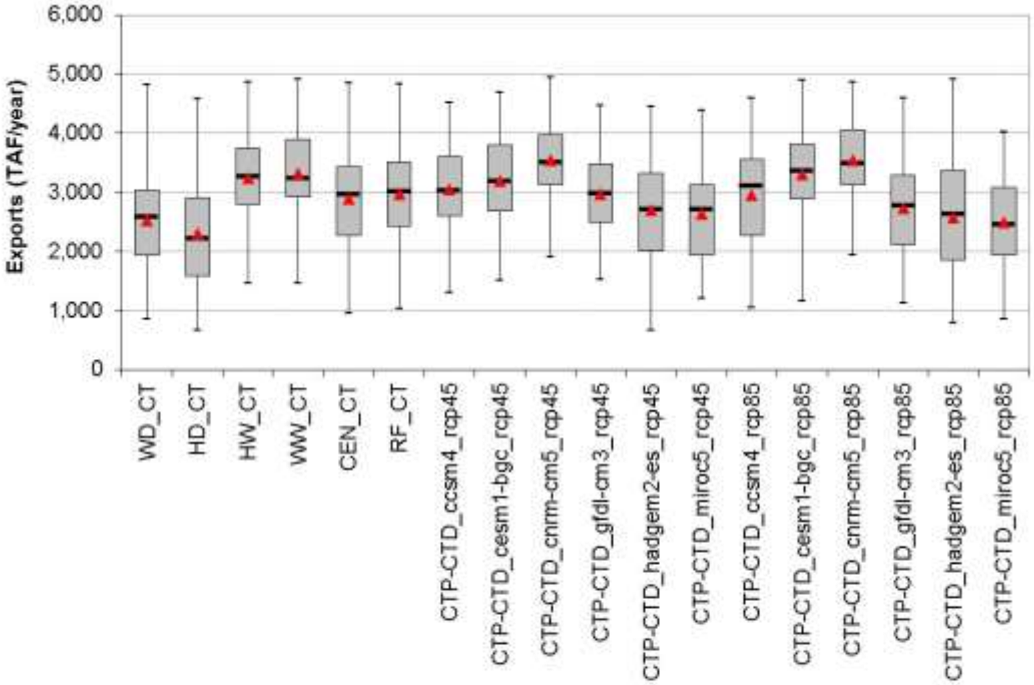


Figure 5-7b. Box plot of average annual **Banks PP pumping** for each climate scenario under the Current Trends socioeconomic scenario (TAF/year).

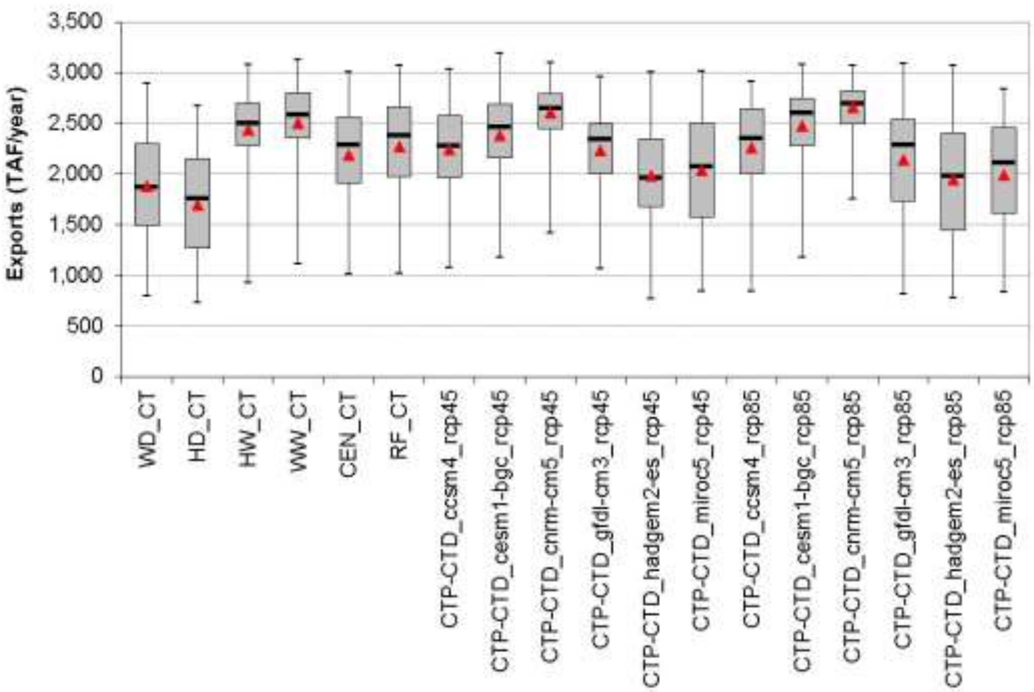


Figure 5-7c. Box plot of average annual **Jones PP pumping** for each climate scenario under the Current Trends socioeconomic scenario (TAF/year).

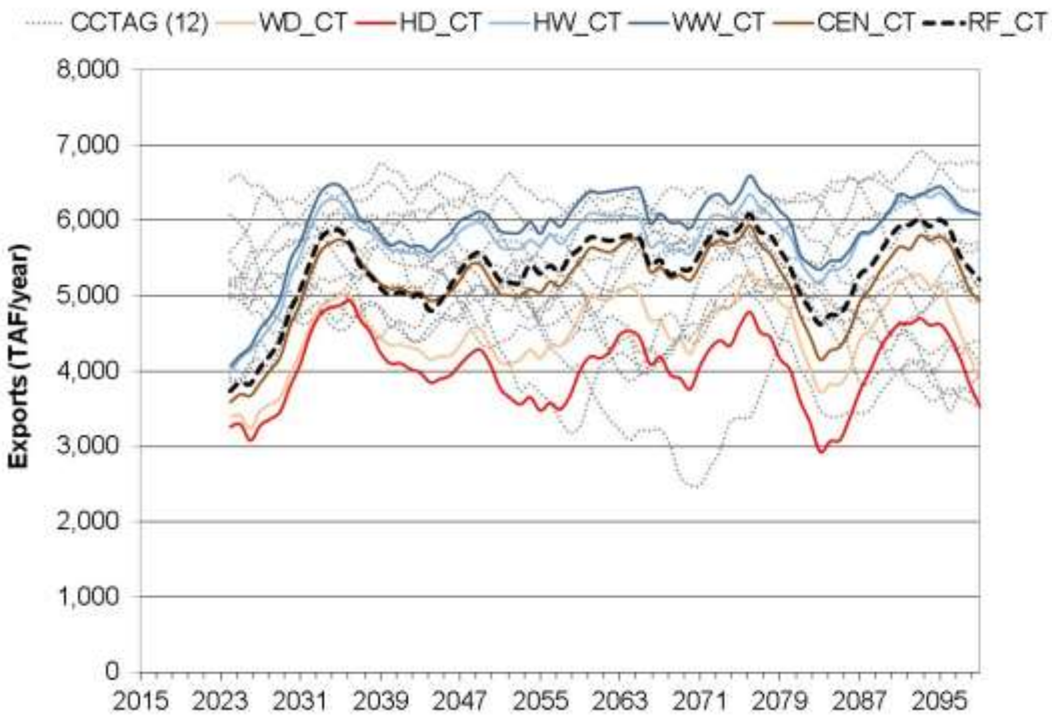


Figure 5-8. Delta exports: 10-year moving average of annual total Delta exports in the baseline in each climate scenario under the Current Trends socioeconomic scenario.

Table 5-5. Delta Exports: Average Annual Exports

Table 5-5a. Average Annual Exports at Banks PP, Jones PP, and Total CVP and SWP in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Banks	2015-2039	2,682	2,348	2,241	2,964	2,951	2,662
	2040-2069	3,092	2,625	2,377	3,344	3,506	3,056
	2070-2099	3,105	2,575	2,257	3,381	3,464	2,922
	2015-2099	**2,976**	**2,526**	**2,295**	**3,246**	**3,328**	**2,893**
Jones	2015-2039	1,990	1,710	1,636	2,146	2,272	1,929
	2040-2069	2,430	1,956	1,691	2,513	2,616	2,326
	2070-2099	2,361	1,936	1,742	2,607	2,596	2,274
	2015-2099	**2,276**	**1,877**	**1,693**	**2,438**	**2,508**	**2,191**
Total	2015-2039	4,672	4,059	3,877	5,110	5,223	4,590
	2040-2069	5,522	4,581	4,068	5,858	6,122	5,383
	2070-2099	5,466	4,511	3,999	5,988	6,060	5,196
	2015-2099	**5,252**	**4,403**	**3,987**	**5,684**	**5,835**	**5,084**

Table 5-5b. Average Annual Exports at Banks PP, Jones PP, and Total CVP and SWP in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for Each Scenario for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Banks	2015-2039	2,682	2,348	2,241	2,964	2,951	2,662
	2040-2069	3,092	2,625	2,377	3,344	3,506	3,056
	2070-2099	3,105	2,575	2,257	3,381	3,464	2,922
	2015-2099	**2,976**	**2,526**	**2,295**	**3,246**	**3,328**	**2,893**
Jones	2015-2039	1,990	1,710	1,636	2,146	2,272	1,929
	2040-2069	2,430	1,956	1,691	2,513	2,616	2,326
	2070-2099	2,361	1,936	1,742	2,607	2,596	2,274
	2015-2099	**2,276**	**1,877**	**1,693**	**2,438**	**2,508**	**2,191**
Total	2015-2039	4,672	4,059	3,877	5,110	5,223	4,590
	2040-2069	5,522	4,581	4,068	5,858	6,122	5,383
	2070-2099	5,466	4,511	3,999	5,988	6,060	5,196
	2015-2099	**5,252**	**4,403**	**3,987**	**5,684**	**5,835**	**5,084**

Table 5-5c. Average Annual Exports at Banks PP, Jones PP, and Total CVP and SWP in the **CCTAG 4.5 RCP** Climate Scenarios for Each Scenario for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_Gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
Banks	2015-2039	2,841	3,082	3,604	2,918	2,956	3,153
	2040-2069	3,122	3,110	3,471	3,011	2,732	2,655
	2070-2099	3,129	3,387	3,552	2,956	2,459	2,196
	2015-2099	**3,042**	**3,199**	**3,539**	**2,964**	**2,701**	**2,639**
Jones	2015-2039	2,200	2,427	2,615	2,257	2,284	2,415
	2040-2069	2,310	2,321	2,595	2,368	1,974	2,055
	2070-2099	2,201	2,417	2,621	2,089	1,747	1,705
	2015-2099	**2,239**	**2,386**	**2,610**	**2,237**	**1,985**	**2,037**
Total	2015-2039	5,041	5,509	6,219	5,175	5,240	5,569
	2040-2069	5,431	5,430	6,066	5,379	4,706	4,711
	2070-2099	5,330	5,804	6,172	5,044	4,205	3,900
	2015-2099	**5,281**	**5,585**	**6,148**	**5,201**	**4,686**	**4,677**

Table 5-5d. Average Annual Exports at Banks PP, Jones PP, and Total CVP and SWP in the **CCTAG 8.5 RCP** Climate Scenarios for Each Scenario for the **Current Trends** Socioeconomic Scenario (in TAF/year).

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_Gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Banks	2015-2039	3,188	3,133	3,634	2,516	2,923	2,515
	2040-2069	2,837	3,126	3,410	3,042	2,294	2,410
	2070-2099	2,891	3,610	3,611	2,584	2,559	2,544
	2015-2099	**2,960**	**3,299**	**3,547**	**2,725**	**2,573**	**2,488**
Jones	2015-2039	2,419	2,430	2,737	1,964	2,306	2,042
	2040-2069	2,196	2,385	2,610	2,371	1,753	1,855
	2070-2099	2,204	2,613	2,640	2,072	1,832	2,091
	2015-2099	**2,264**	**2,479**	**2,658**	**2,146**	**1,944**	**1,993**
Total	2015-2039	5,607	5,563	6,371	4,480	5,229	4,557
	2040-2069	5,033	5,511	6,020	5,413	4,047	4,265
	2070-2099	5,096	6,223	6,250	4,655	4,391	4,634
	2015-2099	**5,224**	**5,778**	**6,204**	**4,871**	**4,516**	**4,481**

Table 5-5e. Average Annual Exports at Banks PP, Jones PP, and Total CVP and SWP in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario (in TAF/year).

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Banks	2015-2039	2,674	2,342	2,242	2,964	2,961	2,651
	2040-2069	3,057	2,670	2,383	3,341	3,503	3,044
	2070-2099	3,066	2,591	2,255	3,384	3,456	2,926
	2015-2099	**2,947**	**2,546**	**2,297**	**3,245**	**3,327**	**2,887**
Jones	2015-2039	1,989	1,715	1,638	2,147	2,271	1,931
	2040-2069	2,428	1,974	1,688	2,528	2,634	2,345
	2070-2099	2,384	1,973	1,769	2,633	2,621	2,317
	2015-2099	**2,283**	**1,897**	**1,702**	**2,453**	**2,523**	**2,213**
Total	2015-2039	4,663	4,058	3,880	5,111	5,232	4,582
	2040-2069	5,485	4,644	4,071	5,869	6,136	5,388
	2070-2099	5,450	4,564	4,025	6,017	6,077	5,243
	2015-2099	**5,231**	**4,443**	**3,999**	**5,698**	**5,850**	**5,100**

5.2.2.4. Change in Groundwater Storage

Indicator:
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.

Measure:
Annual changes in storage in TAF in the Sacramento River, San Joaquin River, Delta, and Tulare Lake regions. *Increases in groundwater storage would imply that the groundwater supply reliability is increasing.*

Under the Current Trends socioeconomic scenario, in all four regions, the annual changes in groundwater storage were dependent on the climate scenarios in that the wetter scenarios (Warm-Wet and Hot-Wet) had greater long-term increases in groundwater storage due to greater natural recharge and lower demand levels.

In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Central Valley average annual change in groundwater storage was 22 TAF/year from 2015 to 2099 and averaged:

- 2015-2039: 0 TAF/year
- 2040-2069: 73 TAF/year
- 2070-2099:-12 TAF/year

Across the range of all socioeconomic-climate scenarios, the average annual change in groundwater storage in the Central Valley was 38 TAF/year, a decrease of 71% compared to Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios. It ranged from:

- For 2014-2039:-85 to 259 TAF/year
- For 2040-2069:-209 to 119 TAF/year
- For 2070-2099:-83 to 248 TAF/year

Figure 5-9 shows the annual changes in total groundwater storage in the Central Valley and in the Sacramento River, East Side streams and Delta, San Joaquin River, and the Tulare Lake regions for each of the ensemble and 12 CCTAG climate scenarios with the Current Trends socioeconomic scenario over water years from 2015 to 2099.

Figure 3-10 shows the cumulative change in groundwater storage in the Central Valley for the same scenarios.

Table 5-6 presents the average annual change in groundwater storage in each scenario. Groundwater storage metrics are presented in the Central Valley and in the Sacramento River, East Side streams and Delta, San Joaquin River, and the Tulare Lake regions.

Figure 5-9. Groundwater storage: annual change

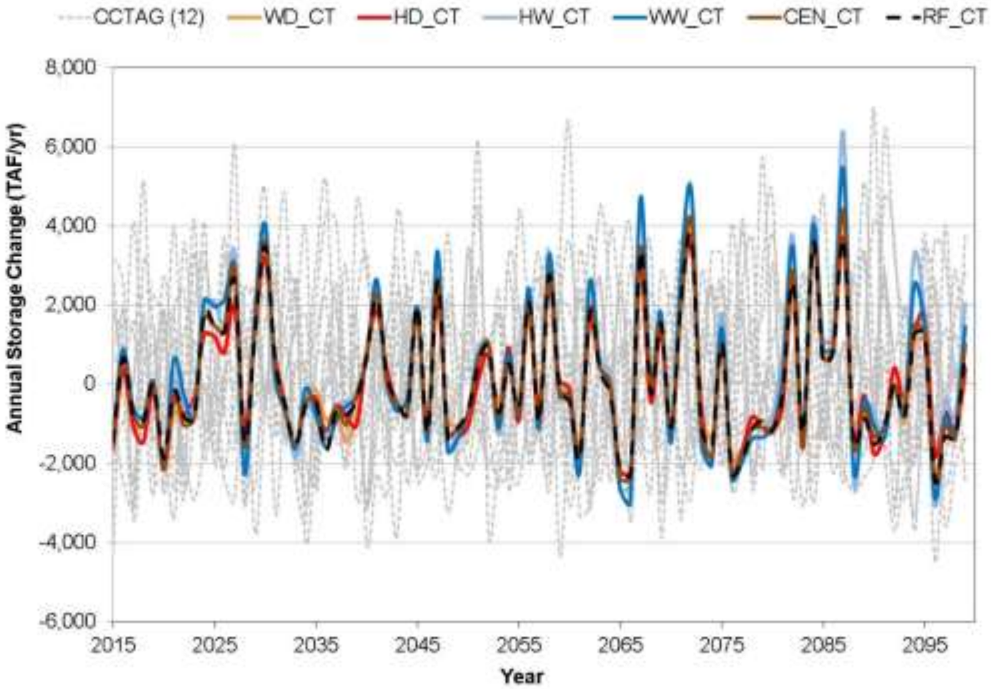


Figure 5-9a. Annual change in groundwater storage in the **Central Valley** in each climate scenario.

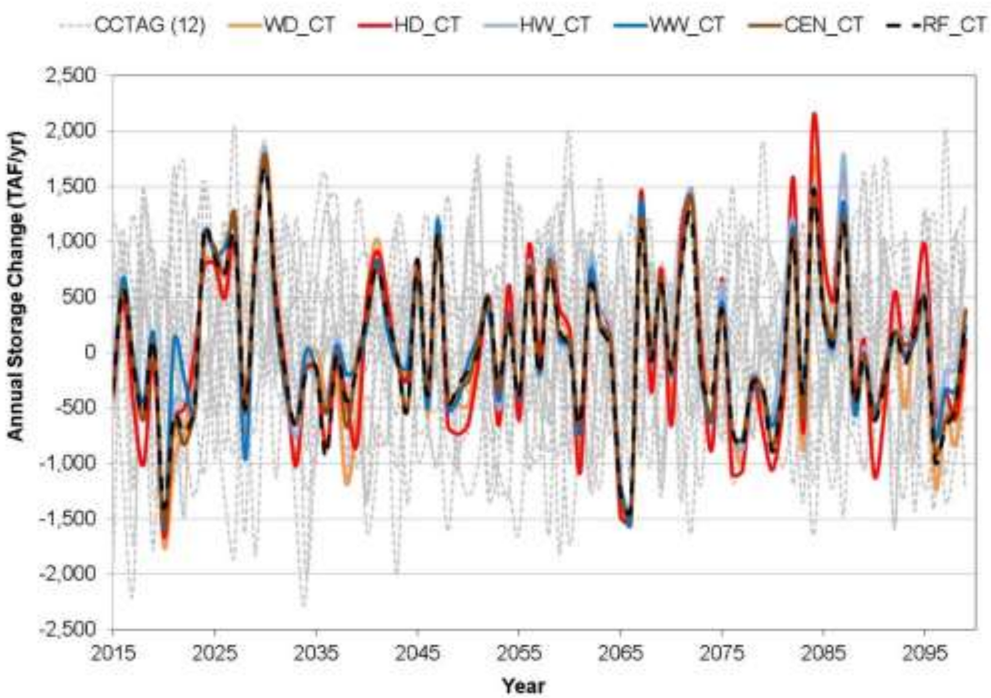


Figure 5-9b. Annual change in groundwater storage in the **Sacramento River system** in each climate scenario.

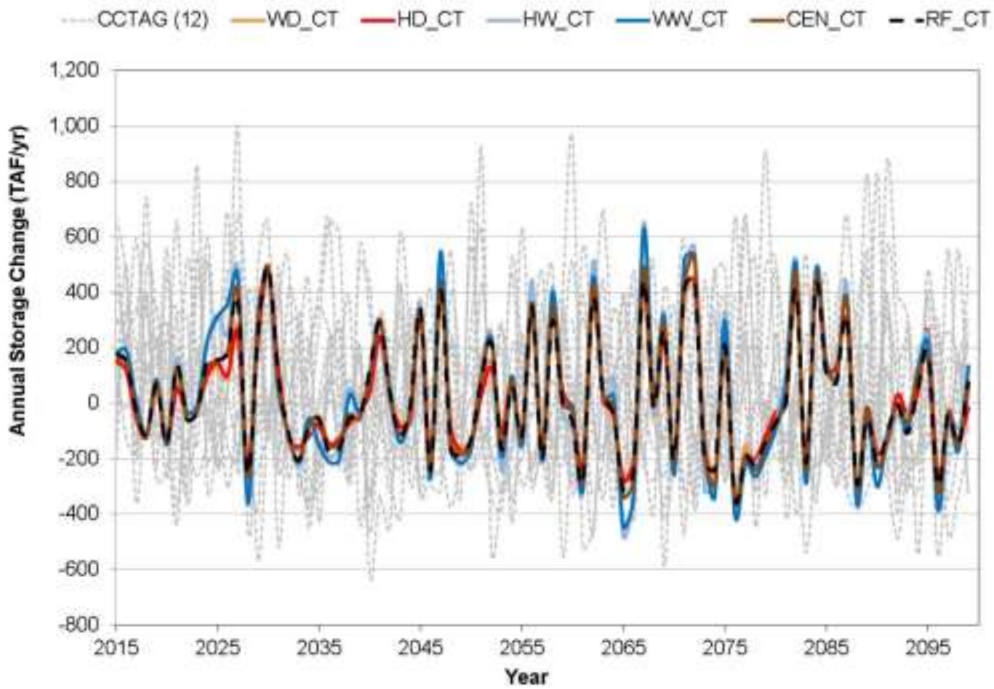


Figure 5-9c. Annual change in groundwater storage in the **Eastside Streams and Delta** in each climate scenario.

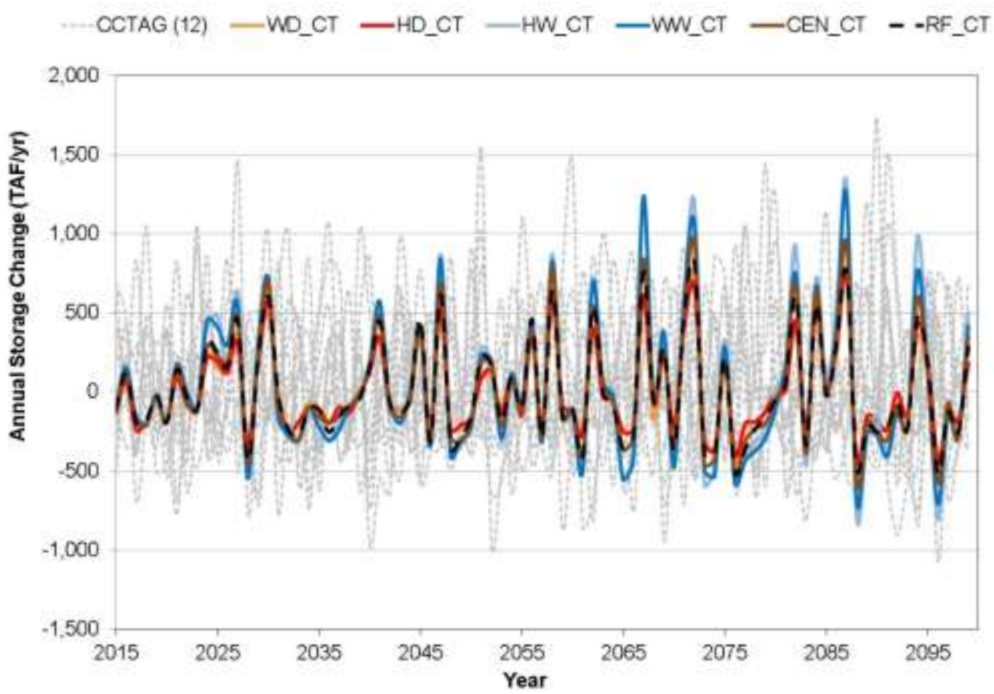


Figure 5-9d. Annual change in groundwater storage in the **San Joaquin River system** in each climate scenario.

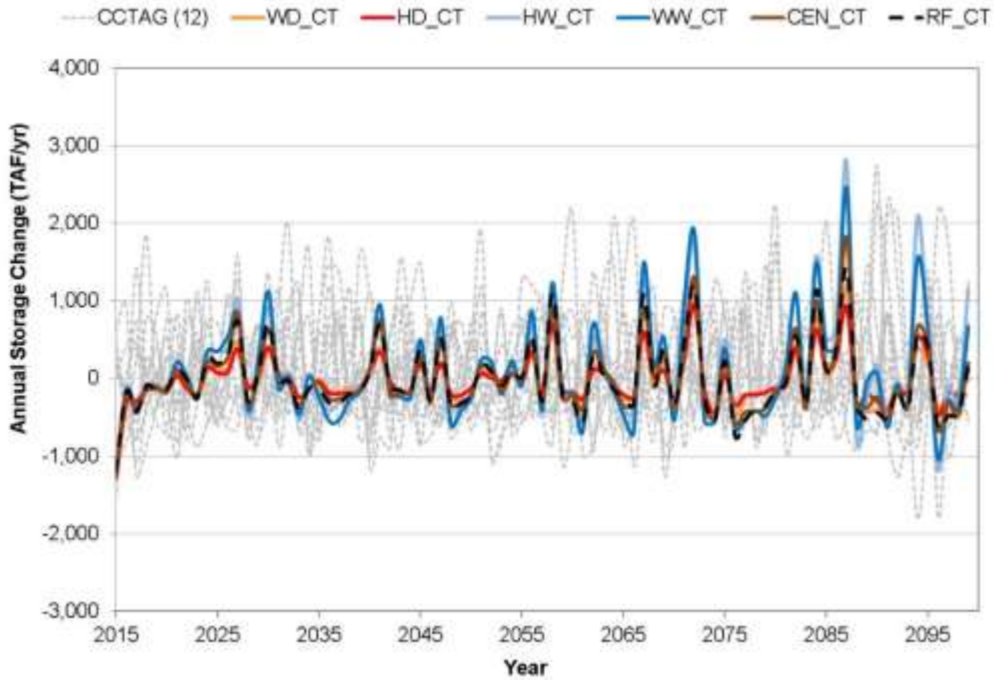


Figure 5-9e. Annual change in groundwater storage in the **Tulare Lake Region** in each climate scenario.

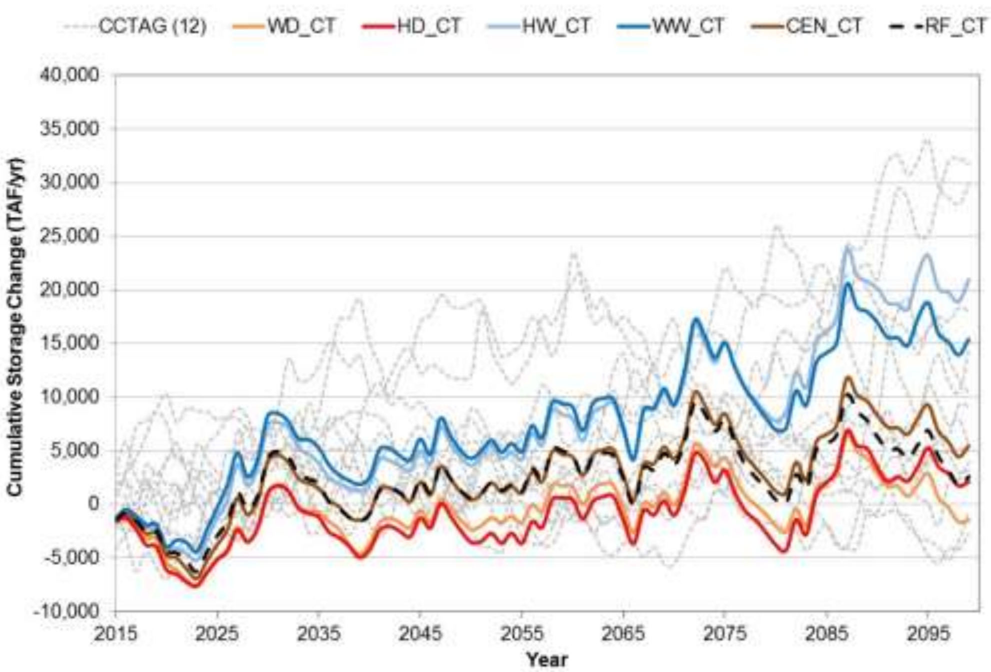


Figure 5-10. Cumulative change in groundwater storage in the Central Valley in each climate scenario.

Table 5-6. Groundwater Storage: Average Annual Change in TAF/Year

Table 5-6a. Average Annual Change in Groundwater Storage in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario (in TAF/Year)

Location	Period	Reference_EG	Warm-Dry_EG	Hot-Dry_EG	Hot-Wet_EG	Warm-Wet_EG	Central_EG
Total Central Valley	2015-2039	-66	-194	-196	49	77	-54
	2040-2069	188	164	149	273	268	202
	2070-2099	-93	-98	13	260	103	-40
	2015-2099	**12**	**-34**	**0**	**199**	**151**	**41**
Sacramento River System	2015-2039	-2	-85	-82	57	83	9
	2040-2069	56	77	63	94	63	68
	2070-2099	-30	-49	30	74	-9	-10
	2015-2099	**9**	**-14**	**9**	**75**	**43**	**23**
Delta and Eastside Streams	2015-2039	-15	-24	-26	-2	0	-14
	2040-2069	41	30	35	66	65	47
	2070-2099	-23	-20	-4	9	-19	-14
	2015-2099	**2**	**-3**	**3**	**25**	**16**	**7**
San Joaquin River System	2015-2039	29	17	16	45	47	29
	2040-2069	33	35	36	46	42	41
	2070-2099	-9	-9	1	-4	-8	-6
	2015-2099	**17**	**14**	**18**	**28**	**25**	**21**
Tulare Lake Region	2015-2039	-79	-102	-103	-51	-52	-78
	2040-2069	57	23	15	66	98	47
	2070-2099	-31	-19	-14	180	139	-10
	2015-2099	**-16**	**-30**	**-30**	**70**	**67**	**-10**

Table 5-6b. Average Annual Change in Groundwater Storage in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/Year)

Location	Period	Reference_CT	Warm-Dry_CT	Hot-Dry_CT	Hot-Wet_CT	Warm-Wet_CT	Central_CT
Total Central Valley	2015-2039	-65	-185	-198	49	75	-59
	2040-2069	210	186	172	307	297	226
	2070-2099	-65	-83	63	360	161	6
	2015-2099	**30**	**-17**	**25**	**246**	**181**	**64**
Sacramento River System	2015-2039	0	-76	-83	58	81	4
	2040-2069	73	93	78	119	84	89
	2070-2099	-12	-47	58	109	20	13
	2015-2099	**22**	**-5**	**24**	**97**	**60**	**38**
Delta and Eastside Streams	2015-2039	29	16	15	45	46	28
	2040-2069	34	36	38	48	43	41
	2070-2099	-12	-11	-1	-1	-8	-7
	2015-2099	**16**	**14**	**18**	**29**	**26**	**20**
San Joaquin River System	2015-2039	-15	-25	-27	-2	1	-14
	2040-2069	45	36	39	72	70	51
	2070-2099	-16	-12	7	25	-7	-5
	2015-2099	**6**	**1**	**8**	**33**	**22**	**12**
Tulare Lake Region	2015-2039	-79	-100	-104	-52	-53	-78
	2040-2069	59	21	17	68	100	44
	2070-2099	-26	-13	-2	227	156	5
	2015-2099	**-13**	**-27**	**-26**	**87**	**73**	**-6**

Table 5-6c. Average Annual Change in Groundwater Storage in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/Year)

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_Gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
Total Central Valley	2015-2039	-34	233	766	132	51	113
	2040-2069	212	127	-229	108	0	-71
	2070-2099	8	32	203	-104	-57	-114
	2015-2099	**66**	**121**	**212**	**38**	**-7**	**-33**
Sacramento River System	2015-2039	-18	75	259	74	18	64
	2040-2069	88	27	-103	47	1	-19
	2070-2099	-21	-34	42	-49	-51	-83
	2015-2099	**18**	**20**	**54**	**20**	**-11**	**-17**
Delta and Eastside Streams	2015-2039	2	26	117	22	9	15
	2040-2069	23	9	-77	21	7	-8
	2070-2099	6	-8	30	-19	3	-3
	2015-2099	**11**	**7**	**17**	**7**	**6**	**1**
San Joaquin River System	2015-2039	58	63	136	66	59	59
	2040-2069	15	11	-53	24	6	5
	2070-2099	-2	0	19	-13	-6	-11
	2015-2099	**21**	**22**	**27**	**23**	**17**	**15**
Tulare Lake Region	2015-2039	-76	69	253	-30	-35	-25
	2040-2069	87	80	3	16	-14	-49
	2070-2099	25	74	112	-23	-3	-17
	2015-2099	**16**	**73**	**114**	**-12**	**-18**	**-31**

Table 5-6d. Average Annual Change in Groundwater Storage in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario (in TAF/Year)

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_Gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Total Central Valley	2015-2039	240	308	555	78	345	-22
	2040-2069	-24	15	69	248	-469	-19
	2070-2099	305	791	478	-121	491	173
	2015-2099	**167**	**373**	**352**	**65**	**107**	**46**
Sacramento River System	2015-2039	96	124	183	40	131	13
	2040-2069	-2	-34	11	93	-209	-8
	2070-2099	91	241	133	-28	248	86
	2015-2099	**59**	**109**	**104**	**34**	**52**	**32**
Delta and Eastside Streams	2015-2039	38	58	68	16	56	-5
	2040-2069	3	-11	-8	36	-59	4
	2070-2099	44	92	56	-30	71	35
	2015-2099	**27**	**45**	**36**	**6**	**20**	**12**
San Joaquin River System	2015-2039	74	88	98	61	89	47
	2040-2069	2	-7	-4	28	-46	2
	2070-2099	26	54	29	-25	57	22
	2015-2099	**31**	**42**	**36**	**19**	**30**	**22**
Tulare Lake Region	2015-2039	32	38	207	-39	69	-77
	2040-2069	-27	67	70	91	-156	-17
	2070-2099	144	404	261	-39	114	30
	2015-2099	**50**	**178**	**176**	**6**	**5**	**-19**

Table 5-6e. Average Annual Change in Groundwater Storage in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario (in TAF/Year)

Location	Period	Reference_SG	Warm-Dry_SG	Hot-Dry_SG	Hot-Wet_SG	Warm-Wet_SG	Central_SG
Total Central Valley	2015-2039	-64	-185	-198	53	78	-57
	2040-2069	214	200	180	324	310	240
	2070-2099	-52	-72	81	384	167	18
	2015-2099	**36**	**-9**	**34**	**262**	**188**	**74**
Sacramento River System	2015-2039	2	-75	-82	62	84	8
	2040-2069	77	105	84	130	96	98
	2070-2099	-4	-39	68	116	22	20
	2015-2099	**27**	**2**	**31**	**104**	**67**	**44**
Delta and Eastside Streams	2015-2039	-17	-27	-29	-3	0	-16
	2040-2069	45	36	40	74	72	53
	2070-2099	-16	-12	9	26	-8	-4
	2015-2099	**6**	**1**	**9**	**34**	**22**	**13**
San Joaquin River System	2015-2039	30	17	16	46	47	29
	2040-2069	36	38	40	51	47	44
	2070-2099	-11	-8	2	1	-5	-5
	2015-2099	**17**	**15**	**19**	**32**	**28**	**22**
Tulare Lake Region	2015-2039	-79	-100	-104	-52	-53	-78
	2040-2069	56	21	17	68	95	45
	2070-2099	-23	-12	1	241	157	8
	2015-2099	**-13**	**-27**	**-25**	**92**	**72**	**-5**

5.2.3. 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. See Appendix 5E. *Economics Performance Assessment Tools* for details and references.

Economic attributes used in the Basin Study are net benefits of water supply to urban and agricultural regions and salinity management costs. The results from five economically-based water management models are presented in this section. These models provide the following capabilities:

- Least Cost Planning Simulation model (LCPSIM) provides economic results from changes in water supply for the South San Francisco Bay and South Coast Regions.
- Other Municipal Water Economics model (OMWEM) provides economic results from changes in water supply for urban regions in the Central Valley.
- South Bay Water Quality model (SBWQM) and Lower Colorado River Basin Water Quality Model (LCRBWQM) estimate salinity management costs for deliveries made through Delta exports in the South San Francisco Bay and South Coast Regions, respectively.
- Statewide Agricultural Production model (SWAP) provides economic results from changes in water supply for agricultural regions in the Central Valley.

To capture the range of future uncertainty, the economic models were analyzed for the:

- Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios
- Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios
- Central Tendency climate/Current Trends socioeconomic scenarios
- Hot-Dry climate/Expanded Growth socioeconomic scenarios
- Warm-Wet climate/Slow Growth socioeconomic scenarios

Because these economics models were designed to analyze differences among scenarios rather than the absolute values for a single scenario, the results are summarized in terms of differences in average annual net benefits between the three future socioeconomic-climate scenarios and Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF), which represents current socioeconomic and climate conditions. The results from the economic models are presented at three future levels of development. Three levels of development were selected to represent early (2025), mid (2055), and late (2085) twenty-first century socioeconomic and climate conditions. This approach allowed for a clearer understanding of how the changes in socioeconomic and climate factors affected the net economic benefits over different timeframes during the twenty-first century.

The Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios (RF_CT) represent the expected changes in economic values due to projected changes in population, land use, crop demands, and other projections but without the effect of climate change. Therefore, a comparison of results in the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios (RF_CT) to other scenarios shown on each figure provides an indication of the effect of climate change alone on water supply and water quality benefits for urban and agricultural uses. Results included:

- The urban economic models (LCPSIM and OMWEM) showed decreases in net economic benefits (that is an increase in water supply costs and shortages) of about $3.3 billion per year in the later period of the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios (RF_CT) scenario, due primarily to increasing population.

- The Central Tendency climate/Current Trends socioeconomic scenarios and Hot-Dry climate/Expanded Growth socioeconomic scenarios showed more economic costs in urban regions due to decreased CVP and SWP water deliveries than the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

- The decreases in net economic benefits were greatest in the Hot-Dry climate/Expanded Growth socioeconomic scenarios, which had the lowest Delta exports and highest population increase of these scenarios.

- By contrast, the Warm-Wet climate/Slow Growth socioeconomic scenarios had the smallest decrease in net economic benefits (that is, increase in water supply costs) due to higher Delta exports and lower population increase.

- In all four climate/socioeconomic scenarios, the reductions in net economic benefits were greatest in the late century when the population increases were greatest.

With Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the SWAP model results show significant improvements in agricultural economic benefits of about $8 billion per year in the current trends projection relative to reference socioeconomic conditions. This is primarily due to projected increases in demands for California agricultural commodities, resulting in higher prices and shifts in acreage towards crops with higher average net returns. These changes are also reflected in the other socioeconomic-climate projections, with differences among the Central Tendency climate/Current Trends socioeconomic scenarios, Hot-Dry climate/Expanded Growth socioeconomic scenarios, and Warm-Wet climate/Slow Growth socioeconomic scenarios driven by changes in water supplies resulting from the different climate scenarios.

Changes in salinity management costs reflected in SBWQM and LCRBWQM result from changes in the amount of water being diverted and the salinity of the water at the diversion locations for each region. The changes in diversions at these locations were consistent with the changes in exports discussed above. Salinity management costs were greater in Hot-Dry climate/Expanded Growth socioeconomic scenarios because increases in salinity were greater than under the other scenarios.

Because of the improvements in agricultural economic benefits, there is an overall economic benefit of about $2 billion per year in the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios in 2085. In the Central Tendency climate/Current Trends socioeconomic scenarios, the effects of climate change reduce the economic benefits to about $1 billion per year, while the other scenarios range from a projected reduction in economic benefits of about $19 billion per year to a projected improvement of about $6 billion per year.

Figure 5-11 shows the change in net economic benefits for the scenarios listed above at the three future levels of development based on results from the economic models.

Figure 5-11. Net economic benefits

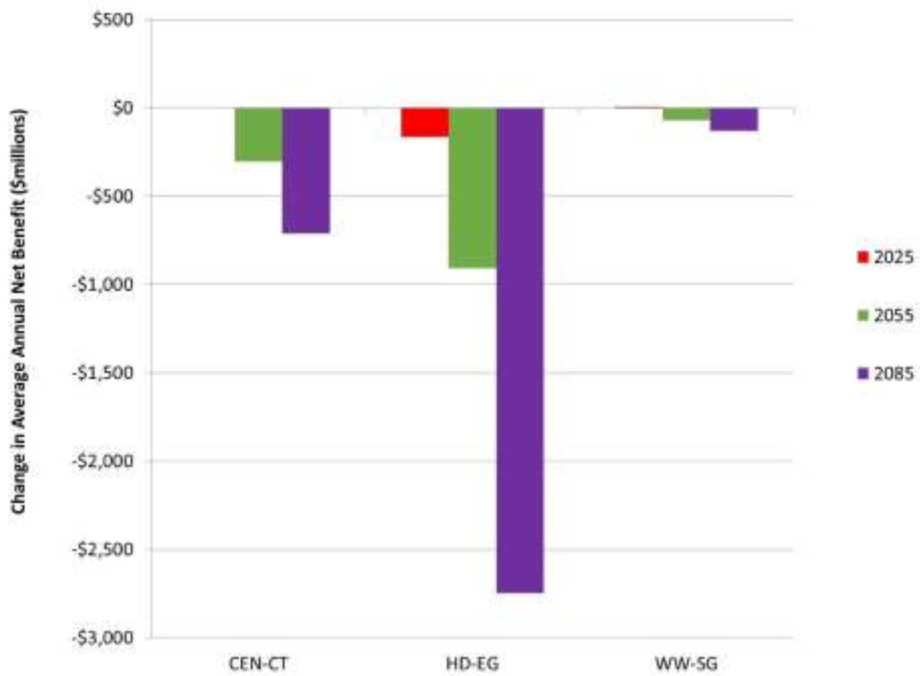


Figure 5-11a. Change in average **annual net benefit in South San Francisco Bay** region from LCPSIM in each scenario relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).

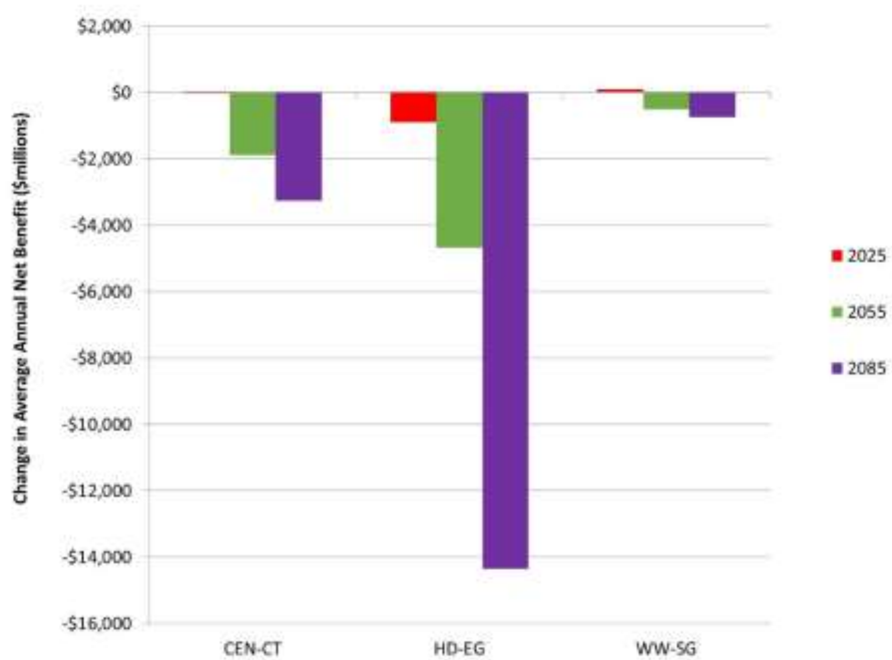


Figure 5-11b. Change in average annual net benefit in **South Coast** region from LCPSIM in each scenario relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).

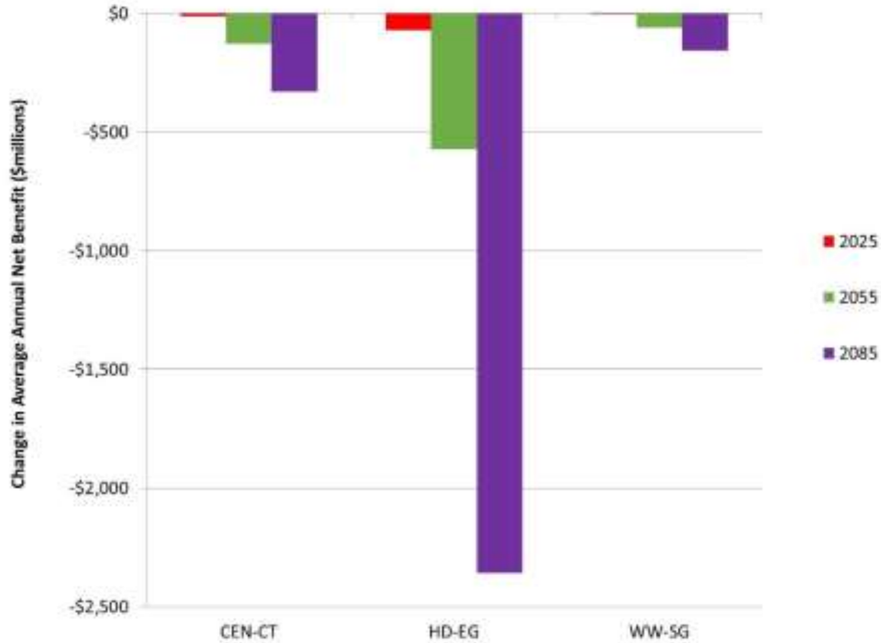


Figure 5-11c. Change in average annual net benefit in **Central Valley urban** areas from OMWEM in each scenario relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).

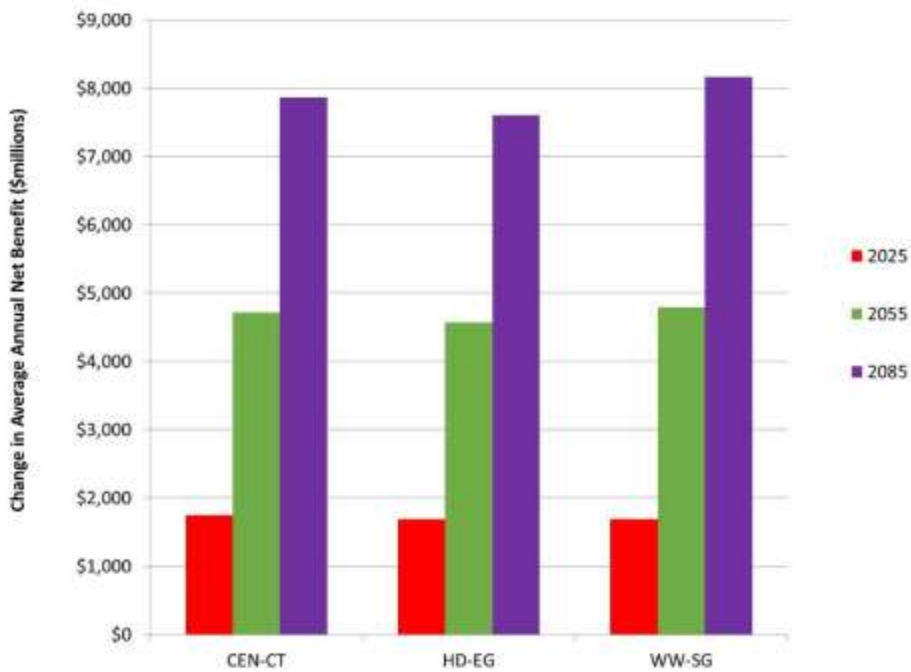


Figure 5-11d. Change in average annual net benefit **Central Valley agricultural** areas from SWAP in each Scenario Relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).

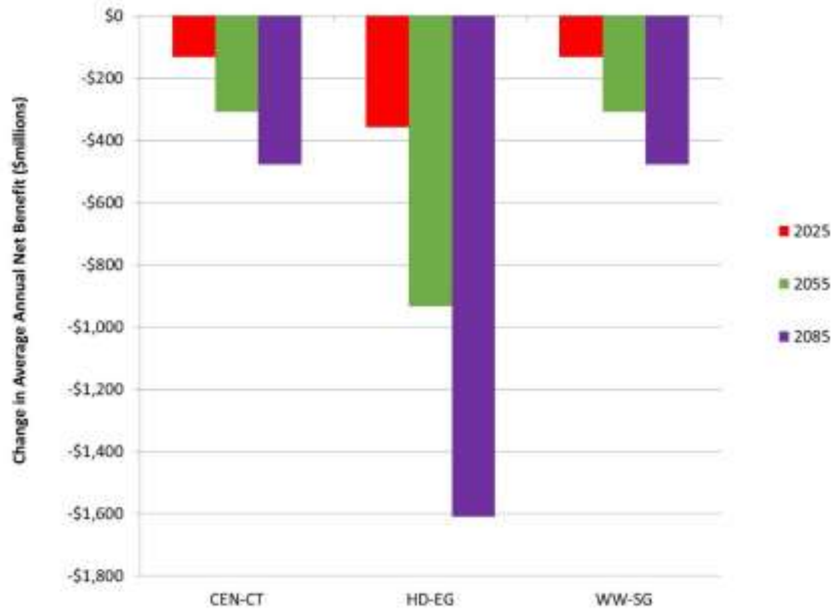


Figure 5-11e. Change in average annual net benefit in **South San Francisco Bay** region salinity management costs from SBWQM in each climate scenario relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).Scenario

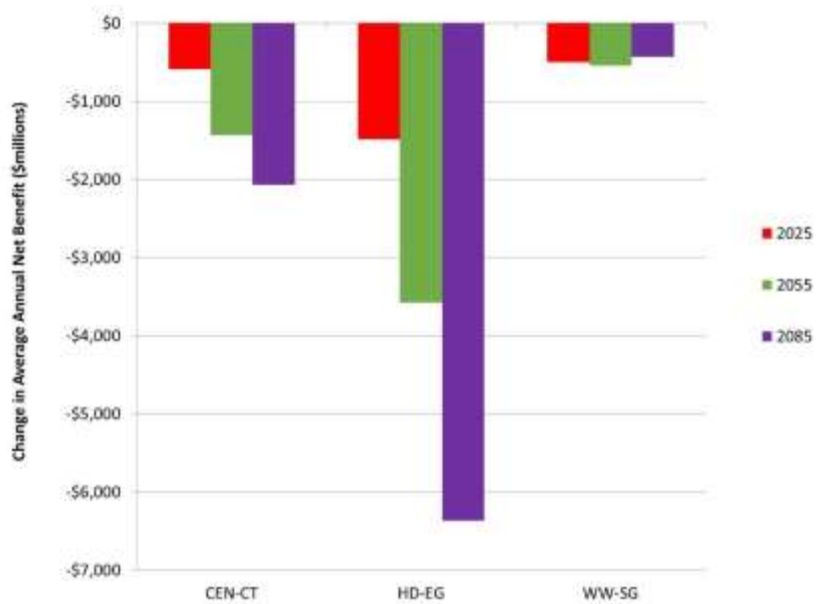


Figure 5-11f. Change in average annual net benefit in **South Coast Region salinity management costs** from LCRBWQM in each scenario relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF).Scenario

5.2.4. Water Quality

Reclamation and DWR 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. 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.

- **Delta Salinity.** Salinity standards were established by the State Water Resources Control Board (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. *The frequency of end-of-May storage below historic levels is the indicator; therefore, decreases in this indicator would imply that water quality is improving.*

5.2.4.1. Delta Salinity

Within the San Francisco Bay (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. Delta salinity standards are specified in units of electrical conductivity (EC) expressed as micro-Siemens per centimeter (µS/cm) at several Delta compliance locations (shown in Figure P-1 in the Preface of this report) including:

Indicator
Delta salinity levels indicate the health of the Bay-Delta ecosystems, levels of seawater intrusion, and water availability. 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.

Measure:
Micro-Siemens per centimeter (µS/cm) of electrical conductivity (EC) in State Water Resources Control Board (SWRCB) Decision 1641 (D1641) compliance locations (Emmaton, Rock Slough, Jersey Point and Vernalis). *Decreases in Delta salinity would imply that water quality is improving.*

- Emmaton and Jersey Point from April through August (ranging from 450 to 2,750 µS/cm, depending on the month and water year type)

- Vernalis and Rock Slough throughout the year (ranging from 631 to 965 µS/cm, depending on the month and water year type).

Under the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, the EC at all locations shows only small differences between the averages for the early, middle, and late portions of the 21st century. However, in the climate change scenarios, the EC results greatly increase as the simulation moves later into the twenty-first century, reflecting the effects of sea level rise on Delta salinity. Among the climate change scenarios, the EC levels are highest among the driest scenarios (e.g., Hot-Dry) and lowest among the wetter scenarios (e.g., Warm-Wet).

- **Emmaton:**
    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average April-to-August EC at Emmaton was 595 µS/cm.
    - Across the range of all socioeconomic-climate scenarios, the average April-to-August EC at Emmaton was 650 µS/cm: an increase of 9% and ranged from a minimum of 490 to a maximum of 841 µS/cm during the 2015-2099 period.
- **Jersey Point:**
    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average April-to-August EC at Jersey Point was 512 µS/cm.
    - Across the range of all socioeconomic-climate scenarios, the average April-to-August EC at Jersey Point was 561 µS/cm: an increase of 10% and ranged from a minimum of 440 to a maximum of 707 µS/cm during the 2015-2099 period.
- **Vernalis:**
    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average annual EC at Vernalis was 579 µS/cm.
    - Across the range of all socioeconomic-climate scenarios, the average annual EC at Vernalis was 570 µS/cm: a reduction of 2% and ranged

from a minimum of 448 to a maximum of 671 µS/cm during the 2015-2099 period.

- **Rock Slough:**
  - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average annual EC at Rock Slough was 362 µS/cm.
  - Across the range of all socioeconomic-climate scenarios, the average annual EC at Rock Slough was 400 µS/cm: an increase of 10% and ranged from a minimum of 356 to a maximum of 464µS/cm during the 2015-2099 period.

Figure 5-12 shows annual exceedances of EC at Emmaton and Jersey Point from April through August and EC at Vernalis and Rock Slough from October through September for each of the ensemble and CCTAG climate scenarios with the Current Trends socioeconomic scenario. Table 5-7 shows the average EC at each location in specific ranges of months at these locations.

Figure 5-12. Annual exceedences of EC at selected locations

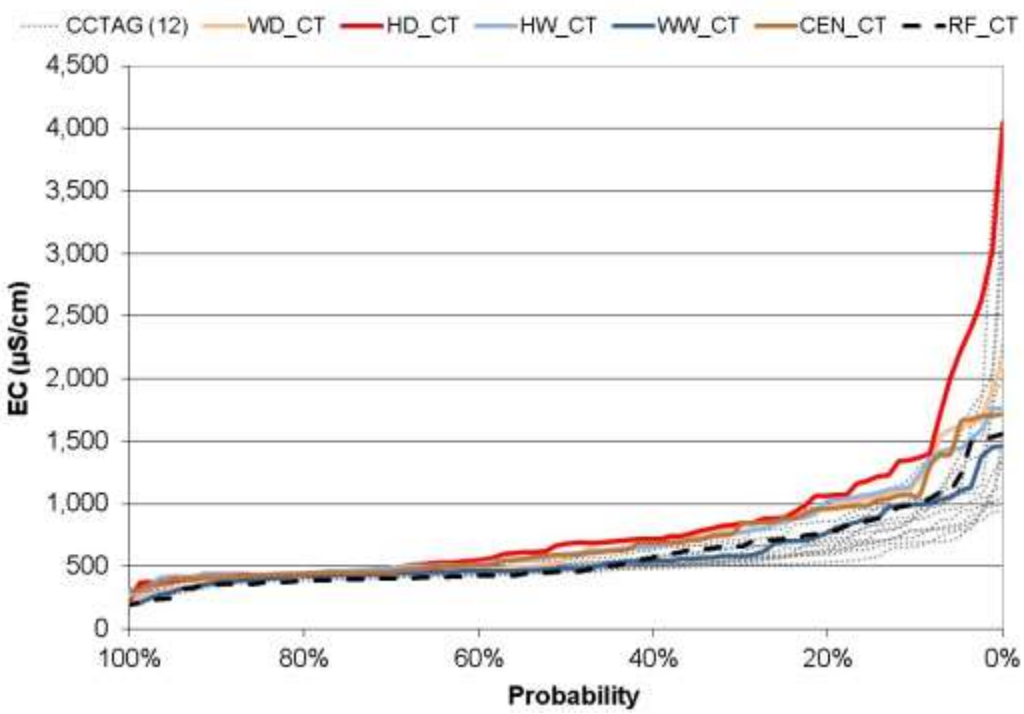


Figure 5-12a. Exceedance plot of average **April-to-August EC at Emmaton** for each scenario.

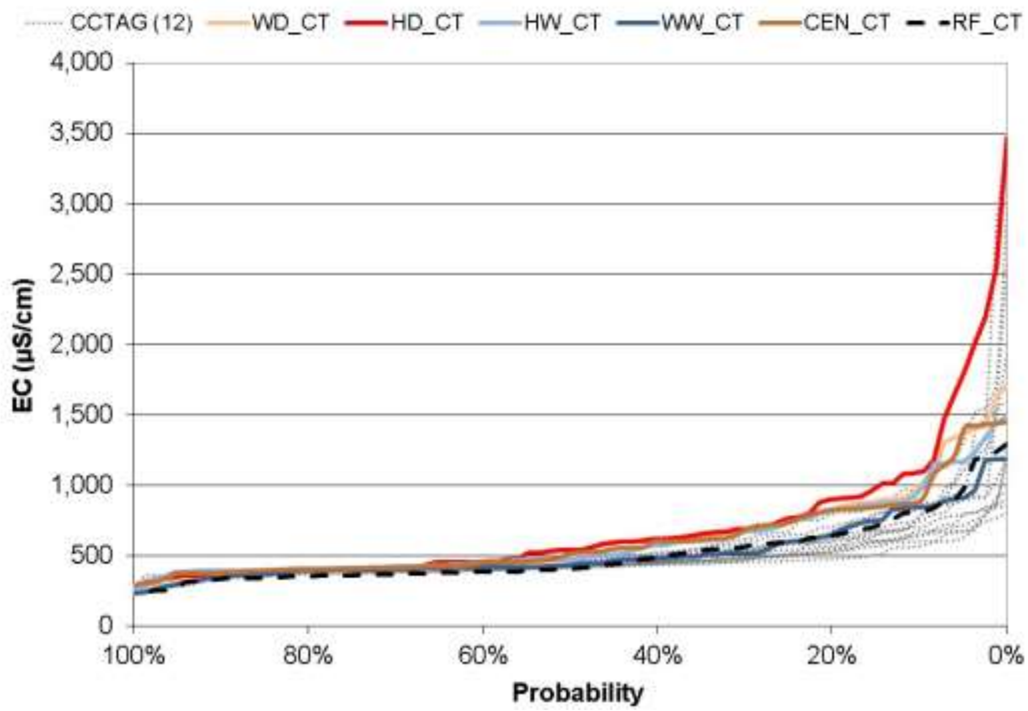


Figure 5-12b. Exceedance plot of average **April-to-August EC at Jersey Point** for each scenario.

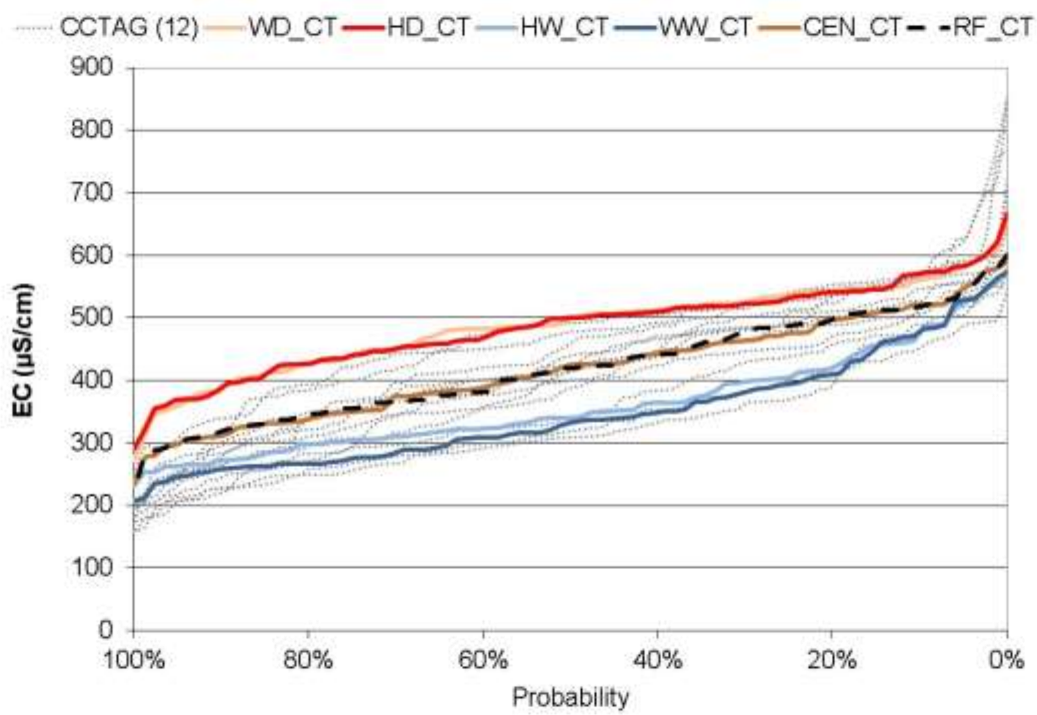


Figure 5-12c. Exceedance plot of **average annual EC at Vernalis** for each scenario.

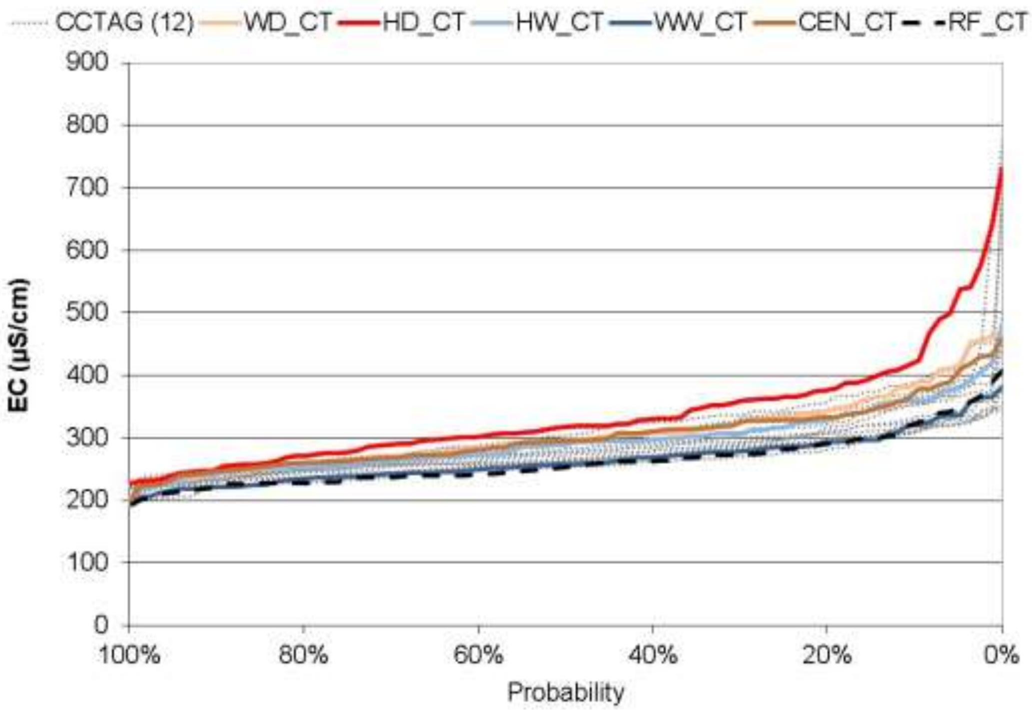


Figure 5-12d. Exceedance plot of **average annual EC at Rock Slough** for each scenario.

Table 5-7. EC at Selected Locations

Table 5-7a. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Vernalis and Rock Slough in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Emmaton	2015-2039	640	772	805	677	602	729
	2040-2069	552	617	716	637	540	622
	2070-2099	602	744	945	822	609	822
	2015-2099	595	708	823	714	583	724
Jersey Point	2015-2039	543	657	693	592	525	627
	2040-2069	481	549	623	556	485	555
	2070-2099	516	647	760	660	538	689
	2015-2099	512	615	692	603	515	623
Vernalis	2015-2039	646	718	717	581	574	649
	2040-2069	553	671	672	481	448	556
	2070-2099	532	606	598	447	428	523
	2015-2099	573	662	659	498	478	572
Rock Slough	2015-2039	382	423	444	405	379	416
	2040-2069	353	409	441	389	351	401
	2070-2099	360	427	492	422	362	445
	2015-2099	364	419	460	405	363	421

Table 5-7b. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Vernalis and Rock Slough in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Emmaton	2015-2039	645	812	811	670	623	733
	2040-2069	556	612	731	643	534	615
	2070-2099	593	733	975	832	621	789
	2015-2099	**595**	**713**	**841**	**717**	**591**	**711**
Jersey Point	2015-2039	546	688	698	586	540	631
	2040-2069	484	542	635	561	481	547
	2070-2099	510	637	787	667	547	660
	2015-2099	**512**	**619**	**707**	**606**	**522**	**612**
Vernalis	2015-2039	647	720	719	581	575	650
	2040-2069	558	681	683	481	448	561
	2070-2099	543	620	615	445	427	531
	2015-2099	**579**	**671**	**669**	**498**	**478**	**576**
Rock Slough	2015-2039	383	443	447	404	378	417
	2040-2069	354	400	443	393	352	398
	2070-2099	354	424	499	422	368	433
	2015-2099	**362**	**421**	**464**	**406**	**366**	**416**

Table 5-7c. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Vernalis and Rock Slough in the **CCTAG RCP 4.5** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccs	rcp4.5_ce	rcp4.5_cnr	rcp4.5_gfdl-	rcp4.5_had	rcp4.5_mir
Emmaton	2015-2039	535	533	447	511	547	502
	2040-2069	485	495	491	504	548	445
	2070-2099	527	544	526	626	932	756
	2015-2099	514	523	490	549	683	571
Jersey Point	2015-2039	473	469	407	456	485	447
	2040-2069	438	445	444	454	489	408
	2070-2099	472	486	465	538	790	657
	2015-2099	460	467	440	484	594	507
Vernalis	2015-2039	640	550	483	620	585	588
	2040-2069	553	518	461	558	601	629
	2070-2099	525	505	453	557	615	694
	2015-2099	568	523	465	576	601	640

Location	Period	rcp4.5_ccs	rcp4.5_ce	rcp4.5_cnr	rcp4.5_gfdl-	rcp4.5_had	rcp4.5_mir
Rock Slough	2015-2039	369	367	341	370	374	356
	2040-2069	374	366	352	379	415	361
	2070-2099	393	376	374	423	482	427
	2015-2099	379	370	356	392	427	383

Table 5-7d. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Vernalis and Rock Slough in in the **CCTAG RCP 8.5** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnr m-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miro c5_CT
Emmaton	2015-2039	494	452	450	642	558	595
	2040-2069	552	500	508	498	854	532
	2070-2099	691	645	737	802	776	794
	2015-2099	**584**	**537**	**572**	**648**	**740**	**643**
Jersey Point	2015-2039	445	411	412	563	498	522
	2040-2069	491	449	453	444	731	474
	2070-2099	573	541	598	645	609	662
	2015-2099	**507**	**471**	**492**	**550**	**619**	**555**
Vernalis	2015-2039	538	576	442	665	606	684
	2040-2069	601	512	475	544	685	662
	2070-2099	511	409	425	570	566	608
	2015-2099	**551**	**494**	**448**	**589**	**620**	**650**
Rock Slough	2015-2039	355	350	346	400	375	382
	2040-2069	392	380	362	378	460	389
	2070-2099	416	387	404	463	456	448
	2015-2099	**390**	**374**	**372**	**414**	**433**	**408**

Table 5-7e. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Vernalis and Rock Slough in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Emmaton	2015-2039	642	809	811	670	595	730
	2040-2069	540	616	729	641	541	617
	2070-2099	600	721	950	820	622	796
	2015-2099	591	710	831	713	585	714

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Jersey Point	2015-2039	544	686	698	585	519	628
	2040-2069	472	545	634	559	486	550
	2070-2099	515	628	763	657	547	666
	2015-2099	509	616	698	601	517	614
Vernalis	2015-2039	646	718	716	581	574	649
	2040-2069	558	680	681	479	447	559
	2070-2099	540	614	605	439	424	525
	2015-2099	577	668	665	495	476	573
Rock Slough	2015-2039	384	443	447	403	377	415
	2040-2069	350	406	441	392	351	396
	2070-2099	354	429	496	420	368	434
	2015-2099	362	425	462	405	365	415

5.2.4.2. End-of-May Storage

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

Measure:
The percentage of months that projected end-of-May storage is less than the 10th percentile of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF) in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs. *Decreases in this indicator would imply that water quality is improving.*

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. 'The performance metric for end-of-May storage is the percentage of time that the end-of-May storage is less than the 10th percentile value in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF). This low storage volume performance metric is applicable to major reservoirs in the CVP and SWP water management systems.

As shown on the figures, the reservoir storage results differed significantly among the different climate scenarios. Under the Current Trends socioeconomic scenario:

- The median climate scenario (Central Tendency) had storage levels a little lower than the Reference-No-Climate-Change scenario in Lake Shasta and Lake Folsom.

- Lake Oroville, New Melones, and Millerton storage was similar in the Reference-No-Climate-Change and Central Tendency climate scenarios.

- In all five reservoirs, the storage levels in May were higher under the wetter climate scenarios (Hot-Wet and Warm-Wet) than under the Reference-No-Climate-Change scenario, with the highest storage levels in the wetter, less warming climate scenario (Warm-Wet).

- Storage levels were lower under the drier climate scenarios (Warm-Dry and Hot-Dry) than under the Reference-No-Climate-Change scenario, with the lowest storage levels in the drier, more warming scenario (Hot-Dry).

- The 12 CCTAG climate scenarios also showed significant variability between scenarios in end-of-May storage, with greater storage levels in the wetter scenarios and lower storage levels in the drier scenarios.

Shasta and Millerton reservoirs receive the largest average annual runoff in the Sacramento and San Joaquin river watersheds respectively.

- **Shasta Lake.** Across the range of all socioeconomic-climate scenarios, the end-of-May storage in Shasta Lake was less than the 10th percentile value in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios on average in 16% of the years from 2015-2099. The climate-socioeconomic scenarios differed from the Reference-No-Climate-Change scenario by 0% to 45%.

- **Millerton Lake.** Across the range of all socioeconomic-climate scenarios, the end-of-May storage in Millerton Lake was less than the 10th percentile value in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios on average in 8% of the years from 2015-2099. The climate-socioeconomic scenarios differed from the Reference-No-Climate-Change climate scenario by 1% to 13%.

Figure 5-13 shows exceedance plots of storage at the end of May in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs for each of the ensemble and CCTAG climate scenarios with the Current Trends socioeconomic scenario. Table 5-8 shows the percentage of time that the end-of-May storage is less than the 10th percentile value from the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios in these reservoirs for each of the socioeconomic-climate scenarios.

Figure 5-13. End-of-May storage exceedence plots

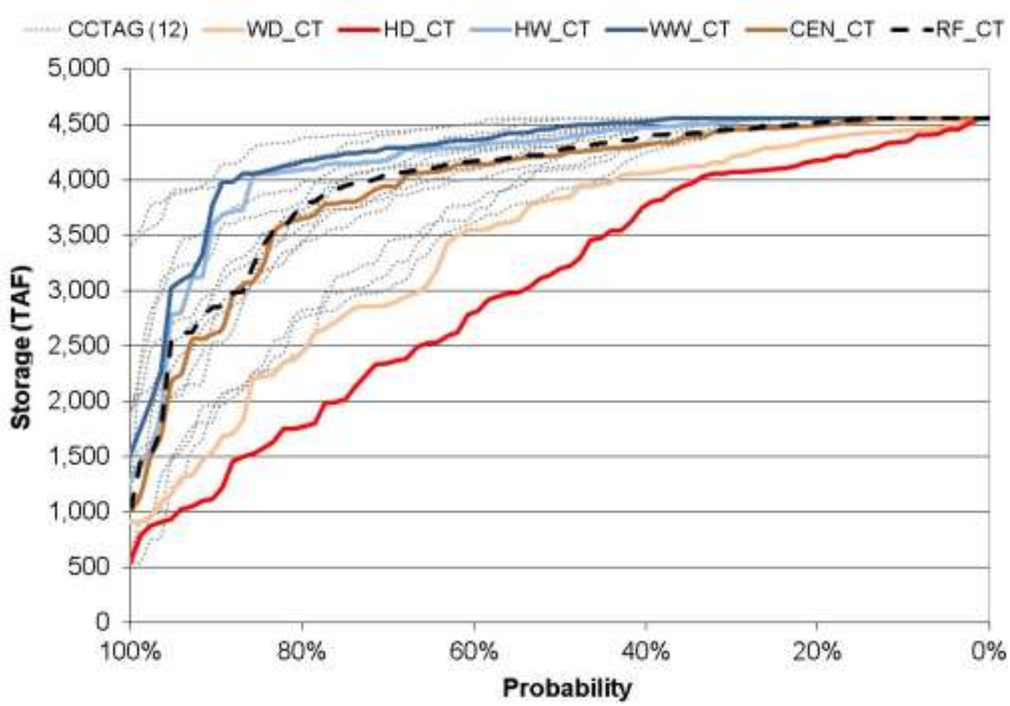


Figure 5-13a. Exceedance plot of **Lake Shasta** end-of-May storage for each climate scenario in the Current Trends socioeconomic scenario.

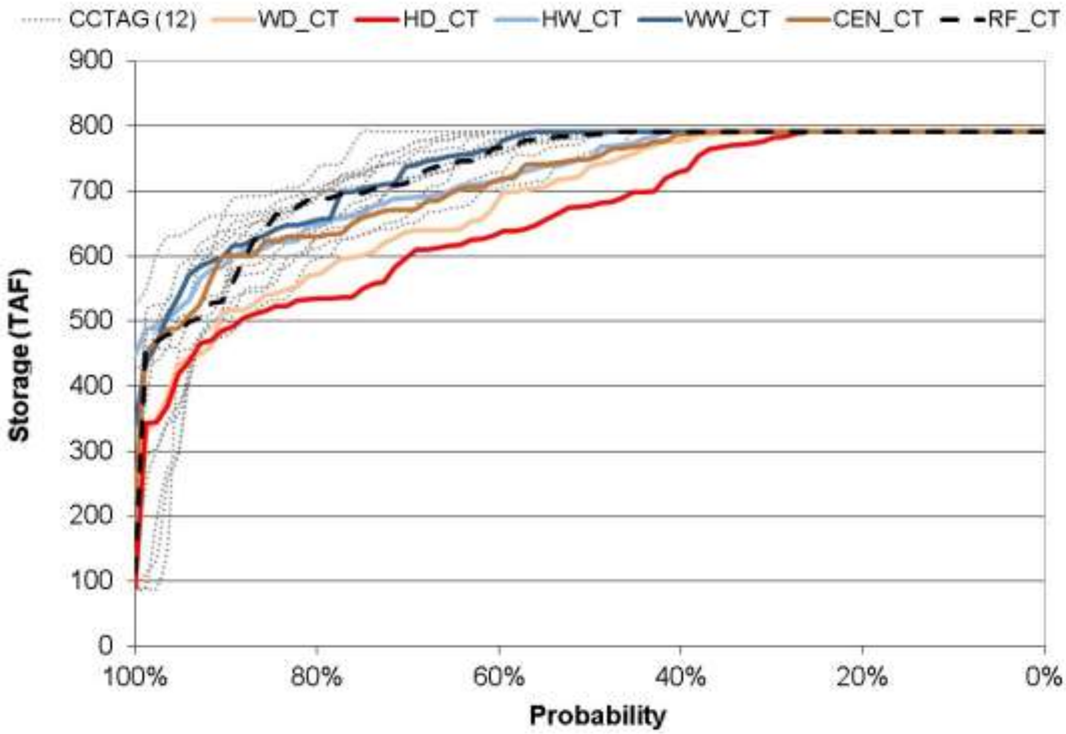


Figure 5-13b. Exceedance plot of **Folsom Lake** end-of-May storage for each climate scenario in the Current Trends socioeconomic scenario.

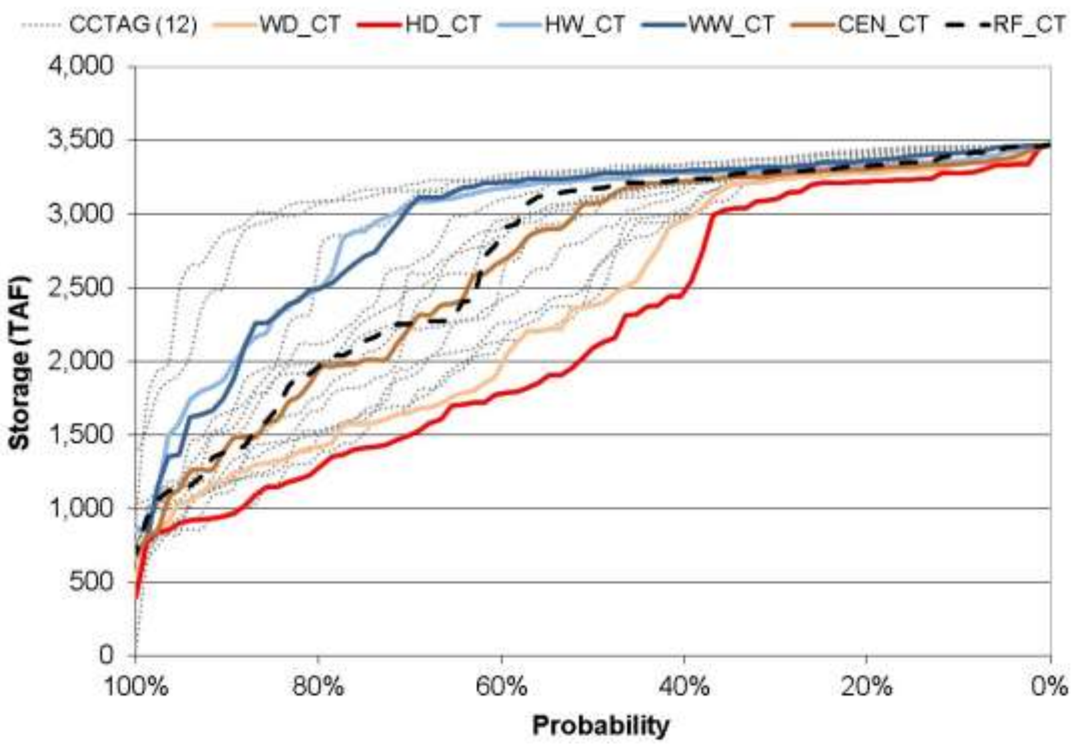


Figure 5-13c. Exceedance plot of **Lake Oroville** end-of-May storage for each climate scenario in the Current Trends socioeconomic scenario.

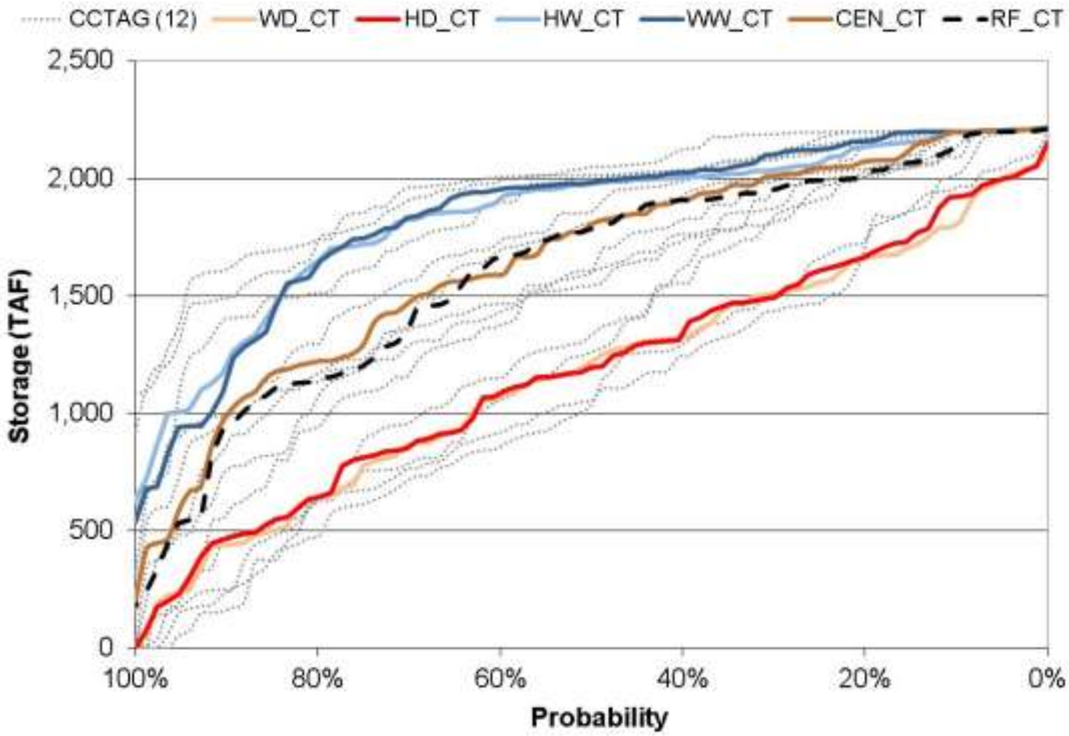


Figure 5-13d. Exceedance plot of **New Melones** end-of-May storage for each climate scenario in the Current Trends socioeconomic scenario.

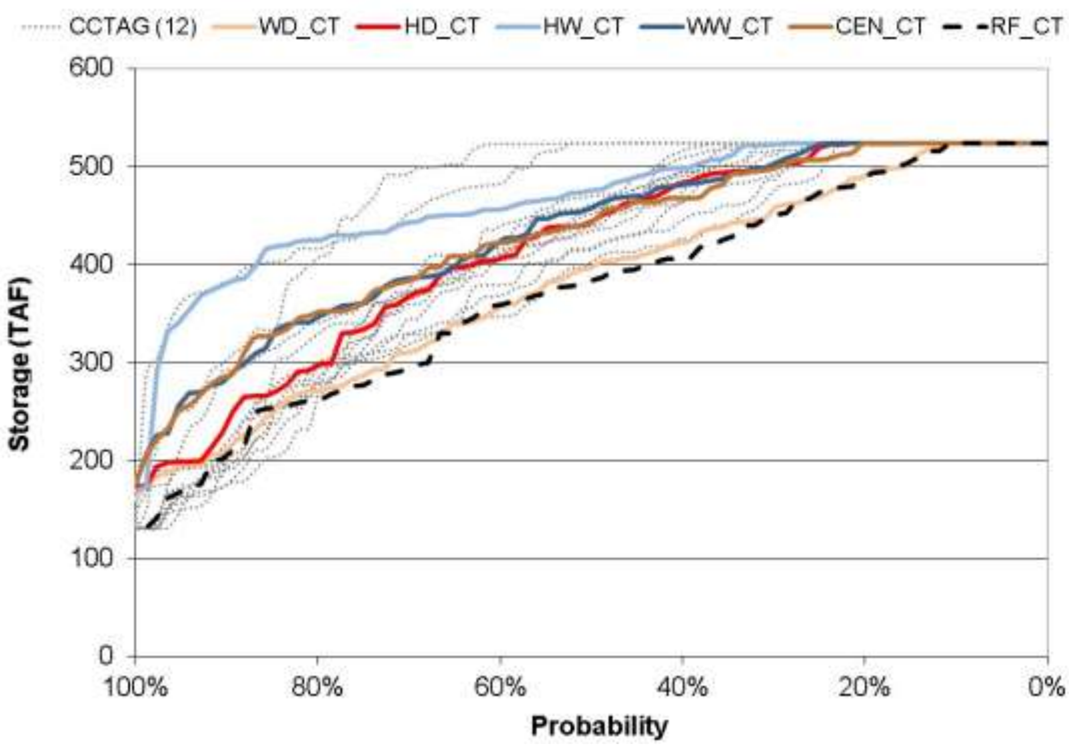


Figure 5-13e. Exceedance plot of **Millerton Lake** end-of-May storage for each climate scenario in the Current Trends socioeconomic scenario.

Table 5-8. End-of-May Storage Less than Indicator Levels

Table 5-8a. Percentage of End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Shasta	2015-2039	24%	56%	52%	20%	16%	28%
	2040-2069	3%	17%	30%	0%	0%	3%
	2070-2099	0%	20%	43%	0%	0%	7%
	2015-2099	**8%**	**29%**	**41%**	**6%**	**5%**	**12%**
Folsom	2015-2039	16%	24%	40%	20%	16%	24%
	2040-2069	13%	13%	33%	20%	10%	17%
	2070-2099	3%	30%	57%	13%	7%	13%
	2015-2099	**11%**	**22%**	**44%**	**18%**	**11%**	**18%**
Oroville	2015-2039	20%	24%	20%	8%	8%	16%
	2040-2069	10%	17%	17%	3%	3%	10%
	2070-2099	0%	27%	37%	0%	3%	0%
	2015-2099	**9%**	**22%**	**25%**	**4%**	**5%**	**8%**
New Melones	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	37%	40%	0%	0%	0%
	2070-2099	13%	30%	23%	3%	7%	10%
	2015-2099	**12%**	**36%**	**36%**	**5%**	**6%**	**11%**
Millerton	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	0%
	2015-2099	**11%**	**13%**	**13%**	**1%**	**5%**	**2%**

Table 5-8b. Percentage of End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Shasta	2015-2039	28%	52%	52%	20%	16%	28%
	2040-2069	3%	17%	33%	0%	0%	3%
	2070-2099	3%	27%	47%	0%	0%	7%
	2015-2099	**11%**	**31%**	**44%**	**6%**	**5%**	**12%**
Folsom	2015-2039	16%	24%	40%	20%	16%	24%
	2040-2069	13%	13%	37%	20%	10%	17%
	2070-2099	3%	30%	57%	13%	7%	13%
	2015-2099	**11%**	**22%**	**45%**	**18%**	**11%**	**18%**
Oroville	2015-2039	20%	20%	20%	8%	8%	16%
	2040-2069	10%	13%	20%	3%	3%	10%
	2070-2099	3%	17%	40%	0%	3%	10%
	2015-2099	**11%**	**16%**	**27%**	**4%**	**5%**	**12%**

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
New Melones	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	37%	40%	0%	0%	0%
	2070-2099	10%	27%	17%	0%	0%	10%
	2015-2099	**11%**	**35%**	**34%**	**4%**	**4%**	**11%**
Millerton	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	0%
	2015-2099	**11%**	**13%**	**13%**	**1%**	**5%**	**2%**

Table 5-8c. Percentage of End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios for the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm 4 _CT	rcp4.5_cn r esm1-bgc_CT	rcp4.5_gf d m-cm5_CT	rcp4.5_ha d l-cm3_CT	rcp4.5_ge m2-ed_CT	rcp4.5_mir oc 5_CT
Shasta	2015-2039	12%	0%	0%	8%	12%	4%
	2040-2069	7%	7%	0%	0%	23%	7%
	2070-2099	13%	3%	0%	13%	33%	33%
	2015-2099	**11%**	**4%**	**0%**	**7%**	**24%**	**15%**
Folsom	2015-2039	16%	4%	0%	8%	16%	8%
	2040-2069	13%	10%	7%	7%	27%	17%
	2070-2099	17%	3%	3%	10%	33%	37%
	2015-2099	**15%**	**6%**	**4%**	**8%**	**26%**	**21%**
Oroville	2015-2039	16%	8%	4%	12%	12%	4%
	2040-2069	3%	10%	0%	10%	17%	20%
	2070-2099	10%	7%	0%	10%	23%	23%
	2015-2099	**9%**	**8%**	**1%**	**11%**	**18%**	**16%**
New Melones	2015-2039	20%	0%	4%	20%	16%	12%
	2040-2069	23%	10%	0%	7%	37%	53%
	2070-2099	20%	13%	0%	27%	33%	67%
	2015-2099	**21%**	**8%**	**1%**	**18%**	**29%**	**46%**
Millerton	2015-2039	12%	8%	4%	8%	16%	8%
	2040-2069	10%	3%	3%	7%	17%	7%
	2070-2099	13%	10%	0%	7%	7%	13%
	2015-2099	**12%**	**7%**	**2%**	**7%**	**13%**	**9%**

Table 5-8d. Percentage of End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios for the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm 4 _CT	rcp8.5_cn r esm1-bgc_CT	rcp8.5_gf d m-cm5_CT	rcp8.5_ha d l-cm3_CT	rcp8.5_ge m2-ed_CT	rcp8.5_mir oc 5_CT
Shasta	2015-2039	0%	0%	0%	28%	8%	20%
	2040-2069	7%	13%	0%	3%	40%	30%
	2070-2099	27%	0%	0%	13%	40%	20%
	2015-2099	**12%**	**5%**	**0%**	**14%**	**31%**	**24%**
Folsom	2015-2039	8%	0%	0%	24%	4%	24%
	2040-2069	7%	13%	7%	13%	43%	37%
	2070-2099	33%	3%	23%	33%	43%	20%
	2015-2099	**16%**	**6%**	**11%**	**24%**	**32%**	**27%**
Oroville	2015-2039	4%	8%	0%	24%	8%	28%
	2040-2069	17%	10%	3%	7%	37%	27%
	2070-2099	17%	3%	0%	20%	10%	20%
	2015-2099	**13%**	**7%**	**1%**	**16%**	**19%**	**25%**
New Melones	2015-2039	0%	8%	0%	36%	24%	44%
	2040-2069	17%	7%	0%	10%	40%	53%
	2070-2099	3%	0%	0%	0%	40%	30%
	2015-2099	**7%**	**5%**	**0%**	**14%**	**35%**	**42%**
Millerton	2015-2039	16%	16%	4%	16%	16%	8%
	2040-2069	13%	13%	0%	3%	20%	17%
	2070-2099	10%	0%	3%	13%	3%	13%
	2015-2099	**13%**	**9%**	**2%**	**11%**	**13%**	**13%**

Table 5-8f. Percentage of End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios for the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference -SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Shasta	2015-2039	32%	52%	52%	20%	16%	28%
	2040-2069	3%	17%	37%	0%	0%	3%
	2070-2099	7%	27%	47%	0%	0%	7%
	2015-2099	**13%**	**31%**	**45%**	**6%**	**5%**	**12%**
Folsom	2015-2039	16%	24%	40%	20%	16%	24%
	2040-2069	13%	13%	40%	20%	10%	17%
	2070-2099	3%	27%	50%	13%	7%	13%
	2015-2099	**11%**	**21%**	**44%**	**18%**	**11%**	**18%**
Oroville	2015-2039	20%	20%	20%	8%	8%	16%
	2040-2069	10%	17%	23%	3%	3%	10%
	2070-2099	3%	13%	37%	3%	3%	10%
	2015-2099	**11%**	**16%**	**27%**	**5%**	**5%**	**12%**

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
New Melones	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	30%	40%	0%	0%	0%
	2070-2099	10%	27%	17%	0%	3%	10%
	2015-2099	**11%**	**33%**	**34%**	**4%**	**5%**	**11%**
Millerton	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	0%
	2015-2099	**11%**	**13%**	**13%**	**1%**	**5%**	**2%**

5.2.5. Hydropower and GHG Emissions

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. Hydropower from the projects is an important renewable energy source and 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.

5.2.5.1. Energy Generation and Use

Net hydropower generation is positive when generation is greater than use. In all the climate scenarios, the CVP system had more hydropower generation than energy use (positive net generation), and the SWP system had more energy use than hydropower generation (negative net generation).The relative levels of net generation among the scenarios were consistent with the CVP pumping and storage and the SWP pumping results for each scenario.

Indicator:
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.

Measure:
Gigawatt hours per year (GWh/year) for all CVP and SWP hydropower and pumping facilities. *Increases in net generation imply that hydropower benefits are increasing.*

- **CVP.** The scenarios with the highest storage levels in CVP reservoirs had the most CVP net generation (due to greater amounts of water in generation facilities) while the scenarios with the lowest storage levels in CVP reservoirs had the least CVP net generation. During the 2015-2099 period:

    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, annual net energy generation for the CVP system was 3,428 GWh/year.

    - Across the range of all socioeconomic-climate scenarios, the annual net energy generation for the CVP was 3,500 GWh/year, an increase of slightly more than 2% and ranged from a minimum of 2,857 to a maximum of 4,383 GWh/year.

- **SWP.** In the SWP system, the scenarios with the greatest amount of pumping at the Banks PP had the most SWP net energy use (due to greater use of pumping facilities on the California Aqueduct), while the scenarios with the lowest amount of pumping at the Banks PP had the least SWP net energy use. During the 2015-2099 period:

    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, annual net energy generation for the SWP system was -4,169 GWh/year.

- Across the range of all socioeconomic-climate scenarios, the annual net energy generation for the SWP was-3,970 GWh/year, an increase of 5% and ranged from a minimum of-4,686 to a maximum of-3,129 GWh/year.

Figure 5-14 shows the 10-year moving average of annual average CVP, SWP, and total SWP + CVP net hydropower generation in each of the ensemble and CCTAG climate scenarios with the current trends socioeconomic scenario. Table 5-9 shows the average annual net energy use for the CVP and SWP systems under each socioeconomic-climate scenario.

Figure 5-14. Annual average hydropower generation: 10-year moving average

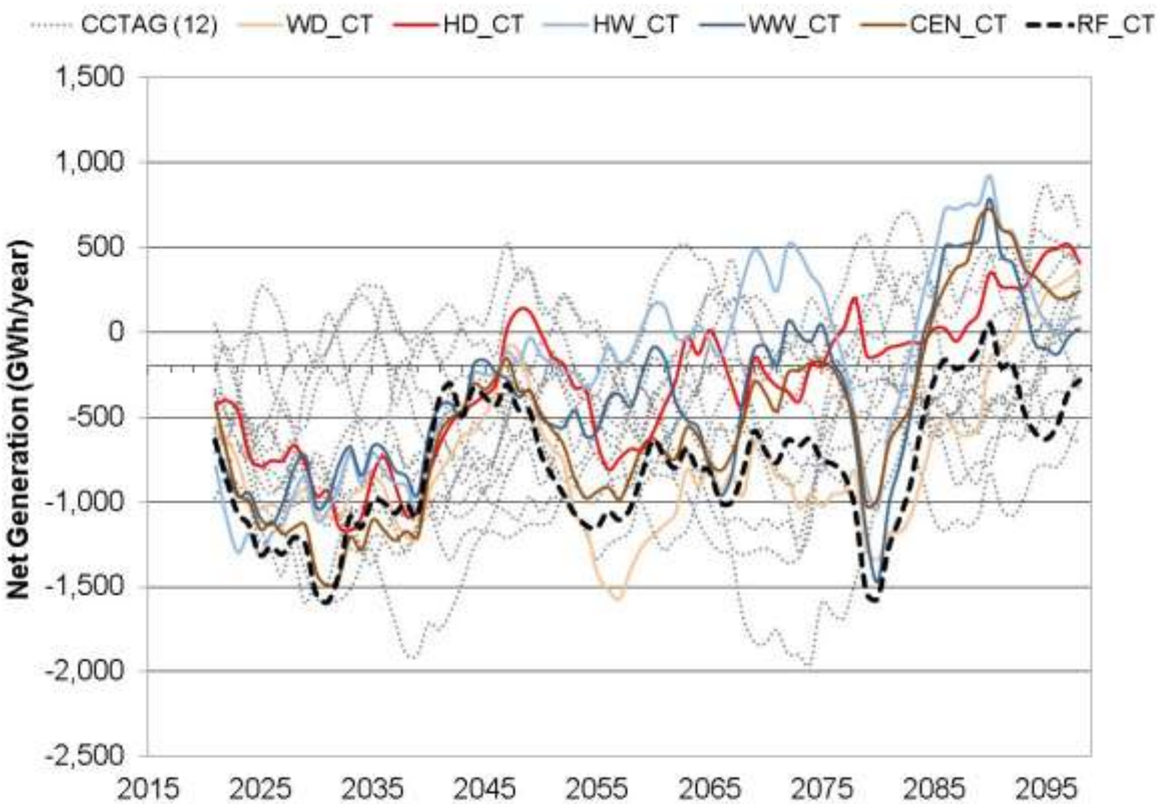


Figure 5-14a. 10-year moving average of annual net energy generation for the combined **CVP and SWP** systems for each scenario.

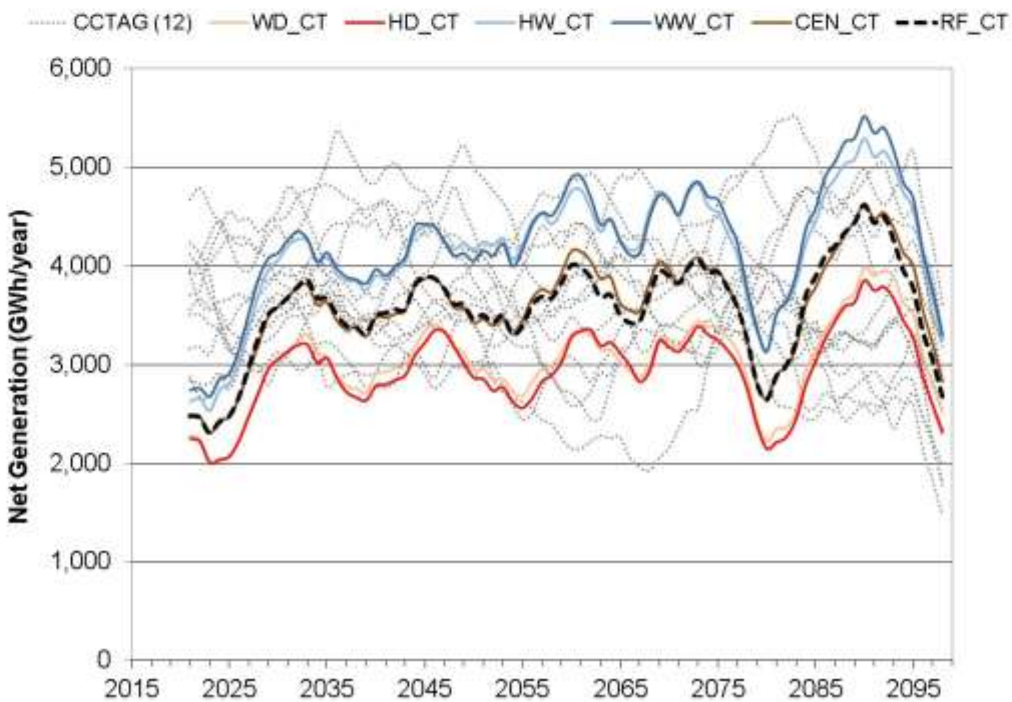


Figure 5-14b. 10-year moving average of annual net energy generation for the **CVP** system for each climate scenario for the Current Trends socioeconomic scenario.

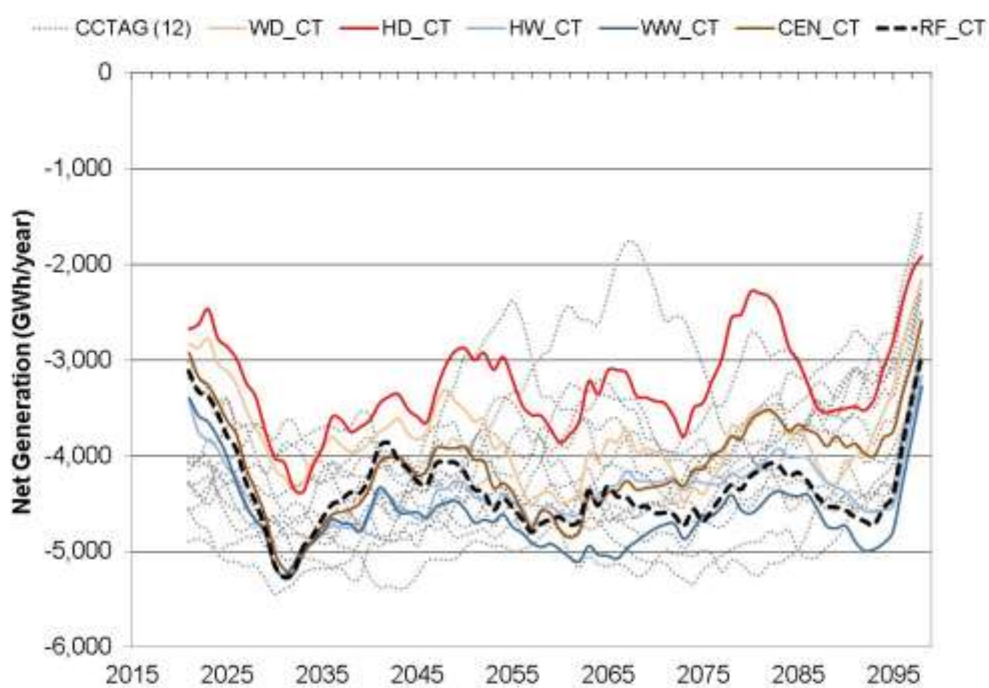


Figure 5-14c. 10-year moving average of annual net energy generation for the **SWP** system for each scenario.

Table 5-9. Average Annual Net Energy Generation

Table 5-9a. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
SWP	2015-2039	-4,123	-3,579	-3,354	-4,413	-4,382	-4,043
	2040-2069	-4,567	-4,176	-3,461	-4,360	-4,773	-4,442
	2070-2099	-4,115	-3,347	-2,628	-3,884	-4,177	-3,449
	2015-2099	**-4,273**	**-3,710**	**-3,157**	**-4,225**	**-4,451**	**-3,989**
CVP	2015-2039	3,218	2,789	2,728	3,571	3,650	3,220
	2040-2069	3,796	3,167	3,106	4,532	4,530	3,852
	2070-2099	3,232	2,822	2,734	3,839	3,920	3,295
	2015-2099	**3,422**	**2,930**	**2,860**	**3,989**	**4,040**	**3,462**
Total	2015-2039	-905	-791	-626	-842	-732	-823
	2040-2069	-771	-1,009	-354	172	-242	-590
	2070-2099	-882	-525	107	-45	-258	-154
	2015-2099	**-851**	**-781**	**-297**	**-236**	**-411**	**-527**

Table 5-9b. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
SWP	2015-2039	-4,147	-3,614	-3,427	-4,390	-4,354	-4,093
	2040-2069	-4,472	-3,993	-3,389	-4,387	-4,765	-4,332
	2070-2099	-3,866	-3,263	-2,541	-3,833	-4,128	-3,345
	2015-2099	**-4,169**	**-3,632**	**-3,129**	**-4,210**	**-4,423**	**-3,935**
CVP	2015-2039	3,220	2,787	2,731	3,570	3,651	3,217
	2040-2069	3,789	3,164	3,109	4,530	4,541	3,845
	2070-2099	3,257	2,849	2,727	3,829	3,920	3,300
	2015-2099	**3,428**	**2,937**	**2,860**	**3,985**	**4,044**	**3,460**
Total	2015-2039	-927	-827	-696	-820	-703	-877
	2040-2069	-683	-828	-280	144	-224	-488
	2070-2099	-610	-415	186	-4	-209	-44
	2015-2099	**-741**	**-695**	**-269**	**-225**	**-379**	**-475**

Table 5-9c. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnr m-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-	rcp4.5_miro c5_CT
SWP	2015-2039	-4,283	-4,628	-4,933	-4,341	-4,154	-4,558
	2040-2069	-4,500	-4,601	-4,905	-4,408	-3,996	-3,899
	2070-2099	-3,884	-4,193	-4,197	-3,569	-2,890	-2,643
	2015-2099	**-4,229**	**-4,479**	**-4,686**	**-4,116**	**-3,693**	**-3,715**
CVP	2015-2039	3,593	3,449	4,371	3,631	3,368	3,573
	2040-2069	3,918	3,536	4,420	3,718	3,118	3,638
	2070-2099	3,167	3,836	4,255	3,375	2,543	2,435
	2015-2099	**3,568**	**3,604**	**4,351**	**3,578**	**3,016**	**3,229**
Total	2015-2039	-690	-1,179	-561	-710	-786	-985
	2040-2069	-582	-1,064	-484	-690	-878	-262
	2070-2099	-717	-357	59	-194	-347	-209
	2015-2099	**-661**	**-875**	**-335**	**-537**	**-676**	**-486**

Table 5-9d. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnr m-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-	rcp8.5_miro c5_CT
SWP	2015-2039	-4,478	-4,623	-4,950	-3,630	-4,140	-3,814
	2040-2069	-4,164	-4,382	-4,633	-4,182	-3,097	-3,476
	2070-2099	-3,277	-3,790	-3,994	-3,149	-3,087	-3,170
	2015-2099	**-3,983**	**-4,272**	**-4,533**	**-3,666**	**-3,442**	**-3,490**
CVP	2015-2039	3,949	3,988	4,568	3,375	3,905	3,254
	2040-2069	3,625	3,618	4,420	4,226	2,572	3,118
	2070-2099	2,813	4,120	4,151	3,118	2,994	2,844
	2015-2099	**3,471**	**3,903**	**4,383**	**3,586**	**3,152**	**3,075**
Total	2015-2039	-529	-635	-382	-255	-236	-561
	2040-2069	-539	-764	-213	44	-525	-358
	2070-2099	-464	330	157	-32	-93	-326
	2015-2099	**-512**	**-369**	**-150**	**-80**	**-289**	**-415**

Table 5-9e. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
SWP	2015-2039	-4,133	-3,591	-3,429	-4,387	-4,358	-4,086
	2040-2069	-4,412	-4,070	-3,413	-4,389	-4,752	-4,297
	2070-2099	-3,797	-3,302	-2,561	-3,850	-4,131	-3,347
	2015-2099	**-4,121**	**-3,663**	**-3,144**	**-4,215**	**-4,421**	**-3,921**
CVP	2015-2039	3,218	2,783	2,727	3,569	3,652	3,217
	2040-2069	3,788	3,171	3,104	4,525	4,535	3,834
	2070-2099	3,257	2,808	2,727	3,822	3,912	3,283
	2015-2099	**3,427**	**2,925**	**2,857**	**3,980**	**4,040**	**3,451**
Total	2015-2039	-915	-807	-702	-818	-706	-870
	2040-2069	-624	-899	-309	136	-217	-463
	2070-2099	-539	-494	165	-28	-219	-64
	2015-2099	**-694**	**-738**	**-287**	**-235**	**-381**	**-470**

5.2.5.2. Greenhouse Gas Emissions

Indicator:
Greenhouse gas emissions indicate the carbon intensity of CVP and SWP operations.

Measure:
Metric tons of carbon dioxide equivalents (mTCO2e) per year of power generation of emissions at CVP and SWP hydropower and pumping facilities

The GHG emissions considered in this report are an indicator of environmental footprint or carbon intensity of the operations of the CVP and SWP systems. Hydropower generation is assumed to occur without producing GHG emissions. The effects of groundwater pumping on GHG emissions are not included in the simulations. When the CVP and SWP have positive net hydropower generation, the surplus energy can be made available to reduce reliance on fossil fuel-based sources of electricity used either by the projects or elsewhere and thereby reduce overall GHG emissions. These "offsets" are shown in the ensuing table as negative changes in GHG emissions, and primarily when net hydropower generation is positive. The unit of measurement for GHG emissions is metric tons of carbon dioxide equivalents (mTCO_2e) per year of power generation.

The CVP system had potential GHG offsets because it had positive net hydropower generation, and the SWP system had GHG emissions because it had negative net hydropower generation. Additionally, the magnitude of GHG emission results were greatest in the wetter scenarios where the net generation results were greatest, and lowest in the drier scenarios where the net generation results were lowest.

- **CVP.** The CVP system was assumed to provide excess power to an electrical grid system which produces 300 mTCO_2e GHG emissions per GWh generated the twenty-first century. The year-to-year changes in GHG emission results for the CVP system are consistent with changes in net generation.
    - In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average annual GHG offset in the CVP system were 1,547,971 mTCO_2e/year.
    - Across the range of all socioeconomic-climate scenarios, the average annual GHG offset for the CVP was 1,580,703 mTCO_2e/year, an increase of slightly more than 2%, and ranged from a minimum of 1,290,149 to a maximum of 1,979,323 mTCO_2e/year from 2015-2099.
- **SWP.** The sources of power for the SWP are assumed to gradually transition from sources with higher GHG emissions to those with lower GHG emissions over the course of the 21st century. This assumption is based on the California Department of Water Resources' Climate Action Plan (DWR 2012). Therefore, SWP emissions drop sharply over the first

half of the century, resulting in less GHG emissions per unit of energy consumed.

- In the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios, average annual GHG emissions in the SWP system were 480,129 $mTCO_2e$/year.

- Across the range of all socioeconomic-climate scenarios, the average annual GHG emission for the SWP was 472,004 $mTCO_2e$/year, a decrease of 2%, and ranged from a minimum 368,494 up to a maximum 557,394 of $mTCO_2e$/year during the 2015-2099 period.

Figure 5-15 shows the 10-year moving average of annual average GHG emissions or potential GHG offsets for the SWP, CVP, and total SWP + CVP systems in each of the climate scenarios with the current trends socioeconomic scenario.

Table 5-10 presents the average annual GHG emissions in the SWP system, potential GHG offsets in the CVP system, and the net total for the CVP and SWP systems under each socioeconomic-climate scenario.

Figure 5-15. Annual GHG emissions: 10-year moving average

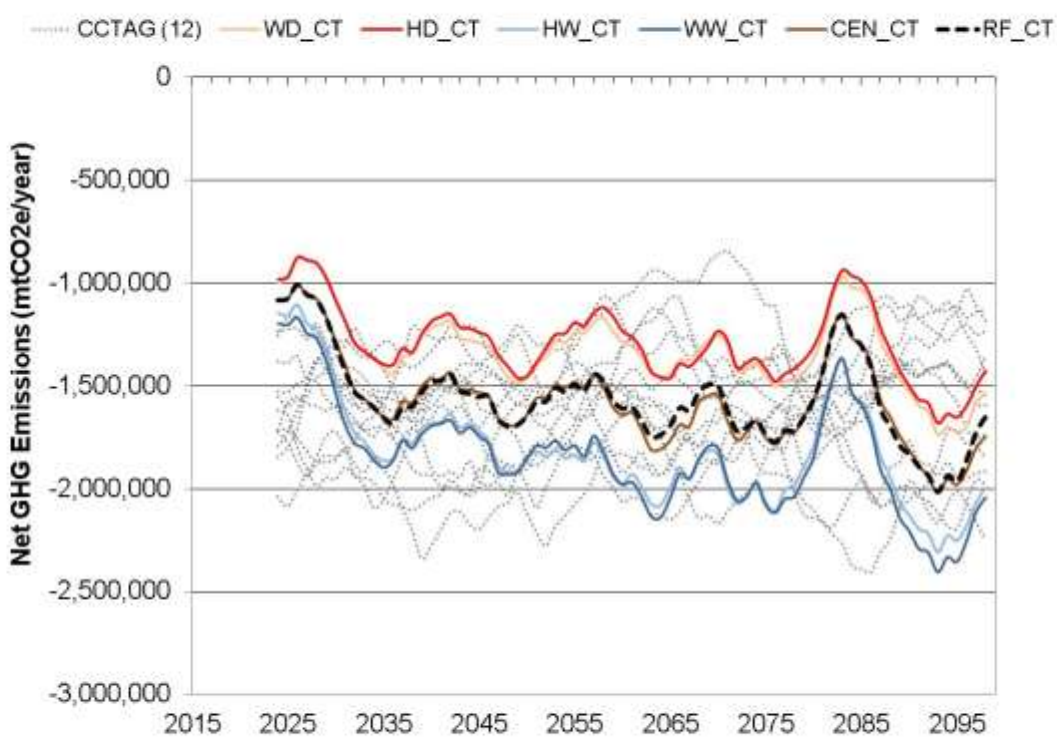


Figure 5-15a. 10-year moving average of annual GHG emissions or potential offsets for the **CVP system** for each scenario.

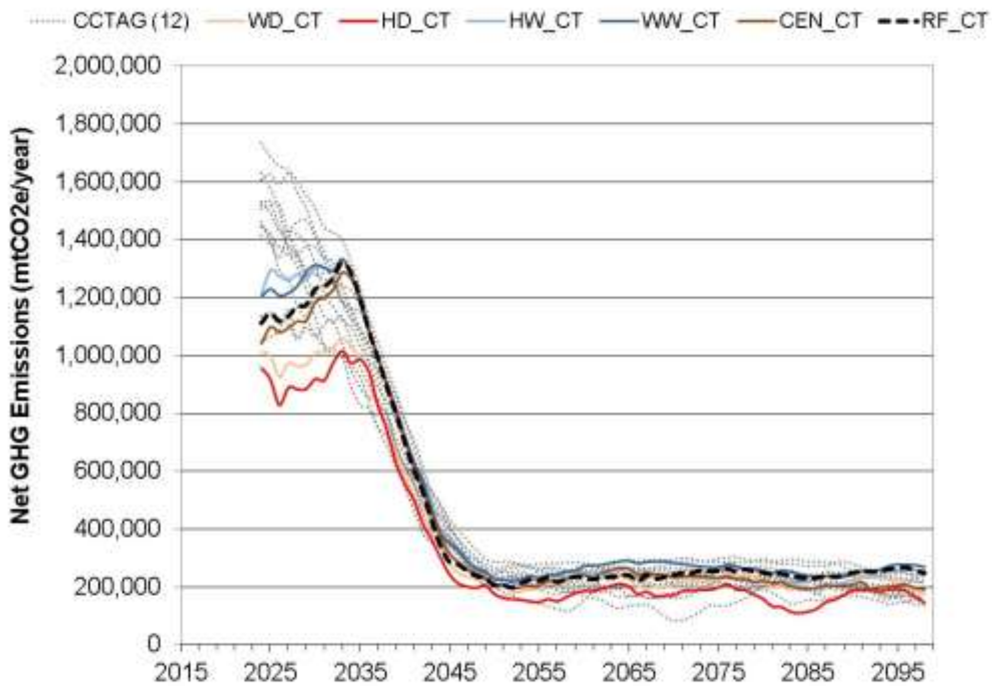


Figure 5-15b. 10-year moving average of annual GHG emissions or potential offsets for the **SWP system** for each scenario.

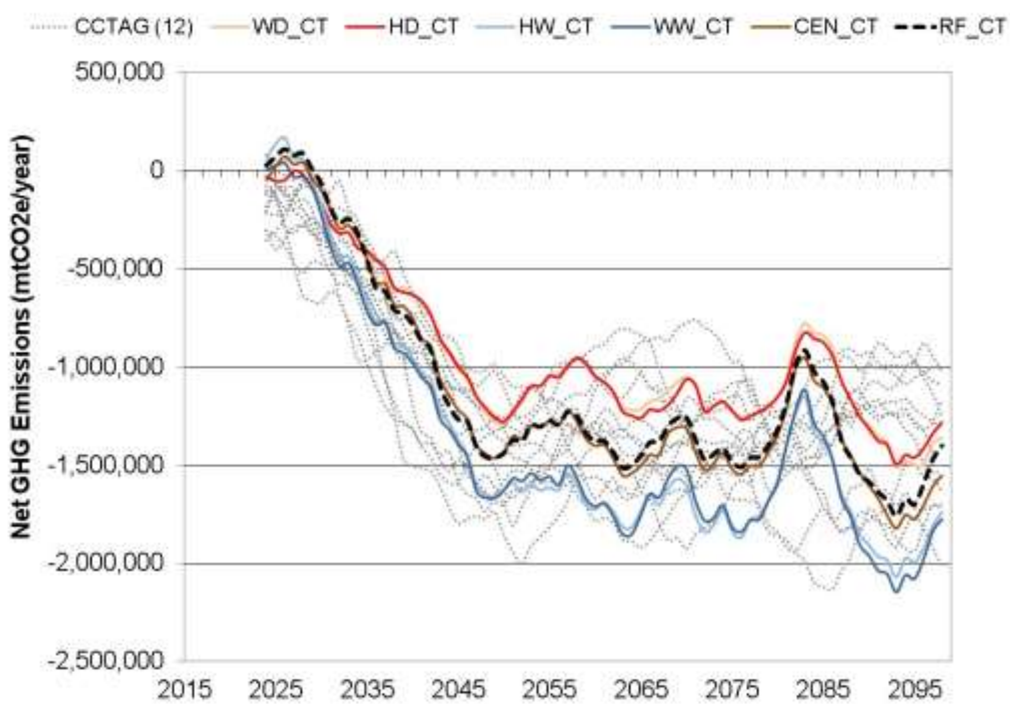


Figure 5-15c. 10-year moving average of annual GHG emissions or potential offsets for the **combined CVP and SWP systems** for each scenario.

Table 5-10. Average Annual GHG Emissions

Table 5-10a. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
SWP	2015-2039	929,439	806,556	743,975	997,264	988,621	901,983
	2040-2069	245,563	229,357	185,476	234,981	261,759	237,989
	2070-2099	254,078	208,404	152,556	237,818	257,675	212,509
	2015-2099	**484,197**	**422,392**	**368,494**	**498,994**	**511,484**	**459,642**
CVP	2015-2039	-1,403,118	-1,215,807	-1,189,198	-1,557,075	-1,591,242	-1,404,064
	2040-2069	-1,654,904	-1,380,635	-1,354,416	-1,975,978	-1,975,176	-1,679,504
	2070-2099	-1,578,429	-1,378,230	-1,335,264	-1,874,768	-1,914,041	-1,608,950
	2015-2099	**-1,545,217**	**-1,323,014**	**-1,291,677**	**-1,801,235**	**-1,824,433**	**-1,563,414**
Total	2015-2039	-473,679	-409,252	-445,223	-559,811	-602,621	-502,082
	2040-2069	-1,409,341	-1,151,278	-1,168,940	-1,740,997	-1,713,418	-1,441,515
	2070-2099	-1,324,351	-1,169,826	-1,182,708	-1,636,950	-1,656,366	-1,396,441
	2015-2099	**-1,061,020**	**-900,623**	**-923,183**	**-1,302,240**	**-1,312,949**	**-1,103,772**

Note: negative values represent potential GHG offsets.

Table 5-10b. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
SWP	2015-2039	939,084	814,152	763,781	993,080	982,049	918,319
	2040-2069	234,220	213,833	182,474	236,458	260,654	230,791
	2070-2099	242,834	197,728	147,819	231,781	255,607	202,437
	2015-2099	**480,129**	**416,293**	**372,849**	**496,281**	**508,205**	**459,713**
CVP	2015-2039	-1,403,968	-1,215,223	-1,190,523	-1,556,584	-1,591,734	-1,402,404
	2040-2069	-1,651,935	-1,379,699	-1,355,415	-1,975,203	-1,979,810	-1,676,280
	2070-2099	-1,590,259	-1,391,033	-1,331,824	-1,869,733	-1,914,005	-1,611,646
	2015-2099	**-1,547,971**	**-1,326,289**	**-1,291,467**	**-1,799,290**	**-1,826,247**	**-1,562,491**
Total	2015-2039	-464,884	-401,071	-426,742	-563,505	-609,686	-484,084
	2040-2069	-1,417,714	-1,165,866	-1,172,941	-1,738,745	-1,719,156	-1,445,489
	2070-2099	-1,347,426	-1,193,305	-1,184,005	-1,637,951	-1,658,398	-1,409,209
	2015-2099	**-1,067,842**	**-909,996**	**-918,617**	**-1,303,009**	**-1,318,042**	**-1,102,778**

Note: negative values represent potential GHG offsets.

Table 5-10c. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the CVP and SWP Systems in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
SWP	2015-2039	996,088	1,060,186	1,160,073	998,955	1,007,115	1,080,240
	2040-2069	247,703	258,868	274,595	243,484	220,302	203,093
	2070-2099	245,873	258,325	258,128	221,772	170,804	153,675
	2015-2099	**505,529**	**535,352**	**575,394**	**497,840**	**477,208**	**491,210**
CVP	2015-2039	-1,566,528	-1,503,762	-1,905,966	-1,582,925	-1,468,400	-1,557,969
	2040-2069	-1,708,073	-1,541,826	-1,927,234	-1,620,862	-1,359,388	-1,585,967
	2070-2099	-1,546,625	-1,873,326	-2,078,027	-1,648,235	-1,241,856	-1,188,947
	2015-2099	**-1,611,156**	**-1,627,346**	**-1,964,770**	**-1,615,911**	**-1,362,044**	**-1,458,140**
Total	2015-2039	-570,440	-443,576	-745,893	-583,970	-461,285	-477,729
	2040-2069	-1,460,370	-1,282,958	-1,652,639	-1,377,378	-1,139,087	-1,382,874
	2070-2099	-1,300,752	-1,615,001	-1,819,900	-1,426,462	-1,071,053	-1,035,272
	2015-2099	**-1,105,627**	**-1,091,994**	**-1,389,376**	**-1,118,072**	**-884,836**	**-966,931**

Note: negative values represent potential GHG offsets.

Table 5-10d. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the CVP and SWP Systems in the **CCTAG 8.5 RCP** Climate RCP Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
SWP	2015-2039	1,036,829	1,068,995	1,144,861	842,069	951,165	838,482
	2040-2069	224,863	242,042	254,119	225,210	168,432	187,079
	2070-2099	191,842	237,799	251,322	191,755	190,932	187,057
	2015-2099	**495,357**	**526,275**	**560,804**	**428,216**	**445,357**	**411,962**
CVP	2015-2039	-1,721,824	-1,738,561	-1,991,812	-1,471,476	-1,702,532	-1,418,601
	2040-2069	-1,580,366	-1,577,439	-1,927,317	-1,842,538	-1,121,390	-1,359,472
	2070-2099	-1,373,466	-2,012,001	-2,027,243	-1,522,366	-1,462,218	-1,388,981
	2015-2099	**-1,567,625**	**-1,762,399**	**-1,979,323**	**-1,619,144**	**-1,423,459**	**-1,388,668**
Total	2015-2039	-684,994	-669,567	-846,951	-629,407	-751,367	-580,119
	2040-2069	-1,355,503	-1,335,397	-1,673,198	-1,617,328	-952,959	-1,172,392
	2070-2099	-1,181,625	-1,774,202	-1,775,921	-1,330,611	-1,271,286	-1,201,924
	2015-2099	**-1,072,268**	**-1,236,124**	**-1,418,519**	**-1,190,928**	**-978,102**	**-976,706**

Note: negative values represent potential GHG offsets.

Table 5-10e. Average Annual GHG Emissions or Potential GHG Offsets (mTCO$_2$e/year) for the CVP and SWP Systems in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Trends Socioeconomic Scenario

Location	**Period**	**Reference-SG**	**Warm-Dry-SG**	**Hot-Dry-SG**	**Hot-Wet-SG**	**Warm-Wet-SG**	**Central-SG**
SWP	2015-2039	936,069	809,841	764,125	992,438	983,690	915,656
	2040-2069	228,802	217,563	182,541	236,488	262,990	228,063
	2070-2099	238,490	204,062	149,930	232,385	255,694	201,573
	2015-2099	**475,861**	**418,022**	**373,620**	**496,250**	**509,632**	**457,562**
CVP	2015-2039	-1,402,904	-1,213,527	-1,188,980	-1,556,147	-1,592,298	-1,402,429
	2040-2069	-1,651,468	-1,382,408	-1,353,534	-1,972,940	-1,977,163	-1,671,785
	2070-2099	-1,590,525	-1,371,139	-1,331,443	-1,866,206	-1,910,157	-1,602,954
	2015-2099	**-1,547,516**	**-1,320,750**	**-1,290,149**	**-1,797,281**	**-1,824,351**	**-1,558,308**
Total	2015-2039	-466,834	-403,685	-424,855	-563,709	-608,608	-486,774
	2040-2069	-1,422,666	-1,164,845	-1,170,994	-1,736,452	-1,714,173	-1,443,722
	2070-2099	-1,352,035	-1,167,076	-1,181,514	-1,633,821	-1,654,462	-1,401,381
	2015-2099	**-1,071,655**	**-902,728**	**-916,529**	**-1,301,031**	**-1,314,719**	**-1,100,745**

Note: negative values represent potential GHG offsets.

5.2.6. 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.

Two attributes of interest were used to characterize the flood control resource category:

- **Flood control storage availability.** The percentage of months when reservoir storage is within 10 TAF of the flood storage pool in selected reservoirs.

- **Hydropower.** The percentage of months that reservoir flow releases exceed hydropower penstock capacities.

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, the Summary Report provides results for flood control storage.

5.2.6.1. Flood Control Storage Availability

Wetter scenarios hit the flood conservation pool more often than the Reference-No-Climate-Change scenario and the drier scenarios reached into the flood conservation pool less often.

Under the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, from 2015-2099:

Indicator:
The amount of flood control storage available indicates changing flood management risks.

Measure:
Percentage of months when reservoir storage is within 10 TAF of the flood storage pool at Shasta, Folsom, Oroville, New Bullards Bar, New Melones, New Don Pedro, McClure, Millerton, and Pine Flat Reservoirs. *A decrease in this indicator signifies a reduction in flood risk while an increase means less available flood conservation storage and increased risk.*

- **Lake Shasta:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 35% of all months
  - Across the range of socioeconomic-climate scenarios, from 2015-2099, the range is from: 13% to 59% of all months
- **Folsom Lake:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 44% of all months
  - Across the range of socioeconomic-climate scenarios, the range is from: 26% to 56% of all months
- **Lake Oroville:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 24% of all months
  - Across the range of socioeconomic-climate scenarios, the range is from: 12% to 41% of all months
- **New Bullards Bar Reservoir:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 23% in all months
  - Across the range of socioeconomic-climate scenarios, the range is from: 15% to 34% of all months
- **New Melones Lake:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 7% of all months
  - Across the range of socioeconomic-climate scenarios, the range is from: 1% to 19% of all months
- **Lake Millerton:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 24% of all months

- Across the range of socioeconomic-climate scenarios, the range is from: 21% to 47% of all months

- **New Don Pedro:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 33% of all months

  - Across the range of socioeconomic-climate scenarios, the range is from: 10% to 48% of all months

- **Lake McClure:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 37% of all months

  - Across the range of socioeconomic-climate scenarios, the range is from: 18% to 62% of all months

- **Pine Flat Reservoir:**
  - In the Reference-No-Climate-Change climate/Current Trends Socioeconomic scenarios, the flood conservation pool is reached 24% of all months

  - Across the range of socioeconomic-climate scenarios, the range is from: 14% to 44% of all months

Table 5-11 shows the percentage of months from October through June that the reservoir storage in Shasta, Folsom, Oroville, New Bullards Bar, New Melones, Millerton, New Don Pedro, McClure and Pine Flat reservoirs is within 10 TAF of the flood conservation pool under each socioeconomic-climate scenario.

Table 5-11. Months Within 10 TAF of the Flood Conservation Pool

Table 5-11a. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Shasta	2015-2039	17%	11%	10%	23%	29%	13%
	2040-2069	43%	14%	10%	53%	63%	39%
	2070-2099	44%	27%	20%	62%	63%	42%
	2015-2099	**36%**	**18%**	**14%**	**47%**	**53%**	**32%**
Folsom	2015-2039	35%	27%	27%	43%	43%	33%
	2040-2069	48%	30%	24%	51%	59%	42%
	2070-2099	50%	33%	27%	47%	55%	40%
	2015-2099	**45%**	**30%**	**26%**	**47%**	**53%**	**39%**
Oroville	2015-2039	13%	8%	8%	19%	22%	13%
	2040-2069	26%	14%	11%	34%	44%	25%
	2070-2099	34%	19%	16%	40%	40%	27%
	2015-2099	**25%**	**14%**	**12%**	**32%**	**36%**	**22%**
New Bullards	2015-2039	20%	12%	13%	23%	24%	19%
	2040-2069	25%	18%	20%	35%	33%	26%
	2070-2099	25%	17%	16%	29%	33%	24%
	2015-2099	**24%**	**16%**	**16%**	**29%**	**30%**	**23%**
New Melones	2015-2039	4%	0%	0%	8%	9%	3%
	2040-2069	5%	0%	0%	14%	19%	6%
	2070-2099	3%	2%	3%	4%	4%	3%
	2015-2099	**4%**	**1%**	**1%**	**9%**	**11%**	**4%**
Millerton	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	37%	38%	27%
	2070-2099	25%	26%	30%	45%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**40%**	**39%**	**30%**
New Don Pedro	2015-2039	25%	14%	14%	32%	37%	24%
	2040-2069	33%	10%	6%	41%	54%	27%
	2070-2099	33%	18%	17%	40%	49%	29%
	2015-2099	**31%**	**14%**	**12%**	**38%**	**47%**	**27%**
McClure	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	16%	14%	47%	56%	36%
	2070-2099	34%	21%	20%	41%	51%	30%
	2015-2099	**37%**	**20%**	**18%**	**43%**	**52%**	**33%**
Pine Flat	2015-2039	17%	12%	12%	24%	27%	19%
	2040-2069	29%	16%	15%	34%	39%	26%
	2070-2099	27%	18%	17%	38%	43%	24%
	2015-2099	**25%**	**15%**	**15%**	**32%**	**37%**	**23%**

Table 5-11b. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Shasta	2015-2039	16%	10%	10%	23%	29%	13%
	2040-2069	43%	14%	10%	52%	61%	37%
	2070-2099	43%	25%	18%	59%	60%	38%
	2015-2099	**35%**	**17%**	**13%**	**46%**	**51%**	**30%**
Folsom	2015-2039	34%	27%	26%	42%	43%	33%
	2040-2069	48%	30%	25%	51%	59%	43%
	2070-2099	50%	33%	28%	48%	56%	41%
	2015-2099	**44%**	**30%**	**26%**	**47%**	**53%**	**39%**
Oroville	2015-2039	13%	8%	8%	19%	22%	14%
	2040-2069	26%	13%	12%	33%	43%	24%
	2070-2099	30%	20%	15%	37%	39%	24%
	2015-2099	**24%**	**14%**	**12%**	**30%**	**35%**	**21%**
New Bullards	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	18%	19%	34%	33%	26%
	2070-2099	24%	17%	15%	28%	33%	24%
	2015-2099	**23%**	**16%**	**16%**	**29%**	**30%**	**23%**
New Melones	2015-2039	4%	0%	0%	8%	9%	3%
	2040-2069	7%	0%	0%	17%	20%	8%
	2070-2099	10%	6%	4%	19%	22%	12%
	2015-2099	**7%**	**2%**	**2%**	**15%**	**17%**	**8%**
Millerton	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	37%	38%	27%
	2070-2099	25%	26%	30%	45%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**40%**	**39%**	**30%**
New Don Pedro	2015-2039	26%	14%	14%	32%	36%	24%
	2040-2069	35%	11%	6%	42%	54%	29%
	2070-2099	36%	24%	18%	45%	51%	32%
	2015-2099	**33%**	**16%**	**13%**	**40%**	**48%**	**28%**
McClure	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	15%	14%	47%	56%	36%
	2070-2099	35%	22%	20%	42%	52%	31%
	2015-2099	**37%**	**20%**	**18%**	**43%**	**52%**	**33%**
Pine Flat	2015-2039	17%	12%	12%	23%	27%	18%
	2040-2069	29%	14%	15%	33%	38%	25%
	2070-2099	27%	18%	17%	38%	43%	24%
	2015-2099	**24%**	**15%**	**15%**	**32%**	**36%**	**23%**

Table 5-11c. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_cc sm4_CT	rcp4.5_c es m1-bgc_CT	rcp4.5_cnr m-cm5_CT	rcp4.5_gfd l-cm3_CT	rcp4.5_ha d gem2-ed_CT	rcp4.5_mir o c5_CT
Shasta	2015-2039	33%	32%	55%	37%	33%	40%
	2040-2069	41%	36%	55%	39%	19%	30%
	2070-2099	37%	46%	66%	31%	16%	13%
	2015-2099	**38%**	**38%**	**59%**	**36%**	**22%**	**27%**
Folsom	2015-2039	39%	48%	60%	44%	44%	52%
	2040-2069	44%	46%	54%	44%	33%	42%
	2070-2099	45%	50%	56%	43%	33%	32%
	2015-2099	**43%**	**48%**	**56%**	**44%**	**36%**	**41%**
Oroville	2015-2039	21%	25%	44%	15%	23%	31%
	2040-2069	24%	24%	38%	20%	13%	18%
	2070-2099	20%	35%	41%	20%	11%	7%
	2015-2099	**22%**	**28%**	**41%**	**18%**	**15%**	**18%**
New Bullards	2015-2039	20%	23%	36%	24%	22%	24%
	2040-2069	26%	22%	32%	23%	19%	21%
	2070-2099	26%	24%	34%	26%	17%	16%
	2015-2099	**24%**	**23%**	**34%**	**24%**	**19%**	**20%**
New Melones	2015-2039	4%	6%	20%	4%	8%	5%
	2040-2069	8%	10%	15%	5%	4%	2%
	2070-2099	9%	12%	17%	5%	4%	0%
	2015-2099	**7%**	**10%**	**18%**	**4%**	**5%**	**2%**
Millerton	2015-2039	29%	36%	37%	28%	27%	23%
	2040-2069	31%	43%	47%	34%	34%	22%
	2070-2099	39%	27%	51%	28%	24%	19%
	2015-2099	**33%**	**36%**	**46%**	**30%**	**29%**	**21%**
New Don Pedro	2015-2039	20%	30%	44%	20%	28%	32%
	2040-2069	25%	29%	35%	14%	18%	12%
	2070-2099	26%	36%	34%	23%	14%	6%
	2015-2099	**24%**	**32%**	**37%**	**19%**	**20%**	**16%**
McClure	2015-2039	31%	56%	61%	44%	50%	37%
	2040-2069	43%	56%	59%	40%	38%	21%
	2070-2099	49%	49%	61%	37%	29%	17%
	2015-2099	**42%**	**53%**	**60%**	**40%**	**38%**	**24%**
Pine Flat	2015-2039	24%	35%	40%	29%	30%	24%
	2040-2069	28%	35%	39%	27%	23%	17%
	2070-2099	34%	32%	38%	24%	19%	13%
	2015-2099	**29%**	**34%**	**39%**	**27%**	**23%**	**18%**

Table 5-11d. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
Shasta	2015-2039	44%	44%	59%	20%	40%	26%
	2040-2069	39%	43%	61%	45%	19%	21%
	2070-2099	34%	55%	61%	27%	15%	26%
	2015-2099	**39%**	**48%**	**61%**	**31%**	**24%**	**24%**
Folsom	2015-2039	45%	53%	64%	35%	48%	36%
	2040-2069	42%	48%	52%	50%	29%	35%
	2070-2099	40%	58%	51%	35%	37%	39%
	2015-2099	**42%**	**53%**	**55%**	**40%**	**38%**	**36%**
Oroville	2015-2039	32%	25%	43%	11%	28%	13%
	2040-2069	16%	29%	35%	24%	13%	10%
	2070-2099	21%	41%	40%	11%	13%	14%
	2015-2099	**22%**	**32%**	**39%**	**16%**	**17%**	**13%**
New Bullards	2015-2039	23%	24%	36%	19%	25%	17%
	2040-2069	23%	23%	30%	26%	15%	17%
	2070-2099	23%	34%	34%	24%	22%	22%
	2015-2099	**23%**	**27%**	**33%**	**23%**	**21%**	**19%**
New Melones	2015-2039	11%	9%	21%	4%	7%	0%
	2040-2069	3%	10%	12%	7%	3%	0%
	2070-2099	10%	23%	23%	4%	5%	3%
	2015-2099	**8%**	**15%**	**19%**	**5%**	**5%**	**1%**
Millerton	2015-2039	32%	29%	48%	21%	29%	23%
	2040-2069	26%	32%	40%	32%	23%	16%
	2070-2099	43%	56%	54%	29%	44%	30%
	2015-2099	**34%**	**40%**	**47%**	**28%**	**32%**	**23%**
New Don Pedro	2015-2039	33%	21%	50%	12%	24%	10%
	2040-2069	16%	30%	29%	23%	11%	7%
	2070-2099	30%	56%	47%	14%	17%	13%
	2015-2099	**26%**	**36%**	**41%**	**16%**	**17%**	**10%**
McClure	2015-2039	51%	47%	76%	26%	39%	28%
	2040-2069	29%	42%	54%	42%	21%	21%
	2070-2099	40%	70%	57%	28%	30%	26%
	2015-2099	**39%**	**53%**	**62%**	**32%**	**29%**	**25%**
Pine Flat	2015-2039	32%	32%	49%	22%	30%	20%
	2040-2069	27%	32%	35%	28%	13%	16%
	2070-2099	35%	52%	49%	21%	27%	22%
	2015-2099	**31%**	**39%**	**44%**	**24%**	**23%**	**19%**

Table 5-11e. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and **Ensemble** Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Shasta	2015-2039	16%	10%	10%	22%	29%	14%
	2040-2069	42%	14%	9%	52%	61%	36%
	2070-2099	42%	25%	18%	58%	60%	37%
	2015-2099	**34%**	**17%**	**13%**	**45%**	**51%**	**30%**
Folsom	2015-2039	34%	27%	26%	42%	44%	33%
	2040-2069	48%	29%	25%	52%	59%	44%
	2070-2099	49%	33%	28%	49%	56%	41%
	2015-2099	**44%**	**30%**	**26%**	**48%**	**53%**	**40%**
Oroville	2015-2039	14%	8%	8%	19%	21%	14%
	2040-2069	26%	13%	12%	34%	44%	23%
	2070-2099	28%	20%	15%	39%	39%	25%
	2015-2099	**23%**	**14%**	**12%**	**31%**	**36%**	**21%**
New Bullards	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	17%	19%	34%	33%	26%
	2070-2099	24%	16%	15%	28%	32%	24%
	2015-2099	**23%**	**15%**	**16%**	**29%**	**30%**	**23%**
New Melones	2015-2039	4%	0%	0%	8%	8%	3%
	2040-2069	6%	0%	0%	17%	19%	7%
	2070-2099	10%	6%	5%	18%	21%	11%
	2015-2099	**7%**	**2%**	**2%**	**15%**	**17%**	**7%**
Millerton	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	38%	38%	27%
	2070-2099	25%	26%	30%	45%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**40%**	**39%**	**30%**
New Don Pedro	2015-2039	24%	14%	14%	32%	36%	23%
	2040-2069	34%	10%	6%	41%	54%	28%
	2070-2099	36%	23%	18%	46%	51%	30%
	2015-2099	**32%**	**16%**	**13%**	**40%**	**48%**	**27%**
McClure	2015-2039	34%	24%	21%	41%	45%	32%
	2040-2069	43%	15%	14%	47%	57%	36%
	2070-2099	34%	22%	20%	42%	52%	31%
	2015-2099	**37%**	**20%**	**18%**	**43%**	**52%**	**33%**
Pine Flat	2015-2039	17%	12%	12%	23%	27%	18%
	2040-2069	28%	14%	14%	33%	37%	25%
	2070-2099	26%	18%	17%	38%	42%	24%
	2015-2099	**24%**	**15%**	**14%**	**32%**	**36%**	**23%**

5.2.6.2. Frequency of Releases Above Hydropower Penstock Capacities

This study examined the frequency of releases at three dams:

Indicator:
Releasing water over the amount of water that can go through a penstock indicates increased potential of flood control measures.

Measure:
Percentage of months from October through June in which releases are greater than the penstock capacities at Keswick (15,000 cfs), Thermalito (10,000 cfs), and Natoma (3,000 cfs)

- **Keswick Dam.** Shasta Dam stores Sacramento River water for releases to the south. The dam provides a flood control barrier on the river to protect inhabited areas downstream. When in operation, Shasta Powerplant uses part of the releases for hydroelectric power. Keswick Dam acts as Shasta Dam`s afterbay, stabilizing the erratic water flow released through Shasta Powerplant. Keswick Reservoir also captures water diverted from the Trinity River through the Trinity River Division. Keswick Powerplant further generates power using Sacramento River water. The Keswick Power Plant runs throughout the day at a relatively constant rate, providing a uniform release to the Sacramento River.

- **Thermalito.** DWR stores winter and spring runoff in Lake Oroville for release to the Feather River as necessary for project purposes (water supply, power generation, flood protection, fish and wildlife enhancement, and recreation). These releases generate power at the Hyatt-Thermalito Power Plant Complex (Thermalito).

- **Natoma.** The Folsom and Nimbus powerplants generate power using the water releases mandated for downstream appropriators, flood control, fish, and other uses. To avoid fluctuations in flow in the lower American River, Nimbus Dam and Lake Natoma serve as a regulating facility for Folsom Dam.

As with the flood conservation pool results, the flood releases exceeding the penstock capacities occur more often with the wetter climate scenarios and less often with the drier climate scenarios.

Under the Reference-No-Climate-Change/Current Trends Socioeconomic scenarios from 2015-2099, releases made above penstock capacities:

- Keswick: 12% of all months
- Thermalito: 4% of all months
- Natoma: 21% of all months

Across the range of all socioeconomic-climate scenarios, releases made above penstock capacities range from:

- Keswick: 8% to 23% of all months
- Thermalito: 2% to 12% of all months
- Natoma: 13% to 33% of all months

Table 5-12 shows the percentage of months from October through June in which releases are greater than the penstock capacities at Keswick (15,000 cubic feet per second [cfs]), Thermalito (10,000 cfs), and Natoma (3,000 cfs) under each socioeconomic-climate scenario.

Table 5-12. Reservoir Releases Exceed Penstock Capacities

Table 5-12a. Percentage of Months from October through June that Releases Exceed Penstock Capacities in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Keswick	2015-2039	8%	6%	6%	10%	10%	9%
	2040-2069	13%	9%	9%	20%	19%	13%
	2070-2099	14%	11%	9%	20%	18%	14%
	2015-2099	**12%**	**9%**	**8%**	**17%**	**16%**	**12%**
Thermalito	2015-2039	3%	0%	1%	4%	5%	3%
	2040-2069	4%	2%	2%	9%	10%	6%
	2070-2099	7%	4%	3%	12%	12%	8%
	2015-2099	**5%**	**2%**	**2%**	**9%**	**9%**	**6%**
Natoma	2015-2039	20%	12%	14%	23%	22%	17%
	2040-2069	21%	14%	13%	24%	26%	19%
	2070-2099	21%	15%	14%	26%	30%	20%
	2015-2099	**21%**	**14%**	**13%**	**25%**	**26%**	**19%**

Table 5-12b. Percentage of Months from October through June that Releases Exceed Penstock Capacities in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Keswick	2015-2039	8%	7%	6%	10%	11%	9%
	2040-2069	13%	9%	10%	21%	19%	15%
	2070-2099	14%	11%	10%	21%	19%	14%
	2015-2099	**12%**	**9%**	**9%**	**18%**	**16%**	**13%**
Thermalito	2015-2039	3%	1%	1%	4%	5%	3%
	2040-2069	4%	2%	2%	9%	10%	6%
	2070-2099	7%	3%	3%	12%	12%	8%
	2015-2099	**4%**	**2%**	**2%**	**9%**	**9%**	**6%**
Natoma	2015-2039	20%	13%	14%	23%	22%	17%
	2040-2069	21%	14%	13%	24%	27%	19%
	2070-2099	21%	16%	15%	27%	30%	20%
	2015-2099	**21%**	**14%**	**14%**	**25%**	**27%**	**19%**

Table 5-12c. Percentage of Months from October through June that Releases Exceed Penstock Capacities in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
Keswick	2015-2039	16%	11%	20%	14%	13%	13%
	2040-2069	16%	15%	24%	14%	12%	16%
	2070-2099	13%	18%	25%	16%	10%	10%
	2015-2099	**15%**	**15%**	**23%**	**15%**	**12%**	**13%**
Thermalito	2015-2039	5%	3%	10%	2%	3%	4%
	2040-2069	5%	5%	12%	3%	3%	3%
	2070-2099	3%	10%	14%	5%	2%	1%
	2015-2099	**4%**	**6%**	**12%**	**3%**	**3%**	**3%**
Natoma	2015-2039	20%	24%	36%	24%	27%	24%
	2040-2069	26%	26%	30%	21%	22%	17%
	2070-2099	23%	27%	34%	21%	19%	17%
	2015-2099	**23%**	**25%**	**33%**	**22%**	**22%**	**19%**

Table 5-12d. Percentage of Months from October through June that Releases Exceed Penstock Capacities in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
Keswick	2015-2039	18%	9%	23%	11%	18%	12%
	2040-2069	14%	17%	24%	20%	9%	10%
	2070-2099	11%	24%	26%	15%	11%	14%
	2015-2099	**14%**	**17%**	**24%**	**15%**	**13%**	**12%**
Thermalito	2015-2039	5%	5%	10%	3%	4%	0%
	2040-2069	3%	6%	10%	4%	1%	1%
	2070-2099	6%	13%	15%	4%	4%	3%
	2015-2099	**5%**	**8%**	**12%**	**4%**	**3%**	**2%**
Natoma	2015-2039	26%	25%	36%	19%	27%	19%
	2040-2069	20%	25%	29%	24%	15%	15%
	2070-2099	21%	33%	29%	18%	21%	17%
	2015-2099	**22%**	**28%**	**31%**	**20%**	**21%**	**17%**

Table 5-12e Percentage of Months from October through June that Releases Exceed Penstock Capacities in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Keswick	2015-2039	8%	7%	6%	10%	11%	9%
	2040-2069	13%	9%	10%	21%	19%	16%
	2070-2099	14%	11%	10%	22%	19%	14%
	2015-2099	**12%**	**9%**	**9%**	**18%**	**16%**	**13%**
Thermalito	2015-2039	3%	1%	1%	4%	5%	3%
	2040-2069	4%	2%	2%	9%	10%	6%
	2070-2099	6%	3%	3%	12%	12%	8%
	2015-2099	**4%**	**2%**	**2%**	**9%**	**9%**	**6%**
Natoma	2015-2039	20%	13%	14%	23%	22%	17%
	2040-2069	22%	14%	13%	24%	27%	19%
	2070-2099	21%	16%	16%	27%	30%	20%
	2015-2099	**21%**	**14%**	**14%**	**25%**	**27%**	**19%**

5.2.7. Recreation

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

Indicator:
Reduced reservoir storage decreases the reservoir's surface area, which in turn reduces potential recreational uses on the reservoir.

Measure:
percentage of months from May through September that reservoir surface area is less than the reservoir's historic period median surface area for Shasta, Folsom, Oroville, New Bullards Bar, New Melones, New Don Pedro, McClure, Millerton, and Pine Flat reservoirs. *Decreases in this indicator (in other words, more reservoir area) would imply that recreational opportunities are improved.*

All reservoirs show a greater frequency of falling below the median value under most of the climate scenarios. Shasta, Millerton and Pine Flat reservoirs were selected as representative of potential recreational impacts in the Sacramento Valley, San Joaquin Valley and Tulare Lake regions respectively. Under the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, from 2015-2099, the reservoirs have surface areas that are less than the performance metric's median surface area between 30 and 62% of all months.

- **Shasta Reservoir:**
    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Shasta Reservoir was below the surface area metric 48% of the months.
    - Across the range of all socioeconomic-climate scenarios, the percentage of months that Shasta Reservoir was below the surface area metric was 53% of the months from May to September during the period from 2015-2099, and ranged from a minimum of 20% to a maximum of 88% during the 2015-2099 period.
- **Millerton Reservoir:**
    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Lake Millerton was below the surface area metric 51% of all months.
    - Across the range of all socioeconomic-climate scenarios, the percentage of months that Millerton Reservoir was below the surface area metric was 63% of the months from May to September during the period from 2015-2099, and ranged from a minimum of 51% to a maximum of 76% during the 2015-2099 period.

- **Pine Flat Reservoir:**
    - In Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Pine Flat Reservoir was below the surface area metric 30% of all months.
    - Across the range of all socioeconomic-climate scenarios, the percentage of months that Pine Flat Reservoir was below the surface area metric was 31% of the months from May to September during the period from 2015-2099, and ranged from a minimum of 9% to a maximum of 54% during the 2015-2099 period.

Table 5-13 shows the percentage of months from May through September that the reservoir surface areas in Shasta, Folsom, Oroville, New Bullards Bar, New Melones, New Don Pedro, McClure, Millerton, and Pine Flat reservoirs are less than the reservoir's median surface area in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF-RF) (with reference climate and current socioeconomic conditions) for each socioeconomic-climate scenario.

Table 5-13. Reservoir Surface Area Less than Indicator Levels

Table 5-13a. Percentage of Months from May through September that Reservoir Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Shasta	2015-2039	76%	85%	85%	73%	56%	80%
	2040-2069	23%	69%	95%	28%	11%	49%
	2070-2099	31%	61%	81%	11%	11%	47%
	2015-2099	**41%**	**71%**	**87%**	**35%**	**24%**	**57%**
Folsom	2015-2039	67%	77%	82%	62%	48%	75%
	2040-2069	26%	61%	81%	38%	22%	48%
	2070-2099	25%	60%	75%	35%	25%	47%
	2015-2099	**38%**	**65%**	**80%**	**44%**	**31%**	**56%**
Oroville	2015-2039	63%	79%	80%	53%	51%	68%
	2040-2069	31%	53%	72%	25%	11%	41%
	2070-2099	38%	57%	75%	28%	33%	50%
	2015-2099	**43%**	**62%**	**75%**	**34%**	**31%**	**52%**
New Bullards	2015-2039	69%	86%	86%	73%	59%	75%
	2040-2069	53%	75%	85%	67%	51%	69%
	2070-2099	53%	66%	77%	68%	53%	62%
	2015-2099	**58%**	**75%**	**83%**	**69%**	**54%**	**68%**

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
New Melones	2015-2039	73%	88%	90%	63%	55%	75%
	2040-2069	37%	99%	100%	27%	22%	47%
	2070-2099	52%	76%	75%	39%	37%	61%
	2015-2099	**53%**	**88%**	**88%**	**42%**	**37%**	**60%**
New Don Pedro	2015-2039	52%	68%	72%	43%	43%	52%
	2040-2069	50%	79%	84%	31%	29%	57%
	2070-2099	53%	61%	61%	29%	24%	55%
	2015-2099	**52%**	**70%**	**72%**	**34%**	**31%**	**55%**
McClure	2015-2039	49%	65%	76%	48%	40%	60%
	2040-2069	44%	73%	79%	52%	36%	59%
	2070-2099	55%	73%	80%	71%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Millerton	2015-2039	54%	66%	71%	56%	46%	60%
	2040-2069	45%	64%	80%	76%	45%	64%
	2070-2099	54%	69%	77%	75%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**70%**	**51%**	**66%**
Pine Flat	2015-2039	33%	49%	50%	23%	22%	49%
	2040-2069	25%	44%	52%	25%	9%	29%
	2070-2099	31%	54%	55%	15%	1%	35%
	2015-2099	**29%**	**49%**	**53%**	**21%**	**10%**	**37%**

Table 5-13b. Percentage of Months from May through September that Reservoir Surface Area Is Less than the Monthly in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Shasta	2015-2039	78%	85%	85%	73%	56%	81%
	2040-2069	30%	72%	95%	31%	12%	55%
	2070-2099	41%	63%	83%	17%	17%	52%
	2015-2099	**48%**	**72%**	**88%**	**38%**	**27%**	**61%**
Folsom	2015-2039	62%	77%	82%	63%	51%	75%
	2040-2069	29%	61%	84%	38%	24%	48%
	2070-2099	29%	61%	79%	37%	27%	52%
	2015-2099	**39%**	**66%**	**82%**	**45%**	**33%**	**57%**
Oroville	2015-2039	63%	80%	80%	54%	49%	68%
	2040-2069	37%	53%	74%	26%	12%	47%
	2070-2099	43%	59%	76%	29%	35%	52%
	2015-2099	**47%**	**63%**	**76%**	**35%**	**31%**	**55%**

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
New Bullards	2015-2039	70%	88%	86%	74%	59%	78%
	2040-2069	59%	78%	89%	68%	54%	71%
	2070-2099	57%	71%	80%	73%	54%	70%
	2015-2099	**62%**	**78%**	**85%**	**72%**	**56%**	**73%**
New Melones	2015-2039	73%	88%	92%	63%	54%	75%
	2040-2069	35%	97%	98%	25%	22%	47%
	2070-2099	49%	73%	71%	30%	30%	61%
	2015-2099	**51%**	**86%**	**87%**	**38%**	**34%**	**60%**
New Don Pedro	2015-2039	54%	68%	72%	40%	43%	54%
	2040-2069	49%	77%	84%	31%	28%	55%
	2070-2099	52%	59%	59%	28%	24%	55%
	2015-2099	**52%**	**68%**	**72%**	**33%**	**31%**	**55%**
McClure	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	73%	79%	52%	36%	59%
	2070-2099	55%	73%	80%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Millerton	2015-2039	54%	66%	71%	56%	46%	60%
	2040-2069	45%	64%	80%	76%	45%	64%
	2070-2099	54%	69%	77%	75%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**70%**	**51%**	**66%**
Pine Flat	2015-2039	34%	49%	50%	26%	22%	49%
	2040-2069	25%	45%	53%	26%	10%	31%
	2070-2099	32%	53%	55%	15%	1%	36%
	2015-2099	**30%**	**49%**	**53%**	**22%**	**11%**	**38%**

Table 5-13c. Percentage of Months from May through September that Reservoir Surface Area Is Less than the Monthly Median in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-	rcp4.5_cnrm-	rcp4.5_gfdl-cm3_C	rcp4.5_hadgem2-	rcp4.5_miroc5_CT
Shasta	2015-2039	54%	39%	23%	42%	37%	38%
	2040-2069	44%	49%	30%	47%	79%	71%
	2070-2099	47%	36%	20%	65%	84%	89%
	2015-2099	**48%**	**41%**	**24%**	**52%**	**68%**	**68%**
Folsom	2015-2039	55%	45%	31%	50%	44%	46%
	2040-2069	47%	52%	35%	53%	71%	65%
	2070-2099	45%	37%	32%	59%	71%	84%
	2015-2099	**48%**	**45%**	**33%**	**54%**	**63%**	**66%**

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-	rcp4.5_cnrm-	rcp4.5_gfdl-cm3_C	rcp4.5_hadgem2-	rcp4.5_miroc5_CT
Oroville	2015-2039	57%	38%	20%	54%	48%	41%
	2040-2069	46%	45%	33%	47%	65%	59%
	2070-2099	46%	39%	10%	60%	70%	84%
	2015-2099	**49%**	**41%**	**21%**	**53%**	**62%**	**62%**
New Bullards	2015-2039	68%	70%	57%	73%	70%	63%
	2040-2069	76%	69%	69%	74%	85%	80%
	2070-2099	67%	58%	59%	71%	79%	86%
	2015-2099	**71%**	**66%**	**62%**	**72%**	**78%**	**77%**
New Melones	2015-2039	76%	49%	24%	67%	68%	63%
	2040-2069	63%	54%	45%	73%	67%	81%
	2070-2099	50%	52%	27%	70%	81%	100%
	2015-2099	**62%**	**52%**	**32%**	**70%**	**72%**	**82%**
New Don Pedro	2015-2039	70%	42%	34%	63%	51%	64%
	2040-2069	53%	51%	47%	67%	68%	83%
	2070-2099	50%	57%	36%	68%	73%	85%
	2015-2099	**57%**	**50%**	**39%**	**66%**	**65%**	**78%**
McClure	2015-2039	60%	27%	30%	37%	28%	56%
	2040-2069	48%	29%	36%	49%	49%	73%
	2070-2099	36%	42%	27%	57%	62%	75%
	2015-2099	**47%**	**33%**	**31%**	**48%**	**47%**	**69%**
Millerton	2015-2039	61%	45%	50%	41%	42%	55%
	2040-2069	57%	53%	57%	58%	67%	70%
	2070-2099	56%	57%	67%	71%	72%	77%
	2015-2099	**58%**	**52%**	**59%**	**58%**	**61%**	**68%**
Pine Flat	2015-2039	39%	17%	12%	24%	24%	34%
	2040-2069	37%	13%	19%	27%	36%	51%
	2070-2099	19%	25%	5%	41%	41%	47%
	2015-2099	**31%**	**19%**	**12%**	**31%**	**34%**	**44%**

Table 5-13d. Percentage of Months from May through September that Reservoir Surface Area Is Less than the Monthly Median in the **CCTAG 8.5 RCP** Climate Scenarios for the Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnr m-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Shasta	2015-2039	26%	28%	10%	70%	42%	58%
	2040-2069	49%	47%	23%	33%	73%	71%
	2070-2099	61%	31%	25%	61%	83%	71%
	2015-2099	**46%**	**36%**	**20%**	**53%**	**68%**	**67%**
Folsom	2015-2039	38%	34%	20%	65%	42%	53%
	2040-2069	50%	46%	39%	45%	75%	66%
	2070-2099	64%	39%	48%	69%	76%	67%
	2015-2099	**52%**	**40%**	**36%**	**59%**	**66%**	**63%**
Oroville	2015-2039	30%	27%	8%	58%	51%	60%
	2040-2069	49%	39%	27%	38%	67%	66%
	2070-2099	60%	23%	20%	53%	73%	70%
	2015-2099	**47%**	**30%**	**19%**	**49%**	**65%**	**66%**
New Bullards	2015-2039	69%	53%	50%	82%	65%	70%
	2040-2069	70%	73%	70%	77%	83%	83%
	2070-2099	71%	64%	70%	74%	79%	75%
	2015-2099	**70%**	**64%**	**64%**	**77%**	**76%**	**77%**
New Melones	2015-2039	46%	58%	7%	93%	60%	94%
	2040-2069	70%	45%	42%	59%	73%	87%
	2070-2099	52%	17%	24%	77%	68%	77%
	2015-2099	**56%**	**39%**	**25%**	**75%**	**68%**	**85%**
New Don Pedro	2015-2039	54%	54%	22%	77%	61%	79%
	2040-2069	70%	57%	39%	57%	73%	81%
	2070-2099	39%	14%	18%	60%	63%	61%
	2015-2099	**54%**	**41%**	**26%**	**64%**	**66%**	**74%**
McClure	2015-2039	37%	34%	9%	58%	44%	46%
	2040-2069	55%	51%	35%	51%	74%	67%
	2070-2099	59%	27%	57%	64%	69%	70%
	2015-2099	**51%**	**37%**	**35%**	**57%**	**63%**	**62%**
Millerton	2015-2039	55%	44%	36%	58%	46%	57%
	2040-2069	63%	57%	74%	68%	84%	75%
	2070-2099	64%	64%	77%	80%	78%	81%
	2015-2099	**61%**	**56%**	**64%**	**69%**	**71%**	**72%**
Pine Flat	2015-2039	19%	8%	0%	42%	30%	24%
	2040-2069	27%	18%	27%	38%	57%	51%
	2070-2099	16%	1%	11%	36%	23%	44%
	2015-2099	**21%**	**9%**	**13%**	**38%**	**37%**	**40%**

Table 5-13e. Percentage of Months from May through September that Reservoir Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Shasta	2015-2039	78%	85%	85%	73%	56%	81%
	2040-2069	32%	73%	95%	32%	12%	57%
	2070-2099	43%	63%	83%	19%	20%	52%
	2015-2099	**49%**	**73%**	**88%**	**39%**	**28%**	**62%**
Folsom	2015-2039	62%	77%	82%	63%	52%	74%
	2040-2069	31%	61%	84%	41%	24%	48%
	2070-2099	32%	61%	78%	38%	27%	55%
	2015-2099	**41%**	**66%**	**81%**	**46%**	**33%**	**58%**
Oroville	2015-2039	62%	80%	80%	54%	50%	68%
	2040-2069	36%	57%	74%	22%	17%	46%
	2070-2099	49%	59%	76%	29%	33%	51%
	2015-2099	**48%**	**64%**	**76%**	**34%**	**32%**	**54%**
New Bullards	2015-2039	73%	88%	87%	74%	61%	78%
	2040-2069	59%	84%	93%	69%	57%	75%
	2070-2099	58%	71%	84%	77%	57%	74%
	2015-2099	**63%**	**81%**	**88%**	**73%**	**58%**	**76%**
New Melones	2015-2039	73%	90%	94%	63%	55%	75%
	2040-2069	36%	99%	99%	26%	22%	47%
	2070-2099	52%	75%	67%	30%	35%	61%
	2015-2099	**52%**	**88%**	**86%**	**38%**	**36%**	**60%**
New Don Pedro	2015-2039	53%	70%	73%	43%	43%	58%
	2040-2069	49%	79%	84%	32%	29%	57%
	2070-2099	53%	59%	60%	30%	25%	56%
	2015-2099	**52%**	**69%**	**72%**	**35%**	**32%**	**57%**
McClure	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	73%	79%	52%	36%	59%
	2070-2099	55%	73%	80%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Millerton	2015-2039	54%	66%	71%	56%	46%	60%
	2040-2069	45%	64%	80%	76%	45%	64%
	2070-2099	54%	69%	77%	75%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**70%**	**51%**	**66%**
Pine Flat	2015-2039	34%	49%	53%	26%	23%	49%
	2040-2069	25%	45%	53%	26%	12%	32%
	2070-2099	35%	53%	55%	16%	2%	39%
	2015-2099	**31%**	**49%**	**54%**	**22%**	**12%**	**40%**

5.2.8. Ecological Resources

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

The attributes of interest selected as indicators of ecological resources were selected primarily to address concerns with respect to endangered aquatic species and their habitats in the Central Valley and the Sacramento-San Joaquin Delta:

- Reservoir cold water pool
- River temperatures
- Floodplain processes in the Sacramento River
- Pelagic species habitat
  - Spring Delta outflows
  - Delta salinity levels
- Old and Middle River reverse flows for:
  - Delta smelt
  - Adult salmon migration
  - Food web productivity in the Delta

5.2.8.1. Storage for Cold Water Pool Management

When storage in Lake Shasta levels is below 2,200 TAF at the end of September or below 3,800 TAF at the end of April, managing water temperatures in the Sacramento River during the warm season months becomes increasingly difficult. Storage levels in Shasta Reservoir at the end of April and September are useful measures of the availability of cold water for management of water temperatures needed by salmonid species for survival.

Indicator:
Storage above minimum levels at the end of September and April indicates the availability of cold water to support populations of listed salmonids and other fish species.

Measure:
Shasta Reservoir storage at the end of April (>3,800 TAF) and at the end of September (>2,200 TAF)

In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Lake Shasta storage was below the April and September minimum storage levels 24% of the time in April and 21% of the time in September during 2015-2099.

Across the range of all socioeconomic-climate scenarios, Lake Shasta storage was below the April and September minimum storage levels 33% and 28%, respectively during 2015-2099 period, corresponding to an increase of 9% in April and of 7% in September. Levels ranged from a minimum of 7% to a maximum of 75% for April and ranged from a minimum of 5% to a maximum of 61% for September.

- **September:**
    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Lake Shasta storage was below the September minimum storage levels 24% of the time,
    - Across the range of all socioeconomic-climate scenarios, this ranged from .5% to 75% of the time.
- **April:**
    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, Lake Shasta storage was below the April minimum storage levels 21% of the time,
    - Across the range of all socioeconomic-climate scenarios, this ranged from 5% to 68% of the time.

Table 5-14 shows the percentage of years that Lake Shasta storage is less than 2,200 TAF at the end of September and the percentage of years that Lake Shasta storage is less than 3,800 TAF/year at the end of April for each scenario.

Table 5-14. End-of-September Storage Less than Indicator Levels

Table 5-14a. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
September	2015-2039	52%	76%	80%	44%	32%	56%
	2040-2069	7%	37%	70%	7%	3%	13%
	2070-2099	7%	47%	57%	0%	0%	13%
	2015-2099	20%	52%	68%	15%	11%	26%
April	2015-2039	48%	64%	64%	44%	32%	52%
	2040-2069	7%	40%	60%	3%	3%	7%
	2070-2099	10%	33%	53%	0%	0%	10%
	2015-2099	20%	45%	59%	14%	11%	21%

Table 5-14b. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
September	2015-2039	56%	80%	80%	44%	32%	56%
	2040-2069	10%	43%	73%	3%	3%	17%
	2070-2099	10%	50%	70%	0%	0%	30%
	2015-2099	**24%**	**56%**	**74%**	**14%**	**11%**	**33%**
April	2015-2039	48%	68%	64%	44%	32%	52%
	2040-2069	7%	40%	60%	3%	3%	7%
	2070-2099	13%	40%	57%	0%	0%	20%
	2015-2099	**21%**	**48%**	**60%**	**14%**	**11%**	**25%**

Table 5-14c. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in the **CCTAG 4.5. RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
September	2015-2039	44%	20%	16%	28%	36%	28%
	2040-2069	30%	27%	7%	20%	50%	33%
	2070-2099	20%	20%	3%	33%	60%	73%
	2015-2099	**31%**	**22%**	**8%**	**27%**	**49%**	**46%**
April	2015-2039	28%	16%	12%	24%	28%	8%
	2040-2069	23%	20%	0%	17%	43%	27%
	2070-2099	17%	23%	3%	27%	53%	53%
	2015-2099	**22%**	**20%**	**5%**	**22%**	**42%**	**31%**

Table 5-14d. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in the **CCTAG 8.5. RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
September	2015-2039	16%	16%	0%	48%	32%	44%
	2040-2069	33%	33%	7%	17%	63%	57%
	2070-2099	43%	17%	13%	50%	67%	43%
	2015-2099	**32%**	**22%**	**7%**	**38%**	**55%**	**48%**
April	2015-2039	16%	8%	4%	48%	20%	44%
	2040-2069	30%	27%	0%	10%	63%	47%
	2070-2099	37%	7%	10%	27%	53%	30%
	2015-2099	**28%**	**14%**	**5%**	**27%**	**47%**	**40%**

Table 5-14e. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
September	2015-2039	60%	80%	80%	44%	32%	56%
	2040-2069	10%	43%	77%	3%	3%	13%
	2070-2099	10%	50%	70%	3%	0%	30%
	2015-2099	**25%**	**56%**	**75%**	**15%**	**11%**	**32%**
April	2015-2039	48%	68%	64%	44%	32%	52%
	2040-2069	7%	40%	60%	3%	3%	7%
	2070-2099	13%	47%	60%	0%	0%	20%
	2015-2099	**21%**	**51%**	**61%**	**14%**	**11%**	**25%**

5.2.8.2. River Temperature

To understand the effects of climate change on river water temperatures, the Sacramento and San Joaquin water temperature models were simulated for four scenario combinations:

> **Indicator:**
> In-stream water temperatures at key locations during summer and fall indicate habitat suitability for critical life stages of fish such as Chinook salmon and steelhead.
>
> **Measure:**
> Exceedance of average temperatures from July to September at key locations on the Sacramento and San Joaquin River systems.

- The Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF) as a baseline.
- Central Tendency Climate/Current Trends Socioeconomic scenarios as a "middle of the road" condition
- Hot-Dry Climate/Expanded Growth Socioeconomic scenarios as an upper boundary condition
- Warm-Wet Climate/Slow Growth Socioeconomic scenarios as a lower boundary condition

The differences on the Sacramento River reflect a range of about 5 degrees on average between the two most extreme climate conditions and also a difference of about 4 degrees between the Keswick and Jelly's Ferry where the majority of the spawning and rearing habitat in the upper Sacramento River occurs. On the American River, there is a range of about 3 degree on average between the two most extreme climate conditions. Findings included:

- Water temperatures in Warm-Wet/Slow Growth scenarios were slightly lower than those in Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF), reflecting the effects of increased Shasta and Folsom cold water pool, and greater flows in the river.
- Conversely, the water temperatures in Central Tendency/Current Trends scenarios were slightly higher and the water temperatures in Hot-Dry/Expanded Growth scenarios were significantly higher than those in Reference-No-Climate-Change/Current Trends scenarios at both locations, reflecting the changes in the storage and flow at both locations.

Mean July–September water temperatures in the Sacramento and American rivers were:

- **Sacramento River at Keswick:**
    - In Hot-Dry climate/Expanded Growth socioeconomic scenarios: 57.4 °F

- Warm-Wet climate/Slow Growth socioeconomic scenarios: 52.5°F

- **Sacramento River at Jelly's Ferry:**
  - In Hot-Dry climate/Expanded Growth socioeconomic scenarios: 61.4°F
  - Warm-Wet climate/Slow Growth socioeconomic scenarios: 56.7°F

- **American River below Nimbus Dam:**
  - In Hot-Dry climate/Expanded Growth socioeconomic scenarios: 63.7 °F
  - Warm-Wet climate/Slow Growth socioeconomic scenarios: 60.4°F

The mean August through November water temperatures in the San Joaquin River were evaluated:

- **San Joaquin River at Lost Lake (just downstream of Millerton Lake).** The mean daily water during these months ranged from 54.1 to 55.8°F across the four scenarios. With respect to Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF-RF) scenario, Hot-Dry Climate/Expanded Growth Socioeconomic scenarios showed reduced water temperatures at this location, and Central Tendency Climate/Current Trends Socioeconomic and Warm-Wet/Slow Growth Socioeconomic scenarios showed a small increase. The warming occurred because Millerton Lake has limited capacity to hold high flows, so when there were higher inflows to Millerton (as occurred frequently in climate scenarios Central Tendency and Warm-Wet), the thermocline in the lake was disturbed as the high flows flushed out any cold water sitting in the lake. This caused warm flows to be passed down the river, resulting in warmer water temperatures at Lost Lake. Conversely, when there were lower inflows into Millerton (as occurred frequently in the Hot-Dry climate scenario), the thermocline in the lake was retained; and the water released from Millerton was colder, resulting in cooler water temperatures at Lost Lake, as observed in the Hot-Dry climate/Expanded Growth socioeconomic scenarios.

- **San Joaquin River at Vernalis.** Farther downstream on the San Joaquin River at Vernalis, the mean daily water temperatures increased under all climate scenarios due to the effects of all operations in the San Joaquin River system including the tributaries. In contrast to the Lost Lake results, warming was greatest in the Hot-Dry climate scenario and smallest in the Warm-Wet climate scenario at Vernalis. At Vernalis, the mean daily water temperature for these scenarios ranged from a low of 67.9°F in Warm-Wet Climate/Slow Growth socioeconomic scenarios to a high of 71.3°F in Hot-Dry Climate/Expanded Growth socioeconomic scenarios, with Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios (RF_RF) at 66.9°F.

Figure 5-16 shows exceedance plots of daily water temperatures from July through September for these four scenarios in the Sacramento River at Keswick and Jelly's Ferry and in American River below Nimbus as well as in the San Joaquin River at Lost Lake and Vernalis from August through November.

Figure 5-16. Exceedences of Average Temperatures

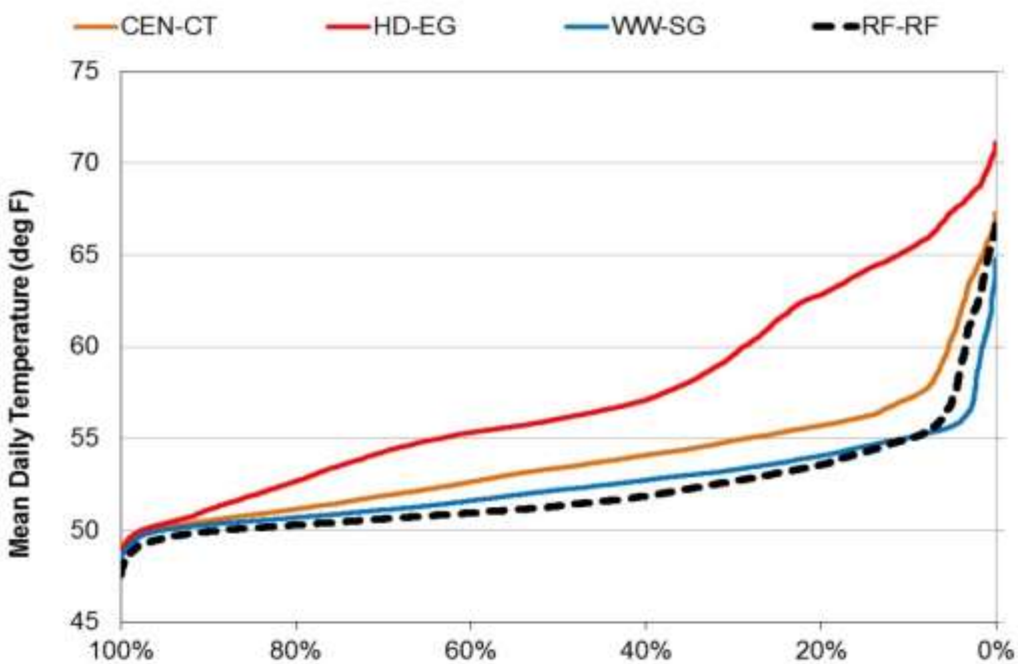


Figure 5-16a. Exceedance of average temperature on the Sacramento River at **Keswick** from **July to September.**

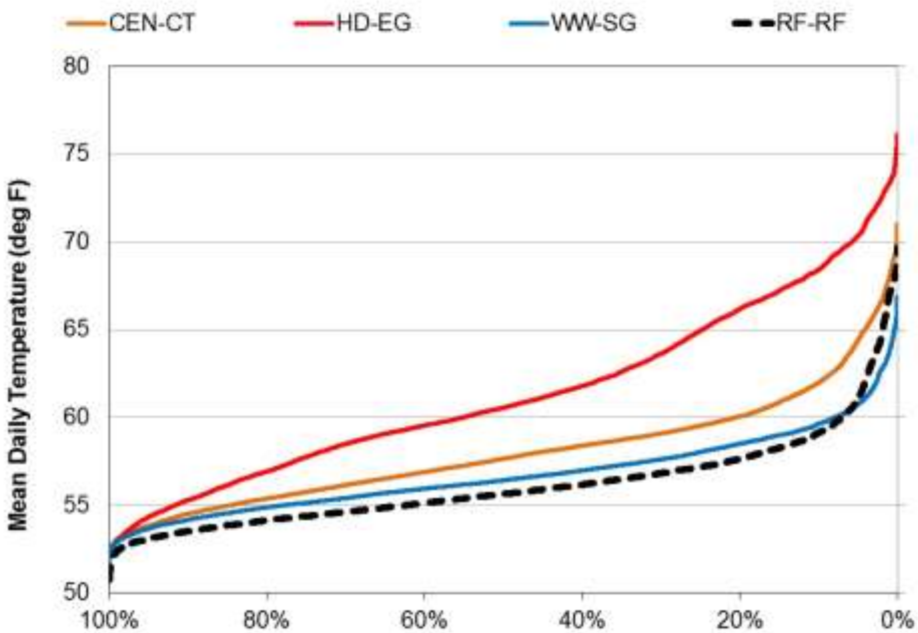


Figure 5-16b. Exceedance of average temperature on the Sacramento River at **Jelly's Ferry** from **July to September.**

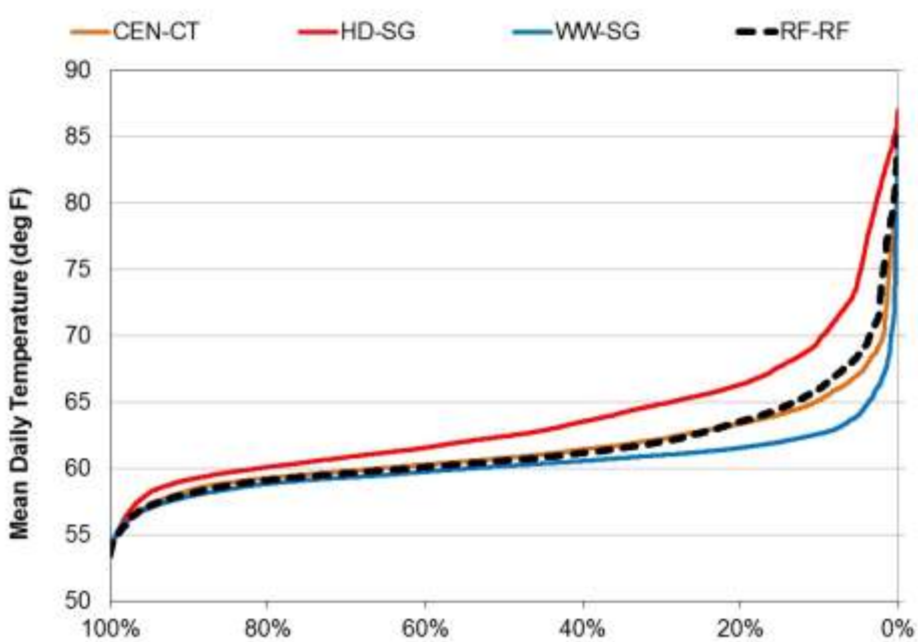


Figure 5-16c. Exceedance of average temperature on American River below **Nimbus** from **July to September.**

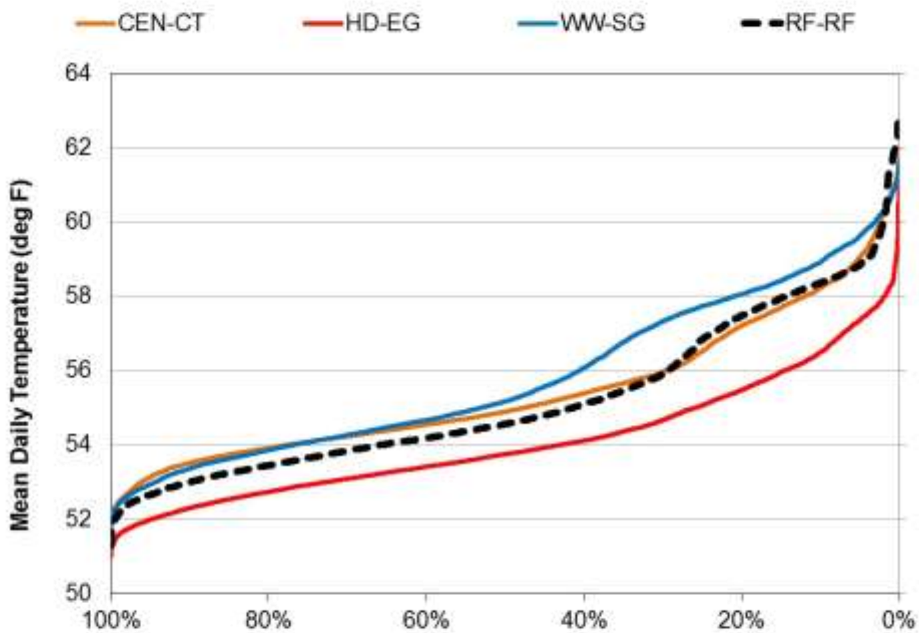


Figure 5-16d. Exceedance of average temperature on San Joaquin River at **Lost Lake** from **July to September.**

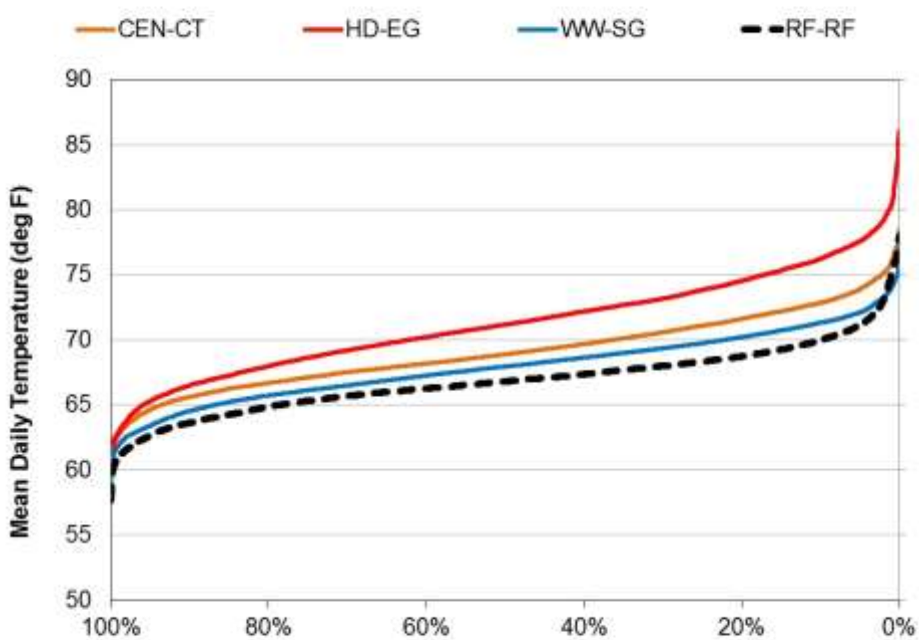


Figure 5-16e. Exceedance of average temperature on San Joaquin River at **Vernalis** from **July to September.**

5.2.8.3. Floodplain Processes: Instream Flows for Channel Maintenance and Habitat Creation

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.

Indicators:
In-stream flows during February through June in these reaches indicate floodplain processes capable of sustaining favorable riparian habitat conditions in the Sacramento River watershed.

Measure:
Keswick Dam below Shasta Reservoir: flows over 15,000 cfs

At the mouth of Feather River: flows over at 10,000 cfs

American River flows at Natoma: flows over 3,000 cfs
Decreases in this indicator would imply that floodplain processes are improved.

Flows above the indicator levels are usually associated with winter storms and large spring snowmelt events. An increasing percentage of months with flows less than the indicator levels indicates downstream flow conditions that are less favorable to establishment and maintenance of conditions favorable to riparian habitats. The floodplain process flows are more frequent in the Feather and American River systems than in the Sacramento River.

- **Keswick Dam**
  - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, instream flow minimums are not met in 84% of all months
  - Across the range of all socioeconomic-climate scenarios, the percentage of months that Keswick flows were below the flow metric was 82% of the months from February through June during the period from 2015-2099, a decrease of 2% and ranged from a minimum of 72% to a maximum of 88% during the 2015-2099 period.
- **At the mouth of Feather River**
  - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, instream flow minimums are not met in 74% of all months.
  - Across the range of all socioeconomic-climate scenarios, the percentage of months that Feather River flows at the mouth were below the flow metric was 73% of the months from February through June during the period from 2015-2099, a decrease of 1% and ranged from a minimum of 59% to a maximum of 84% during the 2015-2099 period.

- **American River flows at Natoma.**
    - Across the range of all socioeconomic-climate scenarios, the percentage of months that American River flows at Natoma were below the flow metric was 54% of the months from February through June during the period from 2015-2099, an increase of 7% and ranged from a minimum of 44% to a maximum of 62% during the 2015-2099 period.

Table 5-15 shows the percentage of months from February through June that Instream Flow Minimums for Sacramento River flows at Keswick, Feather River at the mouth, and American River flows at Natoma are not met.

Table 5-15. Flows Less than Indicator Values

Table 5-15a. Percentage of Months from February through June that Flows are Less than the Indicator Values in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Sacramento River at Keswick (15,000 cfs)	2015-2039	87%	90%	90%	86%	87%	87%
	2040-2069	85%	87%	87%	79%	80%	84%
	2070-2099	83%	85%	87%	79%	79%	83%
	2015-2099	**85%**	**87%**	**88%**	**81%**	**82%**	**85%**
Feather River at the Mouth (10,000 cfs)	2015-2039	81%	86%	84%	75%	72%	82%
	2040-2069	73%	85%	87%	65%	57%	77%
	2070-2099	70%	77%	80%	62%	64%	72%
	2015-2099	**74%**	**83%**	**84%**	**67%**	**64%**	**76%**
American River at Natoma (3,000 cfs)	2015-2039	41%	53%	51%	46%	42%	48%
	2040-2069	47%	59%	61%	62%	49%	57%
	2070-2099	55%	71%	71%	69%	58%	67%
	2015-2099	**48%**	**61%**	**62%**	**60%**	**50%**	**58%**

Table 5-15b. Percentage of Months from February through June that Flows are Less than the Indicator Values in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Sacramento River at Keswick (15,000 cfs)	2015-2039	88%	89%	90%	86%	86%	87%
	2040-2069	84%	87%	84%	77%	80%	81%
	2070-2099	81%	84%	86%	77%	79%	82%
	2015-2099	**84%**	**86%**	**87%**	**80%**	**81%**	**83%**
Feather River at the Mouth (10,000 cfs)	2015-2039	80%	86%	84%	75%	72%	82%
	2040-2069	72%	86%	87%	64%	57%	77%
	2070-2099	71%	77%	80%	65%	63%	72%
	2015-2099	**74%**	**83%**	**84%**	**68%**	**64%**	**76%**
American River at Natoma (3,000 cfs)	2015-2039	40%	54%	50%	46%	42%	49%
	2040-2069	47%	59%	60%	61%	48%	56%
	2070-2099	52%	68%	68%	68%	54%	63%
	2015-2099	47%	61%	60%	59%	48%	56%

Table 5-15c. Percentage of Months from February through June that Flows are Less than the Indicator Values in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
Sacramento River at Keswick (15,000 cfs)	2015-2039	80%	82%	78%	82%	78%	83%
	2040-2069	80%	79%	75%	83%	79%	78%
	2070-2099	85%	76%	69%	79%	83%	83%
	2015-2099	**82%**	**79%**	**73%**	**81%**	**80%**	**81%**
Feather River at the Mouth (10,000 cfs)	2015-2039	76%	66%	54%	74%	63%	70%
	2040-2069	71%	71%	65%	75%	77%	79%
	2070-2099	74%	67%	55%	71%	81%	81%
	2015-2099	**73%**	**68%**	**59%**	**73%**	**75%**	**77%**
American River at Natoma (3,000 cfs)	2015-2039	58%	42%	39%	51%	38%	43%
	2040-2069	49%	45%	50%	56%	44%	59%
	2070-2099	47%	53%	49%	54%	49%	51%
	2015-2099	**51%**	**47%**	**46%**	**54%**	**44%**	**52%**

Table 5-15d. Percentage of Months from February through June that Flows are Less than the Indicator Values in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
Sacramento River at Keswick (15,000 cfs)	2015-2039	78%	87%	75%	84%	73%	81%
	2040-2069	80%	75%	72%	72%	87%	86%
	2070-2099	85%	68%	69%	76%	83%	79%
	2015-2099	**81%**	**76%**	**72%**	**77%**	**81%**	**82%**
Feather River at the Mouth (10,000 cfs)	2015-2039	68%	62%	52%	76%	64%	78%
	2040-2069	72%	64%	65%	68%	82%	83%
	2070-2099	73%	57%	66%	79%	78%	80%
	2015-2099	**71%**	**61%**	**62%**	**74%**	**75%**	**80%**
American River at Natoma (3,000 cfs)	2015-2039	46%	44%	35%	48%	46%	44%
	2040-2069	56%	47%	53%	51%	59%	56%
	2070-2099	62%	50%	65%	63%	55%	61%
	2015-2099	**55%**	**47%**	**52%**	**54%**	**54%**	**54%**

Table 5-15e Percentage of Months from February through June that Flows are Less than the Indicator Values in the Reference-No-Climate-Change and **Ensemble** Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Sacramento River at Keswick (15,000 cfs)	2015-2039	88%	89%	90%	86%	86%	87%
	2040-2069	84%	87%	84%	77%	80%	80%
	2070-2099	81%	83%	86%	75%	79%	82%
	2015-2099	**84%**	**86%**	**87%**	**79%**	**81%**	**83%**
Feather River at the Mouth (10,000 cfs)	2015-2039	80%	86%	84%	75%	72%	82%
	2040-2069	71%	85%	87%	64%	57%	77%
	2070-2099	71%	77%	80%	65%	63%	72%
	2015-2099	**74%**	**82%**	**84%**	**68%**	**64%**	**77%**
American River at Natoma (3,000 cfs)	2015-2039	39%	54%	50%	45%	43%	49%
	2040-2069	46%	59%	59%	61%	48%	55%
	2070-2099	51%	66%	67%	67%	52%	63%
	2015-2099	**46%**	**60%**	**60%**	**59%**	**48%**	**56%**

5.2.8.4. Pelagic Species Habitat-Flows

Indicator:
Spring Delta outflows above these levels have been shown to benefit longfin and delta smelt populations.

Measure:
Delta outflow (>28,000 cfs and >44,000)

Pelagic species are fish that live and spawn in open water in the estuaries of the Bay-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.

In the Reference-No-Climate-Change/Current Trends scenario, Delta outflow was less than 28,000 cfs in 65% of all months and less than 44,000 cfs in 82% of all months.

The drier scenarios have more months with lower Delta outflows than do the wetter scenarios because high flow events are less frequent in the drier climate scenarios. The differences between climate scenarios are similar across 21st century.

- **28,000 cfs threshold**. The percentage of months below this threshold ranged from 43% under a CCTAG climate/Current Trends socioeconomic scenario to 82% under the Hot-Dry climate/Expanded Growth socioeconomic scenarios.

- **44,000 cfs threshold.** The percentage of months below this threshold ranged from 62% under a CCTAG climate/Current Trends socioeconomic scenario to 93% under the Hot-Dry climate/Expanded Growth socioeconomic scenarios.

Table 5-16 shows the percentage of months from March through May that the Delta outflow is less than 28,000 cfs and 44,000 cfs in each scenario.

Table 5-16. Delta Outflow Less than Indicator Values

Table 5-16a. Percentage of Months in Each Scenario that March-through-May Delta Outflow Flow is Less than 28,000 cfs and 44,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
Delta Outflow < 28,000 cfs	2015-2039	69%	81%	84%	64%	57%	71%
	2040-2069	53%	79%	80%	48%	43%	63%
	2070-2099	69%	81%	81%	54%	50%	70%
	2015-2099	**64%**	**80%**	**82%**	**55%**	**50%**	**68%**
Delta Outflow < 44,000 cfs	2015-2039	83%	93%	93%	80%	73%	88%
	2040-2069	81%	90%	91%	72%	63%	84%
	2070-2099	83%	93%	96%	76%	73%	88%
	2015-2099	**82%**	**92%**	**93%**	**76%**	**70%**	**87%**

Table 5-16b. Percentage of Months in Each Scenario that March-through-May Delta Outflow Flow is Less than 28,000 cfs and 44,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
Delta Outflow < 28,000 cfs	2015-2039	69%	81%	84%	64%	57%	71%
	2040-2069	54%	80%	80%	49%	43%	63%
	2070-2099	72%	81%	82%	54%	50%	70%
	2015-2099	**65%**	**81%**	**82%**	**55%**	**50%**	**68%**
Delta Outflow < 44,000 cfs	2015-2039	83%	93%	93%	80%	73%	87%
	2040-2069	81%	91%	91%	72%	64%	84%
	2070-2099	83%	92%	96%	76%	72%	88%
	2015-2099	**82%**	**92%**	**93%**	**76%**	**70%**	**86%**

Table 5-16c. Percentage of Months in Each Scenario that March-through-May Delta Outflow Flow is Less than 28,000 cfs and 44,000 cfs in the **CCTAG 4.5. RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
Delta Outflow < 28,000 cfs	2015-2039	64%	47%	39%	60%	47%	52%
	2040-2069	53%	50%	49%	58%	63%	66%
	2070-2099	67%	59%	40%	69%	84%	79%
	2015-2099	**61%**	**52%**	**43%**	**62%**	**66%**	**66%**
Delta Outflow < 44,000 cfs	2015-2039	83%	68%	53%	76%	64%	69%
	2040-2069	74%	70%	64%	73%	78%	82%
	2070-2099	89%	70%	66%	91%	93%	93%
	2015-2099	**82%**	**69%**	**62%**	**80%**	**79%**	**82%**

Table 5-16d. Percentage of Months in Each Scenario that March-through-May Delta Outflow Flow is Less than 28,000 cfs and 44,000 cfs in the **CCTAG 8.5. RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
Delta Outflow < 28,000 cfs	2015-2039	51%	52%	36%	68%	51%	60%
	2040-2069	58%	53%	42%	44%	70%	71%
	2070-2099	67%	43%	48%	59%	74%	72%
	2015-2099	**59%**	**49%**	**42%**	**56%**	**66%**	**68%**
Delta Outflow < 44,000 cfs	2015-2039	65%	67%	53%	80%	68%	77%
	2040-2069	80%	68%	66%	62%	86%	89%
	2070-2099	87%	62%	74%	84%	94%	91%
	2015-2099	**78%**	**65%**	**65%**	**75%**	**84%**	**86%**

Table 5-16e. Percentage of Months in Each Scenario that March-through-May Delta Outflow Flow is Less than 28,000 cfs and 44,000 cfs in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Slow Growth Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
Delta Outflow < 28,000 cfs	2015-2039	69%	81%	84%	64%	57%	71%
	2040-2069	54%	81%	80%	49%	43%	63%
	2070-2099	73%	81%	82%	54%	50%	69%
	2015-2099	**65%**	**81%**	**82%**	**55%**	**50%**	**67%**
Delta Outflow < 44,000 cfs	2015-2039	83%	93%	93%	80%	73%	87%
	2040-2069	81%	91%	91%	72%	64%	84%
	2070-2099	83%	92%	96%	76%	72%	89%
	2015-2099	**82%**	**92%**	**93%**	**76%**	**70%**	**87%**

5.2.8.4.1. Pelagic Species Habitat-Salinity

Indicator:
Meeting the salinity goals specified in the U.S. Fish and Wildlife Service (USFWS) Biological Opinion (BiOp) (2008) for salinity levels in the Delta indicates the area of pelagic species habitat.

Measure:
X2 position in Bay-Delta >74 km and >81 km
Decreases in this indicator would imply that the habitat conditions for Delta smelt are improving.

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. 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 s melt 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).

X2 is the location of the two parts per thousand (ppt) salinity concentration in the interior Delta (termed “X2”). Maintaining X2 positions of less than 74 kilometers (km) and 81 km from the Golden Gate Bridge are goals specified in the USFWS BiOp, and maintaining them is important for Delta smelt habitat conditions. *Thus, greater percentages of months exceeding this location are not desirable.*

5.2.8.4.2.1 Delta Salinity Levels from February through June

In all of the climate scenarios, the average X2 position increased as the simulation moved later into the 21st century due to rising sea levels:

- The X2 position results under the wetter climate scenarios (Hot-Wet and Warm-Wet) were similar to those of the Reference-No-Climate-Change climate scenario because the increased flows into the Delta in those wetter scenarios compensated for the increased sea level rise.

- The X2 position was greater under the Central Tendency and the drier climate scenarios (Warm-Dry and Hot-Dry), where sea level rise combined with reduced Delta inflows relative to Reference-No-Climate-Change climate scenario resulted in greater X2 positions.

For February through June from 2015-2099:

- **74 km:**
    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, X2 is greater than the 74 km performance metric in 24% of the months from February through June for the 2015-2099 period.

    - Across the range of all scenarios, the X2 location is greater than the performance metric on average in 31% of the months, an increase of 29%, and ranges from a minimum of 15% to a maximum of 53%.

- **81 km:**

    - In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, X2 is greater in 6% of the months.

    - Across the range of all scenarios, the X2 location is greater than the performance metric on average in 7% of the months, an increase of 17%, and ranges from a minimum of 1% to a maximum of 16%.

Figure 5-17 shows the exceedance of the X2 position from February through June for each of the scenarios.

Figure 5-18 shows a box plot of the average X2 position from February through June.

Table 5-17 shows the percentage of months from February through June that the average distance measured from the Golden Gate Bridge to the X2 position is greater than 74 km and 81 km.

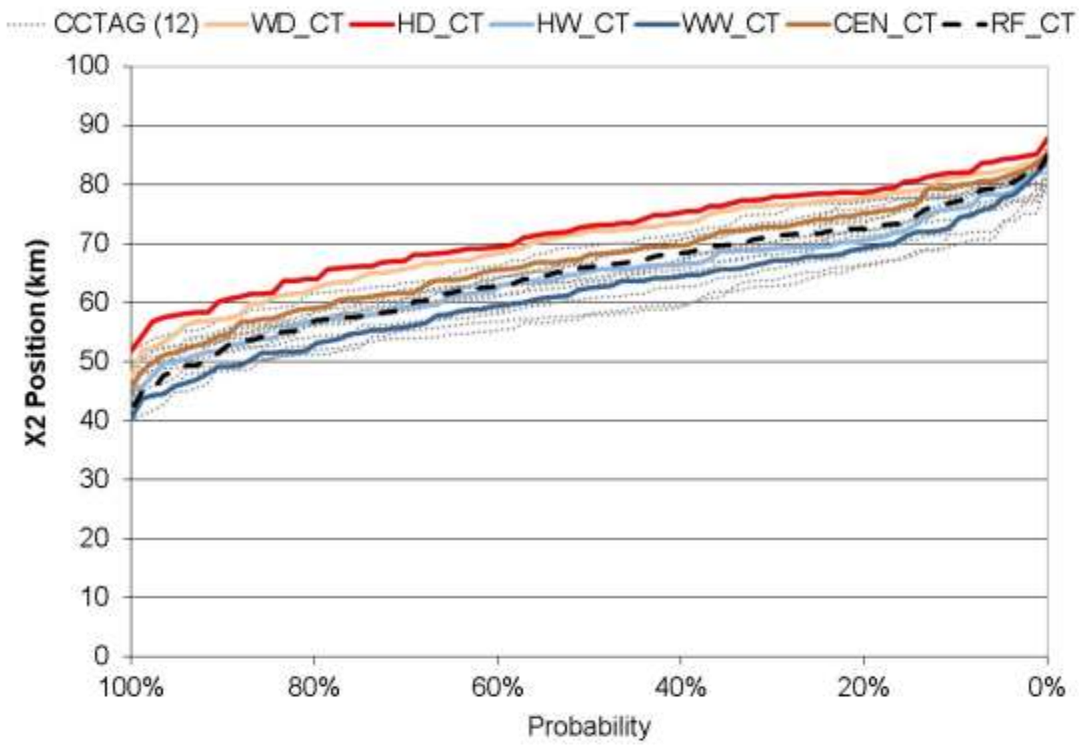


Figure 5-17. Exceedance of average February-to-June X2 position in the baseline in each scenario.

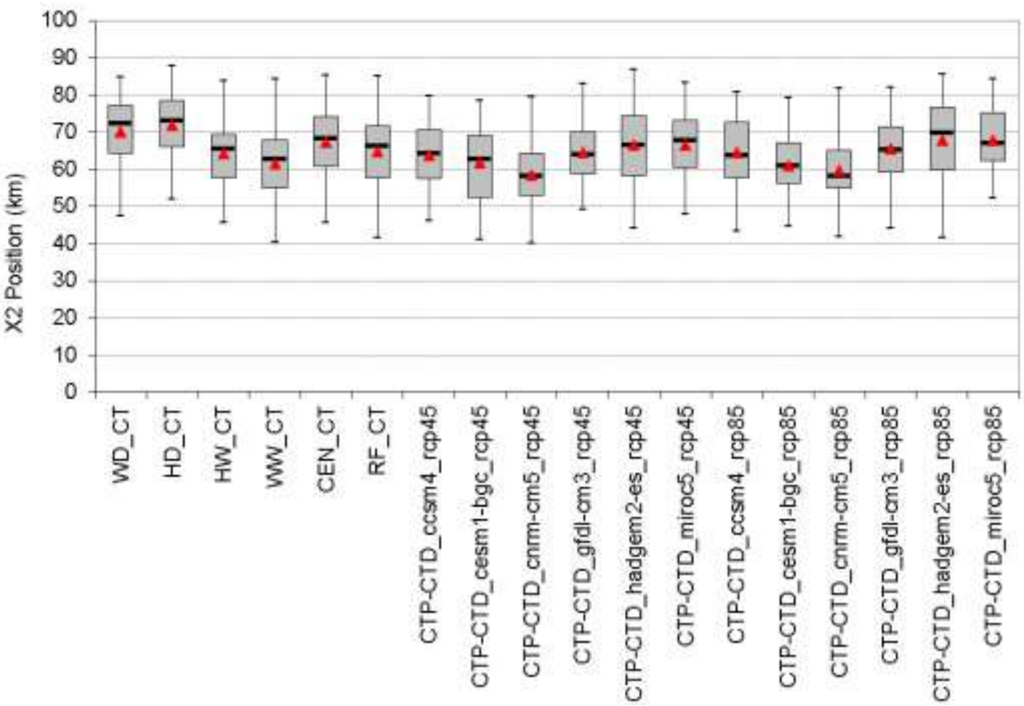


Figure 5-18. Box plot of average February-to-June X2 position in the baseline in each scenario.

Table 5-17. X2 Position Greater than Indicator Value

Table 5-17a. Percentage of months that the February-to-June X2 position is greater than metric values in each scenario in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
X2 (>74 km)	2015-2039	30%	45%	48%	26%	22%	37%
	2040-2069	19%	37%	44%	24%	15%	26%
	2070-2099	21%	46%	63%	27%	17%	35%
	2015-2099	**23%**	**42%**	**52%**	**26%**	**18%**	**32%**
X2 (>81 km)	2015-2039	7%	14%	15%	4%	6%	9%
	2040-2069	5%	8%	12%	5%	3%	8%
	2070-2099	5%	13%	19%	9%	1%	12%
	2015-2099	**5%**	**12%**	**16%**	**6%**	**3%**	**10%**

Table 5-17b. Percentage of months that the February-to-June X2 position is greater than metric values in each scenario in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
X2 (>74 km)	2015-2039	30%	45%	49%	26%	22%	37%
	2040-2069	19%	35%	44%	25%	15%	25%
	2070-2099	22%	50%	65%	28%	17%	35%
	2015-2099	**24%**	**43%**	**53%**	**26%**	**18%**	**32%**
X2 (>81 km)	2015-2039	7%	13%	15%	4%	5%	9%
	2040-2069	5%	8%	12%	6%	3%	8%
	2070-2099	5%	13%	19%	10%	3%	13%
	2015-2099	**6%**	**11%**	**16%**	**7%**	**4%**	**10%**

Table 5-17c. Percentage of months that the February-to-June X2 position is greater than metric values in each scenario in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
X2 (>74 km)	2015-2039	34%	16%	15%	18%	26%	24%
	2040-2069	21%	19%	16%	22%	34%	24%
	2070-2099	22%	23%	13%	30%	43%	48%
	2015-2099	**25%**	**20%**	**15%**	**24%**	**35%**	**32%**
X2 (>81 km)	2015-2039	4%	3%	1%	2%	6%	2%
	2040-2069	3%	1%	1%	1%	7%	1%
	2070-2099	2%	2%	0%	4%	11%	12%
	2015-2099	**3%**	**2%**	**1%**	**3%**	**8%**	**5%**

Table 5-17d. Percentage of months that the February-to-June X2 position is greater than metric values in each scenario in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
X2 (>74 km)	2015-2039	14%	14%	5%	31%	25%	29%
	2040-2069	29%	24%	17%	21%	51%	41%
	2070-2099	41%	14%	25%	37%	45%	37%
	2015-2099	**29%**	**17%**	**16%**	**30%**	**41%**	**36%**
X2 (>81 km)	2015-2039	2%	0%	0%	11%	6%	6%
	2040-2069	5%	4%	1%	1%	11%	6%
	2070-2099	7%	2%	1%	9%	5%	7%
	2015-2099	**5%**	**2%**	**1%**	**7%**	**8%**	**7%**

Table 5-17e. Percentage of months that the February-to-June X2 position is greater than metric values in each scenario in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
X2 (>74 km)	2015-2039	30%	45%	49%	26%	22%	37%
	2040-2069	19%	37%	44%	24%	15%	26%
	2070-2099	22%	51%	65%	29%	17%	35%
	2015-2099	**23%**	**44%**	**53%**	**26%**	**18%**	**32%**
X2 (>81 km)	2015-2039	7%	14%	15%	4%	5%	9%
	2040-2069	5%	9%	12%	6%	3%	8%
	2070-2099	5%	13%	19%	10%	3%	13%
	2015-2099	**6%**	**12%**	**16%**	**7%**	**3%**	**10%**

5.2.8.4.2.2 Delta Salinity Levels from September through November

Another attribute of interest selected to assess changes in habitat suitable for endangered pelagic species such as the Delta smelt is X2 position from September through November. The extent of pelagic species in the Delta is highly correlated with the X2 position. Maintaining an X2 position of less than 74 km and 81 km are goals that are specified in the USFWS BiOp.

Table 5-18 shows the percentage of months from September through November that the average X2 position is greater than 74 km and 81 km for each scenario.

Table 5-18. September through November Frequency of X2 Positions Greater than Indicator Value

Table 5-17a. Percentage of Months that September-through-November X2 Position is Greater than Metric Value in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
X2 (>74 km)	2015-2039	96%	96%	96%	95%	93%	95%
	2040-2069	96%	98%	97%	94%	90%	97%
	2070-2099	89%	96%	99%	91%	86%	93%
	2015-2099	**93%**	**96%**	**97%**	**93%**	**89%**	**95%**
X2 (>81 km)	2015-2039	84%	88%	85%	89%	83%	91%
	2040-2069	84%	93%	90%	79%	70%	88%
	2070-2099	78%	86%	94%	81%	64%	84%
	2015-2099	**82%**	**89%**	**90%**	**83%**	**72%**	**87%**

Table 5-17b. Percentage of Months that September-through-November X2 Position is Greater than Metric Value in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
X2 (>74 km)	2015-2039	96%	96%	96%	95%	93%	96%
	2040-2069	96%	98%	97%	94%	91%	97%
	2070-2099	89%	96%	99%	91%	86%	93%
	2015-2099	**93%**	**96%**	**97%**	**93%**	**90%**	**95%**
X2 (>81 km)	2015-2039	87%	91%	91%	89%	81%	91%
	2040-2069	83%	92%	91%	81%	71%	87%
	2070-2099	78%	84%	94%	82%	68%	83%
	2015-2099	**82%**	**89%**	**92%**	**84%**	**73%**	**87%**

Table 5-17c. Percentage of Months that September-through-November X2 Position is Greater than Metric Value in the **CCTAG 4.5 RCP** Climate Scenarios for **the Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_cesm1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
X2 (>74 km)	2015-2039	91%	93%	80%	96%	93%	92%
	2040-2069	93%	96%	90%	93%	100%	98%
	2070-2099	96%	96%	92%	99%	99%	98%
	2015-2099	**93%**	**95%**	**88%**	**96%**	**98%**	**96%**
X2 (>81 km)	2015-2039	81%	85%	69%	84%	83%	81%
	2040-2069	88%	84%	73%	90%	94%	81%
	2070-2099	87%	80%	82%	97%	96%	90%
	2015-2099	**85%**	**83%**	**75%**	**91%**	**91%**	**84%**

Table 5-17d. Percentage of Months that September-through-November X2 Position is Greater than Metric Value in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_cesm1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
X2 (>74 km)	2015-2039	91%	91%	83%	95%	89%	93%
	2040-2069	98%	97%	93%	98%	96%	99%
	2070-2099	96%	93%	89%	100%	98%	94%
	2015-2099	**95%**	**94%**	**89%**	**98%**	**95%**	**96%**
X2 (>81 km)	2015-2039	79%	79%	77%	85%	77%	83%
	2040-2069	89%	86%	77%	83%	92%	90%
	2070-2099	92%	78%	81%	98%	94%	91%
	2015-2099	**87%**	**81%**	**78%**	**89%**	**89%**	**88%**

Table 5-17e. Percentage of Months that September-through-November X2 Position is Greater than Metric Value in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
X2 (>74 km)	2015-2039	96%	96%	96%	95%	93%	96%
	2040-2069	96%	98%	97%	94%	91%	97%
	2070-2099	89%	96%	99%	91%	86%	93%
	2015-2099	**93%**	**96%**	**97%**	**93%**	**90%**	**95%**
X2 (>81 km)	2015-2039	88%	91%	91%	89%	81%	91%
	2040-2069	83%	93%	91%	82%	71%	87%
	2070-2099	76%	88%	94%	81%	67%	84%
	2015-2099	**82%**	**91%**	**92%**	**84%**	**73%**	**87%**

5.2.8.5. Delta Flow-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.

Indicator:
Frequency of reverse (negative) flows in the Old and Middle rivers (OMR) indicates that higher salinity water from the Bay is being drawn into the interior Delta as a result of high depletions and exports compared to stream inflows, precipitation, and cross-Delta flows.

Measure:
San Joaquin River in the western Delta at Jersey Point (Qwest)

For Delta smelt:-3,500 cfs from March through June

For Adult Salmonid Migration-5,000 cfs from October through December

For Food Web Productivity:-5,000 cfs from July through September

Decreases in the occurrence of reverse OMR flows (i.e., fewer reverse flows) would imply that habitat conditions could improve.

5.2.8.5.1. For Delta Smelt:-3,500 cfs OMR Reverse Flows from March through June

The entrainment of Delta smelt in the south Delta channels leading to the Banks and Jones pumping plants is negatively correlated with the frequency of reverse OMR flows referred to as more negative than-3,500 cfs. More negative flows result in greater amounts of Delta smelt entrainment and loss.

The drier scenarios have fewer months with more negative OMR flows than do the wetter scenarios because OMR requirements are more stringent in dry and critical year types, which are more frequent in the drier climate scenarios.

- In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, OMR flows were less than-3,500 cfs in 35% of all months.

- Across the range of all socioeconomic-climate scenarios, the percentage of months that exceed the threshold ranged from 24% under the Hot-Dry climate scenario to 41% under a CCTAG scenario. The differences between climate scenarios are similar across the 21st century.

Table 5-19 shows the percentage of months from March through June that OMR flow is less (more negative) than-3,500 cfs.

Table 5-19. OMR Flow More Negative than-3,500 cfs

Table 5-19a. Percentage of Months in Each Scenario that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	30%	17%	16%	32%	33%	27%
	2040-2069	41%	37%	33%	40%	42%	41%
	2070-2099	33%	23%	22%	38%	34%	32%
	2015-2099	**35%**	**26%**	**24%**	**37%**	**36%**	**34%**

Table 5-19b. Percentage of Months in Each Scenario that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	30%	18%	16%	32%	33%	27%
	2040-2069	41%	37%	33%	40%	42%	42%
	2070-2099	33%	23%	23%	38%	34%	33%
	2015-2099	**35%**	**26%**	**24%**	**37%**	**36%**	**34%**

Table 5-19c. Percentage of Months in Each Scenario that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	37%	42%	37%	37%	40%	38%
	2040-2069	33%	38%	41%	43%	33%	39%
	2070-2099	38%	30%	40%	40%	25%	31%
	2015-2099	**36%**	**36%**	**39%**	**40%**	**32%**	**36%**

Table 5-19d. Percentage of Months in Each Scenario that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the CCTAG **8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	**42%**	45%	45%	30%	36%	37%
	2040-2069	36%	41%	41%	39%	25%	33%
	2070-2099	29%	35%	38%	38%	32%	36%
	2015-2099	**35%**	**40%**	**41%**	**36%**	**31%**	**35%**

Table 5-19e.Percentage of Months in Each Scenario that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	30%	18%	16%	32%	33%	27%
	2040-2069	40%	37%	33%	40%	43%	42%
	2070-2099	33%	23%	23%	38%	34%	33%
	2015-2099	**34%**	**26%**	**24%**	**37%**	**37%**	**34%**

5.2.8.5.2. For Adult San Joaquin Salmonid Migration:-5,000 cfs OMR Reverse Flows from October through December

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.*

Increased entrainment of adult salmonids migrating to spawning habitat in the San Joaquin River watershed is positively correlated with the frequency of flows more negative than-5,000 cfs in these channels during the months of October through December.

- In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, OMR flows are more negative than the-5,000 cfs performance metric in 96% of the months from October through December for the 2015-2099 period.

- Across the range of all climate scenarios, the OMR flow is greater than the performance metric on average in 88% of the months from September through November for the 2015-2099 period, a decrease of 8%, and ranges from a minimum of 72% to a maximum of 96% during this period.

Table 5-20 shows the percentage of months from October through December that OMR flow is less (more negative) than-5,000 cfs from 2015 through 2099 and for 2015-2039, 2040-2069, and 2070-2099 periods.

Table 5-20. OMR Flows More Negative than-5,000 cfs

Table 5-20a. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	Period	Reference-EG	Warm-Dry-EG	Hot-Dry-EG	Hot-Wet-EG	Warm-Wet-EG	Central-EG
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	88%	80%	71	91%	93%	85%
	2040-2069	100%	91%	78	93%	98%	96%
	2070-2099	98%	83%	71	90%	93%	87%
	2015-2099	**96%**	**85%**	**73**	**91%**	**95%**	**89%**

Table 5-20b. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	89%	85%	71%	89%	92%	85%
	2040-2069	100%	91%	77%	93%	98%	94%
	2070-2099	98%	82%	68%	91%	93%	87%
	2015-2099	**96%**	**86%**	**72%**	**91%**	**95%**	**89%**

Table 5-20c. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than-5,000 cfs in the **CCTAG 4.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_had gem2-ed_CT	rcp4.5_miro c5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	93%	92%	96%	93%	91%	97%
	2040-2069	94%	93%	96%	97%	82%	88%
	2070-2099	97%	99%	96%	90%	66%	71%
	2015-2099	**95%**	**95%**	**96%**	**93%**	**79%**	**85%**

Table 5-20d. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than-5,000 cfs in the **CCTAG 8.5 RCP** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_had gem2-ed_CT	rcp8.5_miro c5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	92%	99%	95%	76%	93%	83%
	2040-2069	91%	89%	97%	94%	68%	81%
	2070-2099	78%	94%	92%	76%	68%	83%
	2015-2099	87%	94%	95%	82%	75%	82%

Table 5-20e. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	89%	85%	71	88%	93%	85%
	2040-2069	100%	91%	78	93%	98%	94%
	2070-2099	98%	86%	69	91%	93%	87%
	2015-2099	96%	87%	73	91%	95%	89%

5.2.8.6. Delta Flows-Food Web Productivity:-5,000 cfs OMR Reverse Flows from July through September

The more frequent reverse flows above 5,000 cfs in the channels, the more food web productivity is affected.

- In the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios, OMR flows are more negative than the -5,000 cfs indicator in 75% of the months from July through September from 2015-2099.

- Across the range of all scenarios, the OMR flows are greater than the indicator on average in 68% of the months from July through September for the 2015-2099 period, a decrease of 7%, and ranges from a minimum of 43% to a maximum of 93% during this period.

Table 5-21 shows the percentage of months from July through September that OMR flow is less (more negative) than-5,000 cfs under each socioeconomic-climate scenario from 2015 through 2099 and for 2015-2039, 2040-2069, and 2070-2099 periods.

Table 5-21. OMR Flows Less than-5,000 cfs

Table 5-21a. Percentage of Months that July-through-September OMR Flow Is Less (More Negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Expanded Growth** Socioeconomic Scenario

Location	**Period**	**Reference-EG**	**Warm-Dry-EG**	**Hot-Dry-EG**	**Hot-Wet-EG**	**Warm-Wet-EG**	**Central-EG**
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	63%	43%	40	69%	73%	61%
	2040-2069	86%	68%	46	87%	92%	81%
	2070-2099	81%	53%	42	83%	88%	63%
	2015-2099	**77%**	**55%**	**43**	**80%**	**85%**	**69%**

Table 5-21b. Percentage of Months that July-through-September OMR Flow Is Less (More Negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Current Trends** Socioeconomic Scenario

Location	**Period**	**Reference-CT**	**Warm-Dry-CT**	**Hot-Dry-CT**	**Hot-Wet-CT**	**Warm-Wet-CT**	**Central-CT**
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	64%	45%	41%	69%	72%	60%
	2040-2069	88%	64%	47%	89%	91%	82%
	2070-2099	72%	52%	43%	80%	88%	61%
	2015-2099	**75%**	**55%**	**44%**	**80%**	**84%**	**68%**

Table 5-21c. Percentage of Months that July-through-September OMR Flow Is Less (More Negative) than-5,000 cfs in the **CCTAG 4.5 RCP** Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	rcp4.5_ccsm4_CT	rcp4.5_ces m1-bgc_CT	rcp4.5_cnrm-cm5_CT	rcp4.5_gfdl-cm3_CT	rcp4.5_hadgem2-ed_CT	rcp4.5_miroc5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	75%	80%	93%	80%	75%	87%
	2040-2069	76%	71%	93%	77%	59%	60%
	2070-2099	70%	81%	93%	67%	48%	39%
	2015-2099	**73%**	**77%**	**93%**	**74%**	**60%**	**60%**

Table 5-21d. Percentage of Months that July-through-September OMR Flow Is Less (More Negative) than-5,000 cfs in the **CCTAG 8.5 RCP** Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	rcp8.5_ccsm4_CT	rcp8.5_ces m1-bgc_CT	rcp8.5_cnrm-cm5_CT	rcp8.5_gfdl-cm3_CT	rcp8.5_hadgem2-ed_CT	rcp8.5_miroc5_CT
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	87%	84%	95%	65%	71%	63%
	2040-2069	71%	77%	90%	73%	44%	48%
	2070-2099	58%	80%	84%	60%	44%	60%
	2015-2099	**71%**	**80%**	**89%**	**66%**	**52%**	**56%**

Table 5-21e. Percentage of Months that July-through-September OMR Flow Is Less (More Negative) than-5,000 cfs in the Reference-No-Climate-Change and **Ensemble** Climate Scenarios for the **Slow Growth** Socioeconomic Scenario

Location	Period	Reference-SG	Warm-Dry-SG	Hot-Dry-SG	Hot-Wet-SG	Warm-Wet-SG	Central-SG
San Joaquin River in the western Delta at Jersey Point (Qwest)	2015-2039	61%	47%	43	71%	72%	61%
	2040-2069	86%	69%	49	89%	92%	82%
	2070-2099	72%	51%	43	82%	87%	62%
	2015-2099	**74%**	**56%**	**45**	**81%**	**84%**	**69%**

6. Water Management Actions and Adaptation Portfolios

6.1. Objective and Approach

To develop water management actions and portfolios of multiple actions in this Basins Study, team members compiled an initial list of actions based on actions included in other basin studies and planning projects. The team collaborated with cost share partners and stakeholders and reached out to publics to identify additional actions and develop strategies. By April 2015, numerous actions had been submitted, discussed, and refined to a list of 19 Representative Actions.

This report describes the submitted water management actions, the characterization of these actions, development of exploratory portfolios and the performance of these portfolios in addressing the key resource categories identified in section 9503 (c) of the SECURE Water Act. In keeping with the Basin Study Program's objectives, this Basins Study is intended to explore a broad range of water management actions that address the impacts identified in the Section 5. *System Risk and Reliability Assessment.* It is not a study objective to make recommendations for implementing any particular action or portfolio of actions.

6.1.1. Approach for Water Management Actions

This section focuses on answers to the study question: ***What are the actions and strategies that can adapt to future risks to these water and related resources?***

The discussion examines potential water management actions in response to future imbalances in supply and demand: identifying and characterizing individual actions and the subsequent development of portfolios of actions. The effectiveness of the portfolios in improving the reliability of the Central Valley system is described in Section 7. *Adaptation Portfolios Evaluation.* The general approach for developing adaptation strategies is to:

- **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.

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

    1. Increase water supply
    2. Reduce water demand
    3. Improve operational efficiency

4. Improve resource stewardship
5. Improve institutional flexibility
6. Improve data and management
7. Other

- **Develop water management actions.** From these functional groupings, individual water management actions were developed. Descriptions and characterizations of these water management actions are presented in Section 6.3. *Description and Characterization of Adaptation Actions*.

- **Characterize actions.** Each action was characterized using a set of both quantitative criteria including potential yield, timing of implementation, annualized cost per acre-foot, energy use, and qualitative criteria such as technical feasibility and implementation risk.

- **Develop 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 the Central Valley water management system. As such, adaptation portfolios representing potential strategies to address future supply and demand imbalances were developed from the representative actions and action characterization results. Adaptation portfolios were developed by selecting certain action characteristics based on the particular strategy (e.g., remove actions that rated low for implementation risk or technical feasibility).

6.1.2. Water Management Actions Summary

A wide variety and number of water management actions were suggested by cost-share partners, stakeholders, and other participants including:

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

2. **Reduce water demand.** Suggestions include increased agricultural and M&I water use efficiency through conservation and changes in water uses.

3. **Improve operational efficiency.** Suggestions include: groundwater management methods such as groundwater banking, conjunctive use 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, and system

reoperation; 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.

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

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

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

6.2. Characterization of Water Management Actions

6.2.1. Approach for Characterization

Characterization of the water management actions was performed to:

- Describe each of the submitted options
- Provide a relative comparison of the action attributes
- Support developing portfolios

Describing the proposed actions was primarily based on information from long range planning studies, including the California Water Plan Update 2013 (DWR 2014 [WaterPlan]), Mid Pacific Region long term planning studies such as the Central Valley Integrated Resource Plan (Reclamation 2013 [CVP IRP]), and available literature sources. Determining which actions to evaluate followed these steps for each proposed actions:

1. **Review the action for relevance and completeness of data.** In some cases, clarification or additional information was needed for appropriate characterization of the action. Actions that had limited definition or were not directly amenable to characterization through the 11 evaluation criteria were identified and cataloged for future consideration but are not described here.

2. **Validate and refine information submitted with the action.** Criteria information associated with the action was compared with similar

information in relevant case studies or readily available databases to confirm accuracy. If quantitative information was not readily available for a criterion, the study team used its collective expertise and experience to qualitatively evaluate information submitted.

3. **Rate each action using a classification system.** For the appropriate actions, ratings were generated for each criterion using the refined information. Ratings were reviewed by the study team. A characterization summary table was developed by listing each rating for an option. Where possible quantitative information was developed (e.g., cost, yield, and timing). In addition, for each option a rating of A, B, C, D, or E was also assigned for each criterion. In general, the "A" rating is most favorable and the "E" rating is least favorable. If insufficient information was available to assign a rating, the associated entry in the action characterization summary table was left blank. More information on the criteria for ratings is provided in Appendix 6F: *Detailed Action Characterization Criteria and Ratings*.

6.2.2. Criteria and Assumptions

Actions were evaluated based on the 11 criteria shown in Table 6-1.

Table 6-1. Criteria Used to Characterize Representative 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 AF of action yield
How doable is the project?	
Implementation Risk	Risk to achieving successful implementation and operation of action based on factors such as funding mechanisms, competing demands for critical resources, challenging operations, or challenging mitigation requirements

Evaluation Factors	Summary Description of Criteria
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 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

When evaluating actions, the following overarching assumptions were made:

- **Level of Evaluation**. Consistent with the Basin Study Program, actions were evaluated at a reconnaissance level of analysis only. In some cases, very detailed information on the actions was available, but in most cases the actions were only conceptually described in the original form. Additional research was performed to validate and refine the information, but this was of a limited nature and at an appraisal level.

- **Basin-wide Approach.** Where possible, actions were conceptualized as distributed, basin-wide actions (e.g., conservation and reuse) as opposed to actions implemented by specific entities in specific geographies. Several actions, however, were geographically distinct and were retained in this form.

- **Cost of Actions**. All costs presented were developed based on annualized capital costs added to annual operation and maintenance (O&M) costs (power, chemicals, etc.). Costs for infrastructure-related options were derived from industry-based parametric cost estimates that are commonly used for water infrastructure projects. These costs include adjustments for proposed location and the scale of the project.

- **Ramped Implementation of Large Actions**. Several actions were sufficiently large that the potential exists to ramp implementation of the action over time. Therefore, these actions were assumed to be implemented in phases over the course of the 21st century.

- **Independent Characterization of Actions.** Although actions were combined into portfolios, the characterization considered each action independently.

- **Sense of Urgency**. The success rate and timeframe for which similar past projects have been implemented has varied widely. This variation is due to resistance from opponents, urgency from proponents, and political support or opposition. When evaluating permitting and potential timing of completion, it was assumed that there would be wide recognition of the associated issues, and therefore significant political alignment, sense of urgency, and consistent pursuit throughout the feasibility, environmental review, permitting, and implementation stages. The scope, scale, and timing of potential impacts suggest the need for timely action coordinated among the stakeholders. This coordination is an important consideration in rating, in particular, the timing of option availability.

6.2.3. Limitations of Characterization Process

The process undertaken to characterize actions strived to develop an objective and consistent evaluation of the actions. Several iterations of the action characterization were performed in an attempt to normalize ratings wherever possible. However, several limitations are inherently associated with the characterization of such a broad range of actions. These limitations include:

- **Limited Level of Analysis.** The intent of the characterization was to perform a high-level analysis of a broad range of actions potentially available to resolve basin impacts. Study resources did not allow for highly detailed evaluations. Limiting the level of analysis helped ensure that all actions were considered at a high level, but also added uncertainty to the characterization results because all of the potential challenges associated with action development and implementation may not have been considered. Further, the characterization did not specifically consider future financing.

- **Inconsistent Availability of Information.** Some actions considered had more detailed information available from similar projects and other studies. A detailed assessment by individual location for actions was beyond the scope of the study. Instead, the study provides an appraisal-level approach to characterizing these actions, and then applies these characterizations at the appropriate basin scale. The assumptions were adopted for purposes of an appraisal study and do not necessarily reflect achievable, or even desirable, local conservation goals for individual municipalities or agricultural users.

- **Uncertainty.** The characterization was performed based on limited information and reconnaissance level analyses. Therefore, items such as costs, permit requirements, and long-term feasibility are still highly uncertain.

    - *Infrastructure-type projects* are based on similar past projects with adjustments for parameters such as scale and location. These adjustments are approximate, especially for projects where the scale of the project is larger than any previously completed similar project.

    - *Non-structural projects* cost estimates are often even more uncertain as costs for similar past projects are often not fully applicable or fully documented. Moreover, non-structural projects are based on changes in human behavior, making costs harder to quantify.

However, it is important to note that an even wider range of cost variation is possible for many of the infrastructure options and most non-infrastructure options. Despite the uncertainties in estimating the magnitude of costs, a significant effort was made to provide cost estimates that are useful for considering relative costs. Similar statements can be made related to uncertainty when characterizing actions against many other criteria. The characterization process for the non-cost items also has a degree of uncertainty, but it is still useful for providing an understanding of the potential advantages and disadvantages of the different actions by considering a diverse set of criteria.

6.3. Description and Characterization of Adaptation Actions

6.3.1. Reduce Water Demand

6.3.1.1. Increase Agricultural Water Use Efficiency

Agricultural water use efficiency actions have the potential to reduce the overall agricultural water demand in the Central Valley. Three major types of agricultural water use efficiency actions were considered in this study:

1. Improved irrigation efficiencies

2. Conveyance system improvements

3. Changes in irrigation methods (e.g. deficit irrigation) or crop types

In this study, fallowing of projected irrigated lands was not assumed. Because levels of current agricultural water use efficiency measures vary throughout the Central Valley, different levels of potential savings are possible for specific conservation measures. These savings range from essentially no savings, where measures have been fully adopted, to significant savings, where measures have not been adopted or where adoption rates are relatively low.

The California Water Plan Update 2013 considered agricultural water use efficiency measures reflecting reductions in applied water demand of up to 10% by 2020 and up to 20% by 2030 (DWR 2014 [Water Plan]). Agricultural water use efficiency assumptions for this Basins Study are somewhat less aggressive, with assumed reductions in agricultural applied water demand of 10% in 2020 and 20% in 2050, which is assumed to continue through 2100. The resulting reductions in agricultural applied water demand in the central tendency climate scenario with current trends socioeconomic projection (Central Tendency climate/Current Trends socioeconomic scenarios) in the early, mid and late century are shown in Table 6-2a. Demand reductions due to agricultural water use efficiency increase in the mid-century but then reduce somewhat as agricultural acreage decreases and the effects of climate change reduce underlying agricultural demand, as discussed in 4.2.2.1. *Future Projected Agricultural Demand.*

Most of the water applied in agricultural settings is consumptively used by the crops or required for agricultural water management purposes such as leaching salts from soils, pre-irrigation, and crop cooling. Improvements in water use efficiency only result in net water savings when the conserved water was not previously being recovered in hydrologic system (e.g., consumptive use reductions or returns to salt sinks). Estimated savings in non-recoverable losses associated with agricultural water use efficiency measures are shown in Table 6-2b. These savings were based on estimates of non-recoverable losses as a proportion of demand reduction contained in the 2006 CALFED Water Use Efficiency Comprehensive Evaluation (CALFED 2006).

Table 6-2. Average Annual Reductions in Agricultural Water Use

Table 6-2a. Estimated Average Annual **Reduction in Applied Water Demand** from Agricultural Water Use Efficiency in Each Region in the Central Tendency Climate/Current Trends Socioeconomic Scenarios (In TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	483	168	493	1,051	0	0	2,195
2040-2069	874	299	903	1,921	0	0	3,998
2070-2099	790	258	777	1,714	0	0	3,539

Table 6-2b. Estimated Average Annual **Reduction in Non-Recoverable Losses** from Agricultural Water Use Efficiency in Each Region in the Central Tendency Climate/Current Trends Socioeconomic Scenarios (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	153	53	156	333	0	0	696
2040-2069	260	89	269	571	0	0	1,189
2070-2099	237	77	233	514	0	0	1,062

Because the agricultural water use efficiency would be ramped up over time, improvements to irrigation management, on-farm irrigation improvements, and changes in crop consumptive use could occur in as early as 10 years. Large infrastructure projects, including conveyance system efficiency improvements and expansion of controlled environment agriculture (e.g., greenhouses), were estimated to require at least 15 years before full implementation due to the planning, permitting, design, and construction needs.

Costs for implementing agricultural water use efficiency measures will vary regionally and with different levels of conservation programs. The 2006 CALFED Water Use Efficiency Comprehensive Evaluation (CALFED 2006) estimated the average cost of reductions in irrecoverable losses to be about $20-$600 per acre-foot per year. For this analysis, the cost has been assumed to be in the middle of the range of estimates at $350 per acre-foot.

In general, agricultural water use efficiency is technically doable and examples exist in regions throughout the Central Valley and California. Irrigation management and efficiency improvement programs have been undertaken at district and state levels, but these programs have not been demonstrated at the basin-scale for the Central Valley. It is not anticipated that significant permitting will be required to implement agricultural water use efficiency. However, agricultural water use efficiency will affect diversion patterns, return flow quantities and locations, and groundwater recharge. The most significant challenge associated with agricultural water use efficiency measures is quantifying and demonstrating the permanency of water savings.

6.3.1.2. Increase Municipal & Industrial Water Use Efficiency

M&I demand could be reduced by using progressively ambitious water conservation best management practices (BMP) and adoption rates targeting residential indoor; commercial, institutional, and industrial (CII); outdoor landscaping; and water loss demands. The Water Conservation Act of 2009 has directed urban retail water suppliers to reduce urban per-capita water use by 20% by the year 2020 (California’s 20x2020 plan). Therefore, achievement of 20% reduction in M&I demand has been included as a base level of water use efficiency in all of the adaptation portfolios.

Above the 20% by 2020 level, the 2013 California Water Plan Update considered M&I water use efficiency measures reflecting reductions in urban per capita use of up to 30% by 2030 and up to 40% by 2040 (DWR 2014 [Water Plan]). The Basins Study has adopted these projection levels, with additional conservation assumed up to 60% of urban per capita use by 2100. The resulting reductions in M&I water demand in the Central Tendency climate/Current Trends socioeconomic scenarios in the early, mid, and late century are shown in Table 6-3. However, it should be noted that most of the water supplied for indoor urban use is returned to the surface or groundwater system in the Central Valley, and indoor efficiency improvements, in these regions only result in small net water savings. Outside of the Central Valley, reductions in per capita use rates will directly translate into water savings from the imported supply areas (e.g., Central Valley and Colorado River systems).

Table 6-3. Estimated Average Annual Reduction in Demand from M&I Water Use Efficiency in Each Region in the Central Tendency Climate/Current Trends Socioeconomic Scenarios (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	176	30	105	197	144	622	1,274
2040-2069	404	73	265	511	360	1,747	3,359
2070-2099	505	105	397	876	563	2,343	4,788

Because levels of current and future conservation vary throughout the study area, different levels of potential savings are possible for a given conservation measure. These savings range from essentially no savings (where measures have been fully implemented) to significant savings (where measures have not been implemented or where adoption rates are relatively low).

Because M&I water use efficiency would be ramped over time, implementation could begin with benefits starting to accrue within 5 years. Large levels of water use efficiency were estimated to require at least 15 years before full implementation due to the planning, permitting, design, and construction needs.

Costs for implementing M&I water use efficiency measures will vary regionally and with different levels of conservation programs. The 2006 CALFED Water Use Efficiency Comprehensive Evaluation estimated the average cost of reductions in irrecoverable losses to be about $223-$522 per acre-foot per year (AFY) (CALFED 2006). For this analysis, the cost has been assumed to be in the middle of this range at $370 per AFYt.

In general, modest levels of M&I water use efficiency are technically doable and comparable examples exist throughout California, the Southwest, and in other arid regions of the world. More aggressive efficiency levels become progressively more difficult to achieve and maintain—and more costly to implement. Programs of this scale are underway at the state level (e.g., California's 20x2020 plan), but these programs have not been demonstrated at the most aggressive levels on as large a scale as the Central Valley.

It is not anticipated that permitting or legal changes will be required to implement these options, but agreements on the methodology and institutional structure will be required to implement these options in this multi-jurisdictional basin. Some policy changes may be required to fully implement the assumed M&I water use efficiency levels, and implementation on such a large scale would likely require substantial conversion of outdoor landscapes to low water use landscaping.

There is some implementation risk in that quantities will fluctuate over time and programs will require continuous funding to maintain overall results. Many water use efficiency measures are based on achieving behavior changes in the way water is valued and used. The realized water use efficiency savings associated with these measures may be dependent on future economic, social, and political conditions that maintain and strengthen these behavior changes. However, once savings are realized through most measures they generally can be maintained, resulting in long-term viability of the options.

M&I water use efficiency is rated high with respect to operational flexibility because the programs can be ramped up quickly (as demonstrated through drought conservation measures) and subsequently slowed (if needed, following droughts) without incurring significant debt service or resulting in stranded assets. There are no inherent energy needs for the M&I water use efficiency options in that they result in reduced demand and reduced need to convey, treat, and deliver water.

6.3.2. Increase Water Supply

6.3.2.1. Increase Regional Reuse

Regional reuse includes M&I wastewater and grey water reuse:

- **Municipal wastewater reuse** includes concepts related to the reuse of municipal wastewater in major urban areas for non-potable purposes such as landscape irrigation or for potable purposes through indirect or direct methods.

- **Industrial wastewater reuse** includes using wastewater flows generated from a variety of industries that are not discharged through municipal wastewater systems. These are typically industries that have their own water supply and are often outside of municipal limits.

- **Grey water is** generally defined as untreated wastewater that has not been contaminated by any toilet discharge, has not been affected by unhealthy bodily wastes, and does not present a threat from contamination by unhealthful processing, manufacturing, or operating wastes (California Water Code, 2010). Grey water reuse systems use such water for outdoor landscape irrigation or other non-potable purposes.

The 2013 California Water Plan Update considered reuse of up to 50% of indoor M&I use by 2050 (DWR 2014 [Water Plan]). The regional reuse assumptions for this analysis are somewhat less aggressive, with assumed reuse of 25% of indoor M&I use by 2050 and of 50% of indoor M&I use by 2100. The resulting water supply amounts in the Central Tendency climate/Current Trends socioeconomic scenarios in the early, mid, and late century are shown in Table 6-4. These reflect water supplies from both M&I wastewater and grey water reuse.

In the Sacramento, San Joaquin, and Tulare Lake basins, M&I reuse is not likely to result in net water savings, as most of the urban return flows are returned downstream to the surface or groundwater system in the Central Valley. Outside of the Central Valley, in areas dependent on imported supplies (including the South San Francisco Bay and South Coast regions), M&I reuse provides a new local supply that could offset the need for imported supplies. For this analysis, M&I reuse shown for the South San Francisco Bay and South Coast regions is assumed to offset the need for other water supply sources in proportion to the regions overall water supply portfolio, while supplies in other regions may not reflect a net water savings (Table 6-4).

Table 6-4. Estimated Average Annual Water Supply from Indoor M&I Water Reuse in Each Region in the Central Tendency Climate/Current Trends Socioeconomic Scenarios (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	24	4	13	31	14	92	177
2040-2069	96	16	59	142	115	172	600
2070-2099	179	28	104	243	221	583	1,359

Because traditional municipal and industrial wastewater non-potable reuse is commonly practiced in the California, these options were assumed to require about 3 years for feasibility, 2 years for permitting, and 5 years for implementation for a total of 10 years. Indirect potable reuse options included an additional 10 years to reflect both their scale as well as associated permitting and implementation challenges due to integration with municipal treated water supplies. Grey water reuse options were also assumed to be implementable within a 10-year timeframe.

The 2013 California Water Plan Update estimates the current capital and operational costs of recycled water to be between $300 and $1,300 per AFY, but notes that for planning purposes the cost should be considered at the higher end of this range (DWR 2014 [Water Plan]). Therefore, for this analysis, the cost has been assumed to be $1,300 per AFY.

In addition to yield, timing, and cost, the municipal, industrial and grey water reuse action was characterized against several other criteria. In general, reuse is highly doable and has been implemented on similar scales in other places in the region, nation, and the world. Reuse scores poorly under operational flexibility due to the likely associated debt service for a stranded asset. Energy needs range from 500 kilowatt hours (kWh) per acre-foot to 4,300 kWh per acre-foot for these options. Indirect potable options use the most energy.

6.3.2.2. Increase Ocean Desalination

Actions to increase ocean desalination would include constructing new or expanding existing (or currently proposed) ocean desalination plants in strategic locations in the South San Francisco Bay, Central Coast, and South Coast Hydrologic Regions. The desalinated water in the South Coast region would be delivered to some of the larger existing operational reservoirs in the Metropolitan Water District of Southern California (MWD) system or in similar reservoirs in MWD member agencies' systems. Desalinated water in the South Bay regions would be delivered to storage facilities of water agencies in that region (i.e., Contra Costa Water District and East Bay Municipal Utility District).

Table 6-5 shows the estimated potential yield from ocean desalination in each region. The 2013 California Water Plan has estimated that 15 ocean desalination plants are under consideration with an estimated potential capacity of 382 TAF (DWR 2014 [Water Plan]). However, these are likely to be low estimates of potential yield from desalination through 2100. The Colorado River Basin Study estimated that yield from potential projections related to ocean desalination in the South Coast region would be limited to a maximum of 600 TAF per year through 2060. This yield amount has been assumed as the maximum potential for the South Coast region in the adaptation portfolio analyses. Potential yield in the South Bay region has been estimated to be up to 200 TAF per year by mid-century (CALFED 2006).

Table 6-5. Estimated Potential Yield from Desalination in Each Region (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	0	0	0	0	100	200	300
2040-2069	0	0	0	0	200	400	600
2070-2099	0	0	0	0	200	600	800

Ocean desalination has unique permitting and legal challenges that make it difficult to estimate the timing for desalination projects. It can be roughly estimated that a 200 million gallons per day (approximately 200 TAF/year) project would require 5 years of feasibility, 10 years of permitting, and 5 years of implementation, totaling 20 years. For planning purposes, this analysis has assumed up to 200 TAF per year of new desalination supply could be available in the South Coast region by 2025, 400 TAF per year by 2050 and 600 TAF per year by 2075. In the South San Francisco Bay Region, it is assumed that up to 100 TAF per year of new desalination supply could become available by 2025 and that up to 200 TAF could become available by 2050.

The 2009 California Water Plan Update estimated the cost of ocean desalination projections to range from $1000 to $2500 per AFY (DWR 2009). More recently, the Colorado Basin Study estimated the cost to be about $1,900-$2,100 per AFY (Reclamation 2012). For this analysis, the cost has been assumed to be between $2,000 and $2,500 per AFY of new supply.

Ocean desalination facilities have been completed in numerous locations around the world, but none at the scale described for the larger concepts included here. Therefore, technical feasibility characterization varies based on scale and precedence for similar actions. When considering long-term viability, there is some concern about the potential for increased electricity costs to impact viability. Desalination does not rate high for operational flexibility criteria because it would have high debt service costs—even when put into an idle mode. Desalination relies on exchanges along rivers to varying degrees, and these exchanges allow the yield to be distributed across numerous locations and could result in a change in how the river reaches are operated.

6.3.2.3. Develop Local Alternative Supplies

Actions considered to develop local alternative supplies include precipitation enhancement and rainwater harvesting. These are described below.

6.3.2.3.1. Precipitation Enhancement

Precipitation enhancement, commonly referred to as cloud seeding, introduces silver iodide in the atmosphere to serve as condensation nuclei that would increase snowfall over mountain regions. Winter cloud seeding operations have been conducted throughout the Western United States since the late 1940s. According to the 2013 California Water Plan Update, about 15 weather modification projects are active in California. Most of these are in the San Joaquin and Tulare Lake regions. The existing weather modification projects are reported to generate about 400 TAF per year in runoff (DWR 2014 [Water Plan]), although direct attribution of supply benefits at larger basin scales is uncertain.

The 2013 California Water Plan also estimates that a reasonable estimate for additional potential yield from cloud seeding projects is about 400 TAF per year. Of this, about 200 TAF per year would be in the Pit River and McCloud River systems upstream of Lake Shasta. Table 6-6 shows the estimate yield from cloud seeding in each region. Because there are already existing cloud seeding projects on most of the San Joaquin and Tulare Lake region watersheds, the bulk of the remaining 200 TAF per year of potential supply would be in the Sacramento River system (DWR 2014 [Water Plan]). For planning purposes, it has been assumed that 50% of this amount could be implemented by 2050, with the remainder implemented by 2100.

Table 6-6. Estimated Average Annual Water Supply from Precipitation Enhancement in Each Region (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	52	1	5	0	0	0	58
2040-2069	199	3	18	0	0	0	220
2070-2099	308	4	28	0	0	0	340

Weather modification programs have been in effect for many years throughout the West. Based on these existing practices, no additional time would be required for feasibility or permitting of smaller-scale projects. Smaller-scale projects could be implemented in 5 years, with each larger-scale project assumed to require an additional 5 years for implementation.

According to the Colorado River Basin Study, annual costs for implementation of cloud seeding projects are estimated at about $20-30 per acre-foot (Reclamation 2012).

Precipitation enhancement ranked high for operational flexibility because it can be easily implemented on various scales from year to year. However, the uncertainty surrounding attributing benefits and quantifying the amount of water that these programs supply, particularly at larger basin scales, is perhaps the greatest factor limiting more widespread use.

6.3.2.3.2. Rainwater Harvesting

Rainwater harvesting is the capture, diversion, and storage of rainwater for non-potable uses. This adaptation action considers how individual household rainwater harvesting can increase local supply in some areas, with particular emphasis on those areas that do not provide return flows to other users downstream. It is assumed that this action would primarily take place in the South San Francisco Bay and South Coast export areas.

Yield estimates for individual rainwater harvesting are based on normal precipitation in specific regions combined with average roof size, landscaped area, and number of households. Using this information, a simple rainwater harvesting tool was developed to estimate the potential yield from implementation of distributed rainwater harvesting systems under each socioeconomic projection. For planning purposes it has been assumed that 50% of the full potential yield could be implemented by 2050, with the remainder implement by 2100. The resulting yield estimates range in the Central Tendency climate/Current Trends Socioeconomic scenarios are about 42 TAF/year by the late 21st century in the South Bay region and about 97 TAF/year by the late 21st century in the South Coast region (Table 6-7).

Table 6-7. Range of Estimated Average Annual Water Supply from Rainwater Harvesting in Each Region in the Central Tendency Climate/Current Trends Socioeconomic Scenarios (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	0	0	0	0	33	75	108
2040-2069	0	0	0	0	38	87	125
2070-2099	0	0	0	0	42	97	139

Rainwater harvesting is already being used in many areas of California. The concept is currently doable, in most cases does not require permitting, and is simple to implement with very little infrastructure. Therefore, a 50-percent adoption rate was used to estimate yield could be achieved within 5 years.

The cost for purchase and installation of a 500-gallon storage tank and irrigation modifications was assumed to be about $1,000 per household. Because of the limited storage capacity and the mismatch in timing of rain events and water demand, harvested rainwater can only deliver approximately 10 percent of outdoor demand, or approximately 0.02 acre-foot per household. As a result, the calculated unit cost of water is estimated at $3,150 per AFY.

Aside from the high capital cost for individual households, the rainwater harvesting option is easy to implement, is already practiced in many areas of California, has no energy needs, and, depending on local laws, does not require any permitting.

6.3.3. Improve Operational Efficiency

6.3.3.1. Conjunctive Groundwater Management

This concept uses groundwater recharge and recovery as an underground water bank. Two main types of conjunctive use concepts are possible: direct recharge or in-lieu recharge.

Under direct recharge programs, an entity could divert surface water to groundwater storage when there is a surplus or reduced need for surface supplies. When there is a critical or increased need for additional supply, the entity could then withdraw an amount of water equivalent to that it previously banked subject to withdrawal limits. This concept is already used in several areas of the Central Valley.

Alternatively, under in-lieu recharge programs, surface water could be used “in-lieu” of groundwater in overdrafted groundwater basins. The reduced groundwater use would allow groundwater storage to accumulate over normal and wet periods. Then, during critical drought periods the stored groundwater could be accessed when surface water supply is limited.

Groundwater banking offers two primary benefits over existing surface storage to:

1. Reduce evaporation compared to surface water storage
2. Provide additional storage capacity when surface storage facilities are full

A recent study of potential storage actions in the Central Valley showed potential average annual yield amounts of about 300 TAF per year for new groundwater storage in the Sacramento Valley and about up to 100 TAF per year for new groundwater storage in the San Joaquin Valley (Lund et al. 2014), with higher potential yield estimates realized in combination with implementation of a new Delta conveyance facility. This study considered approximately 2 MAF of potential groundwater storage capacity in the Sacramento Valley and 2 MAF in the San Joaquin Valley.

It can be roughly estimated that development of a groundwater banking project would require 5 years of feasibility, 5 years of permitting, and 5 years of implementation, totaling 15 years.

Rough estimates considering potential increased yield due to underground storage range from approximately $1,500 to $2,500 per AFY (DWR 2014 [Water Plan]). This analysis assumed a cost of $1,750 per AFY. Groundwater banking projects using infiltration basins would require extensive acquisition of lands if injection wells are not used. They also require construction of well fields to extract groundwater, pipelines, and power supplies. Due to the large investment and significant amount of impacted lands, extensive feasibility studies, permitting, and environmental assessments would be required. In-lieu recharge programs may require additional surface water conveyance facilities to facilitate the use of both surface and groundwater in the impacted areas.

Energy needs will vary by type of recharge method, extraction method, and groundwater depth. However, using groundwater wells to recover water will require more energy than releasing water from a surface water storage facility.

6.3.3.2. Enhance Groundwater Recharge

Enhanced groundwater recharge adds surface water into a groundwater aquifer through surface infiltration, and can include either natural or artificial recharge. For many groundwater basins, natural recharge predominantly occurs though either deep percolation of rainfall in specific overlying areas that are of coarse-grained soils or through stream recharge. In some watersheds, land management and stream development has led to a reduction in the groundwater recharge potential. This adaptation action includes land and river management practices such as increasing the area of permeable surfaces in specific recharge zones, managing irrigation methods in recharge zones, or capturing of stormwater flows for subsequent infiltration.

As estimating the potential for enhanced recharge in all the major groundwater basins in the Central Valley is complex, this appraisal-level study assumed that groundwater recharge could be enhanced by up to 10% of the precipitation runoff in the foothill regions by the end of the century. Table 6-8 shows the estimated potential annual recharge in each region in the Central Tendency climate/Current Trends socioeconomic scenarios. However, it should be noted that these increases in groundwater recharge directly come from a reduction in surface runoff. Thus, much of the groundwater recharge generated from this action may not increase net annual water supply is derived from this action.

Table 6-8. Estimated Average Annual Additional Groundwater Recharge in Each Region (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	55	1	8	4	0	0	68
2040-2069	308	14	271	65	0	0	658
2070-2099	523	45	537	181	0	0	1,286

It can be roughly estimated that development of enhanced groundwater recharge would require 5 years of feasibility, 5 years of permitting, and 5 years of implementation, totaling 15 years.

Rough estimates considering potential increased supply due to groundwater recharge range from $1,000 to $2,000 per AFY (DWR 2014 [Water Plan]). For planning purposes, a cost of $1,250 per AFY has been assumed. Groundwater recharge projects using infiltration basins that would require extensive acquisition of lands if injection wells are not used. Due to the large investment and significant amount of impacted lands, extensive feasibility studies, permitting, and environmental assessments would be required.

6.3.3.3. Improve Salinity and Nutrient Management

This adaptation action includes potential actions to improve management of salt loads and nutrients contained in Central Valley water supplies. Salinity describes a condition where dissolved minerals are present from either natural or anthropogenic origin and carry an electrical charge (ions). Major ionic substances found in water include calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and nitrate. Impacts from these nutrients can occur either in the short-term due to high concentrations or in the long-term due to accumulated loads over time. Salinity conditions in the Sacramento-San Joaquin Delta are critical both for maintaining the health of Delta ecosystems and for ensuring adequate conditions for Delta pumping for downstream water users.

The 2013 California Water Plan Update identifies the following potential actions to manage salinity and other nutrients (DWR 2014 [Water Plan]):

- Source control to use water more efficiently and reduces the magnitude and adverse effects of salinity

- Dilution and displacement to reduce salt concentrations

  Treatment using membrane or distillation technologies

- Salt collection and storage

- Export opportunities such as brine lines to move salt to the ocean

- Real-time salinity management

- Salt recycling

- Adaptation to increasingly saline conditions

Potential benefits from these actions include protecting beneficial uses, increasing useable water supplies, and improving economic stability.

A recent study for the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) program estimated the total net salt accumulation in the Central Valley to be about 7.1 million tons per year, of which about 4.9 million tons occurs in impaired areas (CDM Smith 2014). A concept-level cost analysis estimated that about 690 groundwater extraction facilities and about 30 desalination facilities would be required to remove the salt accumulation in the impaired areas, with an estimated development cost of about $3.5 billion (CDM Smith 2014).

From an implementation standpoint, there are many issues that would need to be addressed. Sustainable salt and nutrient management would require a coordinated planning effort to implement and may be constrained by existing Federal, state, and local policies (DWR 2014 [Water Plan]).

6.3.3.4. Improve River Temperature Management

Water temperature management is a significant operational driver on the Sacramento River and its tributaries. In many years, cold water pools in upstream reservoirs are held in reserve in the winter and spring to maintain sufficient cold water to manage river temperatures throughout the summer and early fall. Large investments have been made to more effectively conserve and withdraw cold water from several reservoirs such as Shasta, Oroville, and Folsom.

Adaptation options typically involve one of two major concepts:

- Manage river water temperature to support anadromous fish species below the reservoirs

- Provide anadromous species access to the colder water in the headwater tributaries that are upstream of the major reservoirs

Managing the water temperature in rivers below the major reservoirs for all species of anadromous fish may be unsustainable throughout the summer and fall under the reduced snowpack and warmer air temperatures that have been projected for future climate conditions and experienced under the current drought conditions.

If enough cold water is not available due to climate conditions or during extreme prolonged dry conditions, temperature management would stress fish access to the colder water in the tributaries upstream of the reservoirs through fish passage mechanisms (e.g., ladders or trucking). Costs for providing access to upstream habitats would likely exceed hundreds of million dollars and feasibility, permitting, and construction would likely take 10-15 years.

Future management flexibility is an adaptation action. However, in scenarios where the supply of cold water is sufficient to manage river temperature downstream of the reservoirs, reservoir operations would continue to release cold water from reservoirs to maximize the period in which temperatures are suitable for fish migration and spawning.

It is not anticipated that these changes would result in additional significant changes in yield for water users, but rather would reflect the growing reality of the tradeoffs that the changing hydrologic regime may bring. Under this assumption, no new facilities would need to be constructed, and it is estimated that the changes in operations could be implemented within 5-10 years. Cost associated with managing reservoir cold water pools and releases would be low because there would not be any development of new facilities.

6.3.3.5. Improve CWP/SWP Operations

This action includes potential modifications to project operations to develop water supply benefits through improved operational efficiencies between the two projects. Potential operational improvements include forecast-based reservoir operations, reoperation of project reservoirs, and further integration of CVP and SWP project operations.

Forecast-based operations would use weather forecasts to better optimize the management of the reservoir’s storage space for flood control and water supply. Reoperation of project reservoirs would involve lowering carryover storage levels and increasing flood reservation by storing excess water in available groundwater banks. Integrating CVP and SWP project operations would involve sharing storage in San Luis Reservoir between the two projects.

For planning purposes, it is assumed that the flood control space and storage/release rules would adapt to the changing hydrologic regime. Shifts in winter and spring runoff timing would permit associated changes in flood control rules. When existing facilities are operated in conjunction with new surface or groundwater storage facilities, increased flood storage capacity would be targeted by moving water into offstream storage. Finally, further integration of the CVP and SWP could be accommodated through improved sharing of export capacity, conveyance capacity, and San Luis storage capacity between the two projects.

Simulations performed by DWR's System Reoperation program with forecast-based operations showed about 20 TAF per year in projected additional deliveries. The System Reoperation program has not yet simulated reoperation of project reservoirs but plans to do so in its next phase of work. Simulations of improved integration of the CVP and SWP under historical delta regulatory conditions have demonstrated improved combined CVP/SWP deliveries on the order of 200 TAF/year.

Costs of this adaptation action would be low because there would not be any development of new facilities. Because no new facilities would need to be constructed, it is estimated that the changes in operations could be implemented within 10 years.

This action scores highly on operational flexibility, but there could be implementation and permitting issues as reservoir operation plans would need to be revised.

6.3.3.6. Improve Tributary and Delta Environmental Flows

The goal of the improve tributary and Delta environmental flows action is to simulate actions intended to provide additional flows for environmental purposes by requiring additional upstream reservoir releases and operational changes to meet Delta outflow requirements designed to produce flows in the river system and in the Delta that are more similar to a natural hydrograph.

The following assumptions are included:

- **Unimpaired flows below Shasta Lake, Lake Oroville, and Folsom Lake as minimum instream flow requirements at these locations.** These are defined as percentages of the inflows into each reservoir.

- **Offramps to limit the required reservoir releases to meet the minimum instream requirements.** These offramps are defined as step functions based on reservoir storage in each certain month.

Because no new facilities would need to be constructed, costs of implementing this action would be low, and it is estimated that the changes in operations could be implemented within 10 years.

The projected water supply reductions would likely make implementation difficult, unless the action was paired with an additional action designed to increase water deliveries to these water users.

6.3.3.7. Improve System Conveyance

The improved system conveyance action assumed the construction of a peripheral conveyance structure with an intake on the Sacramento River and an isolated connection at the CVP and SWP pumping facilities. Similar to studies currently being done under the California Water Fix program it is assumed that the new facilities would include positive-barrier fish screens on the Sacramento River near Hood or Clarksburg; a peripheral conveyance structure and associated conveyance facilities (such as pumps and siphons) that would traverse from the new intake facility along the Sacramento River along a southerly alignment adjacent to, and west of, Interstate 5; and terminal facilities that would allow discharge into the Clifton Court Forebay (CCF) with an intertie between CCF and C.W. Jones PP (see http://www.californiawaterfix.com).

The following conveyance assumptions have been developed for the adaptation action used in this Basins Study:

- 9,000-cfs capacity Division facility at Hood
- No minimum South Delta pumping
- 10,300-cfs Banks PP capacity
- Bypass flow controlled by Rio Vista flow requirements
- Shared SWP and CVP beneficiaries

Note that these assumptions were developed solely for the purpose of this Basins Study and do not reflect Reclamation’s policy regarding the Bay Delta Conservation Plan (California WaterFix) program.

The Delta Conveyance action would generate about 0-500 TAF/year in average annual yield depending on the assumptions of delta conditions and environmental flows that would accompany the action. Assuming that south delta regulatory conditions are sufficiently more constrained than today, water delivery benefits could be as high as 1 MAF/year. The projected cost of the action is $14.9 billion, reflecting an annualized cost of about $300 million. Because environmental documentation is nearing completion, it is estimated that the project could be implemented within 10-15 years (see http://www.californiawaterfix.com).

As proposed changes to the Delta water system are controversial, Delta conveyance will likely face permitting, legal, and implementation challenges. In addition, there are higher energy costs associated with the action due to the need to pump water through the proposed Delta tunnels.

6.3.3.8. Improve Regional/Local Conveyance

This adaptation action includes potential modifications to regional project operations in the San Joaquin and Tulare Lake regions to remove restrictions on conveying water to improve delivery reliability. Expansion of the conveyance infrastructure connecting the California Aqueduct and water users in the Kern and Tulare region would facilitate improved delivery and exchange opportunities. In addition, increased conveyance and regional interties in this region would improve the flexibility of integrating groundwater banks into the San Joaquin and Tulare Lake region delivery systems. Expansion of the conveyance infrastructure such as the Cross Valley Canal, Shafter-Wasco Canal, and Semitropic Intertie would reduce conveyance limitations that contribute to reliability concerns in this region. Due to the simplified representation of these facilities in CalLite-CV, this action has not been simulated in the model.

Costs of this adaptation action are unknown at this time. However, the Delta Mendota Canal-California Aqueduct Intertie project cost nearly $30 million dollars and represents the scale for this type of actions. It is estimated that the implementation of these actions could occur within 10 years.

6.3.3.9. Increase Sacramento Valley Surface Storage

The increase Sacramento Valley surface storage action includes developing and implementing a Shasta Dam enlargement alternative and a North-of-Delta Offstream Storage (NODOS) alternative. The Shasta Dam enlargement included an 18.5 foot dam raise, which provided 634 TAF of additional storage. The Shasta Dam enlargement alternative includes the core elements of the Shasta Lake Water Resource Investigation (SLWRI) program, including use of the additional storage for CVP water supply and Central Valley Project Improvement Act (CVPIA) (b) (2) accounting and for water supply operation allocated for use by the SWP.

The NODOS project is a proposed offstream storage facility that could be used to store water in wetter years and release water in drier years for increasing long-term beneficial use of water throughout regions supplied by the SWP and CVP. The specific alternative used in this Basins Study is the proposed Sites Reservoir, located 10 miles west of Maxwell, in northern Colusa and southern Glenn Counties. The alternative includes 1.81 MAF in new storage capacity and improvements to existing Tehama-Colusa and Glenn-Colusa canals, as well as a new Delevan Pipeline to divert flow from the Sacramento River in wetter periods and release stored water back to the river and local users.

The Shasta Enlargement project is estimated to provide about 133 TAF in average annual yield, with an annualized cost of about $54 million (Reclamation 2013 [Shasta]). This translates to an average cost of $406 per AFY. The NODOS project is estimated to provide about 400-500 TAF in average annual yield, with an annualized cost of about $178-204 million ((DWR 2014 [NODOS])). This translates to an average cost of $408-445 per AFY.

Because environmental documentation has already been completed, it is estimated that these projects could be implemented within 10-15 years. However, as constructing new reservoirs or of expanding existing reservoirs is controversial, Sacramento Valley surface storage would likely face permitting, legal, and implementation challenges.

6.3.3.10. Increase San Joaquin Valley Surface Storage

The increase San Joaquin Valley surface storage adaptation action includes possible development of a new Temperance Flat Reservoir with a capacity of 1,260 TAF upstream of Millerton Lake. Assumptions reflect those used in the Upper San Joaquin River Basin Storage Investigation. Temperance Flat is simulated in the models as a new reservoir located upstream of Millerton Lake on the San Joaquin River. Releases from Temperance Flat would flow into Millerton Lake.

The Temperance Flat project is estimated to provide about 76 TAF in average annual yield, with an annualized cost of about $116-121 million (Reclamation 2014 [Storage]). This translates to an average cost of $1,525-1,589 per AFY. Because environmental documentation has already been completed, it is estimated that this project could be implemented within 10-15 years. However, as constructing new reservoirs or of expanding existing reservoirs is controversial, San Joaquin Valley surface storage would likely face permitting, legal, and implementation challenges.

6.3.3.11. Increase Export Area Surface Storage

The increase export area surface storage adaptation action employs a hypothetical reservoir to represent options including additional surface storage, groundwater storage, or conjunctive use management opportunities within the South-of-Delta export areas. For this Basins Study, this additional storage is simulated as an addition to the existing San Luis Reservoir in CalLite-CV. It is assumed that export water would only fill the new South-of-Delta storage after existing CVP-SWP San Luis accounts were full, and that water would be released from this South-of-Delta storage prior to releasing storage from existing San Luis Reservoir accounts.

This “last in, first out” principle was implemented so that the operation would be in addition to the current reservoir operations. It was assumed that the additional storage would be as large as the existing San Luis Reservoir, with the same CVP/SWP ratio as the existing reservoir, and with the same dead pool and initial storage conditions. Therefore, the maximum simulated storage capacities were 1,067 TAF for the SWP portion and 972 TAF for the CVP portion of the South-of-Delta storage reservoir.

Model simulations of this adaptation action showed increases in deliveries to CVP and SWP water users of about 500 to 1,000 TAF per year (Reclamation 2014 [Climate]).

Based on the cost estimates of other ongoing storage programs, the cost of this action has been estimated at $4,500-6,700 million. This translates to a cost per yield of about $660-1,100 per AFY.

It can be roughly estimated that development of export area surface storage would require 5 years of feasibility, 10 years of permitting, and 5 years of implementation, totaling 20 years. However, as constructing new reservoirs or of expanding existing reservoirs is controversial, export area surface storage would likely face permitting, legal, and implementation challenges.

6.3.3.12. Increase Upper Watershed Surface Storage

This adaptation action includes possible development of new surface storage in upper watersheds upstream of major CVP and SWP reservoirs. Upper watershed surface storage projects can provide multiple benefits, including water supply, flood control, hydropower, and environmental flows. Upper watershed surface storage was analyzed using an example project implemented in the American River watershed upstream of Folsom Lake. Information from previous studies of this project has been used to estimate water supply and other benefits from this proposed project and the change to inflow into Folsom Lake. The project was simulated in the CalLite-CV model by adjusting the inflow into Folsom Lake to account for changes in upstream operations due to the new storage facility. The flood rule curve in Folsom Lake was also adjusted to account for the additional storage space that would be available in the new reservoir.

The proposed upper watershed project would have a maximum storage volume of about 175 TAF per year with an estimated yield of up to 30 TAF per year and net hydropower generation of up to 500 GWh per year (El Dorado County Water Agency [EDCWA] and El Dorado Irrigation District [EID] 1979). Total estimated costs in year 2015 dollars would be about $790 million. The total annualized cost per yield would therefore be about $1,300 per AFY.

It can be roughly estimated that development of upper watershed surface storage would require 5 years of feasibility, 10 years of permitting, and 5 years of implementation, totaling 20 years. However, as constructing new reservoirs or of expanding existing reservoirs is controversial, upper watershed surface storage would likely face permitting, legal, and implementation challenges.

6.3.4. Improve Resource Stewardship

6.3.4.1. Improve Forest Health

A large percentage of the runoff in the Central Valley is derived from the higher elevation watersheds with forests. Previous studies and information have demonstrated that areas where forest cover is reduced by clear-cutting or fires have dramatically increased amounts of runoff. This is the result of reduced interception, decreased evapotranspiration, and sometimes reduced permeability of the soil surface. The magnitude of increased runoff over affected areas may be as much as 10 centimeters, or 4 inches, per year. The forest management adaptation action would entail the replacement of mature forests that have been cleared by harvesting, fires, or insect infestations with stands of replacement growth more likely to be favorable for generating runoff. The forested area in California covers about 37,557,000 acres (DWR 2014 [Water Plan]). Based on information contained in the California Forest Resources, 2001-2005 Five-Year Inventory and Analysis Report (USDA 2008), about 50% of this acreage is in land that drains into the Sacramento River system and Delta eastside streams, and about 21% is in land that drains into the San Joaquin River system and Tulare Lake region.

Analyses performed for the Truckee River Basin Study (Reclamation 2014 [Truckee]) estimated that about 33% of the available acreage could be thinned with an estimated yield of 0.15 AF per acre per year. For this Basins Study, due to the size of the contributing watershed and forest area, it has been assumed that no more than 20% of the forest area could be actively managed for selective harvesting or programmed re-vegetation following fires or other major disturbances. The resulting average annual increase in runoff in the Reference-No-Climate-Change climate scenario is about 1,300 TAF/year as shown in Table 6-9.

Table 6-9. Estimated Average Annual Water Supply from Forest Management in Each Region (in TAF/year)

Period	Sacramento	Delta & Eastside	San Joaquin	Tulare Lake	South SF Bay	South Coast	Total
2015-2039	76	5	22	12	0	0	115
2040-2069	291	19	86	44	0	0	440
2070-2099	450	29	132	69	0	0	680

The Colorado Basin Study identified reported costs for forest management to range from $100 to $1,500 per AFY. Assuming a cost of $1,000 per acre on a 20-year rotation, with annual maintenance costs of about 10 percent of that amount, the unit annual cost of additional runoff generated would be approximately $500 per acre-foot (Reclamation 2012).

The time needed to evaluate the feasibility of forest management activities was estimated to be 7 years. The timeframe for permitting was estimated to be 3 years, largely due to the consideration that these forest management activities are currently being practiced, although not for purposes of increasing runoff. The timing for implementation of forest management practices was estimated at 10 years to conform to time frames experienced with other forest management measures.

Therefore, the total time for development of the forest management group of options is estimated to be 20 years. An additional 10 years is assumed to implement the program at a full scale.

6.3.5. Improve Institutional Flexibility

6.3.5.1. Improve Regulatory Flexibility and Adaptability

The improved regulatory flexibility and adaptability adaptation action includes potential modifications to regulatory requirements and statutory rules to improve water system efficiency to manage through an increasingly variable hydroclimatic regime that is projected in the future. Potential operational improvements include implementing dry-year off-ramps for Delta requirements, changing flood storage curves to account for changes in flow timing due to climate change, and changes to Settlement, Exchange, and Feather River Service Area contracts that allow for a more adaptation allocation during extreme dry conditions.

For planning purposes, several actions may be considered to permit the system to function more effectively during extreme hydroclimatic conditions. First, all Delta and environmental flow requirements would adapt to the evolving water year types that are projected in future climates. Spring and fall delta outflow requirements will be adjusted from current values based on the changes in unimpaired inflows from the eight major tributaries to the delta. Second, all major reservoir flood control rules will be adapted to the changing hydrologic regime in the winter and spring. Flood diagrams will be shifted with the shifts in timing of peak flows. Finally, the “dry year” criteria in which Settlement, Exchange, and Feather River Service Areas contractor deliveries are reduced will be more adaptation to the changing hydrologic regime. A graduated adjustment to the dry year criteria will be implemented based on the changes in unimpaired flows for the tributary that currently governs these criteria.

Costs of this adaptation action would be low because there would not be any development of new facilities and the action does not reduce water supply benefits for any water users. Because no new facilities would need to be constructed, it is estimated that the changes in operations could be implemented within 10 years.

This action scores highly on operational flexibility, but there could be implementation and permitting issues due to the need to revise reservoir operation plans, receiving State Board approval on changes, and negotiating changes to the senior water right holder contracts.

6.3.6. Improve Data Management

While this option could not be simulated, several project and public stakeholders expressed the strong desire to improve data management and use these data more effectively to support near-term and long-term decision-making. Many data sets, spanning hydrological, operational, and biological aspects, currently exist. However, there is limited centralization of this data and limited integration of the cross-resource data sets. Improving the methods in which the data is stored, in which databases are linked, and in which users access the information has been suggested to improve the effectiveness of data to support decision-making.

6.3.7. Summary of Adaptation Actions

The cost, yield, and timing of the adaptation actions are shown in Figure 6-1 (sorted based on cost). Some of the least-cost options (less than $500 per AFY) are related to improving regulatory flexibility and water use efficiency actions in both the municipal and agricultural sectors. Other lower cost options include improving forest health, targeted surface storage in the Sacramento Valley and export areas (less than $1,000 per AFY). Municipal wastewater, system conveyance improvements, and conjunctive management are all expected to provide water at about $1,500-$2,000 per AFY. Ocean desalination and rainwater harvesting actions, while providing a reliable local supply in some geographies, are amongst the highest cost actions considered.

Figure 6-2 provides a summary of the ratings of each action for the 11 evaluation criteria considered in this study. The water use efficiency, municipal wastewater reuse, and enhanced groundwater recharge suggest very high potential across the state as a whole. These actions are also likely to be implemented with relatively low legal and policy implications. Actions such as improving forest health and enhancing precipitation in the upper watershed suggest promise due to the relatively large potential supply gains in relation to the cost. However, the long-term viability was rated relatively low for these actions given the uncertainty to sustain water supply improvements over time. Ocean desalination and municipal wastewater reuse were rated low for energy needs due to the relatively high requirements of these actions, while all of the demand management action resulted in no new energy needs or an energy savings.

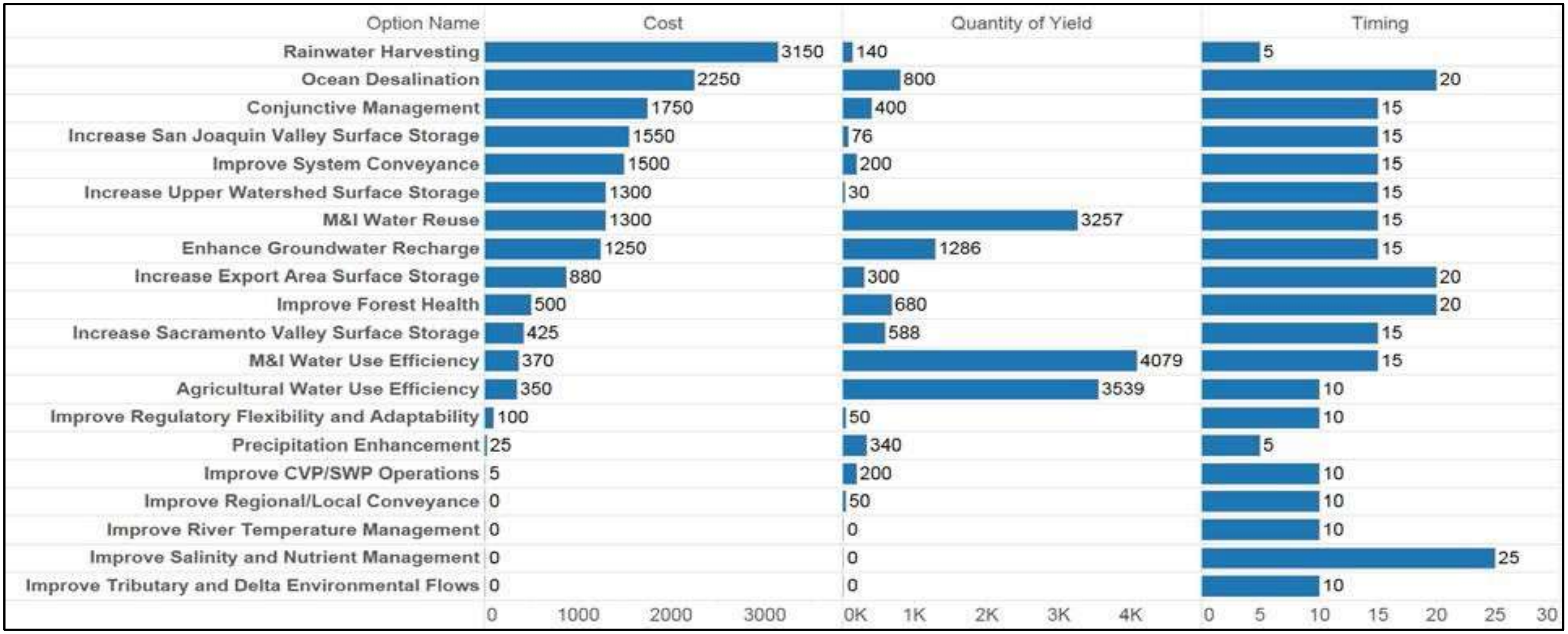


Figure 6-1. Estimated median cost, quantity, and timing for each of the actions. Costs are in$/AFY of supply improvement or demand reduction. New supply or demand reductions are in TAFY. Timing to implementation is in years.

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

Figure 6-2. Summary of water management action characterization for the 11 criteria. In general, “A” is the most favorable rating for the specific criteria while and “E” rating is the least favorable.

6.4. Development of Adaptation Portfolios

6.4.1. Approach for Portfolio Development

This Basins Study developed seven exploratory portfolios to reflect different strategies for selecting and combining actions to address Sacramento and San Joaquin River Basin imbalances between water supply and water demand and other water system vulnerabilities. Various actions were combined into portfolios representing different potential adaptation strategies based on the results of the characterization and development of adaptation actions. Each portfolio consists of a unique selection of actions that were considered to address vulnerabilities that may exist under future socioeconomic-climate scenarios:

- Least Cost
- Regional Self-Reliance
- Healthy Headwaters and Tributaries
- Delta Conveyance and Restoration
- Expanded Water Storage and Groundwater
- Flexible System Operations and Management
- Water Action Plan

These seven dynamic portfolios represent a range of reasonable but different strategies for resolving future supply and demand imbalances. Table 6-10 shows the water management actions that were included in the technical analysis of each portfolio. The objective of each portfolio is described in the sections below.
The portfolios are not intended to represent all possible strategies for grouping actions. Further, the Study did not intend to result in the selection of a particular portfolio or any one action from any portfolio. Rather, the objective of the portfolio analysis was to demonstrate the effectiveness of different strategies at resolving future supply and demand imbalances and other system vulnerabilities.

To assess the effects of the strategy on resolving vulnerabilities to basin resources, the portfolios were modeled dynamically in CalLite-CV and then analyzed.

Table 6-10. Summary of Water Management Actions Included in Each Adaptation Portfolio (Colors indicate functional objectives).

Water Management Action	Least Cost	Regional Self-Reliance	Healthy Headwaters and 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
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

6.4.2. Least Cost

The least cost portfolio includes adaptation actions that either improve system or regional operations at minimal cost and those that provide additional yield at the lowest cost. Included actions:

- Had a mean expected cost of less than $1,000 per acre-foot per year of new supply or savings

- Were conveyance and operational actions that provide a range of potential benefits that may not be directly expressed as cost per new yield were included.

To reflect that “least cost” should not automatically equate with “most uncertain,” actions that had a high degree of uncertainty or long-term viability risks were excluded from this portfolio.

6.4.3. Regional Self-Reliance

The regional self-reliance portfolio is designed to include regional actions that either reduce demand or increase supply at a regional level without affecting CVP and SWP project operations.

6.4.4. Healthy Headwaters and Tributaries

The healthy headwaters and tributaries portfolio includes adaptation actions that improve environmental and water quality in the Central Valley and upper watershed areas.

6.4.5. Delta Conveyance and Restoration

The Delta conveyance and restoration portfolio is designed to improve Delta export reliability by developing a new Delta conveyance facility in combination with improved environmental actions in the Delta.

6.4.6. Expanded Water Storage and Groundwater Management

The expanded water storage and groundwater management portfolio seeks to improve water supply reliability through implementing new surface water storage and groundwater management actions.

6.4.7. Flexible System Operations and Management

The flexible system operations and management portfolio includes actions designed to improve system performance without constructing new facilities or expanding the size of existing facilities.

6.4.8. Water Action Plan

The Water Action Plan portfolio reflects the adaptation actions that are included in the California Water Action Plan (DWR 2014 [Water Plan]). The actions in the California Water Action Plan are similar to the regional self-reliance, healthy headwaters and tributaries, Delta conveyance and restoration, expanded water storage and groundwater management, and flexible system operations and management portfolios described above. This portfolio includes all of the actions that were included in those portfolios, to develop a comprehensive set of actions that includes all of the adaptation actions described in this section.

6.5. Portfolio Implementation Costs

An estimated annualized cost has been developed for each adaptation portfolio using yield and cost information described for each water management action in the above sections. The resulting cost estimates are shown in Table 6-11 for the early, mid and late century and for the average of the full century. These cost estimates reflect the cumulative cost of all actions included in each adaptation portfolio. The annualized cost of actions that change in magnitude over time (such as water use efficiency and reuse) have a higher annualized cost later in the century than in the earlier part of the century.

Table 6-11. Estimated Annualized Cost for each Portfolio (in $millions per year)

Portfolio	Early Century (2015-2039)	Mid Century (2040-2099)	Late Century (2070-2099)	Full Century (2015-2099)
Least Cost	$1,593	$2,703	$3,311	$2,536
Regional Self-Reliance	$2,572	$5,536	$8,289	$5,466
Healthy Headwaters and Tributaries	$430	$673	$829	$644
Delta Conveyance and Restoration	$672	$753	$789	$738
Expanded Water Storage and Groundwater	$2,293	$3,165	$4,030	$3,163
Flexible System Operations and Mgmt.	$987	$1,805	$2,626	$1,806
Water Action Plan	$3,605	$6,732	$9,605	$6,647

6.6. Summary and Limitations

A wide range of water management actions, based on input from stakeholders and the public, was considered in this Basins Study. These actions include those that reduce water demand, increase water supply, improve operational efficiency, improve resource stewardship, and improve institutional flexibility and adaptability in the face of climate change and land changing conditions. Nineteen representative actions were considered and evaluated for a range of economic, policy, technical, and environmental criteria. Seven distinct portfolios, strategically combining these actions, were developed to reflect different possible pathways to help adapt to the evolving water management challenges in the Sacramento River, San Joaquin River, and Tulare Lake Basins.

While the portfolios that have been assembled in this Basins Study are policy-relevant, they should be considered exploratory. The main objective in the development of the portfolios is to gain further understanding in terms of promising actions and the ability to address some the critical vulnerability concerns identified for the Central Valley. The characterization of water management actions performed in this section should be considered conceptual or at the pre-appraisal level. Some actions have been studied for a number of years and are more developed, while others would require significant additional study and pilots to reduce uncertainties.

Notwithstanding these uncertainties and limitations, the water management actions and adaptation portfolios considered in this study represent a large part of the possible future water management opportunities in the Central Valley.

7. Adaptation Portfolios Evaluation

7.1. Objective and Approach

As described in Section 6. *Water Management Actions and Adaptation Portfolios*, this Basins Study developed seven exploratory adaptation portfolios to reflect different strategies for selecting and combining actions to address Sacramento and San Joaquin River Basin imbalances between water supply and water demand and other water system vulnerabilities:

- Least Cost
- Regional Self-Reliance
- Healthy Headwaters and Tributaries
- Delta Conveyance and Restoration
- Expanded Water Storage and Groundwater
- Flexible System Operations and Management
- Water Action Plan

These seven distinct strategies and dynamic adaptation portfolios represent a range of reasonable but different approaches for resolving future supply and demand imbalances. The adaptation portfolios are not intended to represent all possible combinations of actions, and the goal of the portfolio analysis was not to select or recommend a particular adaptation portfolio or action. Rather, the objective of the portfolio analysis was to demonstrate the effectiveness of different strategies at resolving future supply and demand imbalances and other system vulnerabilities.

Each adaptation portfolio consists of a set of water management actions that were considered to address vulnerabilities that may exist under future socioeconomic-climate scenarios. The specific assumptions that defined each adaptation action are described in Section 6. *Water Management Actions and Adaptation Portfolios*. As a consistent basis for comparison, adaptation portfolios were compared to the No Action alternative under the Current Trends socioeconomic scenario for the Reference-No-Climate-Change and ensemble climate scenarios.

The following sections describe the performance of the portfolios relative to the No Action alternative for each of these resource categories. The analysis of the portfolios was performed using the same set of tools for the same system reliability metrics that were used in the system risk and reliability assessment. The system reliability metrics were used to measure the potential improvements and impacts to the system due to implementation of the water management actions included in the portfolios for the following seven major categories:

- Water Delivery
- Economics
- Water Quality
- Hydropower and GHG emissions
- Flood Control
- Recreational Use
- Ecological Resources

7.2. Water Delivery

7.2.1. 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 irrigation of crops crop irrigation, are more susceptible to these influences than urban demands, driven more which are more by population driven.

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.*

The average annual unmet demand in the Central Valley is projected to increase by approximately 2% relative to the Reference-No-Climate-Change/Current Trends socioeconomic scenarios by the end of the 21st century.[7]

Under the No Action alternative analyzed in Section 5, the Central Tendency climate/Current Trends socioeconomic scenarios had unmet demands ranging from 3,192 to 13,082 TAF/year. Unmet demands ranged from 6,198 to 8,753 TAF/year across the climate scenarios from 2015-2099, with ranges from:

- 2015-2039: 7,221 to 9,853 TAF/year
- 2040-2069: 6,064 to 9,364 TAF/year
- 2070-2099: 4,640 to 8,141 TAF/year

See Section 5.2.2.1. *Unmet Demands* for the No Action alternative.

[7] Note: All changes in the No Action alternative are based on the Central Tendency climate/Current Trends socioeconomic scenarios at the end of the 21st century.

PORTFOLIOS

All of the portfolios showed reductions in unmet demand across all of the climate scenarios in the Central Valley, with greater reductions in the late century period when the water management actions have taken full effect. The highest unmet demands in all portfolios were in the San Joaquin and Tulare Lake regions. The largest unmet demands occurred with No Action in the Hot-Dry climate scenario while the lowest occurred with the Water Action Plan under the Warm-Wet climate scenario. The Sacramento River and Delta regions had low unmet demands in the No Action alternative and consequently only small changes in unmet demands with the adaptation portfolios.

Most Reduced Demands: The maximum average unmet demands were associated with the No Action alternative in all scenarios. The largest reductions in unmet demands were in the Least Cost, Regional Self-Reliance and Water Action Plan adaptation portfolios, each of which included aggressive agricultural and M&I water use efficiency actions. The lowest unmet demands were in the Water Action Plan portfolio, which consists of all the water management actions employed in the other portfolios. The Water Action Plan portfolio had unmet demands ranging from 1,588 to 3,382 TAF from 2070-2099, a reduction of 58% to 66% compared to the No Action alternative.

Least Reduced Demands: In contrast, the Healthy Headwaters and Tributaries, Delta Conveyance and Restoration and Flexible Operations and Management portfolios had little effect on reducing unmet demands while both the Least Cost and Regional Self-Reliance performed nearly as well as the Water Plan. These improved performances are mostly related to water management actions that increased water supplies and improved water use efficiencies.

7.2.1.1. Adaptation Portfolio Performance

In all climate scenarios, all adaptation portfolios performed better than the No Action alternative (Figure 7-1). 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 7-1 shows details of the performance of each of the adaptation portfolios relative to the No Action alternatives in four climate scenarios.

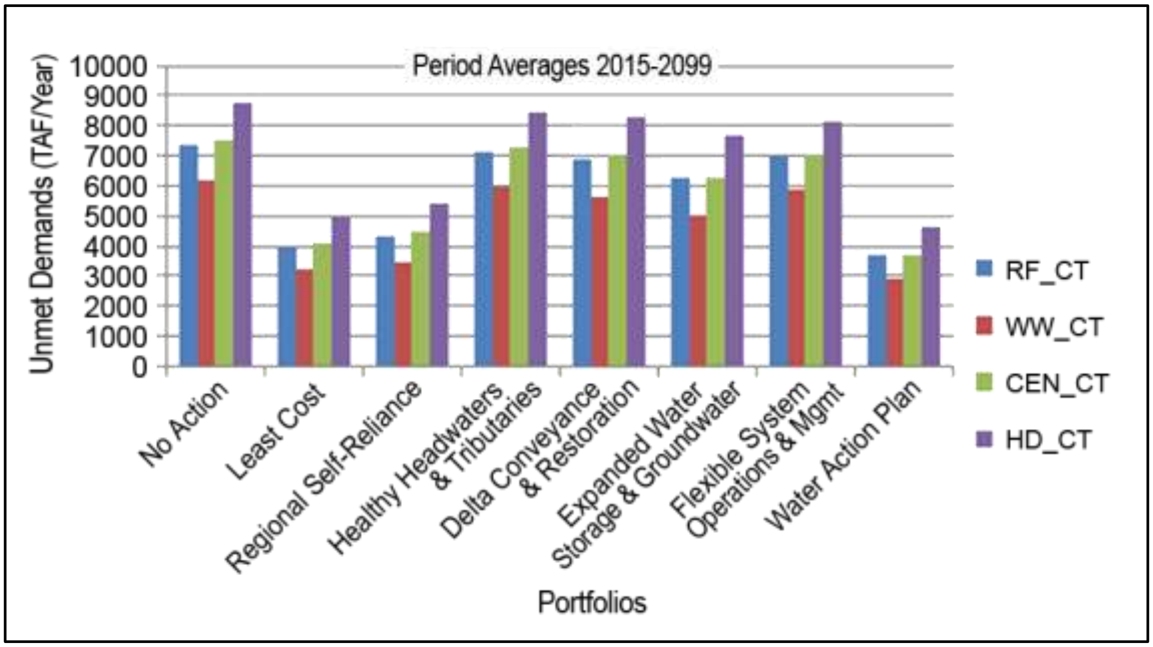


Figure 7-1. Average annual unmet demands in the Central Valley in each adaptation portfolio.[8]

(Lower numbers indicate increased benefits)

Table 7-1. Unmet Water Demands: 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	-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

[8] 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.

7.2.1.2. Adaptation Portfolio Climate Sensitivity

Table 7-2 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 **slightly more** unmet demands.

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

Table 7-2. 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

Figure 7-2 presents annual time series of groundwater, surface water, and local supplies, demand reduction amounts and unmet demand for the Central Valley for the No Action alternative and for each adaptation portfolio with Central Tendency climate/Current Trends socioeconomic scenarios over water years from 2015 to 2099. As Eastside streams and Delta have zero unmet demands, they are not shown.

Figure 7-3 presents the 10-year running average of unmet demands in the Central Valley and in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region for each portfolio with Central Tendency climate/Current Trends socioeconomic scenarios. As Eastside streams and Delta have zero unmet demands, they are not shown.

Table 7-3 shows the average annual unmet demands in the Current Trends socioeconomic scenario for the Reference-No-Climate-Change and ensemble climate scenarios in the Central Valley and in the Sacramento River, San Joaquin River and the Tulare Lake regions for the No Action alternative and adaptation portfolios. As Eastside streams and Delta have zero unmet demands, they are not shown.

Figure 7-2. Unmet demands: time series

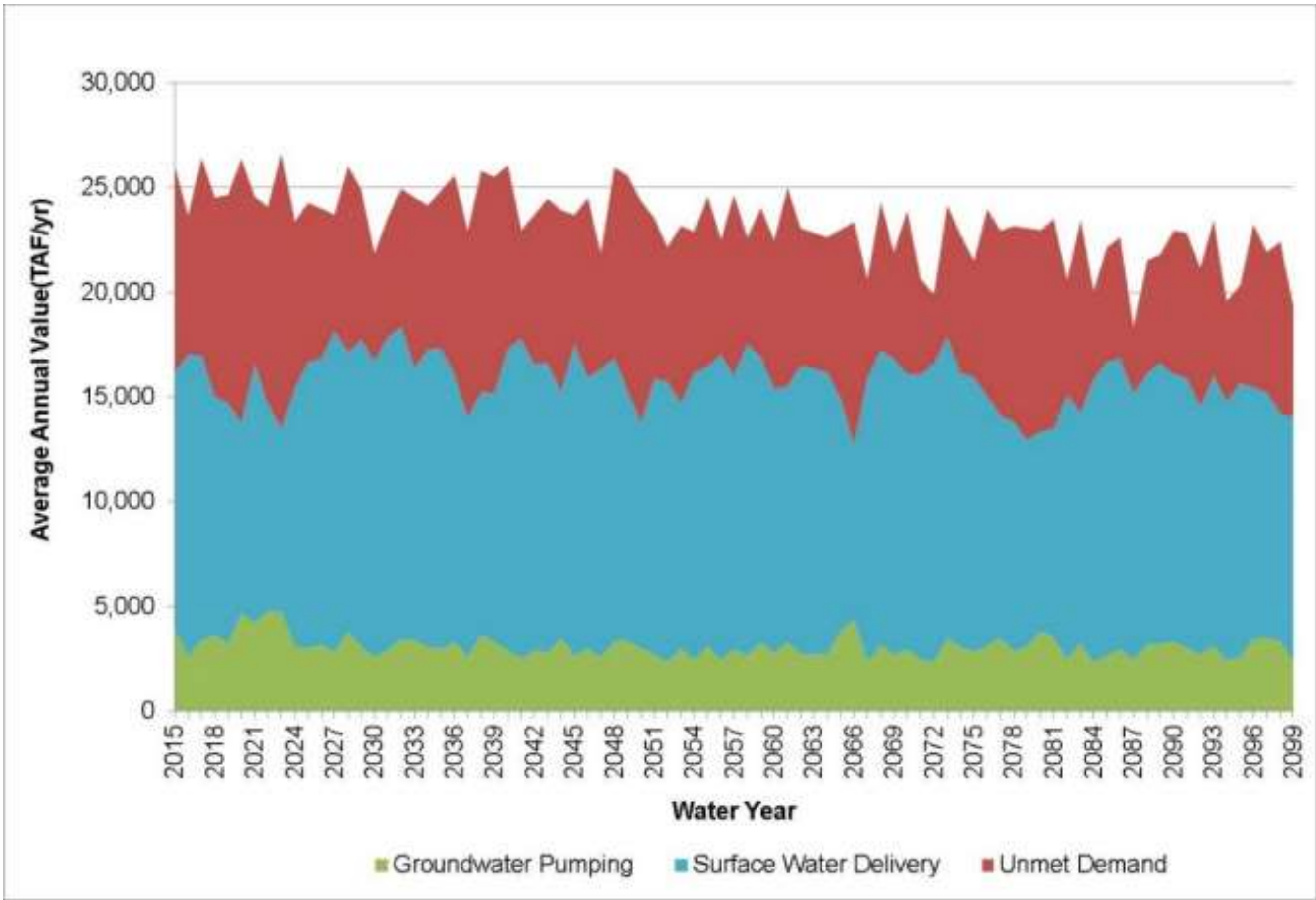


Figure 7-2a. Annual time series of supplies and unmet demand in the Central Valley in the **No Action alternative** in the Central Tendency climate/Current Trends socioeconomic scenarios.

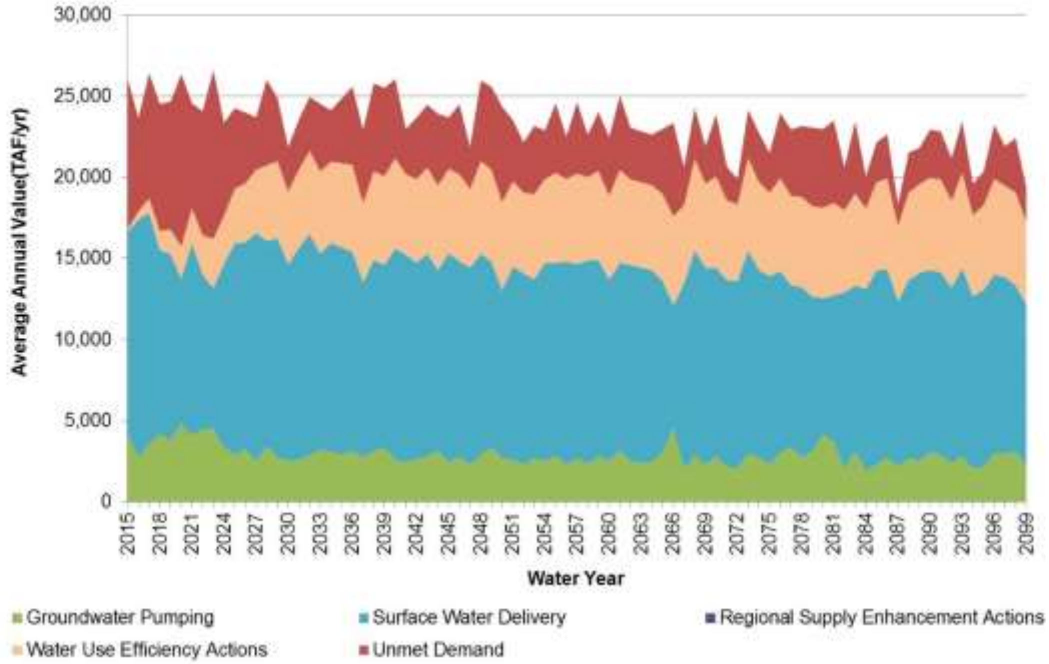


Figure 7-2b. Annual time series of supplies and unmet demand in the Central Valley in the **Least Cost Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

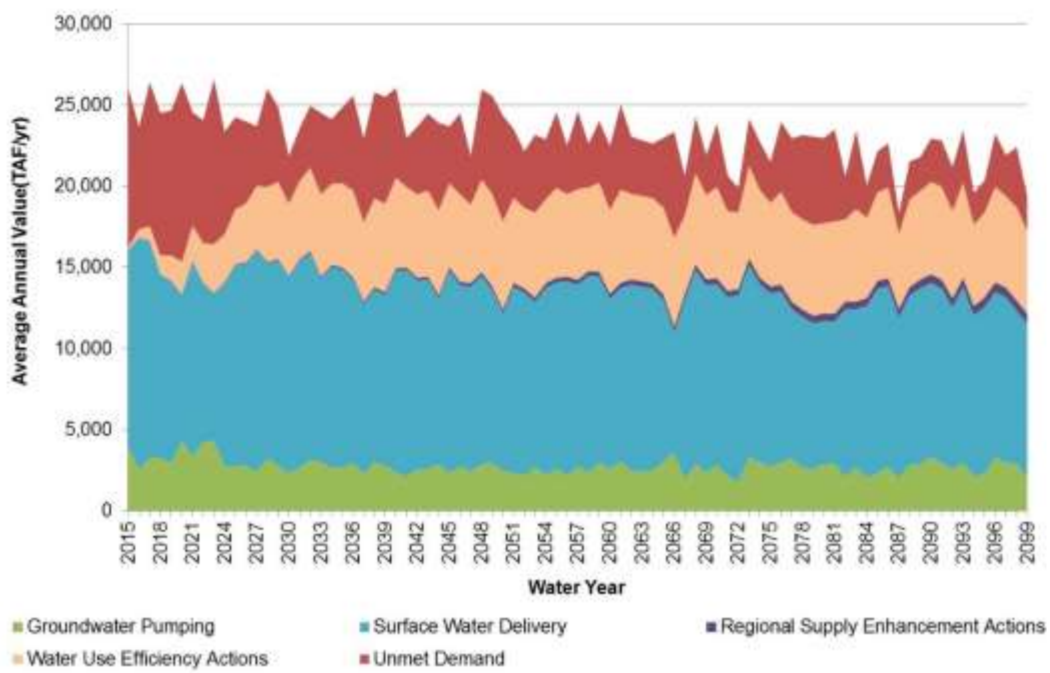


Figure 7-2c. Annual time series of supplies and unmet demand in the Central Valley in the **Regional Self-Reliance Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

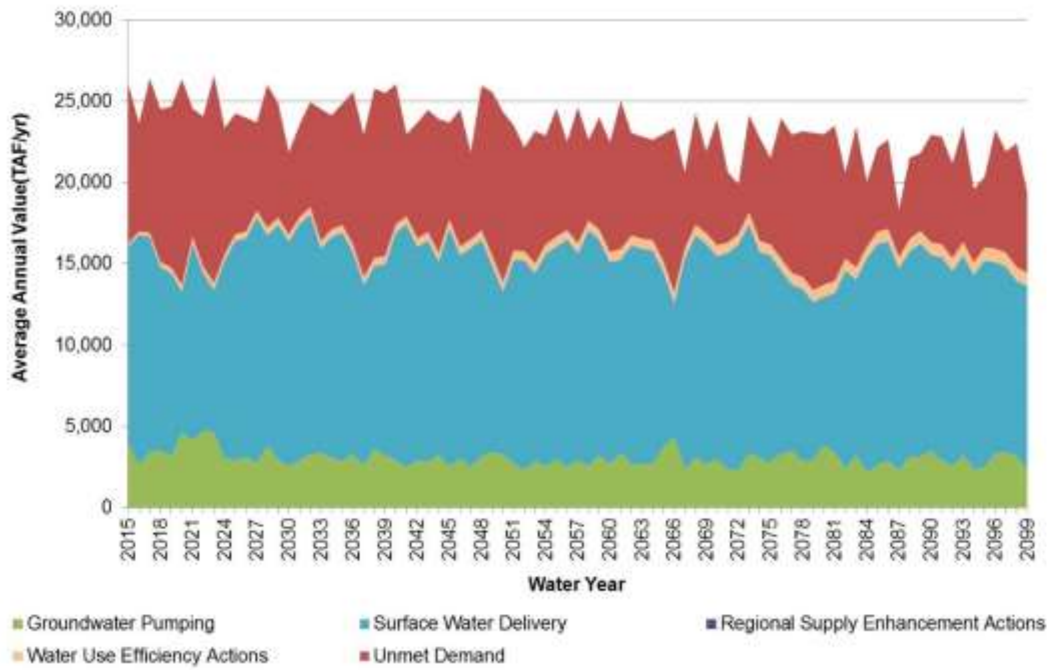


Figure 7-2d. Annual time series of supplies and unmet demand in the Central Valley in the **Healthy Headwaters and Tributaries Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios

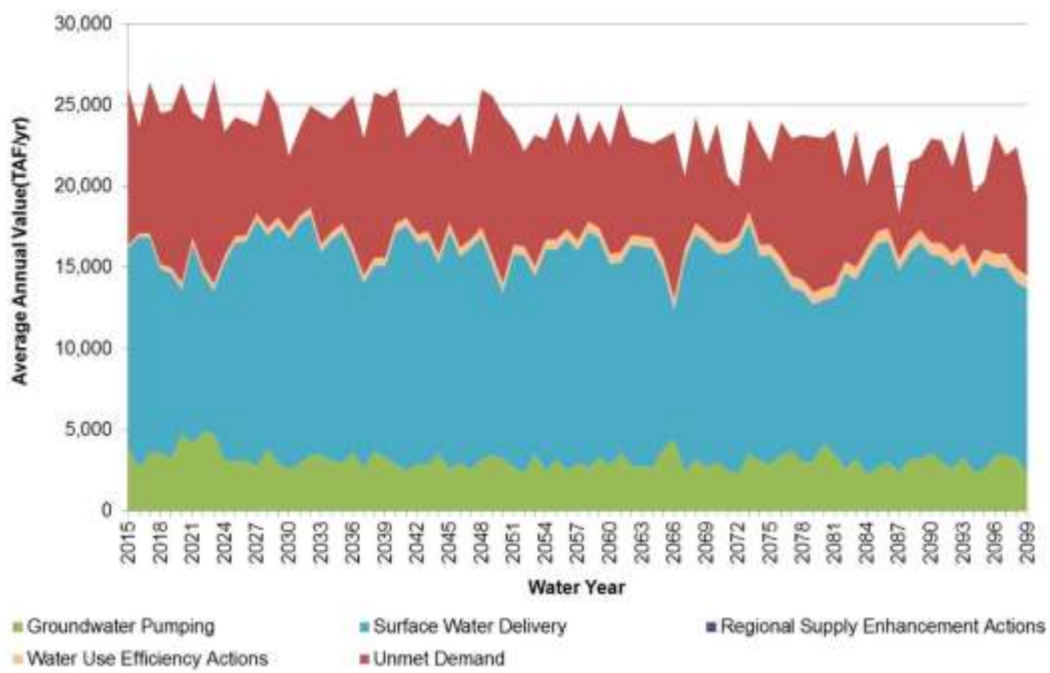


Figure 7-2e. Annual time series of supplies and unmet demand in the Central Valley in the **Delta Conveyance and Restoration Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

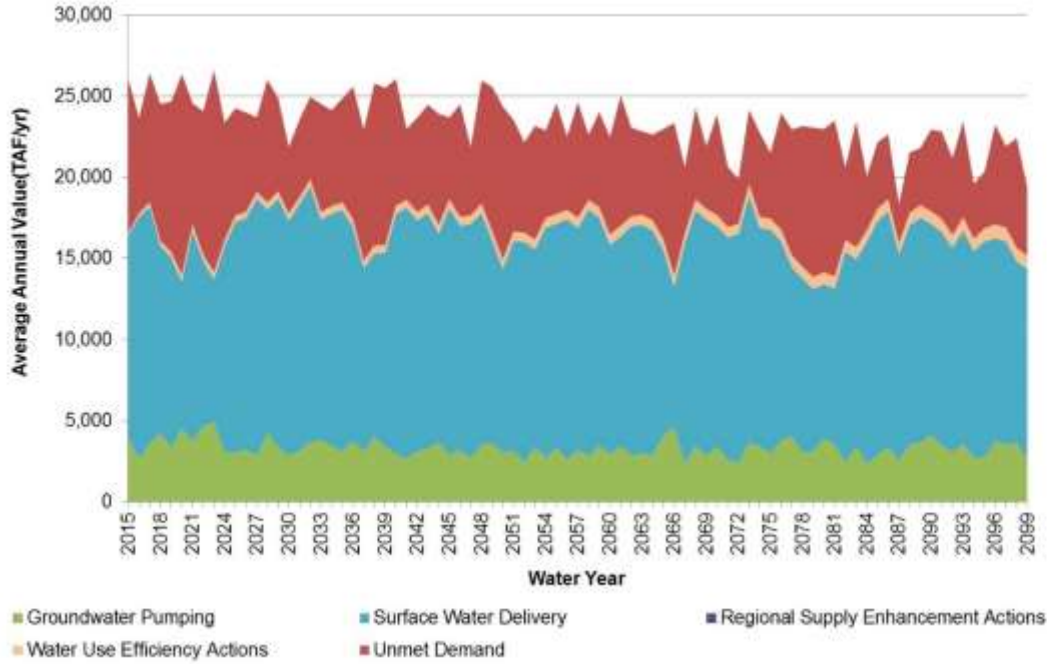


Figure 7-2f. Annual time series of supplies and unmet demand in the Central Valley in the **Expanded Water Storage and Groundwater Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

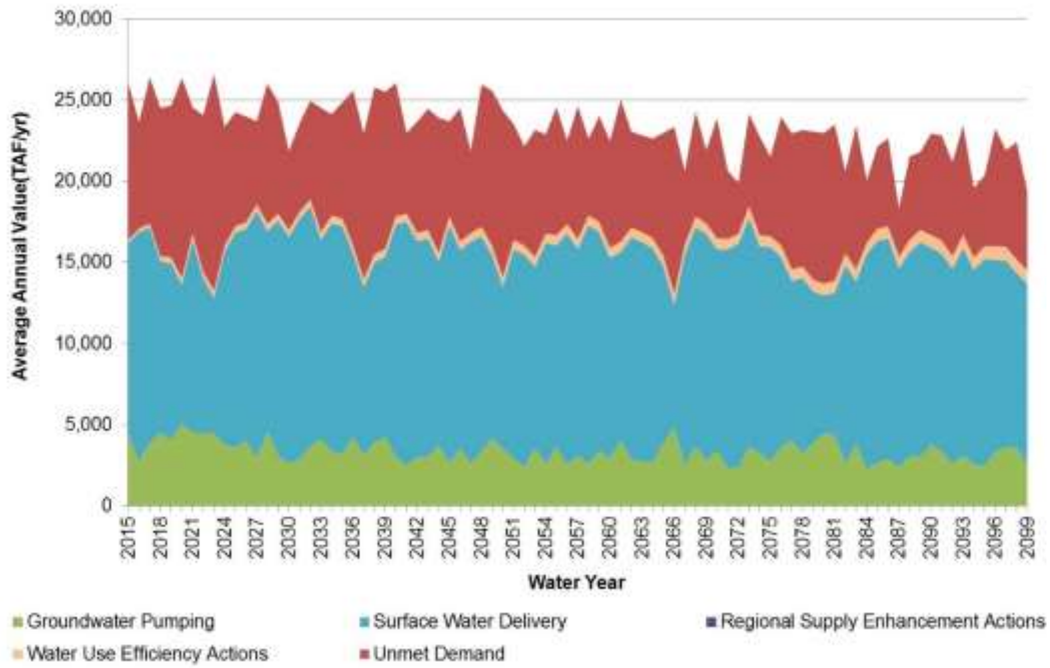


Figure 7-2g. Annual time series of supplies and unmet demand in the Central Valley in the **Flexible System Operations and Management Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

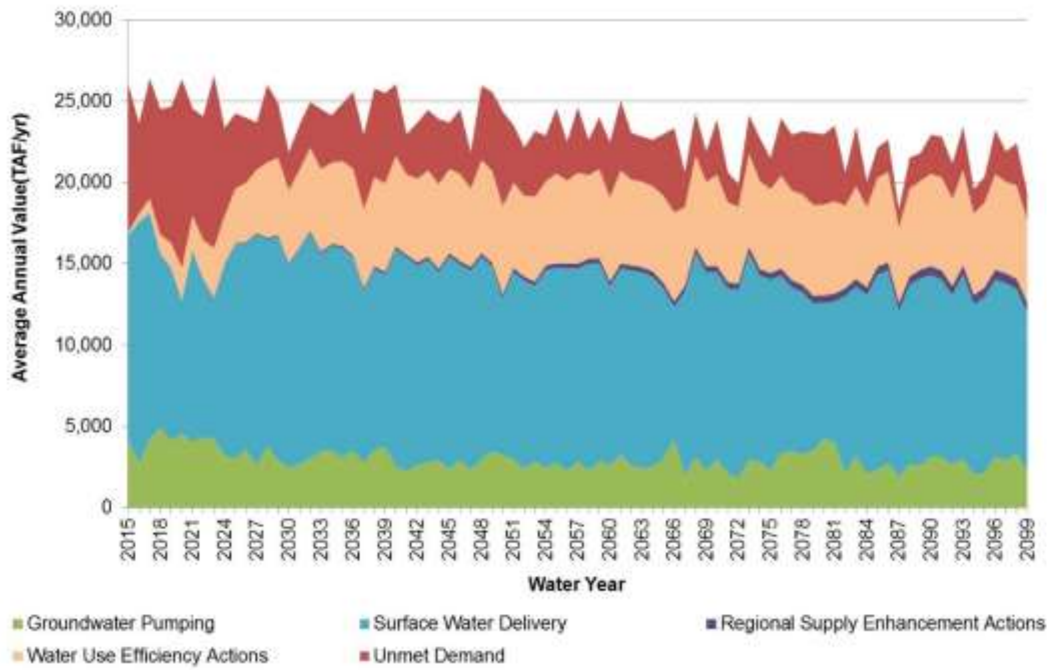


Figure 7-2h. Annual time series of supplies and unmet demand in the Central Valley in the **Water Action Plan Portfolio** in the Central Tendency climate/Current Trends socioeconomic scenarios.

Figure 7-3. Unmet demands: 10-year running average

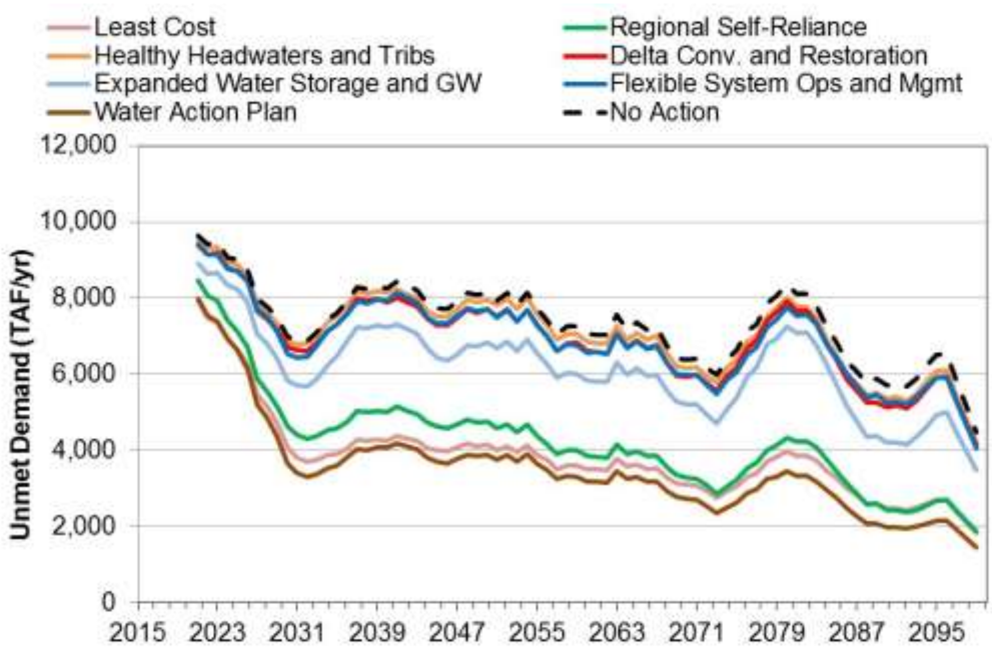


Figure 7-3a. 10-year running average of unmet demand in the **Central Valley** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

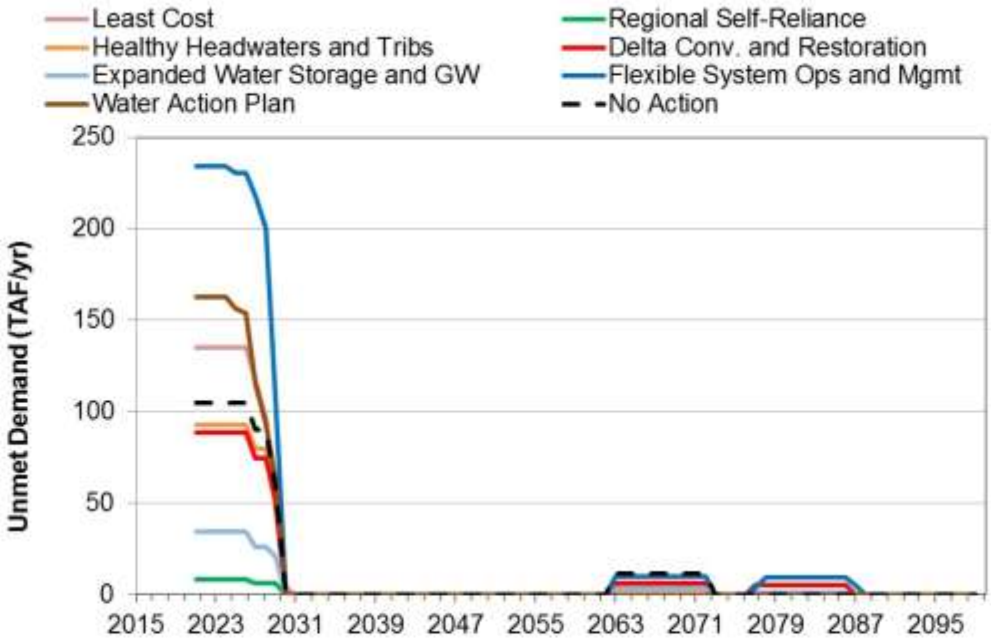


Figure 7-3b. 10-year running average of unmet demand in the **Sacramento River System** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Figure 7-3c. 10-Year Running Average of Unmet Demand in the **San Joaquin River** System in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

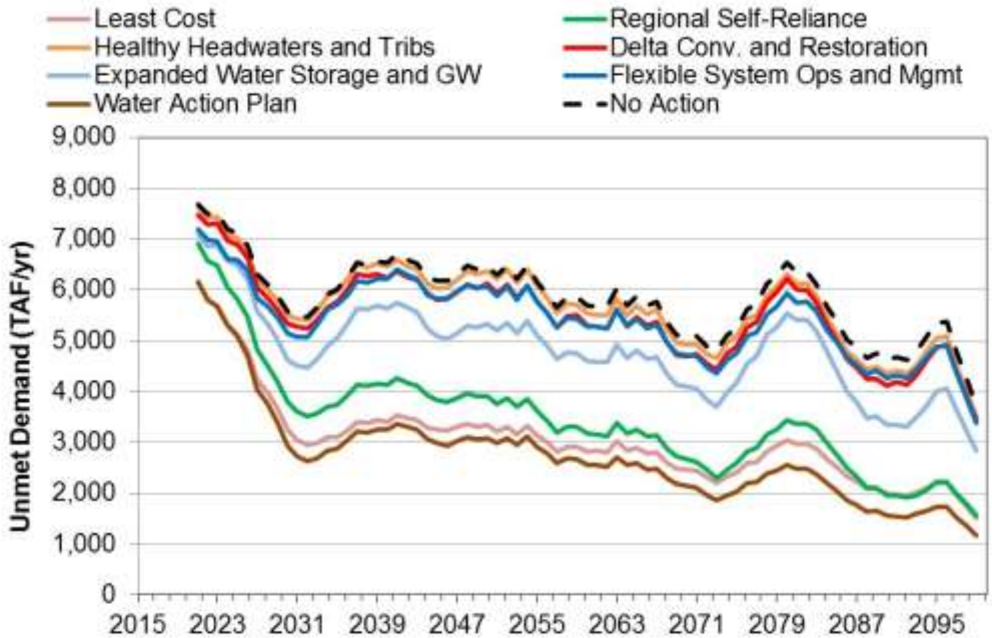


Figure 7-3d. 10-Year Running Average of Unmet Demand in the **Tulare Lake Region** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.[9]

[9] As Eastside streams and Delta have zero unmet demands, they are not shown.

Table 7-3. Unmet Demands: Adaptation Portfolio Comparison

Table 7-3a. Average Annual Unmet Demands in the **Central Valley** in Each Adaptation Portfolio (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	8,146	9,350	9,853	7,818	7,221	8,478
	2040-2069	7,092	8,620	9,364	6,675	6,064	7,434
	2070-2099	6,953	8,141	7,225	4,640	5,396	6,666
	2015-2099	**7,353**	**8,666**	**8,753**	**6,293**	**6,168**	**7,470**
Least Cost Portfolio	2015-2039	5,360	6,515	6,902	5,164	4,740	5,660
	2040-2069	3,519	4,364	4,854	3,304	2,925	3,747
	2070-2099	3,128	3,855	3,379	1,946	2,255	3,007
	2015-2099	**3,922**	**4,817**	**4,936**	**3,372**	**3,222**	**4,049**
Regional Self-Reliance Portfolio	2015-2039	6,023	6,977	7,404	5,798	5,243	6,296
	2040-2069	3,939	4,973	5,498	3,603	3,122	4,202
	2070-2099	3,242	4,128	3,608	1,904	2,231	3,121
	2015-2099	**4,306**	**5,264**	**5,392**	**3,649**	**3,431**	**4,436**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8,029	9,182	9,728	7,750	7,093	8,376
	2040-2069	6,904	8,383	9,048	6,452	5,833	7,237
	2070-2099	6,611	7,670	6,758	4,293	5,065	6,321
	2015-2099	**7,131**	**8,366**	**8,440**	**6,072**	**5,933**	**7,249**
Delta Conveyance and Restoration Portfolio	2015-2039	7,827	9,053	9,564	7,552	6,860	8,201
	2040-2069	6,577	8,141	8,857	6,170	5,535	6,989
	2070-2099	6,369	7,548	6,630	4,030	4,754	6,166
	2015-2099	**6,871**	**8,200**	**8,279**	**5,821**	**5,649**	**7,055**
Expanded Water Storage and Groundwater Portfolio	2015-2039	7,195	8,515	9,019	6,739	6,204	7,542
	2040-2069	5,987	7,505	8,259	5,395	4,958	6,190
	2070-2099	5,754	6,787	5,969	3,343	4,087	5,362
	2015-2099	**6,260**	**7,549**	**7,674**	**5,066**	**5,017**	**6,295**
Flexible System Operations and Mgmt Portfolio	2015-2039	7,804	8,947	9,482	7,542	6,964	8,162
	2040-2069	6,728	8,076	8,648	6,299	5,745	6,992
	2070-2099	6,491	7,481	6,580	4,228	5,001	6,144
	2015-2099	**6,961**	**8,122**	**8,164**	**5,934**	**5,841**	**7,037**
Water Action Plan Portfolio	2015-2039	5,236	6,343	6,719	4,980	4,553	5,513
	2040-2069	3,280	4,147	4,581	2,940	2,618	3,436
	2070-2099	2,734	3,382	2,827	1,588	1,910	2,506
	2015-2099	**3,663**	**4,523**	**4,591**	**3,063**	**2,937**	**3,718**

Table 7-3b. Average Annual Unmet Demands in the **Sacramento River System** in each Adaptation Portfolio in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24	96	122	17	3	42
	2040-2069	6	9	42	1	3	4
	2070-2099	0	44	44	0	0	0
	2015-2099	**9**	**47**	**66**	**5**	**2**	**14**
Least Cost Portfolio	2015-2039	40	97	104	10	11	54
	2040-2069	0	2	3	0	0	0
	2070-2099	0	0	2	0	0	0
	2015-2099	**12**	**29**	**32**	**3**	**3**	**16**
Regional Self-Reliance Portfolio	2015-2039	0	30	35	0	0	3
	2040-2069	0	0	0	0	0	0
	2070-2099	0	0	0	0	0	0
	2015-2099	**0**	**9**	**10**	**0**	**0**	**1**
Healthy Headwaters and Tributaries Portfolio	2015-2039	20	86	117	9	2	37
	2040-2069	3	9	21	1	1	2
	2070-2099	0	36	27	0	0	0
	2015-2099	**7**	**41**	**51**	**3**	**1**	**12**
Delta Conveyance and Restoration Portfolio	2015-2039	20	95	132	14	1	35
	2040-2069	2	4	17	1	1	2
	2070-2099	0	21	33	0	0	2
	2015-2099	**7**	**37**	**56**	**4**	**1**	**12**
Expanded Water Storage and Groundwater Portfolio	2015-2039	10	54	87	1	1	14
	2040-2069	2	6	9	1	0	1
	2070-2099	1	6	15	0	0	0
	2015-2099	**4**	**20**	**34**	**1**	**0**	**5**
Flexible System Operations and Mgmt Portfolio	2015-2039	66	163	193	79	37	94
	2040-2069	3	6	17	1	3	3
	2070-2099	0	11	39	0	0	3
	2015-2099	**20**	**54**	**77**	**24**	**12**	**30**
Water Action Plan Portfolio	2015-2039	46	123	135	43	31	65
	2040-2069	0	2	3	0	0	0
	2070-2099	0	2	3	0	0	0
	2015-2099	**14**	**37**	**42**	**13**	**9**	**19**

Table 7-3c. Average Annual Unmet Demands in the **San Joaquin River System** in each Adaptation Portfolio in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	1,655	1,923	2,071	1,573	1,463	1,707
	2040-2069	1,488	1,795	2,007	1,370	1,257	1,499
	2070-2099	1,462	1,711	1,409	881	1,098	1,328
	2015-2099	**1,528**	**1,803**	**1,815**	**1,257**	**1,261**	**1,500**
Least Cost Portfolio	2015-2039	1,122	1,383	1,495	1,073	998	1,167
	2040-2069	728	880	1,013	690	620	742
	2070-2099	695	827	690	400	507	633
	2015-2099	**832**	**1,009**	**1,041**	**700**	**691**	**829**
Regional Self-Reliance Portfolio	2015-2039	1,112	1,316	1,421	1,071	989	1,142
	2040-2069	745	895	1,012	695	616	753
	2070-2099	681	817	661	397	496	610
	2015-2099	**830**	**991**	**1,008**	**701**	**684**	**817**
Healthy Headwaters and Tributaries Portfolio	2015-2039	1,604	1,862	2,022	1,537	1,424	1,669
	2040-2069	1,429	1,682	1,917	1,319	1,205	1,431
	2070-2099	1,364	1,575	1,272	813	1,023	1,225
	2015-2099	**1,457**	**1,697**	**1,720**	**1,205**	**1,205**	**1,428**
Delta Conveyance and Restoration Portfolio	2015-2039	1,598	1,856	1,993	1,534	1,421	1,657
	2040-2069	1,414	1,684	1,890	1,318	1,202	1,433
	2070-2099	1,369	1,594	1,281	821	1,026	1,227
	2015-2099	**1,452**	**1,703**	**1,705**	**1,206**	**1,204**	**1,426**
Expanded Water Storage and Groundwater Portfolio	2015-2039	1,523	1,811	1,946	1,423	1,320	1,585
	2040-2069	1,350	1,627	1,836	1,228	1,134	1,329
	2070-2099	1,315	1,522	1,234	752	951	1,158
	2015-2099	**1,389**	**1,644**	**1,656**	**1,117**	**1,124**	**1,344**
Flexible System Operations and Mgmt Portfolio	2015-2039	1,684	1,962	2,126	1,595	1,478	1,750
	2040-2069	1,432	1,766	1,970	1,316	1,209	1,451
	2070-2099	1,387	1,658	1,359	813	1,042	1,257
	2015-2099	**1,490**	**1,786**	**1,800**	**1,221**	**1,230**	**1,471**
Water Action Plan Portfolio	2015-2039	1,100	1,365	1,472	1,029	952	1,138
	2040-2069	695	859	981	632	569	704
	2070-2099	649	775	637	355	455	573
	2015-2099	**798**	**978**	**1,004**	**651**	**642**	**785**

Table 7-3d. Average Annual Unmet Demands in the **Tulare Lake** Region in each Adaptation Portfolio in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	6,468	7,331	7,660	6,228	5,755	6,729
	2040-2069	5,599	6,816	7,315	5,304	4,804	5,932
	2070-2099	5,490	6,386	5,772	3,759	4,298	5,338
	2015-2099	**5,816**	**6,816**	**6,872**	**5,031**	**4,905**	**5,957**
Least Cost Portfolio	2015-2039	4,198	5,035	5,303	4,082	3,732	4,439
	2040-2069	2,791	3,482	3,839	2,614	2,306	3,005
	2070-2099	2,433	3,028	2,688	1,546	1,748	2,374
	2015-2099	**3,078**	**3,779**	**3,863**	**2,669**	**2,528**	**3,204**
Regional Self-Reliance Portfolio	2015-2039	4,910	5,632	5,948	4,727	4,254	5,150
	2040-2069	3,194	4,078	4,485	2,908	2,505	3,449
	2070-2099	2,561	3,311	2,948	1,506	1,735	2,511
	2015-2099	**3,475**	**4,264**	**4,373**	**2,948**	**2,748**	**3,618**
Healthy Headwaters and Tributaries Portfolio	2015-2039	6,405	7,234	7,590	6,204	5,667	6,671
	2040-2069	5,472	6,693	7,111	5,132	4,627	5,804
	2070-2099	5,247	6,058	5,458	3,480	4,042	5,096
	2015-2099	**5,667**	**6,628**	**6,668**	**4,864**	**4,726**	**5,809**
Delta Conveyance and Restoration Portfolio	2015-2039	6,209	7,101	7,439	6,005	5,438	6,508
	2040-2069	5,161	6,453	6,950	4,852	4,332	5,553
	2070-2099	5,000	5,933	5,316	3,210	3,728	4,937
	2015-2099	**5,412**	**6,460**	**6,517**	**4,611**	**4,444**	**5,617**
Expanded Water Storage and Groundwater Portfolio	2015-2039	5,662	6,650	6,986	5,315	4,883	5,943
	2040-2069	4,635	5,872	6,414	4,166	3,824	4,860
	2070-2099	4,438	5,258	4,720	2,591	3,136	4,204
	2015-2099	**4,868**	**5,884**	**5,985**	**3,948**	**3,893**	**4,947**
Flexible System Operations and Mgmt Portfolio	2015-2039	6,053	6,822	7,164	5,868	5,449	6,318
	2040-2069	5,293	6,303	6,660	4,982	4,533	5,537
	2070-2099	5,103	5,813	5,183	3,415	3,958	4,884
	2015-2099	**5,450**	**6,283**	**6,287**	**4,689**	**4,599**	**5,536**
Water Action Plan Portfolio	2015-2039	4,090	4,855	5,111	3,908	3,570	4,310
	2040-2069	2,585	3,286	3,598	2,308	2,048	2,732
	2070-2099	2,086	2,605	2,187	1,233	1,455	1,932
	2015-2099	**2,851**	**3,507**	**3,545**	**2,399**	**2,286**	**2,914**

7.2.2. 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)[10] 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 below reservoir storage than under the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF)[11], while the Warm-Wet climate scenario had fewer periods of below reservoir storage. See Section 5.2.2.2. *End-of-September System Storage.*

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

All adaptation portfolios show similar variability as the storage levels varied year-to-year with the hydrology. The differences between the adaptation portfolios increase as the simulation moves towards the end of the 21st century as water management actions are implemented.

More overall storage. The Least Cost, Regional Self Reliance, Flexible System Operations and Water Action Plan portfolios showed improvements in overall Sacramento, San Joaquin and Tulare regional storage levels across the range of climate scenarios relative to the No Action alternative, with the greatest improvement occurring in the Least Cost portfolio.

More carryover storage. The Least Cost, Regional Self-Reliance and Water Action Plan portfolios had significantly more carryover storage in the upstream reservoirs and in San Luis Reservoir than the No Action alternative due to demand reductions in the Sacramento and San Joaquin Valleys and to the effects of regulatory flexibility actions that are included in those portfolios. The Expanded Water Storage and Groundwater portfolio also increased overall system carryover storage due to the new storage actions that are included.

Less carryover storage. In contrast, the Healthy Headwaters and Tributaries and Delta Conveyance portfolios performed only as well as or worse than the No Action alternative in each region. Upstream carryover storage levels were reduced in the Healthy Headwaters and Tributaries portfolio due to releases required for the tributary environmental flow action.

7.2.2.1. Adaptation Portfolio Performance

All adaptation portfolios showed increases in storage under the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) (Figure 7-4). 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 portfolios performed less well than the No Action alternative.

Table 7-4 shows details of the performance of each of the adaptation portfolios relative to the No Action alternative in four climate scenarios.

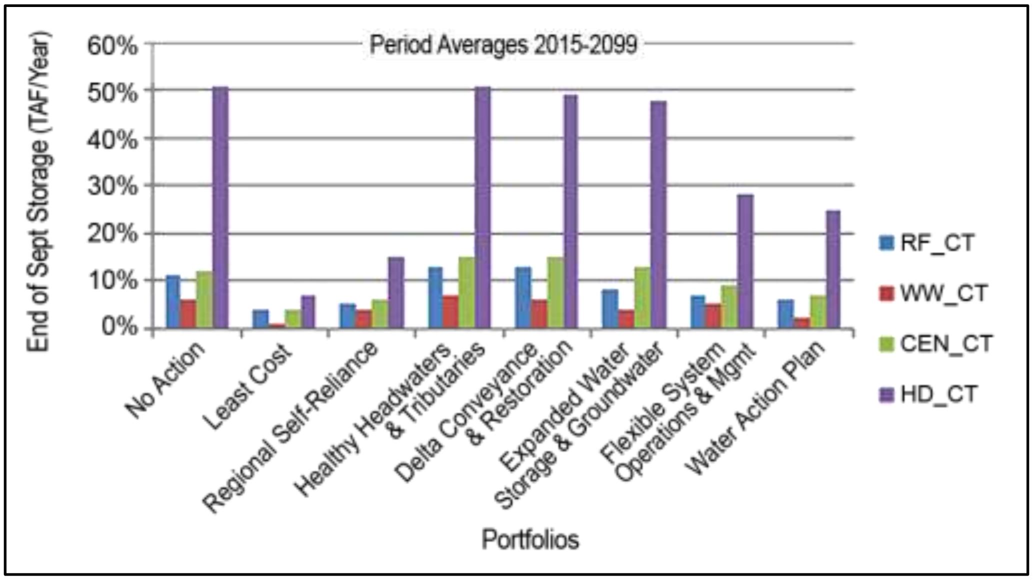

Figure 7-4. End-of-September storage targets: adaptation portfolio performance

(Percentage of years with Sacramento Valley end-of-September storage less than the 10th percentile of storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios.[12]) (Lower numbers indicate increased benefits)

Table 7-4. 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

7.2.2.2. Adaptation Portfolio Climate Sensitivity

[12] 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 (RF_RF).

Table 7-5 shows the 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 7-5. End-of-September Storage Targets: Climate Scenario Sensitivity

(% 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

Figure 7-5 shows exceedance plots of storage at the end of September in the Central Tendency climate/Current Trends socioeconomic scenarios in Shasta, Folsom, Oroville, New Melones and San Luis reservoirs and for total Central Valley, the Sacramento Valley (including Shasta, New Bullards Bar, Oroville, and Folsom reservoirs), San Joaquin Valley (including New Don Pedro, McClure, New Melones, and Millerton reservoirs) and Tulare Lake region (including Pine Flat, Kaweah, Success, and Isabella reservoirs) for each adaptation portfolio.

Figure 7-6 shows the 10-year moving average of end-of-September storage in the Central Tendency climate/Current Trends socioeconomic scenarios in the total Central Valley, Sacramento Valley, San Joaquin Valley, and Tulare Lake region for each adaptation portfolio.

Table 7-6 presents the percentage of time that end-of-September storage is less than the 10th percentile storage value under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-5: End-of-September: exceedance plots.

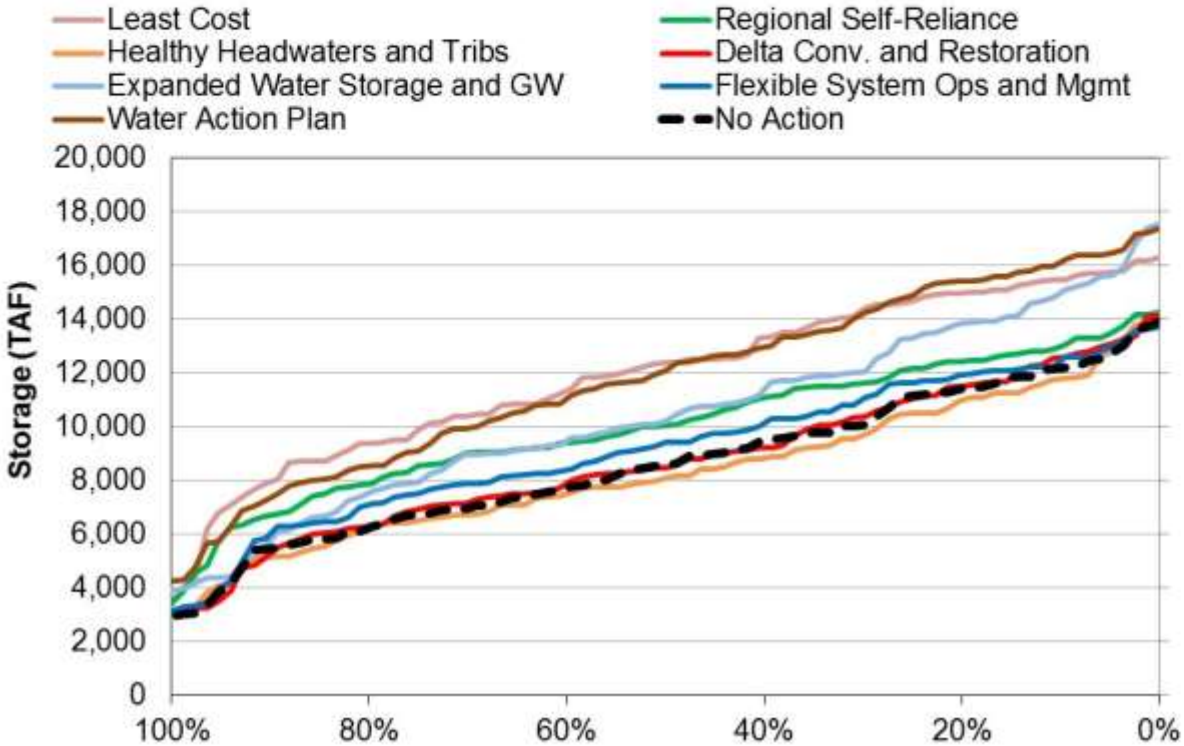

Figure 7-5a. Exceedance plot of **total Central Valley** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

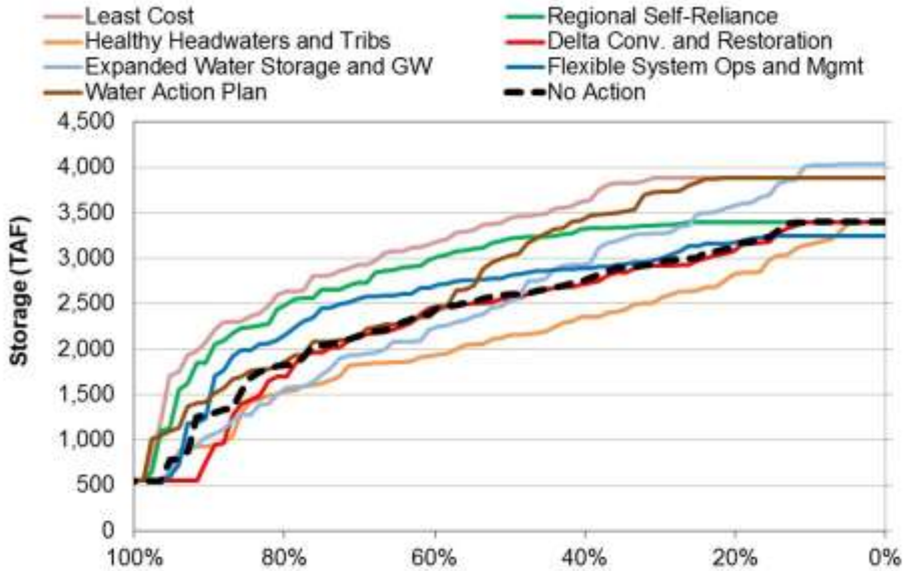

Figure 7-5b. Exceedance plot of **Lake Shasta** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

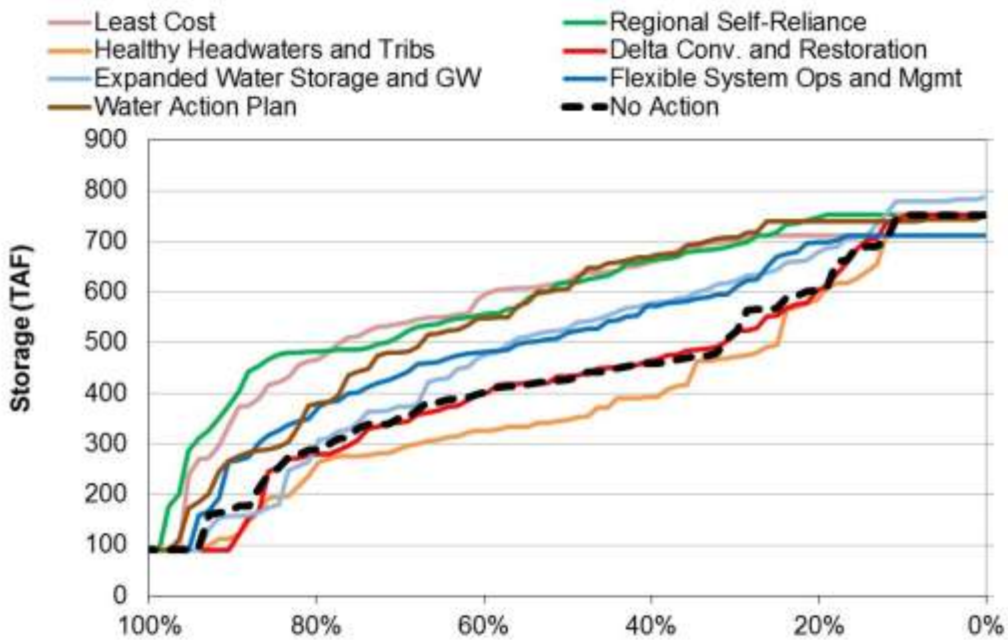

Figure 7-5c. Exceedance plot of **Folsom Lake** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

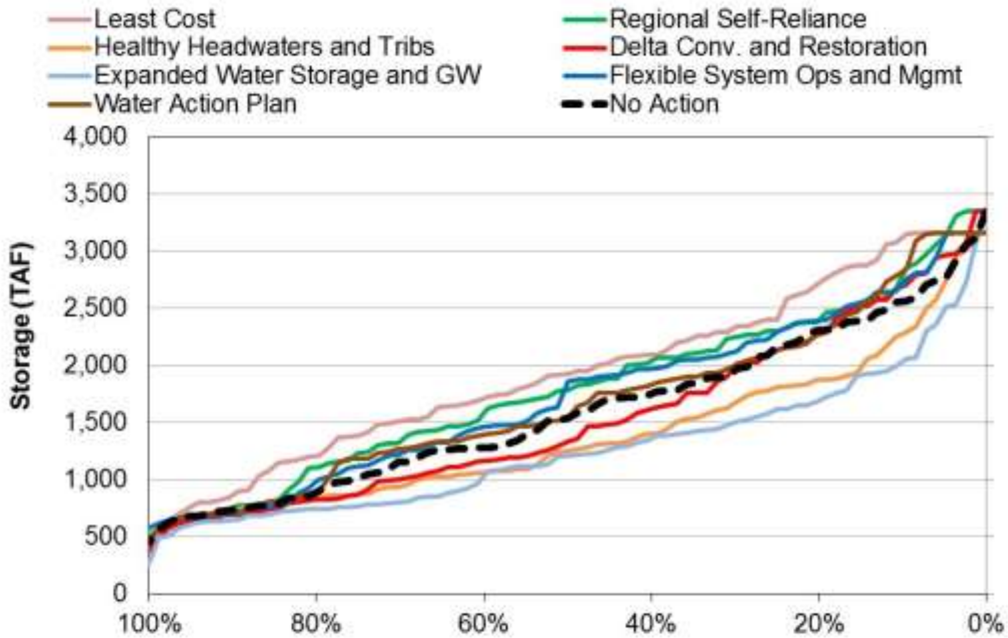

Figure 7-5d. Exceedance plot of **Lake Oroville** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

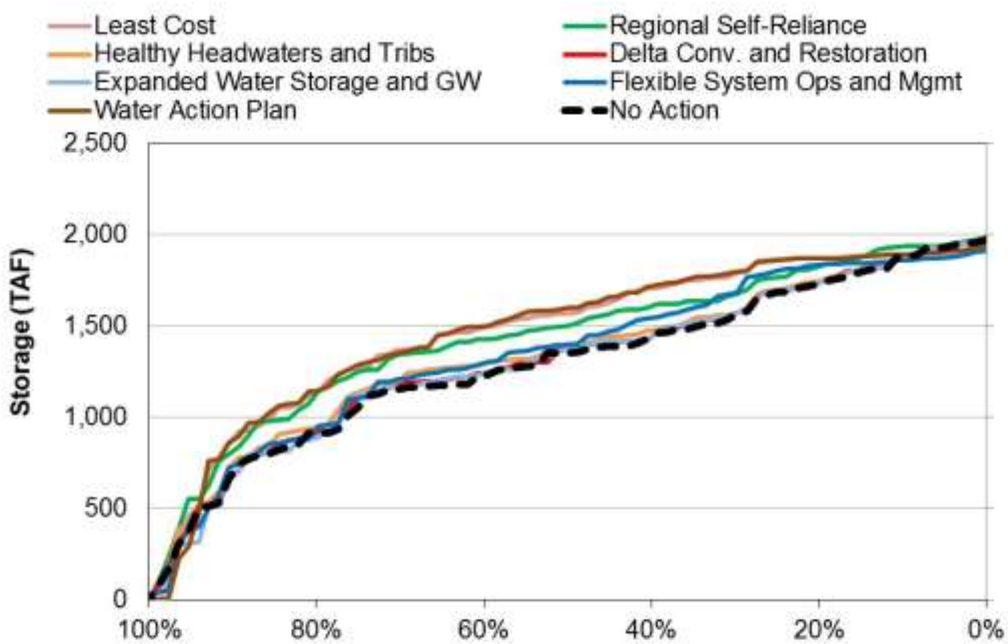

Figure 7-5e. Exceedance plot of **New Melones Reservoir** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

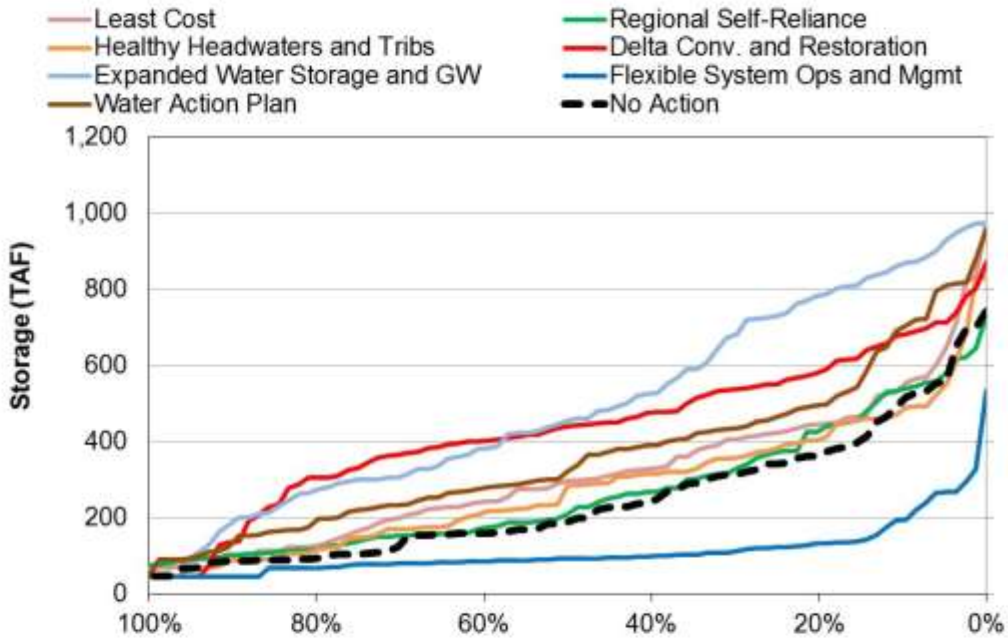

Figure 7-5f. Exceedance plot of **CVP San Luis** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

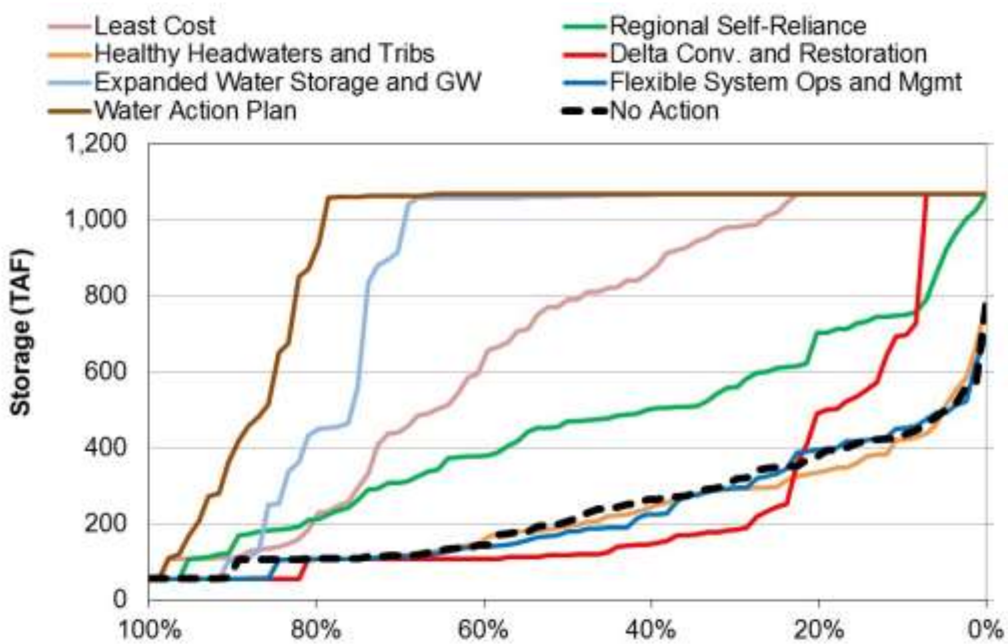

Figure 7-5g. Exceedance plot of **SWP San Luis** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

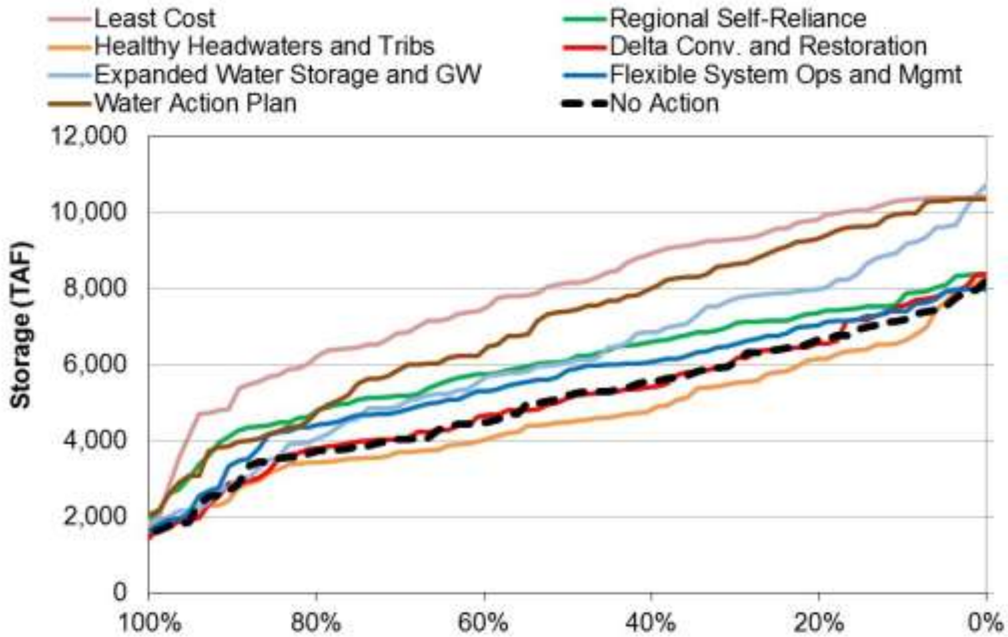

Figure 7-5h. Exceedance plot of **Sacramento Valley** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

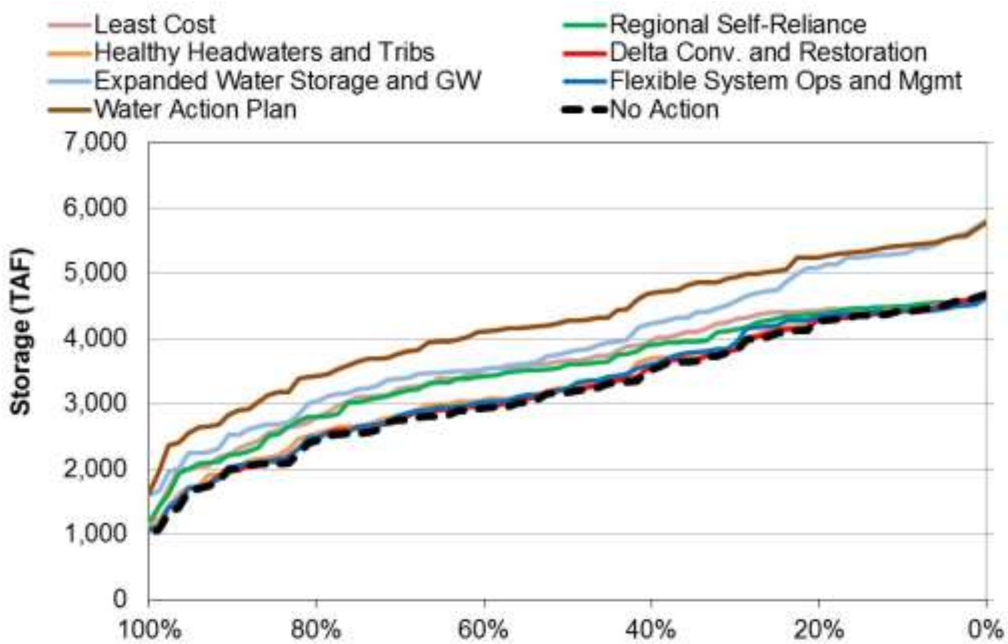

Figure 7-5i. Exceedance plot of **San Joaquin Valley** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

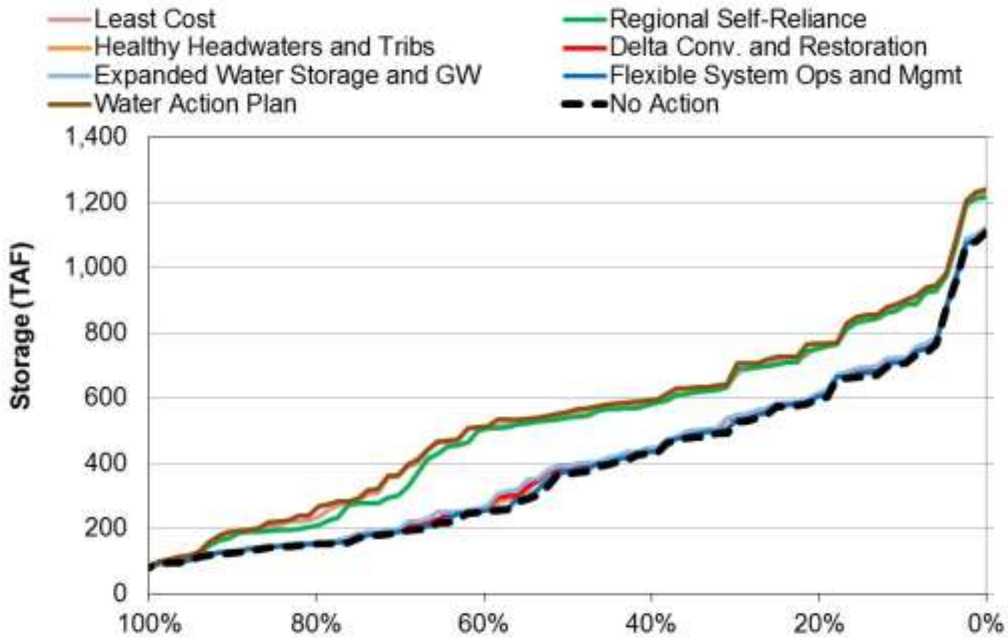

Figure 7-5j. Exceedance Plot of **Tulare Lake Region** end-of-September storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Figure 7-6. End-of-September Storage: 10-year moving average

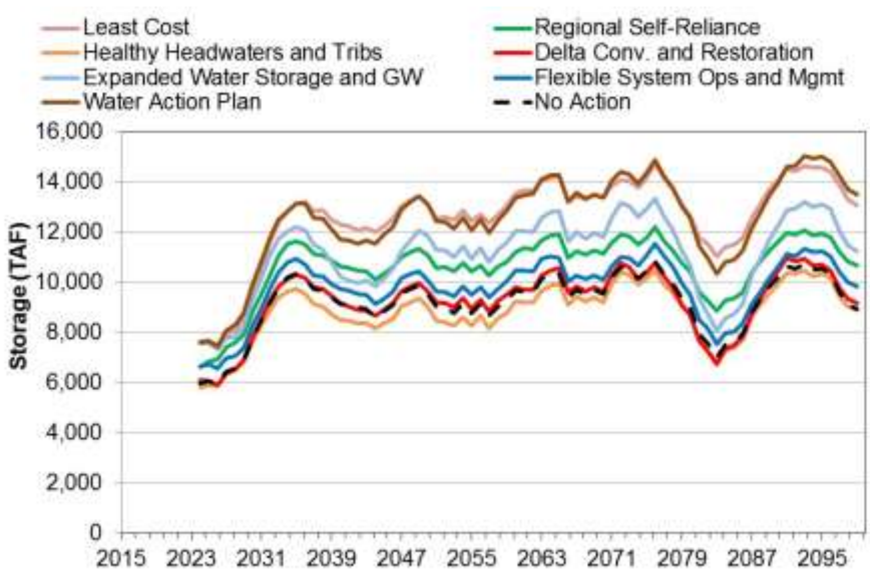

Figure 7-6a. 10-year moving average of total annual end-of-September storage in the **Central Valley** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

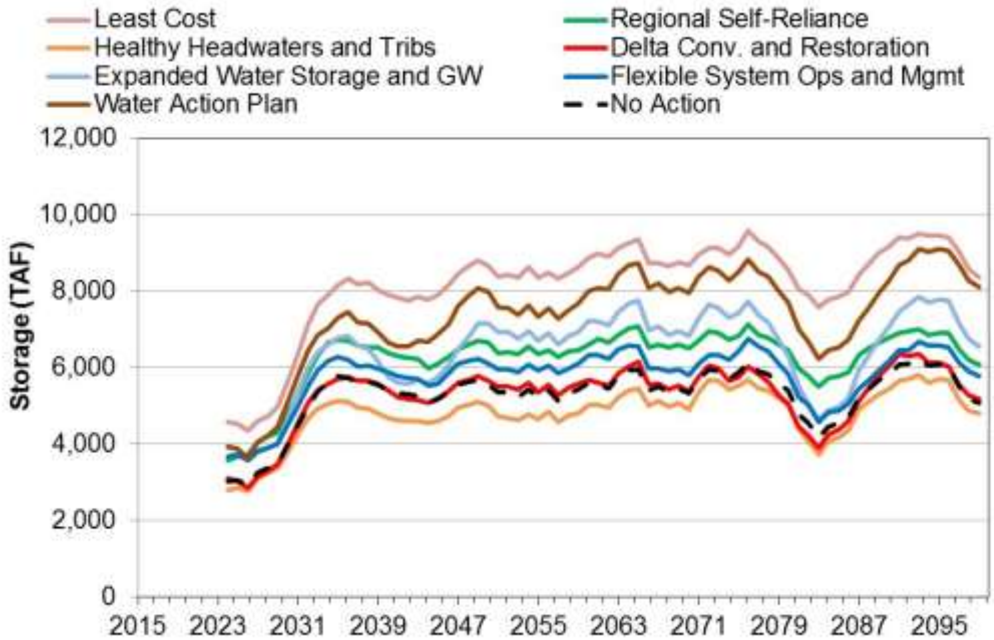

Figure 7-6b. 10-year moving average of total annual end-of-September storage in the **Sacramento Valley** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

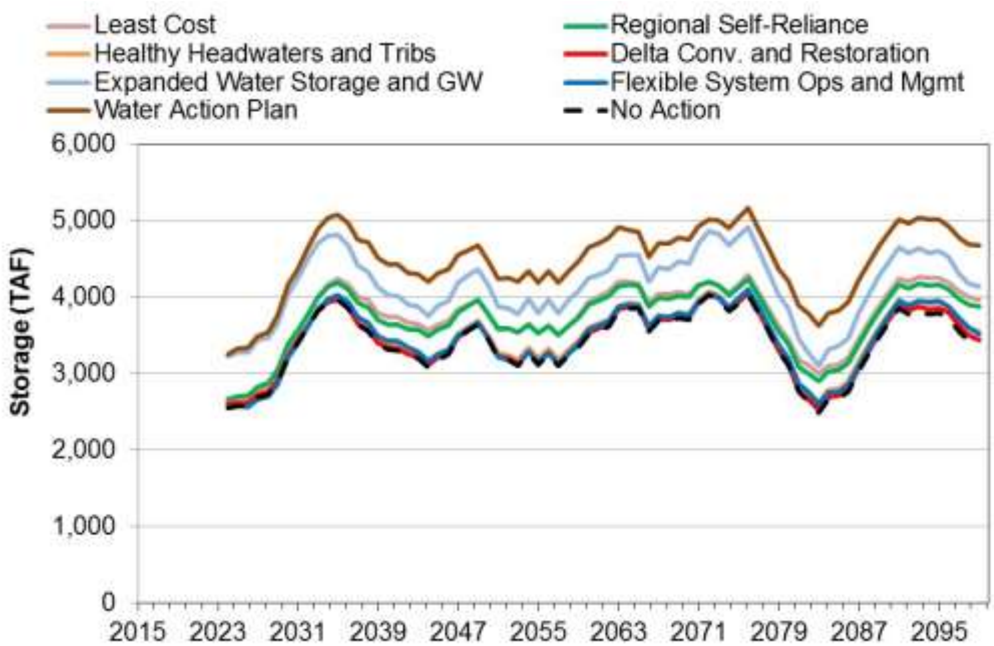

Figure 7-6c. 10-year moving average of total annual end-of-September storage in the **San Joaquin Valley** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

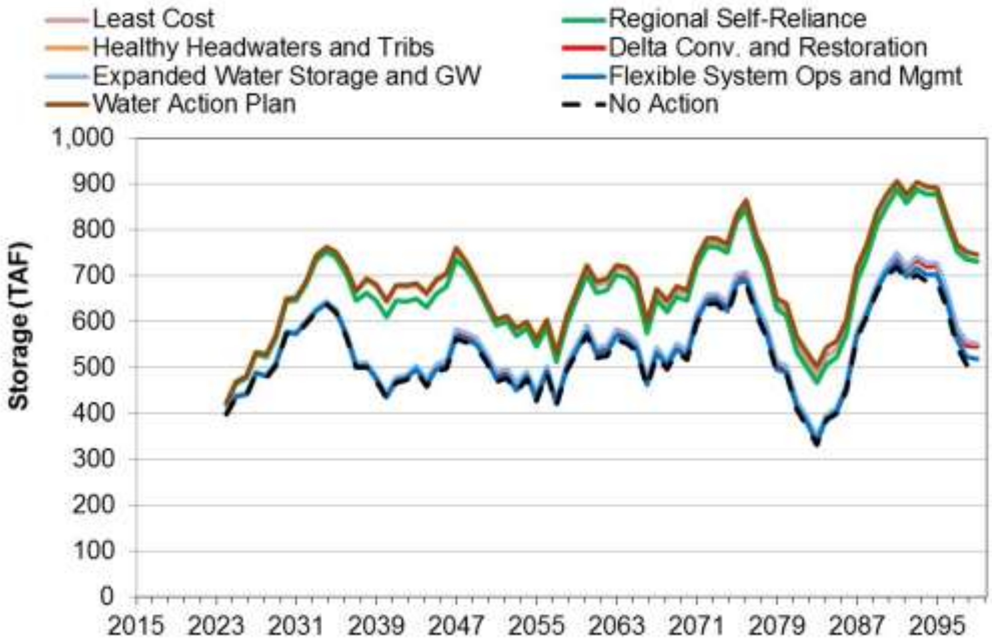

Figure 7-6d. 10-year moving average of total annual end-of-September storage in the **Tulare Lake Region** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-6. End-of-September Storage: Adaptation Portfolio Comparison

Table 7-6a. Percentage of Years with **Lake Shasta** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	32%	52%	56%	24%	16%	32%
	2040-2069	3%	17%	43%	3%	0%	3%
	2070-2099	0%	23%	47%	0%	0%	10%
	2015-2099	**11%**	**29%**	**48%**	**8%**	**5%**	**14%**
Least Cost Portfolio	2015-2039	16%	24%	28%	16%	4%	16%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	0%	0%	3%	0%	0%	0%
	2015-2099	**5%**	**8%**	**11%**	**5%**	**1%**	**5%**
Regional Self-Reliance Portfolio	2015-2039	20%	32%	36%	28%	16%	20%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	0%	0%	17%	0%	0%	0%
	2015-2099	**6%**	**11%**	**18%**	**8%**	**5%**	**6%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	40%	56%	76%	28%	24%	40%
	2040-2069	3%	30%	60%	0%	0%	3%
	2070-2099	7%	27%	53%	0%	0%	13%
	2015-2099	**15%**	**36%**	**62%**	**8%**	**7%**	**18%**
Delta Conveyance and Restoration Portfolio	2015-2039	32%	56%	60%	24%	16%	36%
	2040-2069	3%	17%	50%	0%	0%	3%
	2070-2099	7%	30%	47%	0%	0%	13%
	2015-2099	**13%**	**33%**	**52%**	**7%**	**5%**	**16%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	40%	44%	60%	16%	20%	40%
	2040-2069	3%	27%	57%	0%	3%	3%
	2070-2099	7%	33%	53%	0%	0%	17%
	2015-2099	**15%**	**34%**	**56%**	**5%**	**7%**	**19%**
Flexible System Operations and Mgmt Portfolio	2015-2039	20%	40%	48%	16%	16%	20%
	2040-2069	3%	3%	23%	3%	3%	3%
	2070-2099	3%	13%	30%	0%	0%	10%
	2015-2099	**8%**	**18%**	**33%**	**6%**	**6%**	**11%**
Water Action Plan Portfolio	2015-2039	32%	52%	64%	24%	16%	28%
	2040-2069	3%	13%	30%	3%	3%	3%
	2070-2099	3%	20%	23%	0%	0%	3%
	2015-2099	**12%**	**27%**	**38%**	**8%**	**6%**	**11%**

Table 7-6b. Percentage of Years with **Folsom Lake** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	32%	52%	56%	20%	12%	32%
	2040-2069	3%	17%	43%	3%	3%	3%
	2070-2099	0%	27%	47%	0%	0%	10%
	2015-2099	**11%**	**31%**	**48%**	**7%**	**5%**	**14%**
Least Cost Portfolio	2015-2039	12%	16%	20%	12%	12%	12%
	2040-2069	3%	3%	3%	0%	3%	3%
	2070-2099	0%	7%	3%	0%	0%	0%
	2015-2099	**5%**	**8%**	**8%**	**4%**	**5%**	**5%**
Regional Self-Reliance Portfolio	2015-2039	12%	16%	24%	20%	8%	12%
	2040-2069	3%	3%	3%	0%	0%	3%
	2070-2099	0%	0%	10%	0%	0%	0%
	2015-2099	**5%**	**6%**	**12%**	**6%**	**2%**	**5%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	40%	60%	68%	24%	16%	48%
	2040-2069	7%	27%	50%	3%	3%	3%
	2070-2099	7%	27%	53%	0%	0%	13%
	2015-2099	**16%**	**36%**	**56%**	**8%**	**6%**	**20%**
Delta Conveyance and Restoration Portfolio	2015-2039	32%	52%	56%	20%	16%	32%
	2040-2069	3%	13%	47%	0%	3%	3%
	2070-2099	7%	30%	47%	0%	0%	10%
	2015-2099	**13%**	**31%**	**49%**	**6%**	**6%**	**14%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	20%	40%	52%	12%	16%	32%
	2040-2069	3%	17%	37%	0%	3%	3%
	2070-2099	10%	33%	53%	0%	0%	17%
	2015-2099	**11%**	**29%**	**47%**	**4%**	**6%**	**16%**
Flexible System Operations and Mgmt Portfolio	2015-2039	12%	28%	36%	12%	12%	16%
	2040-2069	3%	3%	23%	3%	3%	3%
	2070-2099	3%	13%	30%	0%	0%	10%
	2015-2099	**6%**	**14%**	**29%**	**5%**	**5%**	**9%**
Water Action Plan Portfolio	2015-2039	28%	36%	48%	20%	16%	20%
	2040-2069	3%	20%	27%	3%	3%	3%
	2070-2099	7%	20%	27%	0%	0%	3%
	2015-2099	**12%**	**25%**	**33%**	**7%**	**6%**	**8%**

Table 7-6c. Percentage of Years with **Lake Oroville** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24%	24%	24%	8%	4%	16%
	2040-2069	7%	20%	27%	3%	3%	7%
	2070-2099	3%	27%	47%	0%	0%	13%
	2015-2099	**11%**	**24%**	**33%**	**4%**	**2%**	**12%**
Least Cost Portfolio	2015-2039	12%	16%	16%	4%	4%	12%
	2040-2069	3%	3%	10%	3%	3%	3%
	2070-2099	3%	7%	7%	0%	0%	0%
	2015-2099	**6%**	**8%**	**11%**	**2%**	**2%**	**5%**
Regional Self-Reliance Portfolio	2015-2039	4%	12%	4%	8%	4%	8%
	2040-2069	7%	10%	10%	3%	0%	10%
	2070-2099	7%	13%	30%	0%	0%	13%
	2015-2099	**6%**	**12%**	**15%**	**4%**	**1%**	**11%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	24%	20%	32%	8%	4%	16%
	2040-2069	10%	13%	30%	3%	3%	7%
	2070-2099	7%	23%	43%	0%	0%	13%
	2015-2099	**13%**	**19%**	**35%**	**4%**	**2%**	**12%**
Delta Conveyance and Restoration Portfolio	2015-2039	20%	32%	28%	8%	8%	28%
	2040-2069	7%	17%	33%	3%	3%	10%
	2070-2099	10%	37%	43%	0%	0%	10%
	2015-2099	**12%**	**28%**	**35%**	**4%**	**4%**	**15%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	24%	28%	28%	8%	12%	24%
	2040-2069	17%	27%	43%	3%	3%	20%
	2070-2099	17%	27%	47%	3%	0%	23%
	2015-2099	**19%**	**27%**	**40%**	**5%**	**5%**	**22%**
Flexible System Operations and Mgmt Portfolio	2015-2039	12%	16%	16%	12%	8%	24%
	2040-2069	7%	20%	17%	3%	3%	7%
	2070-2099	0%	20%	37%	0%	3%	10%
	2015-2099	**6%**	**19%**	**24%**	**5%**	**5%**	**13%**
Water Action Plan Portfolio	2015-2039	20%	28%	24%	8%	8%	20%
	2040-2069	7%	23%	33%	3%	3%	3%
	2070-2099	10%	13%	30%	3%	7%	17%
	2015-2099	**12%**	**21%**	**29%**	**5%**	**6%**	**13%**

Table 7-6d. Percentage of Years with **New Melones** Reservoir End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24%	44%	48%	16%	16%	24%
	2040-2069	0%	37%	40%	0%	0%	0%
	2070-2099	10%	27%	20%	0%	0%	10%
	2015-2099	11%	35%	35%	5%	5%	11%
Least Cost Portfolio	2015-2039	24%	40%	40%	12%	16%	24%
	2040-2069	0%	0%	7%	0%	0%	0%
	2070-2099	0%	10%	10%	0%	0%	0%
	2015-2099	7%	15%	18%	4%	5%	7%
Regional Self-Reliance Portfolio	2015-2039	24%	40%	40%	12%	16%	24%
	2040-2069	0%	7%	13%	0%	0%	0%
	2070-2099	3%	17%	13%	0%	0%	3%
	2015-2099	8%	20%	21%	4%	5%	8%
Healthy Headwaters and Tributaries Portfolio	2015-2039	24%	44%	44%	12%	16%	24%
	2040-2069	0%	27%	23%	0%	0%	0%
	2070-2099	7%	17%	20%	0%	0%	7%
	2015-2099	9%	28%	28%	4%	5%	9%
Delta Conveyance and Restoration Portfolio	2015-2039	24%	44%	48%	12%	16%	24%
	2040-2069	0%	27%	33%	0%	0%	0%
	2070-2099	10%	23%	20%	0%	0%	10%
	2015-2099	11%	31%	33%	4%	5%	11%
Expanded Water Storage and Groundwater Portfolio	2015-2039	24%	44%	48%	12%	16%	24%
	2040-2069	0%	40%	37%	0%	0%	0%
	2070-2099	10%	23%	20%	0%	0%	10%
	2015-2099	11%	35%	34%	4%	5%	11%
Flexible System Operations and Mgmt Portfolio	2015-2039	24%	44%	48%	16%	16%	24%
	2040-2069	0%	27%	33%	0%	0%	0%
	2070-2099	7%	20%	17%	0%	0%	7%
	2015-2099	9%	29%	32%	5%	5%	9%
Water Action Plan Portfolio	2015-2039	24%	36%	40%	16%	20%	24%
	2040-2069	0%	3%	7%	0%	0%	0%
	2070-2099	0%	13%	10%	0%	0%	0%
	2015-2099	7%	16%	18%	5%	6%	7%

Table 7-6e. Percentage of Years with **CVP San Luis** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	8%	12%	16%	0%	0%	4%
	2040-2069	7%	20%	20%	0%	0%	3%
	2070-2099	7%	17%	17%	3%	0%	3%
	2015-2099	**7%**	**16%**	**18%**	**1%**	**0%**	**4%**
Least Cost Portfolio	2015-2039	0%	12%	8%	0%	0%	0%
	2040-2069	0%	0%	0%	3%	0%	0%
	2070-2099	0%	7%	10%	0%	0%	0%
	2015-2099	**0%**	**6%**	**6%**	**1%**	**0%**	**0%**
Regional Self-Reliance Portfolio	2015-2039	8%	0%	0%	0%	0%	0%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	7%	7%	3%	0%	0%	0%
	2015-2099	**5%**	**4%**	**2%**	**0%**	**0%**	**0%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8%	8%	20%	0%	0%	8%
	2040-2069	7%	10%	27%	0%	0%	3%
	2070-2099	0%	7%	17%	0%	0%	3%
	2015-2099	**5%**	**8%**	**21%**	**0%**	**0%**	**5%**
Delta Conveyance and Restoration Portfolio	2015-2039	4%	4%	0%	0%	0%	0%
	2040-2069	0%	0%	3%	0%	0%	10%
	2070-2099	3%	10%	7%	3%	0%	10%
	2015-2099	**2%**	**5%**	**4%**	**1%**	**0%**	**7%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	0%	0%	0%	0%	0%	0%
	2040-2069	0%	0%	3%	0%	0%	0%
	2070-2099	3%	3%	10%	0%	0%	3%
	2015-2099	**1%**	**1%**	**5%**	**0%**	**0%**	**1%**
Flexible System Operations and Mgmt Portfolio	2015-2039	20%	24%	28%	12%	16%	24%
	2040-2069	0%	23%	20%	0%	3%	3%
	2070-2099	7%	30%	37%	3%	3%	17%
	2015-2099	**8%**	**26%**	**28%**	**5%**	**7%**	**14%**
Water Action Plan Portfolio	2015-2039	0%	4%	8%	4%	0%	4%
	2040-2069	0%	0%	3%	0%	0%	0%
	2070-2099	0%	3%	3%	0%	0%	0%
	2015-2099	**0%**	**2%**	**5%**	**1%**	**0%**	**1%**

Table 7-6f. Percentage of Years with **SWP San Luis** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24%	24%	28%	8%	8%	20%
	2040-2069	7%	23%	33%	0%	3%	3%
	2070-2099	7%	30%	43%	3%	0%	3%
	2015-2099	**12%**	**26%**	**35%**	**4%**	**4%**	**8%**
Least Cost Portfolio	2015-2039	4%	16%	16%	0%	0%	8%
	2040-2069	0%	0%	3%	0%	0%	0%
	2070-2099	0%	7%	13%	0%	0%	0%
	2015-2099	**1%**	**7%**	**11%**	**0%**	**0%**	**2%**
Regional Self-Reliance Portfolio	2015-2039	8%	8%	12%	0%	4%	8%
	2040-2069	0%	10%	3%	0%	0%	0%
	2070-2099	7%	20%	7%	0%	0%	7%
	2015-2099	**5%**	**13%**	**7%**	**0%**	**1%**	**5%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	24%	20%	32%	16%	8%	20%
	2040-2069	7%	30%	43%	0%	3%	7%
	2070-2099	0%	30%	40%	0%	0%	10%
	2015-2099	**9%**	**27%**	**39%**	**5%**	**4%**	**12%**
Delta Conveyance and Restoration Portfolio	2015-2039	24%	28%	32%	24%	16%	24%
	2040-2069	7%	27%	33%	0%	3%	10%
	2070-2099	10%	37%	33%	0%	0%	23%
	2015-2099	**13%**	**31%**	**33%**	**7%**	**6%**	**19%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	8%	24%	24%	4%	8%	20%
	2040-2069	3%	13%	23%	0%	0%	0%
	2070-2099	10%	23%	27%	0%	0%	10%
	2015-2099	**7%**	**20%**	**25%**	**1%**	**2%**	**9%**
Flexible System Operations and Mgmt Portfolio	2015-2039	20%	24%	24%	16%	16%	24%
	2040-2069	0%	23%	20%	0%	3%	3%
	2070-2099	7%	30%	30%	3%	3%	17%
	2015-2099	**8%**	**26%**	**25%**	**6%**	**7%**	**14%**
Water Action Plan Portfolio	2015-2039	8%	20%	24%	12%	12%	8%
	2040-2069	3%	7%	20%	0%	0%	0%
	2070-2099	0%	7%	7%	0%	0%	0%
	2015-2099	**4%**	**11%**	**16%**	**4%**	**4%**	**2%**

Table 7-6g. Percentage of Years with **Sacramento Valley** End-of-September Storage Less Than The 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenarios for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	28%	52%	56%	20%	16%	24%
	2040-2069	3%	20%	47%	3%	3%	3%
	2070-2099	3%	33%	50%	0%	0%	10%
	2015-2099	**11%**	**34%**	**51%**	**7%**	**6%**	**12%**
Least Cost Portfolio	2015-2039	12%	16%	16%	8%	4%	12%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	0%	3%	3%	0%	0%	0%
	2015-2099	**4%**	**7%**	**7%**	**2%**	**1%**	**4%**
Regional Self-Reliance Portfolio	2015-2039	12%	24%	28%	24%	12%	16%
	2040-2069	3%	3%	3%	0%	0%	3%
	2070-2099	0%	3%	17%	0%	0%	0%
	2015-2099	**5%**	**9%**	**15%**	**7%**	**4%**	**6%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	28%	52%	56%	20%	20%	32%
	2040-2069	7%	30%	47%	3%	3%	3%
	2070-2099	7%	30%	50%	0%	0%	13%
	2015-2099	**13%**	**36%**	**51%**	**7%**	**7%**	**15%**
Delta Conveyance and Restoration Portfolio	2015-2039	32%	56%	56%	24%	16%	32%
	2040-2069	3%	17%	43%	0%	3%	3%
	2070-2099	7%	30%	50%	0%	0%	13%
	2015-2099	**13%**	**33%**	**49%**	**7%**	**6%**	**15%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	16%	44%	52%	8%	12%	28%
	2040-2069	3%	20%	43%	0%	0%	3%
	2070-2099	7%	30%	50%	0%	0%	10%
	2015-2099	**8%**	**31%**	**48%**	**2%**	**4%**	**13%**
Flexible System Operations and Mgmt Portfolio	2015-2039	16%	32%	32%	16%	12%	16%
	2040-2069	3%	3%	20%	3%	3%	3%
	2070-2099	3%	20%	33%	0%	0%	10%
	2015-2099	**7%**	**18%**	**28%**	**6%**	**5%**	**9%**
Water Action Plan Portfolio	2015-2039	16%	32%	40%	12%	8%	16%
	2040-2069	0%	3%	20%	0%	0%	3%
	2070-2099	3%	10%	17%	0%	0%	3%
	2015-2099	**6%**	**14%**	**25%**	**4%**	**2%**	**7%**

Table 7-6h. Percentage of Years with **San Joaquin Valley** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenario for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	12%	36%	40%	8%	8%	12%
	2040-2069	7%	33%	40%	3%	3%	7%
	2070-2099	13%	27%	20%	0%	0%	10%
	2015-2099	**11%**	**32%**	**33%**	**4%**	**4%**	**9%**
Least Cost Portfolio	2015-2039	12%	24%	32%	8%	4%	8%
	2040-2069	3%	13%	17%	0%	0%	0%
	2070-2099	3%	13%	17%	0%	0%	3%
	2015-2099	**6%**	**16%**	**21%**	**2%**	**1%**	**4%**
Regional Self-Reliance Portfolio	2015-2039	8%	24%	32%	8%	4%	8%
	2040-2069	3%	13%	20%	0%	0%	0%
	2070-2099	3%	13%	20%	0%	0%	7%
	2015-2099	**5%**	**16%**	**24%**	**2%**	**1%**	**5%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	12%	32%	40%	8%	8%	12%
	2040-2069	7%	27%	30%	3%	3%	7%
	2070-2099	10%	20%	20%	0%	0%	10%
	2015-2099	**9%**	**26%**	**29%**	**4%**	**4%**	**9%**
Delta Conveyance and Restoration Portfolio	2015-2039	12%	32%	40%	8%	8%	12%
	2040-2069	7%	27%	33%	3%	3%	7%
	2070-2099	10%	23%	20%	0%	0%	10%
	2015-2099	**9%**	**27%**	**31%**	**4%**	**4%**	**9%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	4%	20%	20%	0%	4%	4%
	2040-2069	0%	20%	20%	0%	0%	0%
	2070-2099	3%	13%	20%	0%	0%	3%
	2015-2099	**2%**	**18%**	**20%**	**0%**	**1%**	**2%**
Flexible System Operations and Mgmt Portfolio	2015-2039	12%	36%	40%	8%	8%	12%
	2040-2069	7%	27%	33%	3%	3%	7%
	2070-2099	10%	20%	20%	0%	0%	10%
	2015-2099	**9%**	**27%**	**31%**	**4%**	**4%**	**9%**
Water Action Plan Portfolio	2015-2039	4%	8%	12%	0%	0%	4%
	2040-2069	0%	0%	10%	0%	0%	0%
	2070-2099	0%	7%	10%	0%	0%	0%
	2015-2099	**1%**	**5%**	**11%**	**0%**	**0%**	**1%**

Table 7-6i. Percentage of Years with **Tulare Lake Region** End-of-September Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change Climate/2006 Historic Demands Socioeconomic Scenario for the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	8%	28%	28%	8%	4%	8%
	2040-2069	17%	43%	47%	7%	7%	23%
	2070-2099	7%	40%	50%	0%	0%	23%
	2015-2099	**11%**	**38%**	**42%**	**5%**	**4%**	**19%**
Least Cost Portfolio	2015-2039	8%	20%	28%	8%	0%	8%
	2040-2069	10%	27%	33%	7%	3%	10%
	2070-2099	0%	27%	33%	0%	0%	3%
	2015-2099	**6%**	**25%**	**32%**	**5%**	**1%**	**7%**
Regional Self-Reliance Portfolio	2015-2039	8%	24%	28%	8%	0%	8%
	2040-2069	10%	27%	37%	7%	3%	10%
	2070-2099	0%	27%	40%	0%	0%	7%
	2015-2099	**6%**	**26%**	**35%**	**5%**	**1%**	**8%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8%	28%	28%	8%	0%	8%
	2040-2069	13%	43%	43%	7%	7%	20%
	2070-2099	7%	40%	47%	0%	0%	20%
	2015-2099	**9%**	**38%**	**40%**	**5%**	**2%**	**16%**
Delta Conveyance and Restoration Portfolio	2015-2039	8%	28%	28%	8%	0%	8%
	2040-2069	13%	43%	43%	7%	7%	20%
	2070-2099	7%	40%	50%	0%	0%	20%
	2015-2099	**9%**	**38%**	**41%**	**5%**	**2%**	**16%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	8%	28%	28%	8%	0%	8%
	2040-2069	10%	43%	43%	7%	7%	20%
	2070-2099	7%	40%	50%	0%	0%	20%
	2015-2099	**8%**	**38%**	**41%**	**5%**	**2%**	**16%**
Flexible System Operations and Mgmt Portfolio	2015-2039	8%	28%	28%	8%	0%	8%
	2040-2069	17%	43%	43%	7%	7%	20%
	2070-2099	7%	40%	50%	0%	0%	23%
	2015-2099	**11%**	**38%**	**41%**	**5%**	**2%**	**18%**
Water Action Plan Portfolio	2015-2039	8%	20%	28%	8%	0%	8%
	2040-2069	10%	27%	33%	7%	0%	10%
	2070-2099	0%	27%	30%	0%	0%	3%
	2015-2099	**6%**	**25%**	**31%**	**5%**	**0%**	**7%**

7.2.3. CVP and SWP Delta Exports

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

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.

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.*

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. Under the No Action alternative, the total average annual export ranged from 3,987 to 5,835 TAF/year from 2015 to 2099 and from:

- 2015-2039: 3,877 to 5,223 TAF/year
- 2040-2069: 4,068 to 6,122 TAF/year
- 2070-2099: 3,999 to 6,060 TAF/year

See Section 5.2.2.2.3. *CVP and SWP Delta Exports.*

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 but significantly decreased in the Hot-Dry climate scenario relative to Reference-No-Climate-Change climate scenario. The trends for the seven portfolios were very similar through the 21st century.

Largest increases in exports: The portfolios that combined improved system conveyance with Sacramento Valley and export area surface storage (Least Cost, Expanded Water Storage and Groundwater, and Water Action Plan) had the largest increases in Delta exports. The Least Cost portfolio had the highest exports among the adaptation portfolios, with exports ranging from 6,010 to 7,319 TAF/year from 2015 to 2099, an increase of 25% to 51% relative to the No Action alternative. However, in the latter part of the simulation the export amounts in the Water Action Plan portfolio are reduced relative to the other adaptation portfolios. This occurs because aggressive regional supply and water use efficiency actions in the export regions in the Water Action Plan and Regional Self Reliance portfolios reduced the demand for CVP and SWP deliveries in those regions.

Modest increases in exports: There were also modest improvements in Delta exports with the Regional Self Reliance portfolio, due to reduced demands in the Sacramento and San Joaquin Valleys, and in the Delta Conveyance and Restoration portfolio, which included improved system conveyance.

Reduced exports. The Healthy Headwaters and Tributaries portfolio showed a modest reduction in Delta exports from the No Action alternative due to the effects of increased environmental flow requirements.

7.2.3.1. Adaptation Portfolio Performance

The Least Cost adaptation portfolio performed better than all of the others, including the Water Action Plan adaptation portfolio (Figure 7-7). 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 7-10 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

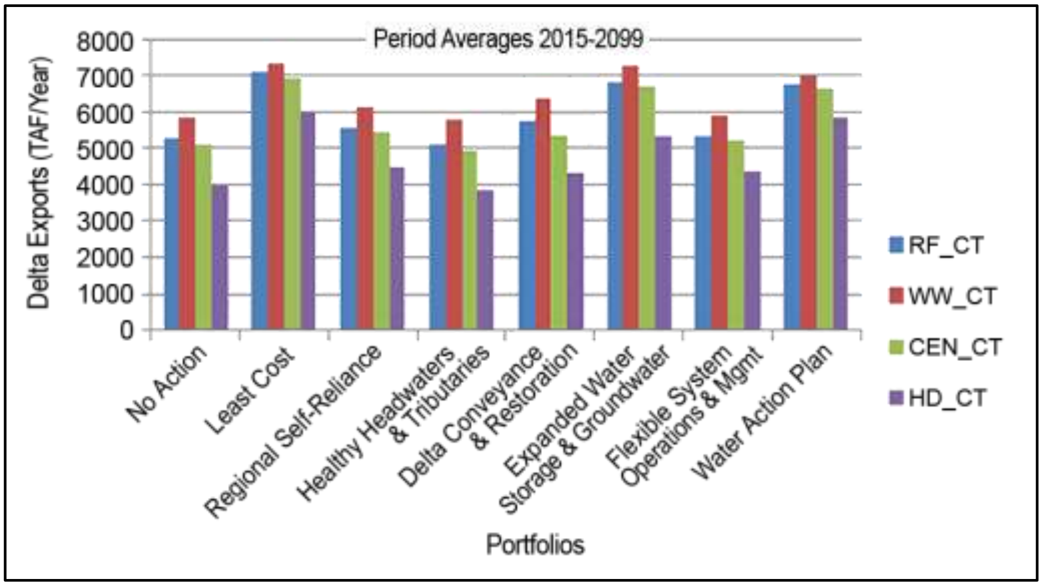

Figure 7-7. Average annual total Delta exports in each portfolio (in TAF/Year).

(Higher numbers indicate increased benefits)

Table 7-7. 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

7.2.3.2. Adaptation Portfolio Climate Sensitivity

Table 7-8 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 7-8. 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

Figure 7-8 shows annual exceedance of Delta exports at Banks Pumping Plant and Jones Pumping Plant, and of total Delta exports for the No Action alternative and each portfolio with Central Tendency climate/Current Trends socioeconomic scenarios.

Figure 7-9 shows 10-year moving average time series of average annual Delta exports in each year for the No Action alternative and each portfolio with the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-9 shows the average annual exports from each pumping facility as well as total average annual exports in the Current Trends socioeconomic scenario for the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-8 . Delta exports: annual exceedance

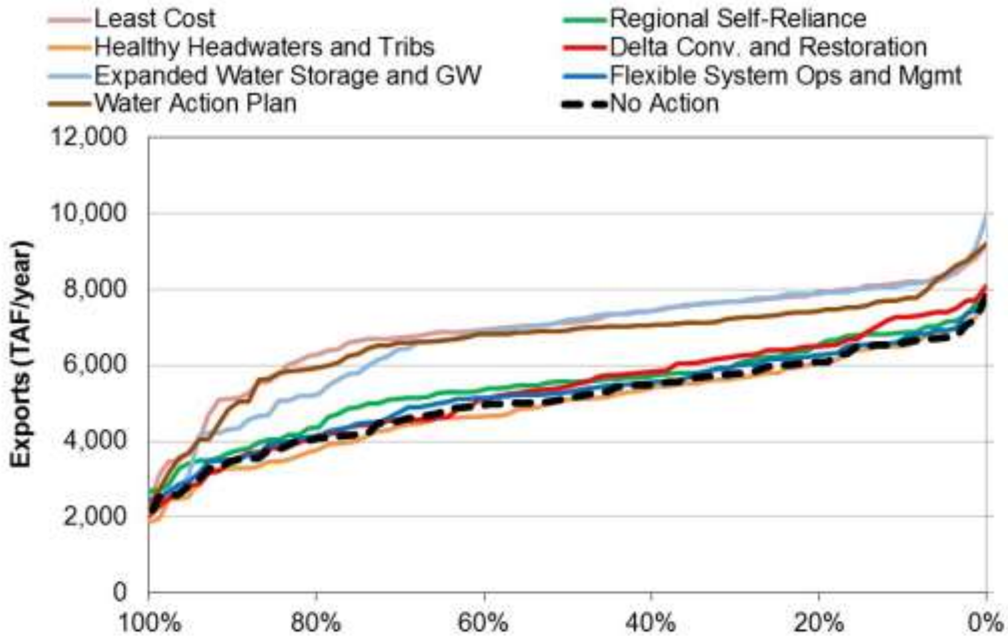

Figure 7-8a. Annual exceedance plot of **total Delta exports for** each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

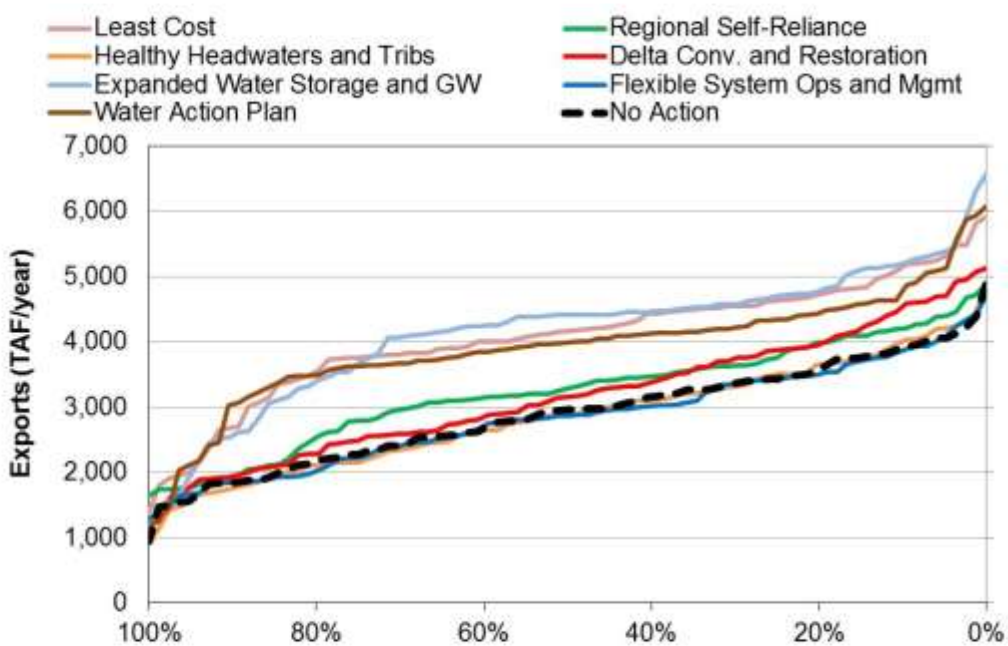

Figure 7-8b. Annual exceedance plot of **Banks PP pumping for** each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

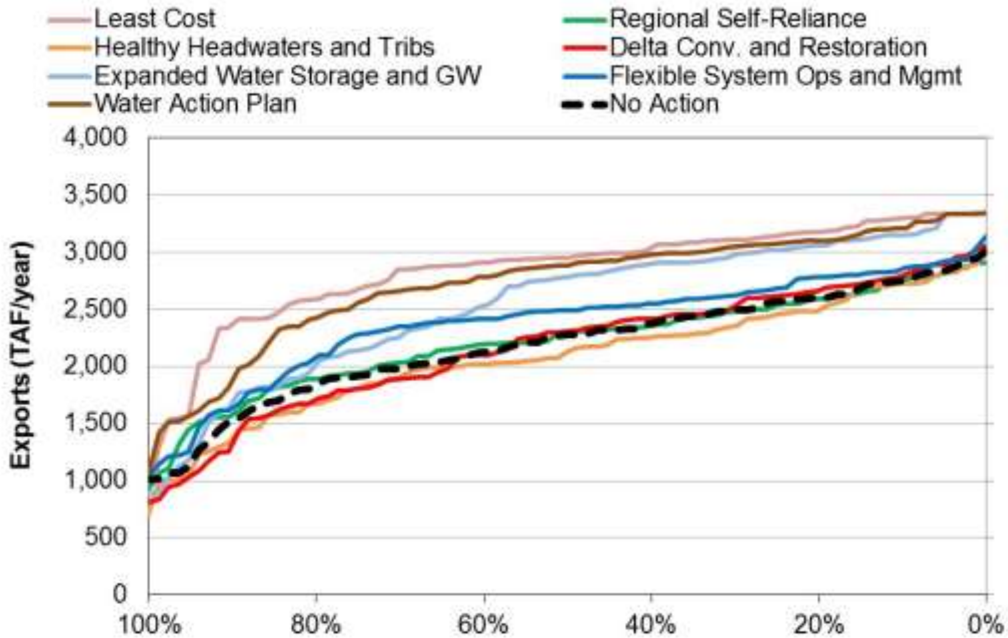

Figure 7-8c. Annual exceedance plot of **Jones PP pumping** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

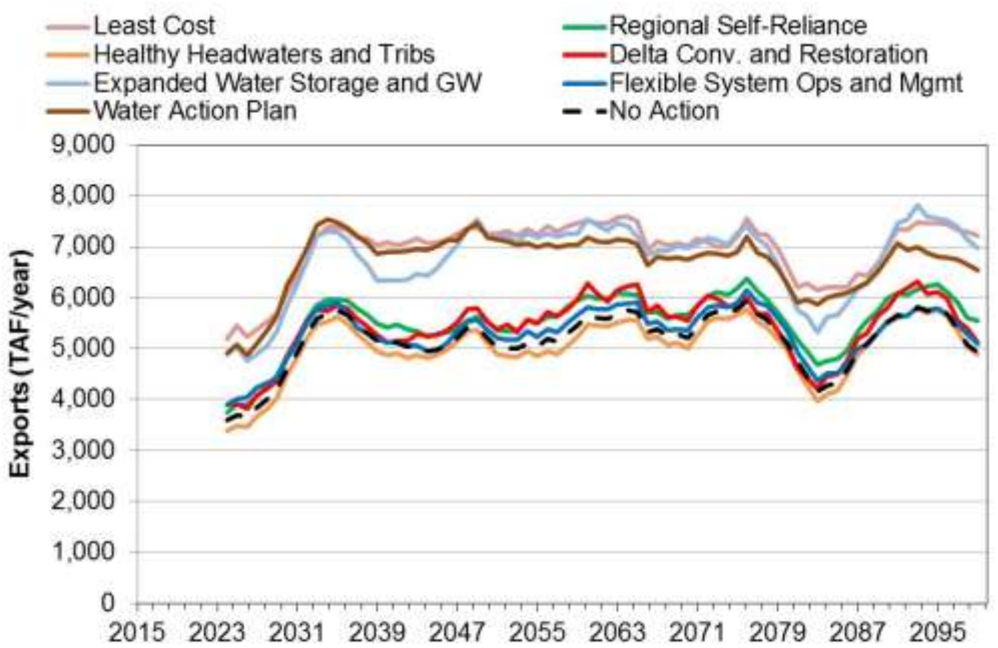

Figure 7-9. Annual total Delta exports: 10-year moving average time series.

(For each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios).

Table 7-9 . CVP and SWP Exports: Adaptation Portfolio Comparison

Table 7-9a. Average Annual **Total Delta Exports** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	4,672	4,059	3,877	5,110	5,223	4,590
	2040-2069	5,522	4,581	4,068	5,858	6,122	5,383
	2070-2099	5,466	4,511	3,999	5,988	6,060	5,196
	2015-2099	**5,252**	**4,403**	**3,987**	**5,684**	**5,835**	**5,084**
Least Cost Portfolio	2015-2039	6,529	5,526	5,409	6,813	6,923	6,387
	2040-2069	7,412	6,982	6,491	7,433	7,552	7,296
	2070-2099	7,241	6,554	6,029	7,409	7,416	6,958
	2015-2099	**7,092**	**6,402**	**6,010**	**7,242**	**7,319**	**6,909**
Regional Self-Reliance Portfolio	2015-2039	4,888	4,350	4,189	5,287	5,549	4,837
	2040-2069	5,812	5,061	4,571	6,209	6,394	5,743
	2070-2099	5,841	5,100	4,599	6,366	6,359	5,665
	2015-2099	**5,551**	**4,866**	**4,469**	**5,993**	**6,133**	**5,449**
Healthy Headwaters and Tributaries Portfolio	2015-2039	4,483	3,931	3,627	4,901	5,143	4,399
	2040-2069	5,396	4,339	3,951	5,784	6,072	5,232
	2070-2099	5,350	4,514	3,967	5,998	5,987	5,131
	2015-2099	**5,111**	**4,280**	**3,861**	**5,599**	**5,769**	**4,951**
Delta Conveyance and Restoration Portfolio	2015-2039	4,963	4,214	4,057	5,246	5,664	4,770
	2040-2069	6,156	4,964	4,416	6,383	6,713	5,791
	2070-2099	5,881	4,827	4,389	6,446	6,555	5,371
	2015-2099	**5,708**	**4,695**	**4,301**	**6,071**	**6,348**	**5,343**
Expanded Water Storage and Groundwater Portfolio	2015-2039	6,172	5,151	4,943	6,689	6,775	5,926
	2040-2069	7,269	6,239	5,521	7,417	7,509	7,264
	2070-2099	6,910	6,046	5,413	7,456	7,453	6,749
	2015-2099	**6,820**	**5,851**	**5,313**	**7,216**	**7,273**	**6,689**
Flexible System Operations and Mgmt Portfolio	2015-2039	4,854	4,406	4,218	5,267	5,311	4,750
	2040-2069	5,612	4,874	4,568	5,956	6,191	5,540
	2070-2099	5,498	4,787	4,330	6,079	6,070	5,332
	2015-2099	**5,349**	**4,706**	**4,381**	**5,797**	**5,890**	**5,234**
Water Action Plan Portfolio	2015-2039	6,434	5,520	5,377	6,670	6,803	6,222
	2040-2069	7,095	6,718	6,245	7,175	7,261	7,090
	2070-2099	6,636	6,089	5,851	6,824	6,812	6,542
	2015-2099	**6,738**	**6,144**	**5,850**	**6,903**	**6,968**	**6,641**

Table 7-9b. Average Annual Exports at **Banks PP** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	2,682	2,348	2,241	2,964	2,951	2,662
	2040-2069	3,092	2,625	2,377	3,344	3,506	3,056
	2070-2099	3,105	2,575	2,257	3,381	3,464	2,922
	2015-2099	**2,976**	**2,526**	**2,295**	**3,246**	**3,328**	**2,893**
Least Cost Portfolio	2015-2039	3,814	3,172	3,116	3,971	4,005	3,755
	2040-2069	4,359	4,157	3,789	4,364	4,443	4,315
	2070-2099	4,268	3,819	3,458	4,350	4,392	4,076
	2015-2099	**4,166**	**3,748**	**3,474**	**4,243**	**4,296**	**4,066**
Regional Self-Reliance Portfolio	2015-2039	2,882	2,581	2,493	3,233	3,300	2,900
	2040-2069	3,382	2,977	2,658	3,761	3,792	3,426
	2070-2099	3,406	2,960	2,629	3,813	3,784	3,317
	2015-2099	**3,243**	**2,855**	**2,599**	**3,624**	**3,644**	**3,233**
Healthy Headwaters and Tributaries Portfolio	2015-2039	2,565	2,272	2,079	2,906	2,954	2,573
	2040-2069	3,084	2,527	2,350	3,375	3,506	3,048
	2070-2099	3,043	2,595	2,240	3,440	3,426	2,924
	2015-2099	**2,917**	**2,476**	**2,232**	**3,260**	**3,315**	**2,864**
Delta Conveyance and Restoration Portfolio	2015-2039	2,952	2,494	2,392	3,165	3,388	2,853
	2040-2069	3,685	3,039	2,739	3,886	4,051	3,497
	2070-2099	3,487	2,881	2,612	3,800	3,877	3,113
	2015-2099	**3,400**	**2,823**	**2,592**	**3,644**	**3,795**	**3,172**
Expanded Water Storage and Groundwater Portfolio	2015-2039	3,865	3,166	3,027	4,166	4,134	3,714
	2040-2069	4,422	3,943	3,514	4,444	4,487	4,504
	2070-2099	4,206	3,777	3,366	4,461	4,484	4,142
	2015-2099	**4,182**	**3,656**	**3,319**	**4,368**	**4,382**	**4,144**
Flexible System Operations and Mgmt Portfolio	2015-2039	2,626	2,393	2,277	2,935	2,942	2,586
	2040-2069	3,057	2,637	2,448	3,329	3,508	3,035
	2070-2099	2,988	2,602	2,324	3,416	3,432	2,892
	2015-2099	**2,906**	**2,553**	**2,354**	**3,244**	**3,315**	**2,852**
Water Action Plan Portfolio	2015-2039	3,927	3,347	3,280	4,052	4,073	3,786
	2040-2069	4,154	4,116	3,855	4,183	4,228	4,201
	2070-2099	3,769	3,505	3,406	3,817	3,810	3,726
	2015-2099	**3,951**	**3,674**	**3,527**	**4,015**	**4,035**	**3,911**

Table 7-9c. Average Annual Exports at **Jones PP** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	1,990	1,710	1,636	2,146	2,272	1,929
	2040-2069	2,430	1,956	1,691	2,513	2,616	2,326
	2070-2099	2,361	1,936	1,742	2,607	2,596	2,274
	2015-2099	**2,276**	**1,877**	**1,693**	**2,438**	**2,508**	**2,191**
Least Cost Portfolio	2015-2039	2,716	2,354	2,293	2,842	2,918	2,632
	2040-2069	3,053	2,825	2,702	3,069	3,109	2,981
	2070-2099	2,973	2,734	2,571	3,059	3,024	2,883
	2015-2099	**2,926**	**2,654**	**2,536**	**2,999**	**3,023**	**2,844**
Regional Self-Reliance Portfolio	2015-2039	2,007	1,768	1,696	2,054	2,249	1,938
	2040-2069	2,430	2,084	1,913	2,448	2,602	2,317
	2070-2099	2,435	2,140	1,970	2,553	2,575	2,348
	2015-2099	**2,307**	**2,011**	**1,869**	**2,369**	**2,489**	**2,216**
Healthy Headwaters and Tributaries Portfolio	2015-2039	1,917	1,659	1,548	1,995	2,189	1,826
	2040-2069	2,313	1,811	1,601	2,408	2,566	2,184
	2070-2099	2,306	1,919	1,727	2,558	2,562	2,207
	2015-2099	**2,194**	**1,805**	**1,630**	**2,340**	**2,453**	**2,087**
Delta Conveyance and Restoration Portfolio	2015-2039	2,011	1,720	1,665	2,081	2,276	1,917
	2040-2069	2,470	1,925	1,677	2,497	2,661	2,294
	2070-2099	2,395	1,946	1,777	2,646	2,678	2,258
	2015-2099	**2,308**	**1,872**	**1,709**	**2,427**	**2,554**	**2,171**
Expanded Water Storage and Groundwater Portfolio	2015-2039	2,307	1,985	1,916	2,522	2,641	2,212
	2040-2069	2,847	2,296	2,006	2,973	3,022	2,760
	2070-2099	2,705	2,269	2,047	2,995	2,969	2,607
	2015-2099	**2,638**	**2,195**	**1,994**	**2,848**	**2,891**	**2,545**
Flexible System Operations and Mgmt Portfolio	2015-2039	2,228	2,013	1,940	2,331	2,369	2,164
	2040-2069	2,555	2,236	2,119	2,627	2,683	2,505
	2070-2099	2,510	2,186	2,007	2,663	2,638	2,440
	2015-2099	**2,443**	**2,153**	**2,027**	**2,553**	**2,575**	**2,382**
Water Action Plan Portfolio	2015-2039	2,508	2,174	2,097	2,618	2,729	2,436
	2040-2069	2,941	2,602	2,390	2,992	3,034	2,889
	2070-2099	2,866	2,584	2,445	3,007	3,002	2,816
	2015-2099	**2,787**	**2,470**	**2,323**	**2,887**	**2,933**	**2,730**

7.2.4. 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.

Under the No Action alternative, Central Valley average annual change in groundwater storage ranged from 17 to 264 TAF/year from 2015 to 2099 and from:

- 2015-2039:-198 to +75 TAF/year
- 2040-2069: +172 to +307 TAF/year
- 2070-2099:-83 to +360 TAF/year

See Section 5.2.2.2.4. *Change in Groundwater Storage.*

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. In all four regions, the annual year-to-year changes in groundwater storage were similar between the seven portfolios.

Decreased Storage: The only adaptation portfolio with decreased storage was the Flexible Systems Operation and Management.

Increased Storage: 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. The cumulative trend shows that the Water Action Plan, Least Cost, and Regional Self Reliance portfolios had the largest long-term increases in groundwater storage, reflecting reduced groundwater pumping in response to aggressive water use efficiency actions.

In the Water Action Plan portfolio, which had the largest long-term increase in groundwater storage, Central Valley average annual change in groundwater storage ranged from +76 to +634 TAF/year from 2015 to 2099 and from:

- 2015-2039:-157 to +287 TAF/year
- 2040-2069: +335 to +627 TAF/year
- 2070-2099:-14 to +1,068 TAF/year

7.2.4.1. Adaptation Portfolio Performance

The maximum increase in groundwater storage occurred with the Water Action Plan (Figure 7-10). Increases in groundwater storage were partly due to the long-term decline in agricultural water demands. As discussed in Section 4. *Water Demand Assessment*, these declines are related to changes in land use as well as changes in climate especially in the late 21st century. 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 7-10 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

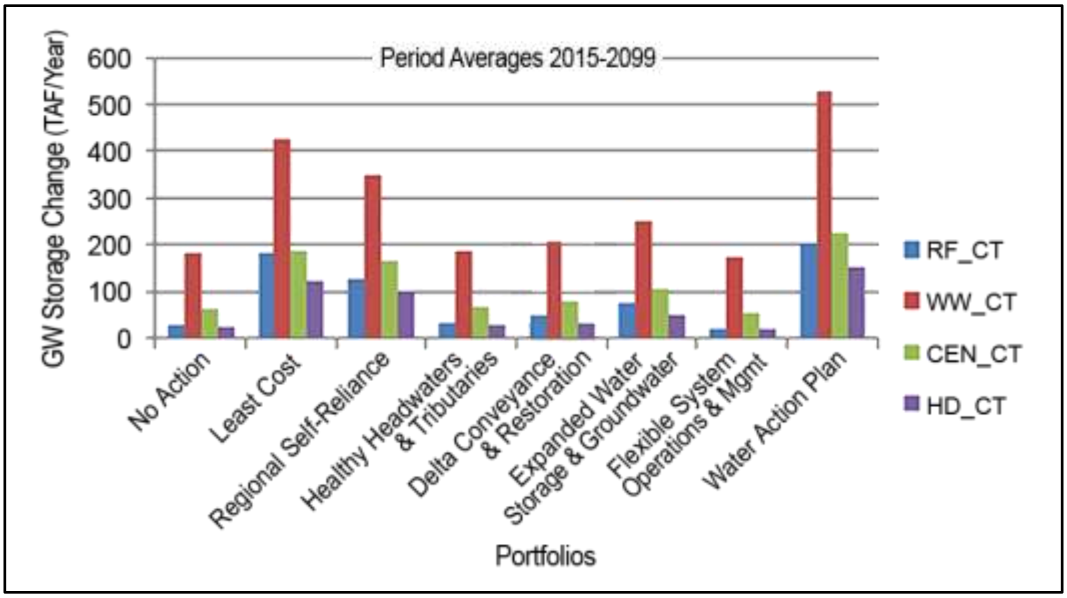

Figure 7-10. Average annual groundwater storage in the Central Valley in each adaptation portfolio.[13]

(Higher numbers indicate increased benefits)

Table 7-10. 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

[13] 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.

7.2.4.2. Adaptation Portfolio Climate Sensitivity

Table 7-11 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 7-11. 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

Figure 7-11 shows the cumulative change in groundwater storage in the Central Valley for each portfolio. Figure 7-12 shows the annual changes in total groundwater storage in the Central Valley and in the Sacramento River, East Side streams and Delta, San Joaquin River and the Tulare Lake regions for the No Action alternative and each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from 2015 to 2099. Table 7-12 present the average annual change in groundwater storage for the Central Valley and in the Sacramento River, East Side streams and Delta, San Joaquin River and the Tulare Lake regions in the Current Trends socioeconomic scenario for the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

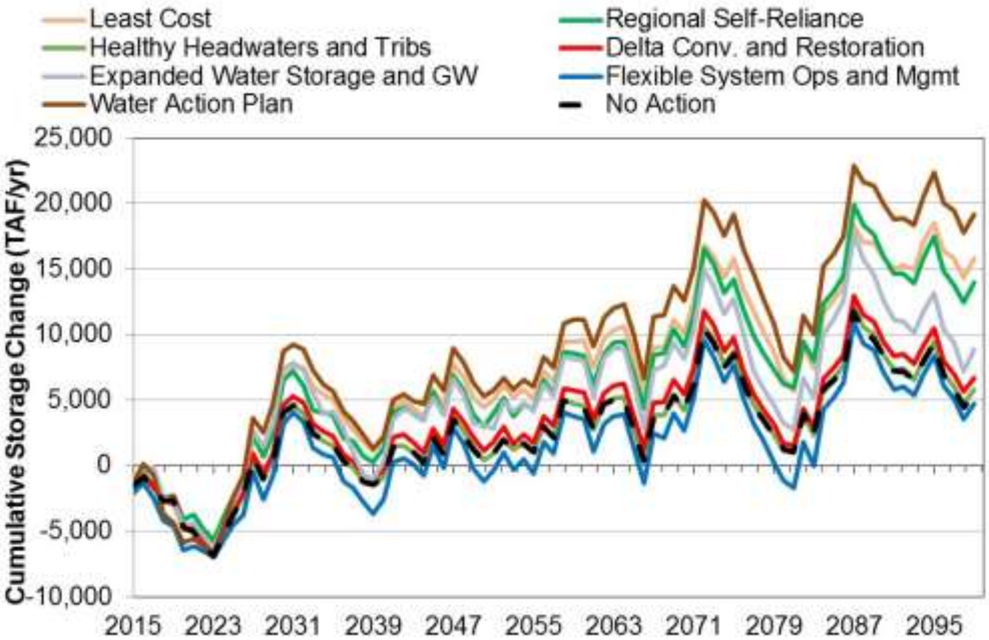

Figure 7-11. Cumulative change in groundwater storage in the Central Valley.

(for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios)

Figure 7-12. Groundwater storage: annual change.

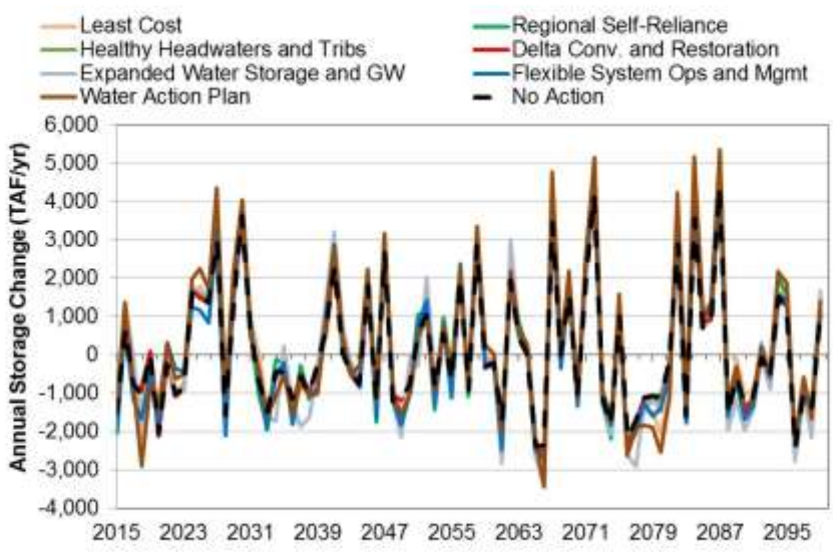

Figure 7-12a. Annual change in groundwater storage in the **Central Valley** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

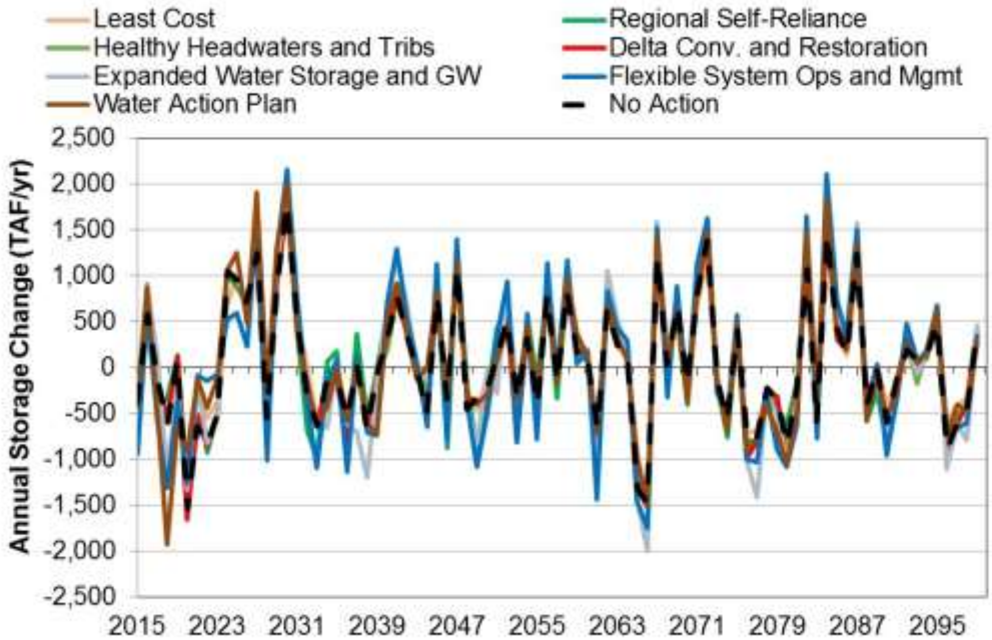

Figure 7-12b. Annual change in groundwater storage in the **Sacramento River System** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

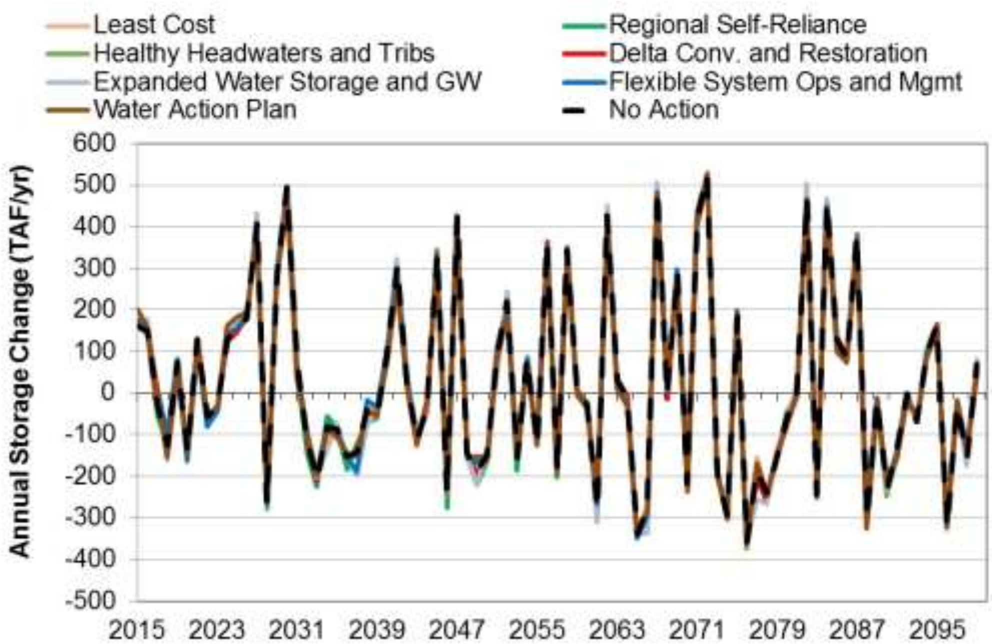

Figure 7-12c. Annual change in groundwater storage in the **Delta and East Side streams** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

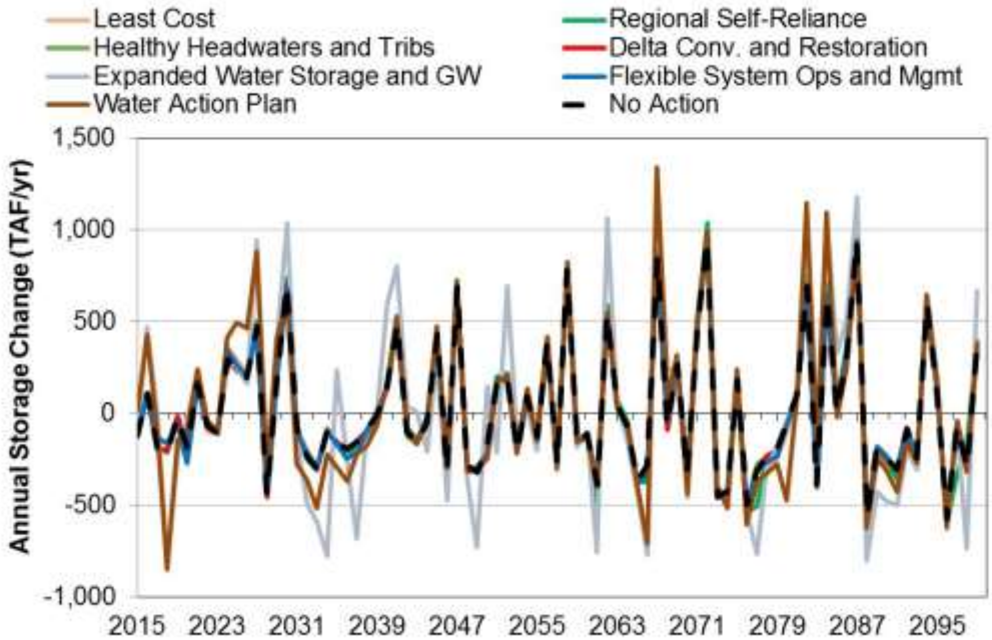

Figure 7-12d. Annual change in groundwater storage in the **San Joaquin River** System in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

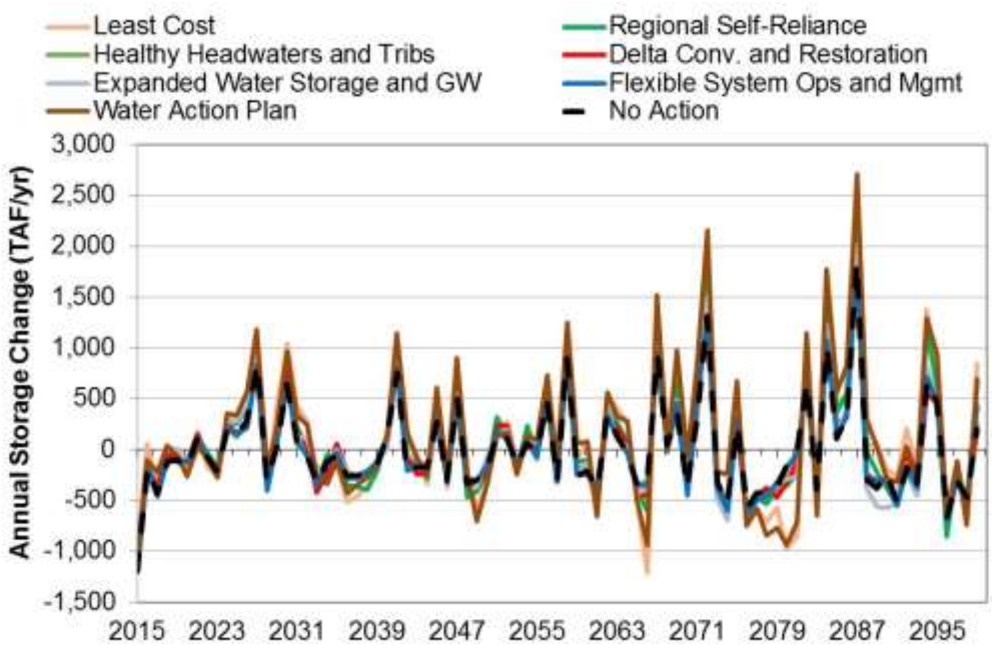

Figure 7-12e. Annual change in groundwater storage in the **Tulare Lake Region** in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-12. Groundwater Storage: Adaptation Portfolio Comparison

Table 7-12a. Average Annual Change in Groundwater Storage in the **Central Valley** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-65	-185	-198	49	75	-59
	2040-2069	210	186	172	307	297	226
	2070-2099	-65	-83	63	360	161	6
	2015-2099	**30**	**-17**	**25**	**246**	**181**	**64**
Least Cost Portfolio	2015-2039	79	-107	-143	213	309	46
	2040-2069	340	277	263	473	519	330
	2070-2099	117	-38	203	870	443	159
	2015-2099	**181**	**54**	**122**	**532**	**427**	**186**
Regional Self-Reliance Portfolio	2015-2039	4	-101	-111	143	203	12
	2040-2069	330	251	236	461	477	334
	2070-2099	29	-34	139	759	355	123
	2015-2099	**125**	**48**	**100**	**469**	**350**	**164**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-57	-183	-204	39	81	-57
	2040-2069	207	188	180	312	303	225
	2070-2099	-57	-70	69	371	169	16
	2015-2099	**35**	**-11**	**29**	**249**	**188**	**68**
Delta Conveyance and Restoration Portfolio	2015-2039	-26	-184	-204	71	120	-42
	2040-2069	228	216	204	334	331	250
	2070-2099	-61	-86	61	378	165	8
	2015-2099	**49**	**-7**	**34**	**269**	**208**	**79**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-12	-190	-199	147	186	-41
	2040-2069	297	237	218	377	396	343
	2070-2099	-62	-57	90	478	166	-14
	2015-2099	**77**	**10**	**51**	**341**	**249**	**104**
Flexible System Operations and Mgmt Portfolio	2015-2039	-136	-240	-260	-23	8	-147
	2040-2069	231	198	193	339	346	252
	2070-2099	-61	-101	78	406	146	26
	2015-2099	**19**	**-35**	**20**	**253**	**173**	**56**
Water Action Plan Portfolio	2015-2039	36	-157	-186	197	287	52
	2040-2069	432	355	339	576	627	411
	2070-2099	126	-14	248	1,068	636	187
	2015-2099	**205**	**76**	**153**	**634**	**527**	**226**

Table 7-12b. Average Annual Change in Groundwater Storage in **the Sacramento River** in (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	0	-76	-83	58	81	4
	2040-2069	73	93	78	119	84	89
	2070-2099	-12	-47	58	109	20	13
	2015-2099	**22**	**-5**	**24**	**97**	**60**	**38**
Least Cost Portfolio	2015-2039	46	-45	-70	92	111	28
	2040-2069	77	116	114	120	91	110
	2070-2099	-2	-19	89	101	14	16
	2015-2099	**40**	**22**	**52**	**104**	**69**	**52**
Regional Self-Reliance Portfolio	2015-2039	38	-9	-13	90	123	53
	2040-2069	116	112	109	167	136	125
	2070-2099	2	-16	73	122	39	28
	2015-2099	**53**	**32**	**61**	**127**	**98**	**69**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8	-73	-87	46	84	7
	2040-2069	68	93	83	122	86	87
	2070-2099	-7	-37	63	102	19	13
	2015-2099	**24**	**0**	**27**	**92**	**62**	**38**
Delta Conveyance and Restoration Portfolio	2015-2039	5	-93	-104	47	81	-2
	2040-2069	71	103	94	124	90	93
	2070-2099	-10	-43	54	98	17	14
	2015-2099	**23**	**-5**	**23**	**92**	**62**	**37**
Expanded Water Storage and Groundwater Portfolio	2015-2039	4	-102	-105	89	117	-16
	2040-2069	114	117	95	146	125	152
	2070-2099	-6	-19	80	112	21	15
	2015-2099	**40**	**6**	**33**	**116**	**85**	**55**
Flexible System Operations and Mgmt Portfolio	2015-2039	-73	-132	-145	-17	10	-82
	2040-2069	89	98	93	147	126	106
	2070-2099	-10	-63	66	142	6	28
	2015-2099	**8**	**-24**	**15**	**97**	**50**	**25**
Water Action Plan Portfolio	2015-2039	19	-89	-112	102	128	32
	2040-2069	134	161	155	165	127	149
	2070-2099	-6	-7	116	131	56	14
	2015-2099	**51**	**30**	**64**	**133**	**102**	**67**

Table 7-12c. Average Annual Change in Groundwater Storage in **the Delta and East Side Streams** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	29	16	15	45	46	28
	2040-2069	34	36	38	48	43	41
	2070-2099	-12	-11	-1	-1	-8	-7
	2015-2099	**16**	**14**	**18**	**29**	**26**	**20**
Least Cost Portfolio	2015-2039	32	18	16	45	47	30
	2040-2069	26	32	35	40	36	34
	2070-2099	-15	-13	-2	-4	-10	-10
	2015-2099	**13**	**12**	**16**	**25**	**22**	**17**
Regional Self-Reliance Portfolio	2015-2039	27	15	14	42	43	26
	2040-2069	28	29	32	41	38	34
	2070-2099	-20	-17	-6	-9	-16	-14
	2015-2099	**10**	**9**	**13**	**23**	**20**	**14**
Healthy Headwaters and Tributaries Portfolio	2015-2039	28	15	14	44	45	27
	2040-2069	33	35	37	48	43	41
	2070-2099	-12	-11	0	-1	-8	-7
	2015-2099	**15**	**13**	**17**	**29**	**25**	**20**
Delta Conveyance and Restoration Portfolio	2015-2039	29	15	14	44	45	27
	2040-2069	33	35	37	47	42	40
	2070-2099	-13	-11	0	-2	-8	-7
	2015-2099	**15**	**13**	**17**	**28**	**25**	**19**
Expanded Water Storage and Groundwater Portfolio	2015-2039	27	14	14	45	46	26
	2040-2069	34	35	37	45	41	42
	2070-2099	-15	-14	-2	-6	-12	-11
	2015-2099	**14**	**12**	**16**	**26**	**23**	**18**
Flexible System Operations and Mgmt Portfolio	2015-2039	31	15	13	46	47	29
	2040-2069	32	38	40	45	40	40
	2070-2099	**-12**	**-12**	**-1**	**-3**	**-8**	**-7**
	2015-2099	16	13	17	28	25	20
Water Action Plan Portfolio	2015-2039	28	13	11	44	45	28
	2040-2069	28	35	39	39	35	34
	2070-2099	-18	-15	-5	-10	-15	-13
	2015-2099	**11**	**10**	**15**	**22**	**20**	**15**

Table 7-12d. Average Annual Change in Groundwater Storage in the **San Joaquin River** System (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-15	-25	-27	-2	1	-14
	2040-2069	45	36	39	72	70	51
	2070-2099	-16	-12	7	25	-7	-5
	2015-2099	**6**	**1**	**8**	**33**	**22**	**12**
Least Cost Portfolio	2015-2039	-8	-24	-28	5	10	-10
	2040-2069	48	44	47	77	73	56
	2070-2099	-14	-14	14	32	-4	-1
	2015-2099	**9**	**4**	**14**	**39**	**27**	**16**
Regional Self-Reliance Portfolio	2015-2039	-14	-25	-27	0	4	-15
	2040-2069	52	42	43	83	78	59
	2070-2099	-14	-13	14	36	0	-4
	2015-2099	**9**	**3**	**12**	**41**	**28**	**15**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-15	-25	-27	-2	1	-14
	2040-2069	44	36	39	71	70	50
	2070-2099	-15	-12	7	28	-7	-4
	2015-2099	**6**	**1**	**9**	**34**	**22**	**12**
Delta Conveyance and Restoration Portfolio	2015-2039	-15	-25	-27	-2	1	-14
	2040-2069	45	36	39	72	70	50
	2070-2099	-15	-12	7	27	-7	-4
	2015-2099	**6**	**1**	**9**	**34**	**22**	**12**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-27	-30	-28	-1	4	-27
	2040-2069	67	30	36	84	87	74
	2070-2099	-24	-15	10	30	-18	-15
	2015-2099	**7**	**-3**	**8**	**39**	**25**	**13**
Flexible System Operations and Mgmt Portfolio	2015-2039	-15	-25	-27	-1	3	-14
	2040-2069	46	39	42	73	70	52
	2070-2099	-14	-14	9	26	-7	-2
	2015-2099	**7**	**2**	**10**	**34**	**23**	**13**
Water Action Plan Portfolio	2015-2039	-23	-38	-40	5	11	-10
	2040-2069	63	66	67	89	82	66
	2070-2099	-15	-22	11	35	-3	-5
	2015-2099	**10**	**5**	**16**	**45**	**31**	**19**

Table 7-12e. Average Annual Change in Groundwater Storage in the **Tulare Lake Region** (in TAF/Year) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-79	-100	-104	-52	-53	-78
	2040-2069	59	21	17	68	100	44
	2070-2099	-26	-13	-2	227	156	5
	2015-2099	**-13**	**-27**	**-26**	**87**	**73**	**-6**
Least Cost Portfolio	2015-2039	10	-56	-61	72	142	-1
	2040-2069	189	86	67	236	320	130
	2070-2099	148	8	103	741	443	154
	2015-2099	**119**	**17**	**41**	**363**	**309**	**100**
Regional Self-Reliance Portfolio	2015-2039	-46	-82	-84	12	33	-52
	2040-2069	134	69	51	171	225	115
	2070-2099	61	13	58	611	332	113
	2015-2099	**53**	**5**	**13**	**278**	**204**	**65**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-77	-101	-104	-48	-49	-77
	2040-2069	62	24	21	71	105	47
	2070-2099	-22	-11	-1	243	164	14
	2015-2099	**-10**	**-25**	**-24**	**95**	**79**	**-1**
Delta Conveyance and Restoration Portfolio	2015-2039	-45	-81	-87	-18	-7	-52
	2040-2069	80	42	34	91	129	67
	2070-2099	-22	-20	-1	254	164	5
	2015-2099	**5**	**-17**	**-15**	**115**	**99**	**10**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-16	-73	-79	14	18	-23
	2040-2069	83	55	51	102	144	76
	2070-2099	-17	-8	2	342	175	-3
	2015-2099	**16**	**-5**	**-5**	**159**	**115**	**19**
Flexible System Operations and Mgmt Portfolio	2015-2039	-78	-99	-102	-51	-52	-79
	2040-2069	64	23	18	73	110	53
	2070-2099	-25	-12	4	241	155	7
	2015-2099	**-11**	**-25**	**-23**	**94**	**76**	**-2**
Water Action Plan Portfolio	2015-2039	13	-43	-45	46	102	2
	2040-2069	207	93	79	283	383	162
	2070-2099	166	30	126	911	597	191
	2015-2099	**132**	**31**	**58**	**433**	**375**	**125**

7.3. Economics

7.3.1. Economic Analysis

See Section 5.2.3. *Economics* for a discussion of the economic analysis and the No Action alternative.

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.

7.3.2. Economic Benefits

The urban economic models (LCPSIM and OMWEM) showed substantial improvements in net economic benefits in the Least Cost, Regional Self-Reliance and Water Action Plan portfolios, especially during the late 21st century period when economic net benefit improvements ranged from $3.6 to 4.3 billion per year in these portfolios. The benefits were greatest in these portfolios because they included the aggressive water use efficiency action. The other portfolios had lesser improvements in net economic benefits ranging from $0.5 to $0.9 billion in the late period of the 21st century.

Agricultural economic benefits (reflected in the SWAP model) were greatest in the portfolios, which had the greatest surface water deliveries to agricultural regions due to the Delta Conveyance and new storage actions:

- Water Action Plan
- Least Cost
- Expanded Water Storage and Groundwater

In contrast, the Healthy Headwaters and Tributaries portfolio had less economic benefits than the No Action alternative because the environmental flow action resulted in less surface water deliveries to agricultural regions.

Changes in salinity management costs reflected in SBWQM and LCRBWQM are a function of the amount of water being diverted and the salinity of the water at the diversion locations for each region. Therefore, the portfolios that included the Delta conveyance action had the highest levels of exports and lowest export salinity had the greatest improvements in salinity management costs:

- Least Cost
- Expanded Water Storage and Groundwater
- Delta Conveyance and Restoration
- Water Action Plan

In the late 21st century, the Water Action Plan ($4.5 billion/year), Regional Self-Reliance ($4.3 billion/year) and Least Cost ($3.9 billion/year) had the largest improvements in total economic net benefits from all sectors. The other portfolios had total economic benefit improvements ranging from $0.7 to $1.5 billion per year in the late 21st century.

Table 7-13 shows details of the performance of each of the portfolios in the Central Tendency climate scenario.

Table 7-13. Economics: Preliminary 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
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.

7.3.3. Cost Effectiveness of Water Supply and Demand Reduction Actions

The cost effectiveness of water supply and demand reduction actions in each adaptation portfolio was assessed for the early, mid, and late periods by comparing the total implementation cost of each portfolio (see Section 6.5. *Portfolio Implementation Costs*) with the total water supply and demand reduction benefit of each adaptation portfolio. The portfolio implementation cost and total water supply and demand reduction benefit for each portfolio are shown in Table 7-14. The table also shows average cost per water supply or demand reduction benefit quantity for each portfolio in the early, mid and late periods of the 21st century and for the full century period.

The Least Cost portfolio had the lowest estimated cost per acre-foot of water supply or demand reduction benefit with an average cost over the 21st century of $432 per acre-foot.

The portfolios with the highest cost per acre-foot of water supply or demand reduction benefit were:

- Flexible System Operations and Management portfolio (with a cost of $1,863 per acre-foot)
- Expanded Water Storage and Groundwater portfolio (with a cost of $1,351 per acre-foot)

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 7-13). 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.

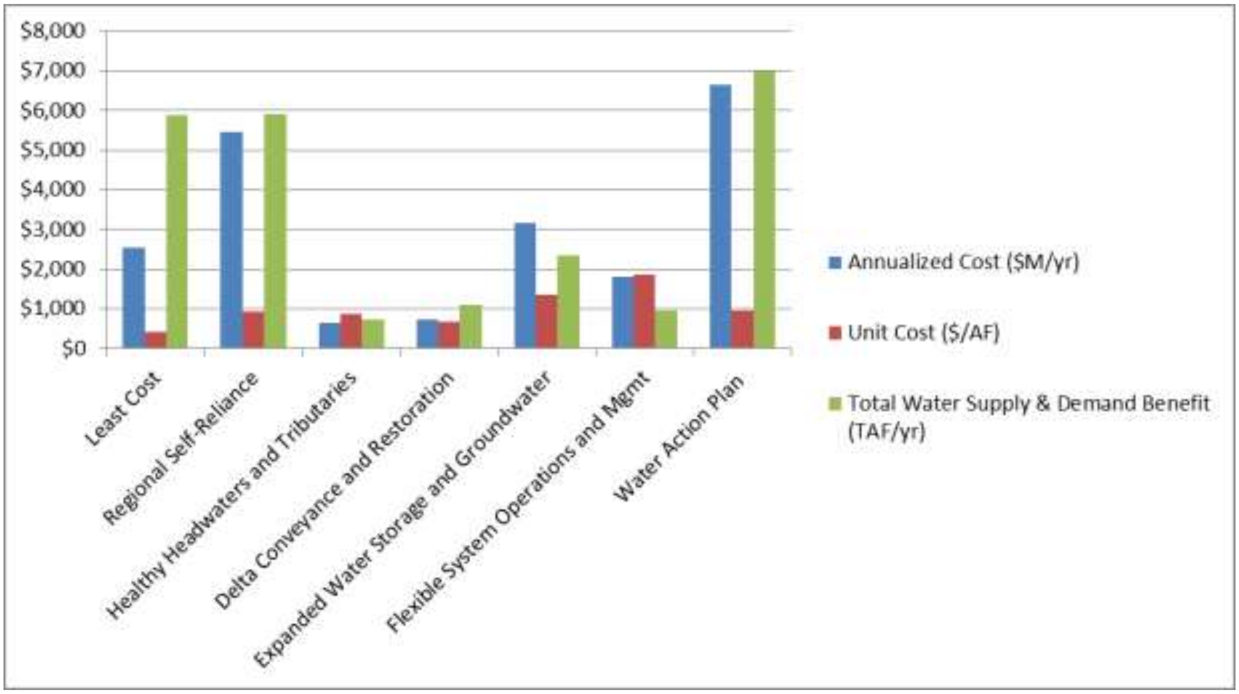

Figure 7-13. Economics benefits and costs.

Annualized portfolio cost (in $ millions/year) and unit cost per water supply and demand benefit (in $/af) in the Central Tendency climate scenario in each adaptation portfolio relative to the No Action alternative.[14]

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[14] 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 7-14. Economics: Preliminary Costs and Benefits

Water Supply and Demand Reduction Benefits (in TAF/Year), Annualized Portfolio Cost (in $ millions/year) and Unit Cost per Water Supply and Demand Benefit (in $/AF) in the Central Tendency climate/Current Trends socioeconomic scenarios in Each Adaptation Portfolio.

Portfolio	Period	Central Valley Unmet Demand Reduction (TAF/yr)	Change in Central Valley GW Storage (TAF/yr)	Exports to South Bay and South Coast Regions (TAF/yr)	South Bay and South Coast Supply and Demand Actions (TAF/yr)	Total Water Supply and Demand Benefit (TAF/yr)	Total Annualized Cost ($ millions/yr)	Cost per Water Supply and Demand Benefit ($/AF)
Least Cost Portfolio	2015-2039	2,818	105	568	766	4,257	$1,593	$374
	2040-2069	3,687	104	603	2,028	6,422	$2,703	$421
	2070-2099	3,659	153	652	2,374	6,838	$3,311	$484
	2015-2099	**3,421**	**122**	**610**	**1,723**	**5,876**	**$2,536**	**$432**
Regional Self-Reliance Portfolio	2015-2039	2,182	71	-11	1,174	3,416	$2,572	$753
	2040-2069	3,232	108	-173	3,155	6,322	$5,536	$876
	2070-2099	3,545	117	-343	4,535	7,854	$8,289	$1,055
	2015-2099	**3,034**	**100**	**-185**	**2,955**	**5,903**	**$5,466**	**$926**
Healthy Headwaters and Tributaries Portfolio	2015-2039	102	2	-57	570	617	$430	$697
	2040-2069	197	-1	-16	589	769	$673	$874
	2070-2099	345	10	-30	470	795	$829	$1,042
	2015-2099	**221**	**4**	**-33**	**543**	**735**	**$644**	**$876**
Delta Conveyance and Restoration Portfolio	2015-2039	277	17	76	570	940	$672	$715
	2040-2069	445	24	215	589	1,273	$753	$591
	2070-2099	500	2	112	470	1,084	$789	$728
	2015-2099	**415**	**15**	**138**	**543**	**1,111**	**$738**	**$664**
Expanded Water Storage and Groundwater Portfolio	2015-2039	936	18	479	570	2,003	$2,293	$1,144
	2040-2069	1,244	117	616	589	2,566	$3,165	$1,233
	2070-2099	1,304	-20	638	470	2,392	$4,030	$1,685
	2015-2099	**1,175**	**40**	**584**	**543**	**2,342**	**$3,163**	**$1,351**
Flexible System Operations and Mgmt Portfolio	2015-2039	316	-88	-35	570	763	$987	$1,294
	2040-2069	442	26	19	589	1,076	$1,805	$1,678
	2070-2099	522	20	15	470	1,027	$2,626	$2,557
	2015-2099	**433**	**-8**	**2**	**543**	**970**	**$1,806**	**$1,863**
Water Action Plan Portfolio	2015-2039	2,965	111	380	1,174	4,630	$3,605	$779
	2040-2069	3,998	185	149	3,155	7,487	$6,732	$899
	2070-2099	4,160	181	-137	4,535	8,739	$9,605	$1,099
	2015-2099	**3,752**	**162**	**116**	**2,955**	**6,984**	**$6,647**	**$952**

GW = groundwater

Figure 7-14 shows the improvement in net economic benefits in the No Action alternative and each portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios relative to the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenarios reflecting current socioeconomic conditions and the Reference-No-Climate-Change condition, at the three future levels of developments based on results from LCPSIM, OMWEM, SWAP, LCRBWQM and SBWQM models.

Figure 7-14. Net economic benefits.

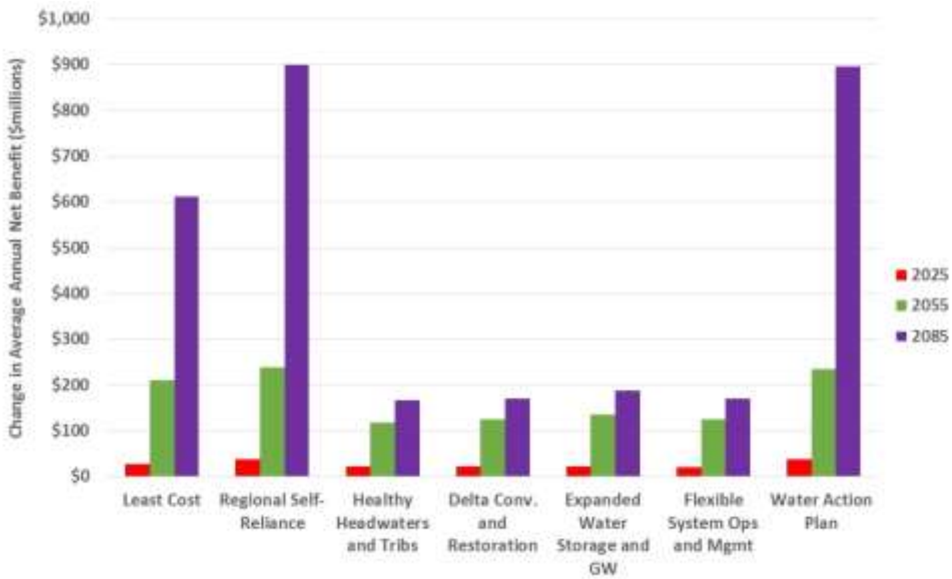

Figure 7-14a. Change in average annual net benefit in **South San Francisco Bay Region** from LCPSIM in each portfolio each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

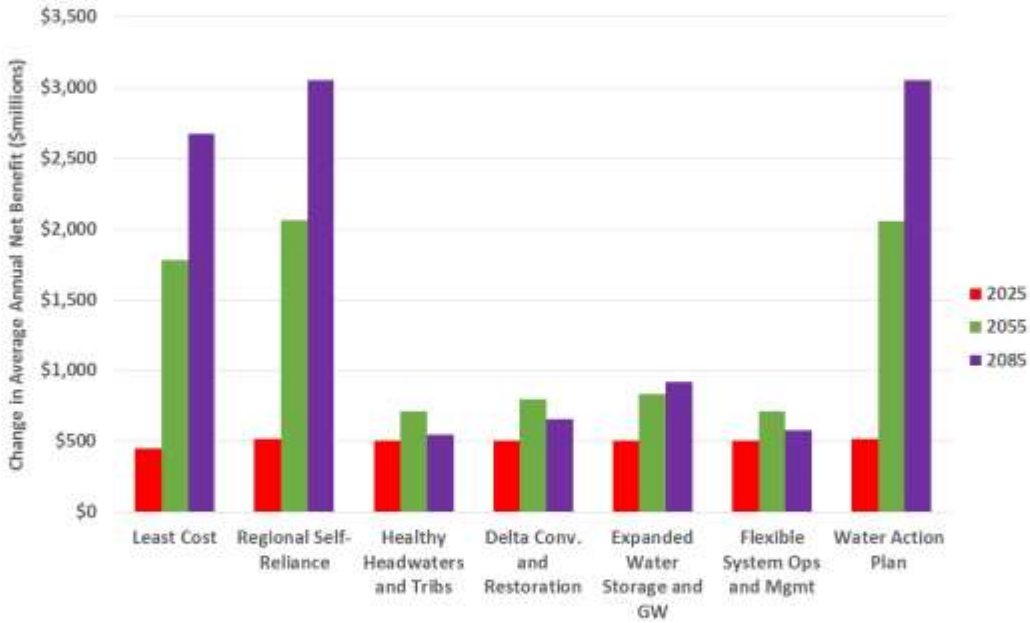

Figure 7-14b. Change in average annual net benefit in **South Coast Region** from LCPSIM in each portfolio in the each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

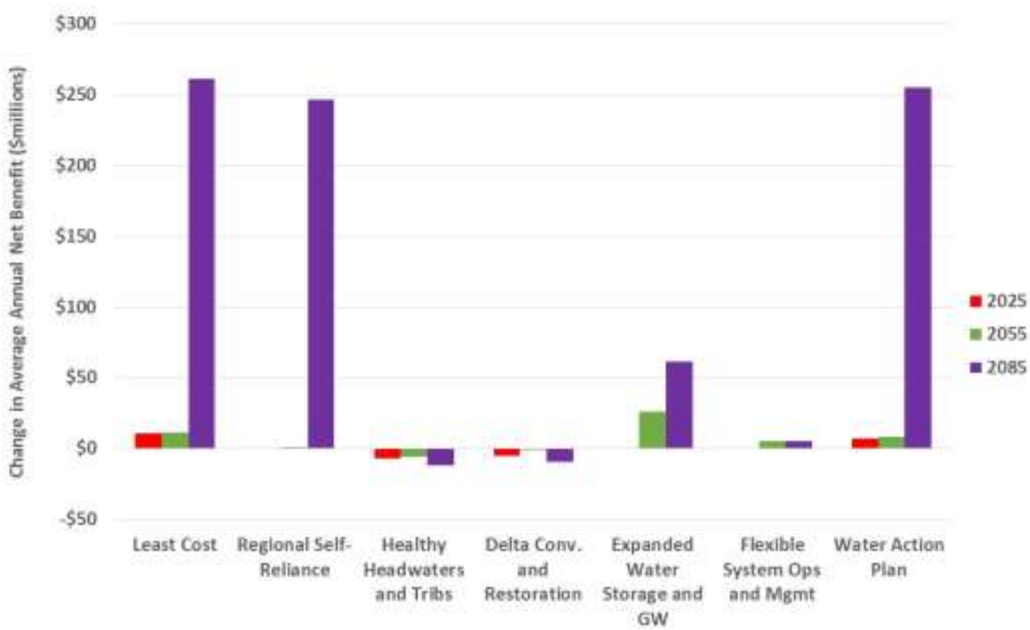

Figure 7-14c. Change in average annual net benefit in Central Valley urban areas from OMWEM in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

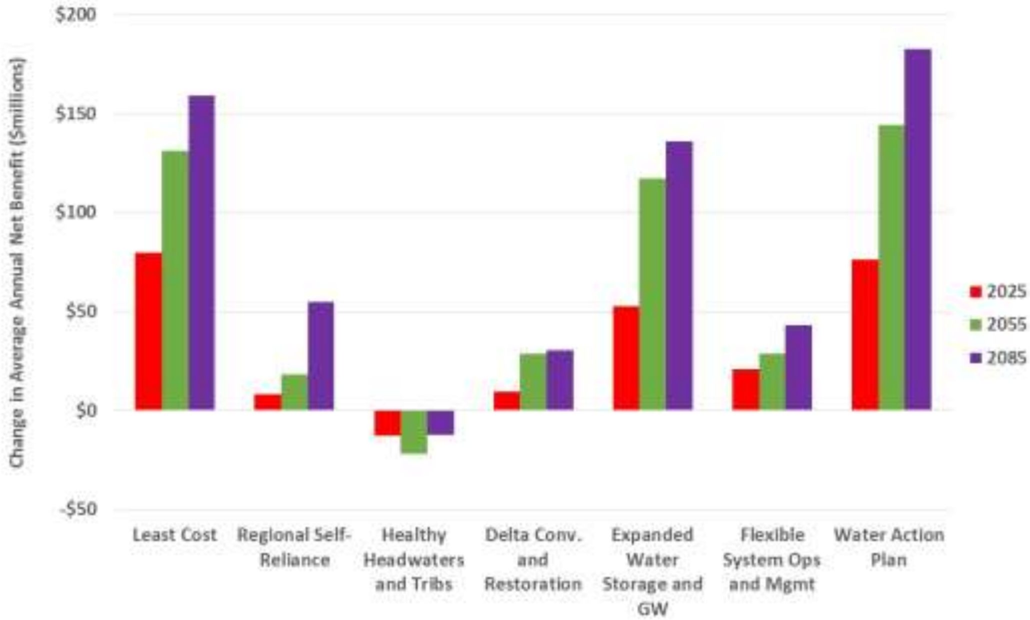

Figure 7-14d. Change in average annual net benefit for **Central Valley agricultural areas** from SWAP in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

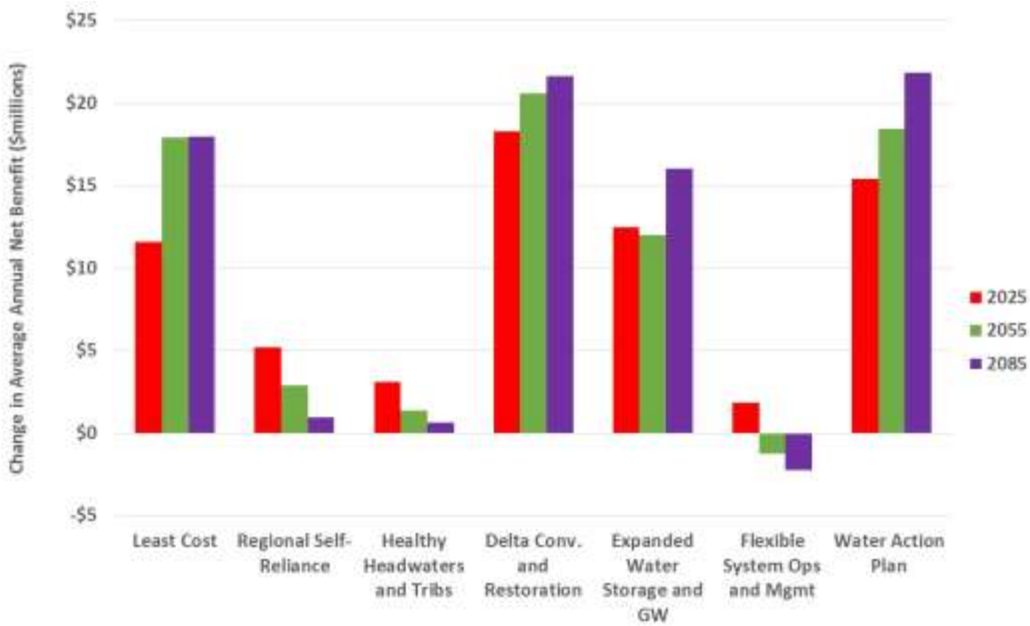

Figure 7-14e. Change in average annual net benefit in **South San Francisco Bay Region salinity management costs** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

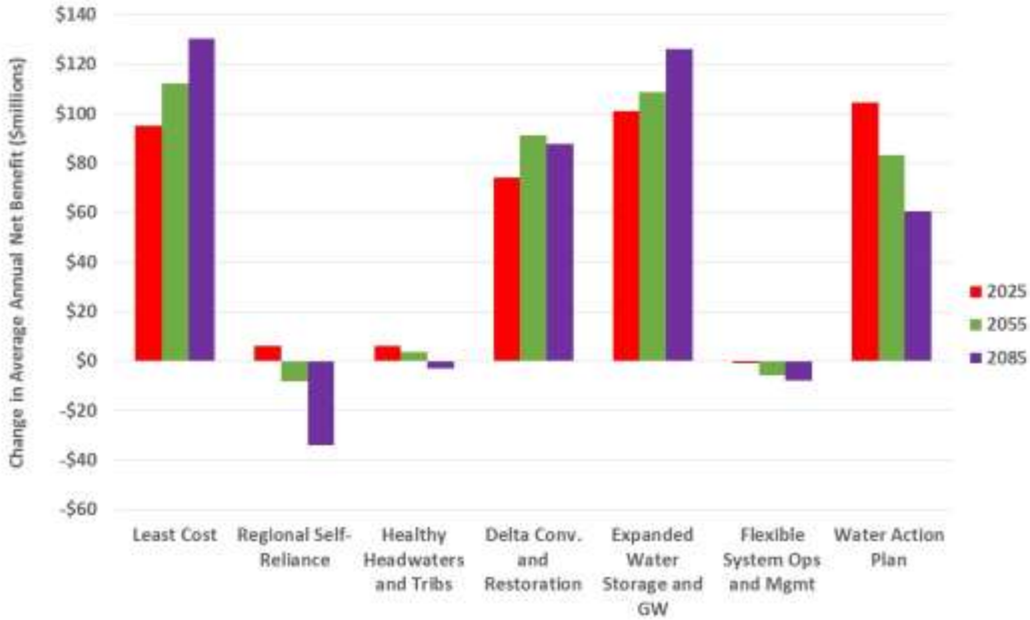

Figure 7-14f. Change in average annual net benefit in **South Coast Region salinity management costs** from each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios from the Reference-No-Climate-Change climate/Current Trends socioeconomic scenarios.

7.4. Water Quality

7.4.1. Delta Salinity

Delta salinity conditions provide a measure of the risk that water in the Delta will have higher salinity than what is required to be in compliance with standards for urban and agricultural beneficial uses set by the State Water Resources Control Board (SWRCB) in Decision 1641 (D1641). The salinity standards are specified at several Delta compliance locations including Emmaton and Jersey Point from April through August (ranging from 450 to 2,750 µS/cm, depending on the month and water year type) and at Vernalis and Rock Slough throughout the year (ranging from 631 to 965 µS/cm, depending on the month and water year type).

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.

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.

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.*

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. See Section 5.2.4.1. *Delta Salinity*.

None of the adaptation portfolios achieved any significant reductions in salinity relative to the No Action alternative. 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.

The results for the portfolios show only small differences relative to the No Action alternative for Delta salinity levels. The average change across all locations from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +2%
- Regional Self-Reliance portfolio:-4%
- Healthy Headwaters and Tributaries portfolio: +3%
- Delta Conveyance and Restoration portfolio: +1% in the
- Expanded Water Storage and Groundwater portfolio:-3%
- Flexible System Operations and Management portfolio: +2%
  Water Action Plan portfolio:-2%

Reduced Salinity: The Water Action Portfolio has reduced salinity levels at all four locations. The Regional Self-Reliance, Expanded Water Storage and Groundwater and Water Action Plan portfolios provide the greatest improvement in Delta salinity conditions.

Increased Salinity: The Least Cost, Healthy Headwaters and Tributaries and Flexible System Operations and Management portfolios result in the greatest increase in Delta salinity. The Delta Conveyance and Restoration and Healthy Headwaters and Tributaries portfolios had small increases in salinity at all four locations.

7.4.1.1. Adaptation Portfolio Performance

7.4.1.1.1. Jersey Point

At Jersey Point in the Hot-Dry and Central Tendency climate scenarios, Delta salinity increased in all the portfolios and No Action due to increasing sea level throughout the 21st century (Figure 7-15). 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 under most climate scenarios.

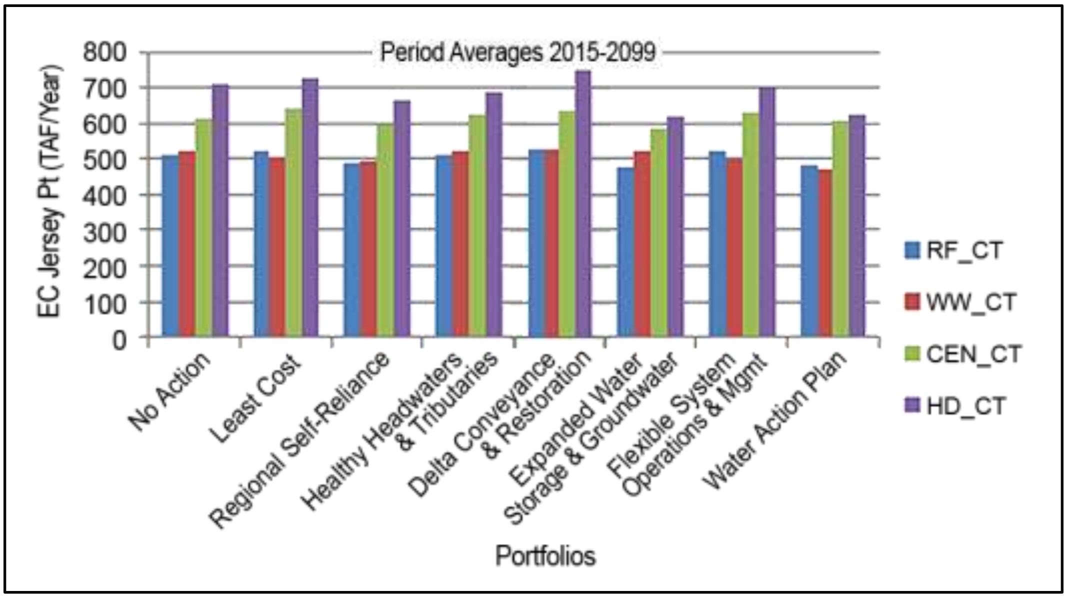

Figure 7-15. Average April-August EC at Jersey Point in each adaptation portfolio.

(Lower numbers indicate increased benefits).

Table 7-15 shows details of the performance of each of the portfolios relative to No Action in each of the four climate-socioeconomic scenarios.

Table 7-15. April-August Salinity Levels at Jersey Point: Adaptation Portfolio Performance

Percent Change Compared to the No Action Alternative (%) (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 7-16) in the Hot-Dry and Central Tendency climate scenarios than in the Reference-No-Climate-Change climate scenario. 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 7-16 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

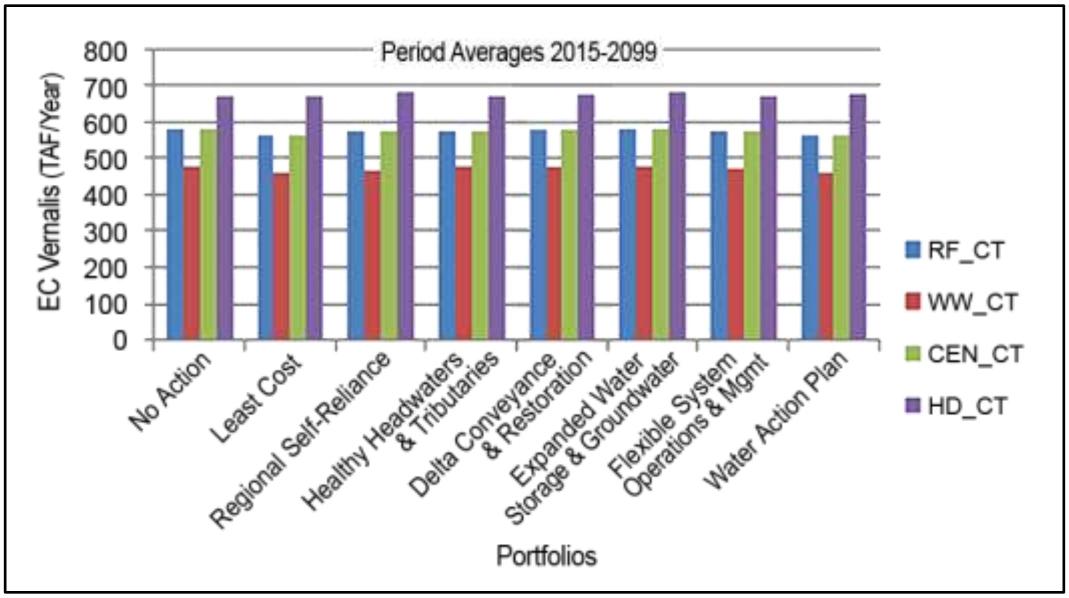

Figure 7-16. Average October through September salinity levels at Vernalis in each adaptation portfolio.[15]

(Lower numbers indicate increased benefits).

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[15] 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 7-16. 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 7-17 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.

- **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 7-17. April-August Salinity in EC (µS/cm) at Jersey Point: Climate Scenario Sensitivity

(% 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 7-18 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 7-18. Annual Salinity Levels at Vernalis: Climate Scenario Sensitivity

(% 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

Figure 7-17 show annual exceedance of EC at Emmaton and Jersey Point from April through August for each portfolio Central Tendency climate/Current Trends socioeconomic scenarios as well as for EC at Vernalis and Rock Slough from October through September.

Table 7-19 shows the average EC in specific ranges of months at the four locations under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-17. Delta salinity levels: annual exceedances

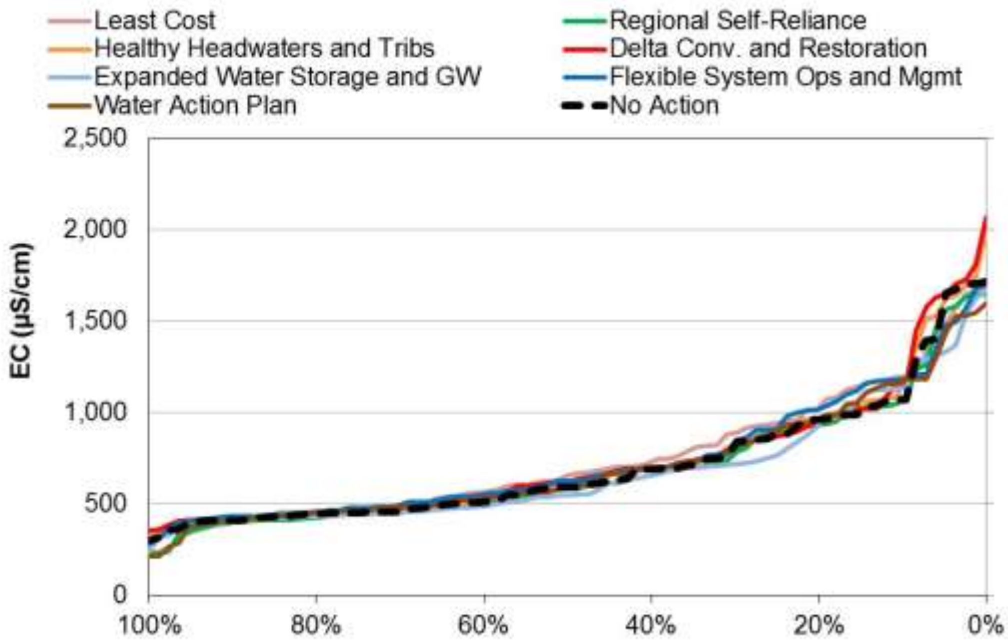

Figure 7-17a. Exceedance plot of average **April-to-August EC at Emmaton** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

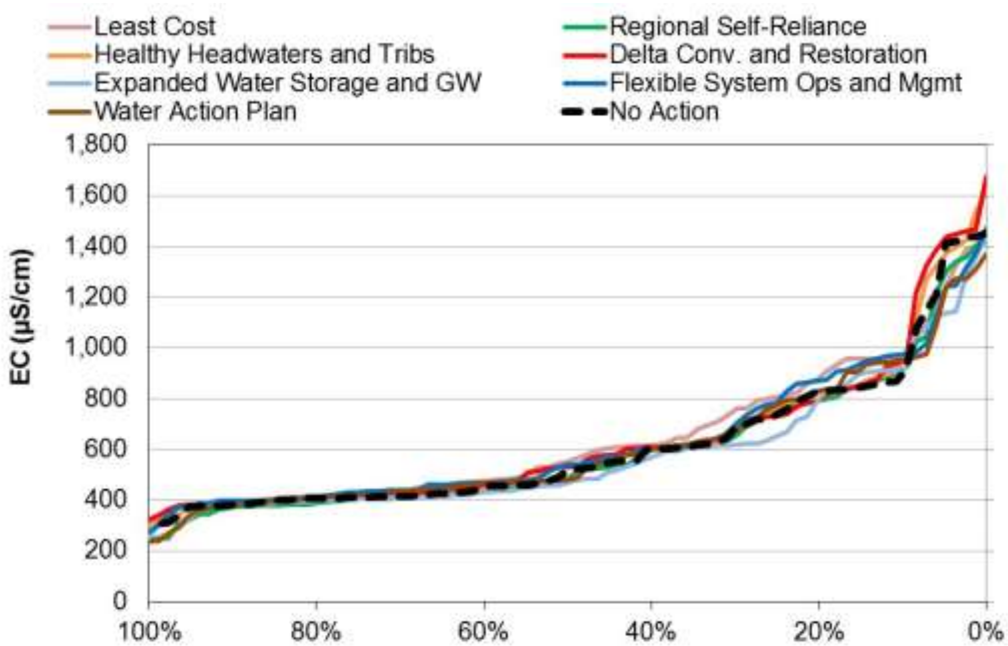

Figure 7-17b. Exceedance plot of average **April-to-August EC at Jersey Point** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

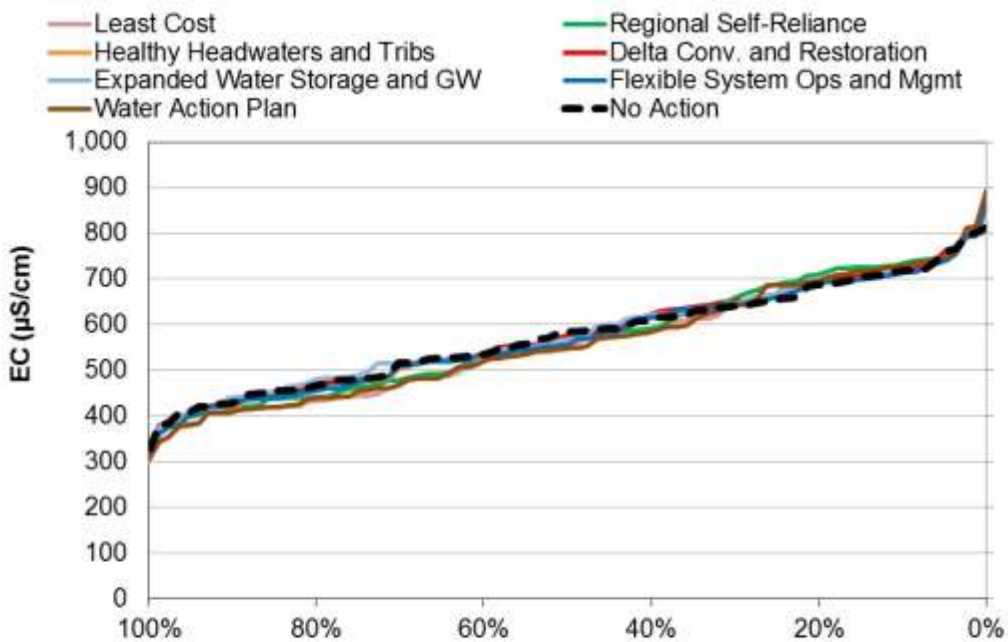

Figure 7-17c. Exceedance plot of average **October through September EC at Vernalis** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

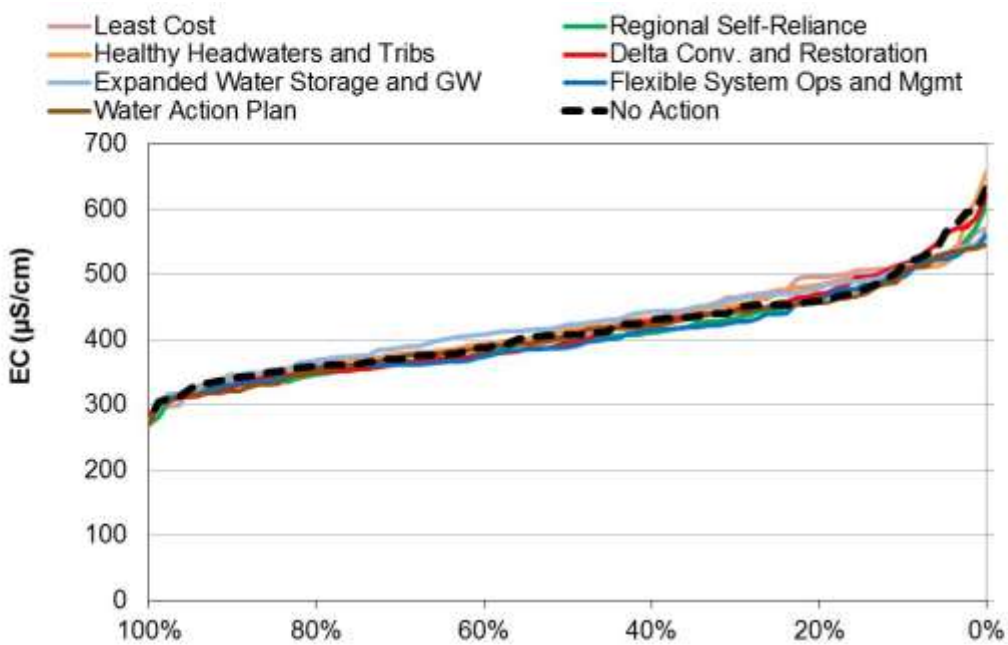

Figure 7-17d. Exceedance Plot of average **October through September EC at Rock Slough** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-19. Salinity Levels: Adaptation Portfolio Comparison

Table 7-19a. Average **April-August EC (µS/cm) at Emmaton** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	645	812	811	670	623	733
	2040-2069	556	612	731	643	534	615
	2070-2099	593	733	975	832	621	789
	2015-2099	**595**	**713**	**841**	**717**	**591**	**711**
Least Cost Portfolio	2015-2039	699	826	818	702	629	746
	2040-2069	551	658	746	642	509	635
	2070-2099	591	816	1042	835	569	852
	2015-2099	**609**	**763**	**871**	**728**	**566**	**744**
Regional Self-Reliance Portfolio	2015-2039	640	815	813	754	636	738
	2040-2069	513	624	678	565	496	592
	2070-2099	545	724	881	713	544	753
	2015-2099	**562**	**716**	**789**	**673**	**554**	**692**
Healthy Headwaters and Tributaries Portfolio	2015-2039	657	821	791	692	628	743
	2040-2069	550	610	705	606	535	625
	2070-2099	593	742	958	788	621	812
	2015-2099	**597**	**719**	**820**	**696**	**593**	**725**
Delta Conveyance and Restoration Portfolio	2015-2039	693	814	833	730	617	768
	2040-2069	567	657	755	619	548	602
	2070-2099	591	783	1088	797	642	852
	2015-2099	**613**	**748**	**895**	**714**	**601**	**739**
Expanded Water Storage and Groundwater Portfolio	2015-2039	640	780	740	712	622	679
	2040-2069	503	516	614	603	538	599
	2070-2099	515	624	850	796	623	759
	2015-2099	**548**	**632**	**735**	**703**	**593**	**679**
Flexible System Operations and Mgmt Portfolio	2015-2039	665	787	790	643	587	714
	2040-2069	564	628	785	638	504	627
	2070-2099	604	792	935	867	602	855
	2015-2099	**608**	**733**	**840**	**720**	**563**	**733**
Water Action Plan Portfolio	2015-2039	625	685	693	612	545	675
	2040-2069	517	542	620	613	493	618
	2070-2099	545	712	914	790	551	817
	2015-2099	**559**	**644**	**745**	**675**	**529**	**705**

Table 7-19b. Average **April-August EC (μS/cm) at Jersey Point** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	546	688	698	586	540	631
	2040-2069	484	542	635	561	481	547
	2070-2099	510	637	787	667	547	660
	2015-2099	**512**	**619**	**707**	**606**	**522**	**612**
Least Cost Portfolio	2015-2039	587	699	703	611	547	642
	2040-2069	478	579	643	559	461	563
	2070-2099	509	706	832	671	505	712
	2015-2099	**521**	**659**	**727**	**614**	**502**	**639**
Regional Self-Reliance Portfolio	2015-2039	544	692	702	650	552	636
	2040-2069	451	553	589	505	452	528
	2070-2099	476	632	708	607	486	633
	2015-2099	**487**	**622**	**664**	**584**	**493**	**597**
Healthy Headwaters and Tributaries Portfolio	2015-2039	554	694	680	599	544	638
	2040-2069	479	541	614	539	482	556
	2070-2099	509	645	770	665	548	682
	2015-2099	**512**	**623**	**688**	**601**	**523**	**625**
Delta Conveyance and Restoration Portfolio	2015-2039	584	690	715	630	536	659
	2040-2069	492	579	655	549	491	536
	2070-2099	510	678	876	668	564	711
	2015-2099	**526**	**647**	**750**	**615**	**530**	**634**
Expanded Water Storage and Groundwater Portfolio	2015-2039	545	663	640	615	541	591
	2040-2069	444	464	536	535	483	533
	2070-2099	453	543	683	670	547	633
	2015-2099	**477**	**550**	**619**	**606**	**523**	**585**
Flexible System Operations and Mgmt Portfolio	2015-2039	561	669	682	564	513	615
	2040-2069	490	555	678	556	456	556
	2070-2099	517	686	741	695	532	711
	2015-2099	**521**	**635**	**702**	**607**	**500**	**628**
Water Action Plan Portfolio	2015-2039	534	591	605	540	481	587
	2040-2069	453	484	538	535	448	548
	2070-2099	475	620	727	637	492	685
	2015-2099	**484**	**564**	**624**	**572**	**473**	**608**

Table 7-19c. Average **Annual EC (µS/cm) at Vernalis** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	647	720	719	581	575	650
	2040-2069	558	681	683	481	448	561
	2070-2099	543	620	615	445	427	531
	2015-2099	**579**	**671**	**669**	**498**	**478**	**576**
Least Cost Portfolio	2015-2039	636	716	723	568	562	636
	2040-2069	535	669	683	462	428	543
	2070-2099	526	610	607	426	407	515
	2015-2099	**562**	**662**	**668**	**480**	**460**	**561**
Regional Self-Reliance Portfolio	2015-2039	641	719	725	580	568	642
	2040-2069	546	683	697	471	435	555
	2070-2099	539	627	624	435	414	529
	2015-2099	**571**	**674**	**679**	**491**	**467**	**572**
Healthy Headwaters and Tributaries Portfolio	2015-2039	646	720	720	583	573	647
	2040-2069	552	682	687	478	443	559
	2070-2099	538	621	618	442	422	529
	2015-2099	**575**	**672**	**672**	**497**	**474**	**574**
Delta Conveyance and Restoration Portfolio	2015-2039	648	722	721	585	575	649
	2040-2069	558	685	691	482	447	563
	2070-2099	546	627	624	446	428	534
	2015-2099	**580**	**676**	**676**	**500**	**478**	**578**
Expanded Water Storage and Groundwater Portfolio	2015-2039	651	727	731	587	578	654
	2040-2069	559	687	696	481	447	566
	2070-2099	545	629	627	442	424	534
	2015-2099	**581**	**678**	**682**	**498**	**477**	**580**
Flexible System Operations and Mgmt Portfolio	2015-2039	643	722	720	575	570	643
	2040-2069	552	682	688	472	440	557
	2070-2099	540	622	617	437	420	526
	2015-2099	**575**	**672**	**672**	**490**	**471**	**571**
Water Action Plan Portfolio	2015-2039	636	718	729	568	563	637
	2040-2069	538	673	689	461	427	546
	2070-2099	528	618	614	422	403	517
	2015-2099	**564**	**667**	**674**	**479**	**458**	**562**

Table 7-19d. Average **Annual EC (µS/cm) at Rock Slough** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	383	443	447	404	378	417
	2040-2069	354	400	443	393	352	398
	2070-2099	354	424	499	422	368	433
	2015-2099	**362**	**421**	**464**	**406**	**366**	**416**
Least Cost Portfolio	2015-2039	401	431	450	410	383	430
	2040-2069	351	439	475	378	340	395
	2070-2099	355	450	495	406	345	436
	2015-2099	**367**	**441**	**475**	**397**	**354**	**420**
Regional Self-Reliance Portfolio	2015-2039	388	453	466	407	380	421
	2040-2069	329	407	455	348	328	384
	2070-2099	334	421	484	369	341	418
	2015-2099	**348**	**425**	**469**	**373**	**348**	**407**
Healthy Headwaters and Tributaries Portfolio	2015-2039	386	443	433	399	385	418
	2040-2069	361	402	434	382	356	406
	2070-2099	359	438	491	406	366	437
	2015-2099	**368**	**427**	**454**	**395**	**368**	**421**
Delta Conveyance and Restoration Portfolio	2015-2039	379	417	430	399	377	408
	2040-2069	356	405	436	383	360	395
	2070-2099	359	411	507	415	377	432
	2015-2099	**364**	**411**	**459**	**399**	**371**	**412**
Expanded Water Storage and Groundwater Portfolio	2015-2039	402	427	443	422	388	420
	2040-2069	356	412	424	392	364	414
	2070-2099	342	417	503	405	372	437
	2015-2099	**365**	**418**	**458**	**405**	**374**	**424**
Flexible System Operations and Mgmt Portfolio	2015-2039	374	434	434	383	361	392
	2040-2069	349	395	456	383	344	387
	2070-2099	353	431	490	415	356	430
	2015-2099	**358**	**419**	**461**	**394**	**353**	**404**
Water Action Plan Portfolio	2015-2039	395	416	431	395	376	411
	2040-2069	345	414	433	373	333	396
	2070-2099	341	416	484	389	335	418
	2015-2099	**358**	**415**	**450**	**385**	**346**	**408**

7.4.2. End-of-May Storage

The cold water pool is generally managed from May through September. The initial May storage is correlated to the availability of cold water pool to manage through the spring and summer in major reservoirs in the CVP and SWP water management systems.

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.

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.

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.*

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. See Section 5.2.4.2 *End-of-May Storage*.

All 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.

The Least Cost portfolio has the highest storage levels among the portfolios over most of the 21^{st} century in Shasta, Oroville, Folsom, New Melones and Millerton Reservoirs.

The Healthy Headwaters and Tributaries and Delta Conveyance and Restoration portfolios have storage levels at or below the No Action alternative levels.

Shasta and Millerton reservoirs receive the largest average annual runoff in the Sacramento and San Joaquin river watersheds respectively.

Shasta Lake: The end-of-May storage in Shasta Lake was less than the metric value for a range of 5% to 44% across the range of climate scenarios from 2015-2099.

*More Storage***:** The Least Cost portfolio showed the greatest improvement, with a range of 5% to 16% across the range of climate scenarios. The Least Cost portfolio has the highest storage levels among the portfolios in Shasta, Oroville, Folsom, New Melones, and Millerton reservoirs.

Less Storage: The Healthy Headwaters and Tributaries portfolio performed the most poorly, with a range of 6% to 49% across the range of climate scenarios.

Millerton Reservoir: In Millerton Reservoir, the portfolios that include the upper San Joaquin storage action (Expanded Water Storage and Groundwater and Water Action Plan) show a significantly different operation than in the other portfolios because of changes in reservoir operating rules with the additional upstream storage. In the Expanded Water Storage and Groundwater and Water Action Plan portfolios, the Millerton storage levels were never less than the metric value because adding Temperance Flat allows for Millerton Reservoir to be operated at a stable storage level in the vast majority of years.

The end-of-May storage in Millerton Lake was less than the metric value for a range of 2% to 13% across the range of climate scenarios for the years from 2015-2099.

The Delta Conveyance and Restoration portfolio performed the most poorly, with a range of 1% to 18% across the range of climate scenarios.

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 7-18). 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 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 7-20 shows details of the performance of each of the adaptation portfolios relative to the No Action alternative in four climate scenarios.

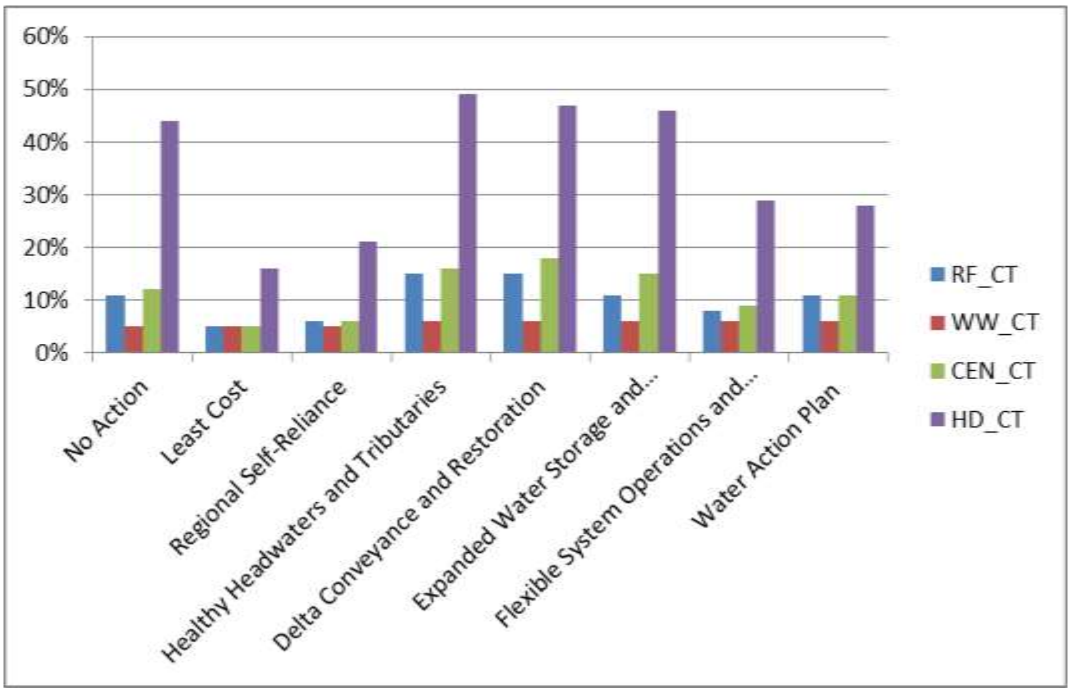

Figure 7-18. End-of-May-Storage (Lake Shasta)

Percentage of years with Lake Shasta End-of-May storage less than the 10th percentile of storage of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the No Action alternative and in each adaptation portfolio.[16] (Lower numbers indicate increased benefits).

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[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 climate.

Table 7-20. 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 7-21 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** occurrences**.**

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

Table 7-21. Lake Shasta End-of-May Storage: Climate Scenario Sensitivity

(% 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

Portfolios	Warm-Wet-CT	Central-CT	Hot-Dry-CT
Flexible System Operations and Mgmt	-25	13	263
Water Action Plan	-45	0	155

Figure 7-19 shows exceedance plots of storage at the end of May in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs for the No Action alternative and each adaptation portfolio with Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-22 shows the percentage of time that the end-of-May storage is less than the 10th percentile value from Reference-No-Climate-Change climate scenario/2006 Historic Demands socioeconomic scenario (RF-RF) in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-19. End-of-May Storage: exceedence plots.

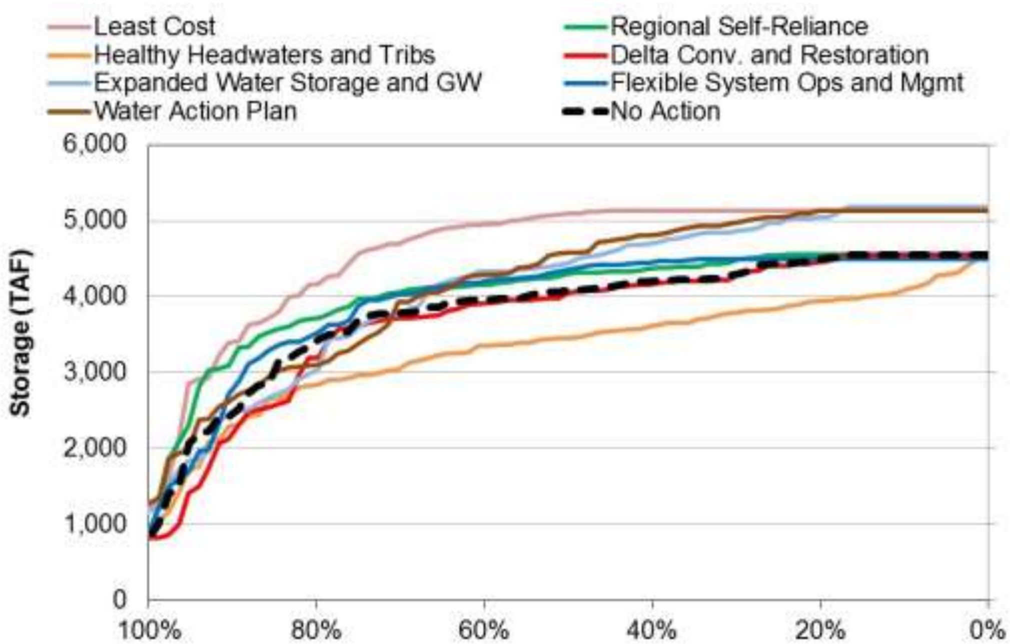

Figure 7-19a. Exceedance plot of **Lake Shasta** end-of-May storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

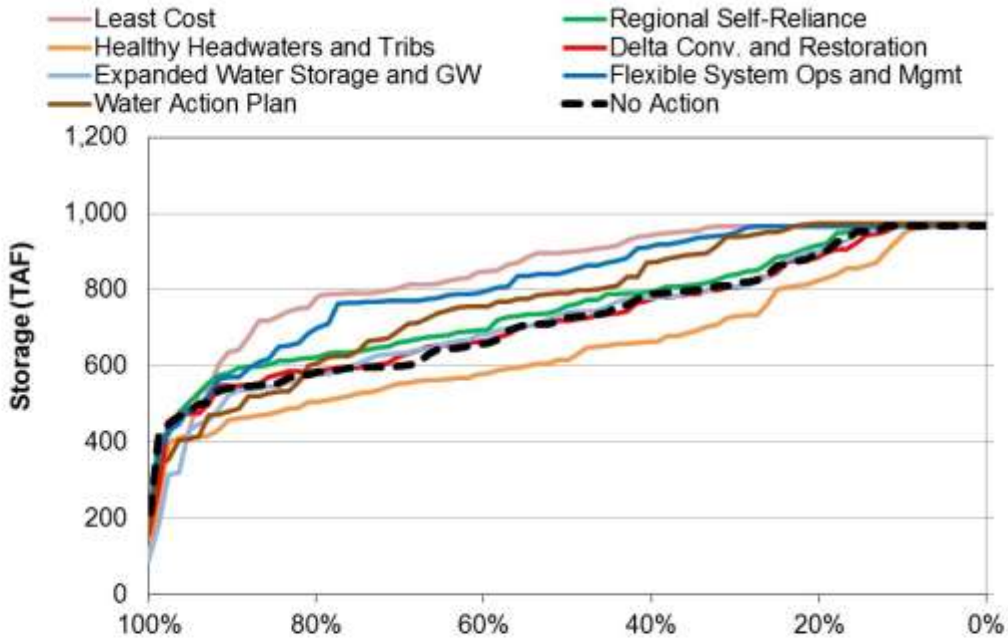

Figure 7-19b. Exceedance plot of **Folsom Lake** end-of-May storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

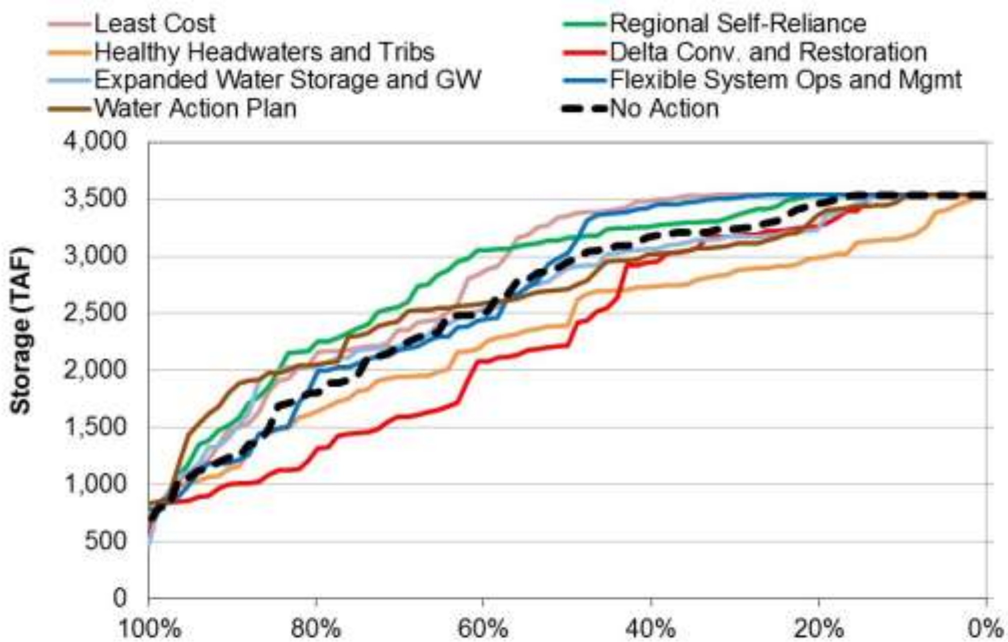

Figure 7-19c. Exceedance plot of **Lake Oroville** end-of-May storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

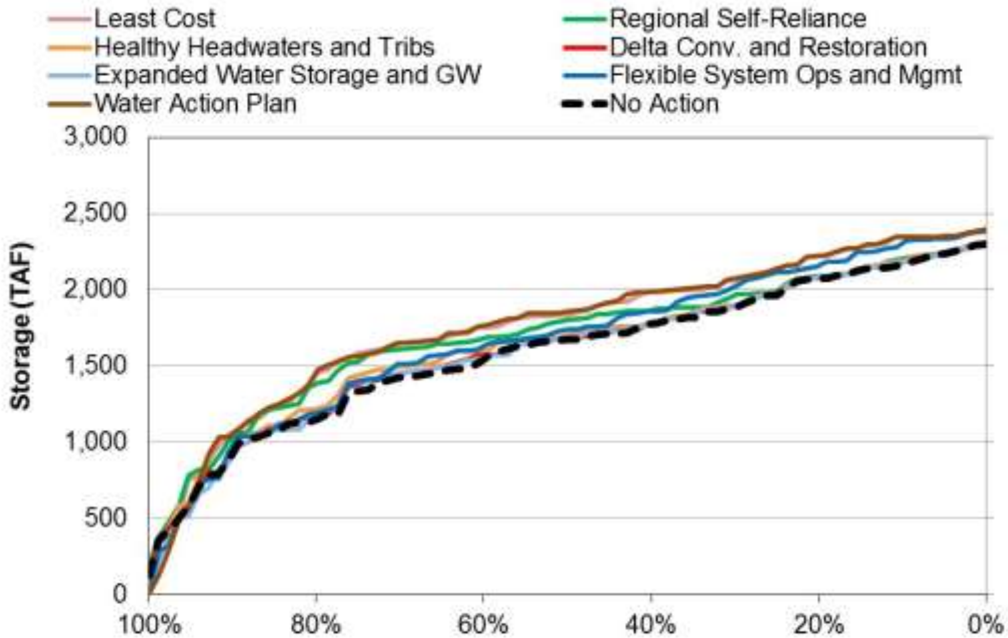

Figure 7-19d. Exceedance plot of **New Melones Reservoir** end-of-May storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

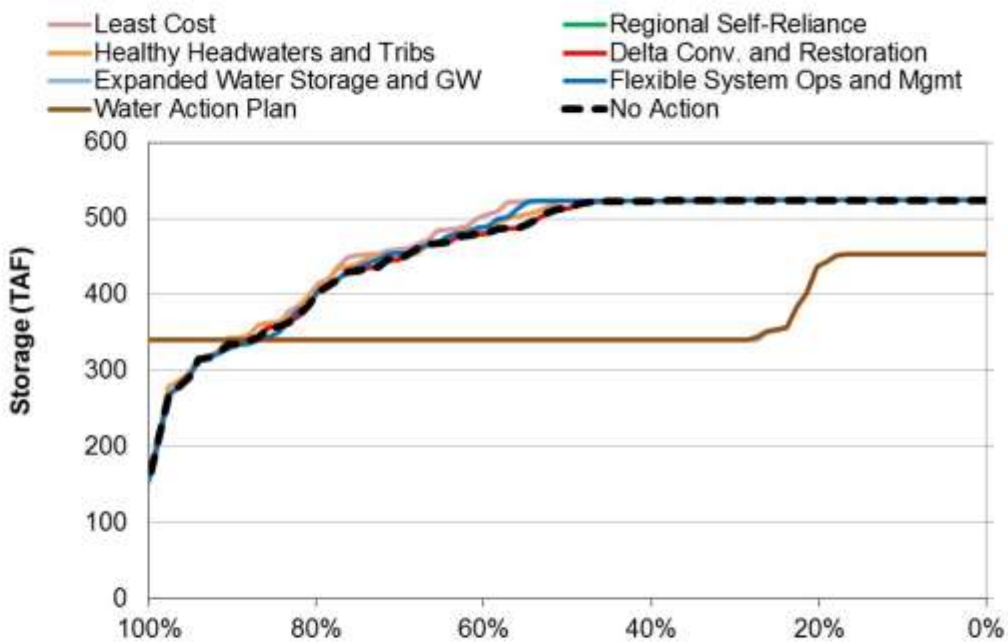

Figure 7-19e.Exceedance plot of **Millerton Reservoir** end-of-May storage for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-22. End-of-May Storage: Adaptation Portfolio Comparison

Table 7-22a. Percentage of Years with **Lake Shasta** End-of-May Storage Less than the 10th Percentile of Storage of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	28%	52%	52%	20%	16%	28%
	2040-2069	3%	17%	33%	0%	0%	3%
	2070-2099	3%	27%	47%	0%	0%	7%
	2015-2099	**11%**	**31%**	**44%**	**6%**	**5%**	**12%**
Least Cost Portfolio	2015-2039	16%	36%	40%	16%	16%	16%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	0%	10%	10%	0%	0%	0%
	2015-2099	**5%**	**15%**	**16%**	**5%**	**5%**	**5%**
Regional Self-Reliance Portfolio	2015-2039	20%	36%	44%	24%	16%	20%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	0%	7%	20%	0%	0%	0%
	2015-2099	**6%**	**14%**	**21%**	**7%**	**5%**	**6%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	40%	60%	64%	24%	20%	44%
	2040-2069	3%	17%	43%	0%	0%	3%
	2070-2099	7%	30%	43%	0%	0%	7%
	2015-2099	**15%**	**34%**	**49%**	**7%**	**6%**	**16%**
Delta Conveyance and Restoration Portfolio	2015-2039	40%	52%	56%	20%	20%	40%
	2040-2069	3%	13%	40%	0%	0%	3%
	2070-2099	7%	27%	47%	0%	0%	13%
	2015-2099	**15%**	**29%**	**47%**	**6%**	**6%**	**18%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	24%	48%	56%	20%	20%	28%
	2040-2069	3%	17%	40%	0%	0%	3%
	2070-2099	7%	23%	43%	0%	0%	17%
	2015-2099	**11%**	**28%**	**46%**	**6%**	**6%**	**15%**
Flexible System Operations and Mgmt Portfolio	2015-2039	16%	44%	48%	16%	16%	20%
	2040-2069	3%	3%	13%	3%	3%	3%
	2070-2099	7%	17%	30%	0%	0%	7%
	2015-2099	**8%**	**20%**	**29%**	**6%**	**6%**	**9%**
Water Action Plan Portfolio	2015-2039	32%	48%	52%	24%	20%	28%
	2040-2069	0%	7%	13%	3%	0%	0%
	2070-2099	3%	13%	23%	0%	0%	7%
	2015-2099	**11%**	**21%**	**28%**	**8%**	**6%**	**11%**

Table 7-22b. Percentage of Years with **Folsom** End-of-May Storage Less than the 10th Percentile of Storage of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	16%	24%	40%	20%	16%	24%
	2040-2069	13%	13%	37%	20%	10%	17%
	2070-2099	3%	30%	57%	13%	7%	13%
	2015-2099	**11%**	**22%**	**45%**	**18%**	**11%**	**18%**
Least Cost Portfolio	2015-2039	16%	24%	24%	16%	16%	16%
	2040-2069	3%	10%	17%	10%	7%	10%
	2070-2099	3%	7%	7%	0%	0%	0%
	2015-2099	**7%**	**13%**	**15%**	**8%**	**7%**	**8%**
Regional Self-Reliance Portfolio	2015-2039	16%	24%	20%	16%	16%	20%
	2040-2069	3%	10%	13%	13%	7%	7%
	2070-2099	0%	3%	23%	7%	3%	0%
	2015-2099	**6%**	**12%**	**19%**	**12%**	**8%**	**8%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	28%	36%	52%	32%	28%	36%
	2040-2069	13%	33%	53%	23%	20%	33%
	2070-2099	17%	50%	63%	23%	20%	47%
	2015-2099	**19%**	**40%**	**56%**	**26%**	**22%**	**39%**
Delta Conveyance and Restoration Portfolio	2015-2039	20%	24%	40%	12%	16%	20%
	2040-2069	10%	20%	33%	17%	10%	17%
	2070-2099	3%	33%	53%	10%	7%	10%
	2015-2099	**11%**	**26%**	**42%**	**13%**	**11%**	**15%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	20%	40%	40%	20%	20%	28%
	2040-2069	7%	23%	37%	17%	7%	17%
	2070-2099	10%	43%	60%	17%	13%	17%
	2015-2099	**12%**	**35%**	**46%**	**18%**	**13%**	**20%**
Flexible System Operations and Mgmt Portfolio	2015-2039	16%	12%	20%	12%	12%	20%
	2040-2069	10%	10%	20%	10%	7%	13%
	2070-2099	0%	7%	30%	0%	0%	3%
	2015-2099	**8%**	**9%**	**24%**	**7%**	**6%**	**12%**
Water Action Plan Portfolio	2015-2039	24%	32%	32%	24%	24%	24%
	2040-2069	10%	23%	27%	10%	7%	17%
	2070-2099	7%	33%	37%	3%	0%	17%
	2015-2099	**13%**	**29%**	**32%**	**12%**	**9%**	**19%**

Table 7-22c. Percentage of Years with **Lake Oroville** End-of-May Storage Less than the 10th Percentile of Storage of the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	20%	20%	20%	8%	8%	16%
	2040-2069	10%	13%	20%	3%	3%	10%
	2070-2099	3%	17%	40%	0%	3%	10%
	2015-2099	**11%**	**16%**	**27%**	**4%**	**5%**	**12%**
Least Cost Portfolio	2015-2039	12%	28%	28%	16%	16%	16%
	2040-2069	3%	3%	17%	3%	3%	7%
	2070-2099	0%	13%	27%	3%	3%	3%
	2015-2099	**5%**	**14%**	**24%**	**7%**	**7%**	**8%**
Regional Self-Reliance Portfolio	2015-2039	8%	12%	4%	4%	4%	8%
	2040-2069	3%	7%	13%	3%	0%	7%
	2070-2099	3%	10%	33%	0%	0%	3%
	2015-2099	**5%**	**9%**	**18%**	**2%**	**1%**	**6%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	16%	20%	24%	12%	8%	16%
	2040-2069	10%	17%	27%	3%	3%	10%
	2070-2099	0%	17%	43%	0%	3%	13%
	2015-2099	**8%**	**18%**	**32%**	**5%**	**5%**	**13%**
Delta Conveyance and Restoration Portfolio	2015-2039	28%	36%	36%	24%	16%	32%
	2040-2069	13%	27%	43%	10%	3%	17%
	2070-2099	20%	33%	47%	10%	10%	20%
	2015-2099	**20%**	**32%**	**42%**	**14%**	**9%**	**22%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	8%	20%	20%	12%	12%	20%
	2040-2069	3%	17%	23%	3%	0%	3%
	2070-2099	7%	20%	43%	0%	0%	7%
	2015-2099	**6%**	**19%**	**29%**	**5%**	**4%**	**9%**
Flexible System Operations and Mgmt Portfolio	2015-2039	16%	24%	24%	12%	12%	20%
	2040-2069	10%	20%	13%	3%	3%	10%
	2070-2099	3%	7%	23%	0%	3%	10%
	2015-2099	**9%**	**16%**	**20%**	**5%**	**6%**	**13%**
Water Action Plan Portfolio	2015-2039	12%	12%	8%	12%	12%	12%
	2040-2069	3%	3%	10%	0%	0%	3%
	2070-2099	0%	0%	10%	0%	0%	0%
	2015-2099	**5%**	**5%**	**9%**	**4%**	**4%**	**5%**

Table 7-22d. Percentage of Years with **New Melones Reservoir** End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	37%	40%	0%	0%	0%
	2070-2099	10%	27%	17%	0%	0%	10%
	2015-2099	**11%**	**35%**	**34%**	**4%**	**4%**	**11%**
Least Cost Portfolio	2015-2039	24%	40%	40%	12%	12%	24%
	2040-2069	0%	3%	3%	0%	0%	0%
	2070-2099	7%	10%	13%	0%	0%	3%
	2015-2099	**9%**	**16%**	**18%**	**4%**	**4%**	**8%**
Regional Self-Reliance Portfolio	2015-2039	24%	40%	40%	12%	12%	24%
	2040-2069	0%	13%	10%	0%	0%	0%
	2070-2099	7%	13%	13%	0%	0%	3%
	2015-2099	**9%**	**21%**	**20%**	**4%**	**4%**	**8%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	24%	44%	44%	12%	12%	24%
	2040-2069	0%	27%	23%	0%	0%	0%
	2070-2099	7%	20%	17%	0%	0%	7%
	2015-2099	**9%**	**29%**	**27%**	**4%**	**4%**	**9%**
Delta Conveyance and Restoration Portfolio	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	30%	33%	0%	0%	0%
	2070-2099	10%	23%	17%	0%	0%	10%
	2015-2099	**11%**	**32%**	**32%**	**4%**	**4%**	**11%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	24%	40%	44%	12%	12%	24%
	2040-2069	0%	43%	40%	0%	0%	0%
	2070-2099	10%	23%	17%	0%	0%	10%
	2015-2099	**11%**	**35%**	**33%**	**4%**	**4%**	**11%**
Flexible System Operations and Mgmt Portfolio	2015-2039	24%	44%	48%	12%	12%	24%
	2040-2069	0%	33%	33%	0%	0%	0%
	2070-2099	7%	17%	17%	0%	0%	7%
	2015-2099	**9%**	**31%**	**32%**	**4%**	**4%**	**9%**
Water Action Plan Portfolio	2015-2039	24%	36%	40%	12%	12%	24%
	2040-2069	0%	3%	10%	0%	0%	0%
	2070-2099	3%	13%	13%	0%	0%	0%
	2015-2099	**8%**	**16%**	**20%**	**4%**	**4%**	**7%**

Table 7-22e. Percentage of Years with **Millerton Reservoir** End-of-May Storage Less than the 10th Percentile of Storage in the Reference-No-Climate-Change climate/2006 Historic Demands socioeconomic scenario (RF_RF) in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	0%
	2015-2099	**11%**	**13%**	**13%**	**1%**	**5%**	**2%**
Least Cost Portfolio	2015-2039	4%	8%	4%	0%	0%	0%
	2040-2069	17%	13%	20%	3%	7%	7%
	2070-2099	7%	10%	13%	0%	3%	0%
	2015-2099	**9%**	**11%**	**13%**	**1%**	**4%**	**2%**
Regional Self-Reliance Portfolio	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	0%
	2015-2099	**11%**	**13%**	**13%**	**1%**	**5%**	**2%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8%	16%	4%	0%	4%	0%
	2040-2069	17%	20%	20%	3%	10%	7%
	2070-2099	7%	13%	13%	0%	3%	3%
	2015-2099	**11%**	**16%**	**13%**	**1%**	**6%**	**4%**
Delta Conveyance and Restoration Portfolio	2015-2039	8%	16%	4%	0%	4%	0%
	2040-2069	17%	23%	20%	3%	10%	7%
	2070-2099	10%	13%	17%	0%	3%	7%
	2015-2099	**12%**	**18%**	**14%**	**1%**	**6%**	**5%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	0%	0%	0%	0%	0%	0%
	2040-2069	0%	0%	0%	0%	0%	0%
	2070-2099	0%	0%	0%	0%	0%	0%
	2015-2099	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
Flexible System Operations and Mgmt Portfolio	2015-2039	8%	8%	4%	0%	0%	0%
	2040-2069	17%	17%	20%	3%	7%	7%
	2070-2099	7%	10%	13%	0%	3%	0%
	2015-2099	**11%**	**12%**	**13%**	**1%**	**4%**	**2%**
Water Action Plan Portfolio	2015-2039	0%	0%	0%	0%	0%	0%
	2040-2069	0%	0%	0%	0%	0%	0%
	2070-2099	0%	0%	0%	0%	0%	0%
	2015-2099	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

7.5. Hydropower and GHG Emissions

7.5.1. Energy Generation and Use

Net hydropower generation is defined as the difference between its generation and use. It is positive when generation is greater than use. 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. Net hydropower generation is measured in units of gigawatt hours per year (GWh/year).

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 million megawatt hours 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 runoff 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 gigawatt hours per year (GWh/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. See Section 5.2.5.1. *Energy Generation and Use*.

CVP: There were only minor differences among the portfolios in CVP net generation because differences in CVP operations are relatively small. The percentage change in average annual net energy generation from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-1%
- Regional Self-Reliance portfolio: +2%
- Healthy Headwaters and Tributaries portfolio: +3%
- Delta Conveyance and Restoration portfolio: +0%
- Expanded Water Storage and Groundwater portfolio: +2%
- Flexible System Operations and Management portfolio: +0%
- Water Action Plan portfolio: +1%

SWP:

Reduced Net Generation: The Least Cost, Regional Self-Reliance, Expanded Water Storage and Groundwater, and Water Action Plan portfolios all result in significant reductions in SWP net generation, mostly due to increased pumping cost as a result of increased pumping at the Banks PP.

Increased Net Generation: The Delta Conveyance and Restoration, Healthy Headwaters and Tributaries, and Flexible System Operations and Management portfolios showed slight increases in net generation.

With the Central Tendency climate scenario from 2015-2099, the percentage change in average annual net energy generation for the SWP system from the No Action alternative is:

- Least Cost portfolio:-29%
- Regional Self-Reliance portfolio:-34%
- Healthy Headwaters and Tributaries portfolio: +3%
- Delta Conveyance and Restoration portfolio: +7%
- Expanded Water Storage and Groundwater portfolio:-34%
- Flexible System Operations and Management portfolio: +3%
- Water Action Plan portfolio:-46%

7.5.1.1. 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 decreases in these portfolios (Figure 7-20). The Delta Conveyance and Restoration adaptation portfolio had slightly reduced performance—primarily because of its increased use of hydropower for CVP pumping.

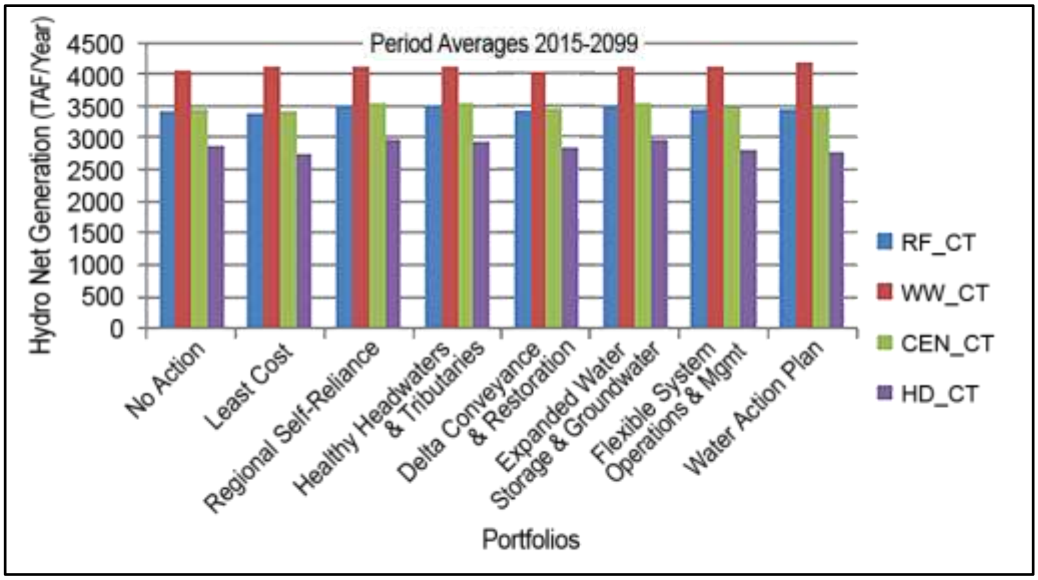

Figure 7-20. Annual Net Energy Generation: Adaptation Portfolio Performance

(Average annual net energy generation (GWh/year) in the CVP system. Higher numbers indicate increased benefits).

Table 7-23 shows details of the performance of each of the adaptation portfolios relative to the No Action alternative in four climate scenarios.

Table 7-23. 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

7.5.1.2. Adaptation Portfolio Climate Sensitivity

Table 7-24 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 7-24. Annual Net Energy Generation: Climate Scenario Sensitivity

(% 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

Figure 7-22 shows the 10-year moving average of annual average SWP, CVP, and total SWP + CVP net hydropower generation in each portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-25 shows the average annual net energy generation for the CVP and SWP systems and total SWP + CVP systems under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-21. Net hydropower generation: 10-year moving average.

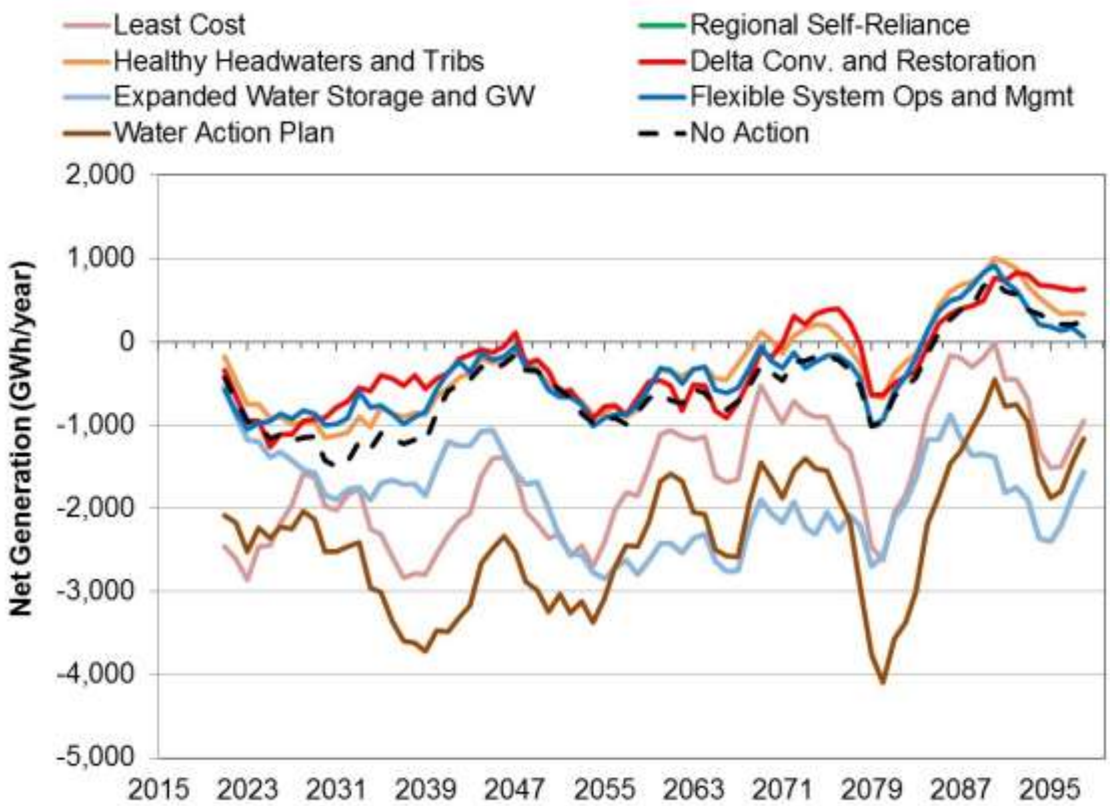

Figure 7-22a. 10-year moving average of annual net energy generation for **the Combined CVP and SWP Systems** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Figure 7-22b. 10-year moving average of annual net energy generation for the **CVP system** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

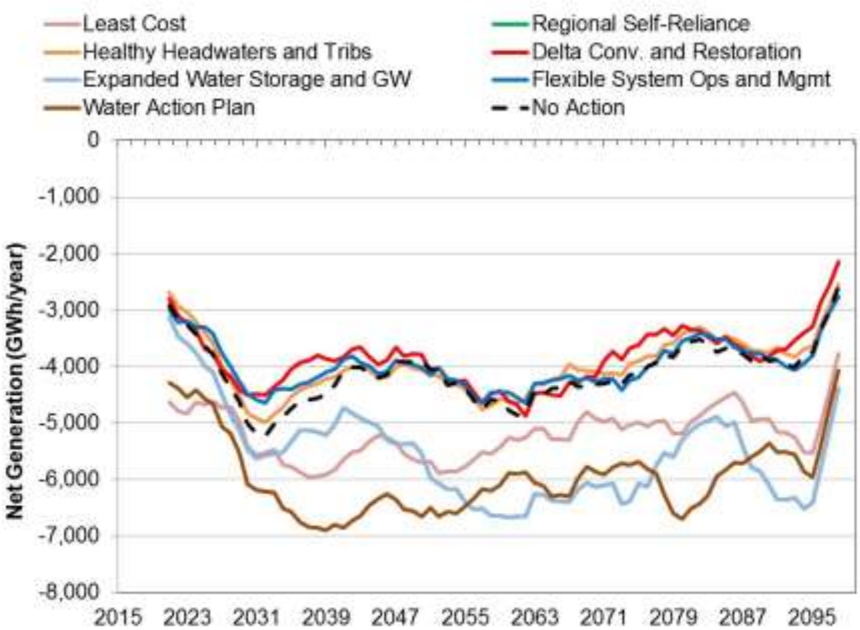

Figure 7-22c. 10-year moving average of annual net energy generation for the **SWP System** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-25. Energy Generation: Adaptation Portfolio Comparison

Table 7-25a. Average Annual Net Energy Generation (GWh/year) in the **CVP and SWP System** in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-927	-827	-696	-820	-703	-877
	2040-2069	-683	-828	-280	144	-224	-488
	2070-2099	-610	-415	186	-4	-209	-44
	2015-2099	**-741**	**-695**	**-269**	**-225**	**-379**	**-475**
Least Cost Portfolio	2015-2039	-2,345	-2,319	-2,260	-1,676	-1,551	-2,276
	2040-2069	-1,493	-2,638	-2,018	-196	-80	-1,408
	2070-2099	-1,606	-1,962	-1,477	-518	-491	-1,211
	2015-2099	**-1,813**	**-2,314**	**-1,924**	**-793**	**-702**	**-1,634**
Regional Self-Reliance Portfolio	2015-2039	-1,307	-1,326	-1,028	-1,327	-1,416	-1,278
	2040-2069	-2,272	-1,789	-863	-1,501	-1,566	-2,159
	2070-2099	-2,350	-2,189	-1,281	-1,773	-1,758	-1,833
	2015-2099	**-1,975**	**-1,763**	**-1,053**	**-1,530**	**-1,578**	**-1,760**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-576	-668	-355	-310	-673	-641
	2040-2069	-519	-484	-126	208	-25	-277
	2070-2099	-292	-284	334	221	39	181
	2015-2099	**-465**	**-481**	**-55**	**40**	**-220**	**-251**
Delta Conveyance and Restoration Portfolio	2015-2039	-594	-715	-440	-319	-665	-568
	2040-2069	-714	-637	-392	159	-86	-336
	2070-2099	-478	-208	101	-62	-168	256
	2015-2099	**-598**	**-525**	**-249**	**-71**	**-305**	**-223**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-1,307	-1,326	-1,028	-1,327	-1,416	-1,278
	2040-2069	-2,272	-1,789	-863	-1,501	-1,566	-2,159
	2070-2099	-2,350	-2,189	-1,281	-1,773	-1,758	-1,833
	2015-2099	**-1,975**	**-1,763**	**-1,053**	**-1,530**	**-1,578**	**-1,760**
Flexible System Operations and Mgmt Portfolio	2015-2039	-765	-1,052	-788	-695	-620	-677
	2040-2069	-610	-851	-521	313	32	-369
	2070-2099	-368	-454	30	-7	-46	-2
	2015-2099	**-584**	**-790**	**-432**	**-126**	**-210**	**-354**
Water Action Plan Portfolio	2015-2039	-2,744	-2,937	-2,772	-2,086	-1,977	-2,639
	2040-2069	-2,234	-3,594	-3,277	-818	-737	-2,183
	2070-2099	-2,072	-2,721	-2,661	-853	-803	-1,960
	2015-2099	**-2,352**	**-3,094**	**-2,910**	**-1,252**	**-1,171**	**-2,263**

Table 7-25b. Average Annual Net Energy Generation (GWh/year) in the **CVP System** in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	3,220	2,787	2,731	3,570	3,651	3,217
	2040-2069	3,789	3,164	3,109	4,530	4,541	3,845
	2070-2099	3,257	2,849	2,727	3,829	3,920	3,300
	2015-2099	**3,428**	**2,937**	**2,860**	**3,985**	**4,044**	**3,460**
Least Cost Portfolio	2015-2039	3,006	2,564	2,496	3,412	3,532	3,009
	2040-2069	3,843	3,089	3,005	4,640	4,717	3,883
	2070-2099	3,271	2,802	2,730	3,985	4,101	3,377
	2015-2099	**3,380**	**2,822**	**2,747**	**4,020**	**4,124**	**3,429**
Regional Self-Reliance Portfolio	2015-2039	3,291	2,856	2,811	3,644	3,731	3,274
	2040-2069	3,894	3,299	3,251	4,628	4,622	3,949
	2070-2099	3,332	2,880	2,794	3,897	3,994	3,351
	2015-2099	**3,512**	**3,016**	**2,957**	**4,065**	**4,123**	**3,532**
Healthy Headwaters and Tributaries Portfolio	2015-2039	3,271	2,833	2,768	3,701	3,697	3,273
	2040-2069	3,905	3,277	3,200	4,656	4,638	3,975
	2070-2099	3,365	2,918	2,789	3,933	4,036	3,390
	2015-2099	**3,520**	**3,013**	**2,923**	**4,105**	**4,131**	**3,552**
Delta Conveyance and Restoration Portfolio	2015-2039	3,199	2,738	2,678	3,608	3,629	3,193
	2040-2069	3,764	3,194	3,120	4,565	4,524	3,857
	2070-2099	3,219	2,830	2,696	3,807	3,881	3,274
	2015-2099	**3,401**	**2,925**	**2,836**	**4,002**	**4,019**	**3,448**
Expanded Water Storage and Groundwater Portfolio	2015-2039	3,291	2,856	2,811	3,644	3,731	3,274
	2040-2069	3,894	3,299	3,251	4,628	4,622	3,949
	2070-2099	3,332	2,880	2,794	3,897	3,994	3,351
	2015-2099	**3,512**	**3,016**	**2,957**	**4,065**	**4,123**	**3,532**
Flexible System Operations and Mgmt Portfolio	2015-2039	3,178	2,691	2,642	3,561	3,678	3,162
	2040-2069	3,839	3,133	3,026	4,599	4,679	3,879
	2070-2099	3,290	2,830	2,758	3,891	3,987	3,335
	2015-2099	**3,442**	**2,888**	**2,812**	**4,025**	**4,123**	**3,465**
Water Action Plan Portfolio	2015-2039	3,075	2,596	2,537	3,535	3,612	3,071
	2040-2069	3,911	3,132	3,053	4,736	4,802	3,949
	2070-2099	3,356	2,874	2,762	4,067	4,142	3,403
	2015-2099	**3,454**	**2,870**	**2,787**	**4,121**	**4,193**	**3,480**

Table 7-25c. Average Annual Net Energy Generation (GWh/year) in the **SWP System** in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-4,147	-3,614	-3,427	-4,390	-4,354	-4,093
	2040-2069	-4,472	-3,993	-3,389	-4,387	-4,765	-4,332
	2070-2099	-3,866	-3,263	-2,541	-3,833	-4,128	-3,345
	2015-2099	**-4,169**	**-3,632**	**-3,129**	**-4,210**	**-4,423**	**-3,935**
Least Cost Portfolio	2015-2039	-5,351	-4,883	-4,756	-5,088	-5,083	-5,284
	2040-2069	-5,336	-5,727	-5,023	-4,836	-4,797	-5,291
	2070-2099	-4,877	-4,764	-4,206	-4,503	-4,592	-4,588
	2015-2099	**-5,193**	**-5,136**	**-4,671**	**-4,813**	**-4,826**	**-5,063**
Regional Self-Reliance Portfolio	2015-2039	-4,598	-4,181	-3,839	-4,970	-5,147	-4,552
	2040-2069	-6,166	-5,087	-4,114	-6,129	-6,189	-6,108
	2070-2099	-5,682	-5,069	-4,075	-5,670	-5,753	-5,184
	2015-2099	**-5,488**	**-4,780**	**-4,010**	**-5,595**	**-5,701**	**-5,292**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-3,847	-3,501	-3,123	-4,011	-4,370	-3,914
	2040-2069	-4,424	-3,761	-3,326	-4,447	-4,663	-4,251
	2070-2099	-3,658	-3,202	-2,455	-3,711	-3,997	-3,208
	2015-2099	**-3,985**	**-3,494**	**-2,978**	**-4,065**	**-4,351**	**-3,803**
Delta Conveyance and Restoration Portfolio	2015-2039	-3,794	-3,452	-3,118	-3,927	-4,294	-3,761
	2040-2069	-4,479	-3,831	-3,512	-4,406	-4,610	-4,193
	2070-2099	-3,697	-3,038	-2,595	-3,869	-4,049	-3,017
	2015-2099	**-3,999**	**-3,449**	**-3,086**	**-4,073**	**-4,324**	**-3,671**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-4,598	-4,181	-3,839	-4,970	-5,147	-4,552
	2040-2069	-6,166	-5,087	-4,114	-6,129	-6,189	-6,108
	2070-2099	-5,682	-5,069	-4,075	-5,670	-5,753	-5,184
	2015-2099	**-5,488**	**-4,780**	**-4,010**	**-5,595**	**-5,701**	**-5,292**
Flexible System Operations and Mgmt Portfolio	2015-2039	-3,944	-3,743	-3,430	-4,256	-4,298	-3,839
	2040-2069	-4,449	-3,985	-3,547	-4,287	-4,646	-4,248
	2070-2099	-3,658	-3,284	-2,728	-3,897	-4,033	-3,337
	2015-2099	**-4,026**	**-3,678**	**-3,244**	**-4,151**	**-4,333**	**-3,819**
Water Action Plan Portfolio	2015-2039	-5,819	-5,533	-5,309	-5,621	-5,589	-5,711
	2040-2069	-6,145	-6,726	-6,330	-5,554	-5,538	-6,131
	2070-2099	-5,428	-5,595	-5,423	-4,920	-4,945	-5,362
	2015-2099	**-5,806**	**-5,964**	**-5,698**	**-5,373**	**-5,364**	**-5,743**

7.5.2. Greenhouse Gas Emissions

Hydropower generation is assumed to occur without GHG emissions. The effects of groundwater pumping on GHG emissions are not included in the simulations. When the CVP and SWP have positive net hydropower generation, the surplus energy can be made available to reduce reliance on fossil fuel-based sources of electricity used either by the projects or elsewhere and thereby reduce overall GHG emissions. These “offsets” are shown in Table 7-26 as negative changes in GHG emissions, and primarily when net hydropower generation is positive. The unit of measurement for GHG emissions is metric tons of carbon dioxide equivalents (mTCO_2e) per year of power generation.

CVP. In the simulations, the CVP system was assumed to provide excess power to an electrical grid system which produces 300 mTCO_2e GHG emissions per GWh generated.

SWP. For the SWP system, the sources of power used by the project are assumed to gradually transition from sources with higher GHG emissions to those with lower GHG emissions over the course of the 21st century. This assumption is based on the California Department of Water Resources’ Climate Action Plan (DWR 2012). Therefore, SWP emissions drop sharply over the first half of the century due to this assumption. See Section 5.2.5.2. *Greenhouse Gas Emissions.*

PORTFOLIOS

The magnitude of GHG emission results were greatest in the wetter scenarios where the net generation results were greatest, and lowest in the drier scenarios where the net generation results were lowest.

CVP: The CVP system had potential GHG offsets because it had positive net hydropower generation. As with changes in CVP net generation, the differences across the portfolios are small. Because the CVP system is assumed to provide excess power to the energy grid (with emissions of 300 mTCO_2e/GWh throughout the 21st century, the year-to-year changes in GHG emission results for the CVP system are consistent with changes in net generation. The percentage change in in average annual GHG offset for the CVP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +1%
- Regional Self-Reliance portfolio:-2%
- Healthy Headwaters and Tributaries portfolio:-3%
- Delta Conveyance and Restoration portfolio: +0
- Expanded Water Storage and Groundwater portfolio:-2%
- Flexible System Operations and Management portfolio: +0%
- Water Action Plan portfolio:-1%

SWP: The SWP system had GHG emissions because it had negative net hydropower generation.

Increased Emissions: Corresponding to the changes in SWP net generation, the Least Cost, Regional Self-Reliance, Expanded Water Storage and Groundwater, and Water Action Plan portfolios all result in significant increases average annual GHG emissions in the SWP system.

Reduced Emissions: The Delta Conveyance and Restoration, Flexible Systems Operations and Management, and the Healthy Headwaters and Tributaries portfolios all had slightly reduced emissions.

The percentage change in average annual GHG offset for the SWP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +33%
- Regional Self-Reliance portfolio: +22%
- Healthy Headwaters and Tributaries portfolio:-4%
- Delta Conveyance and Restoration portfolio:-9%
- Expanded Water Storage and Groundwater portfolio: +22%
- Flexible System Operations and Management portfolio:-5%
- Water Action Plan portfolio: +44%

Figure 7-22 shows the 10-year moving average of annual average GHG emissions or potential GHG offsets for the SWP, CVP, and total SWP and CVP systems in each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-26 presents the average annual GHG emissions in the SWP system, potential GHG offsets in the CVP system, and the net total for the CVP and SWP systems under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Figure 7-22. Annual GHG emissions: 10-year moving average.

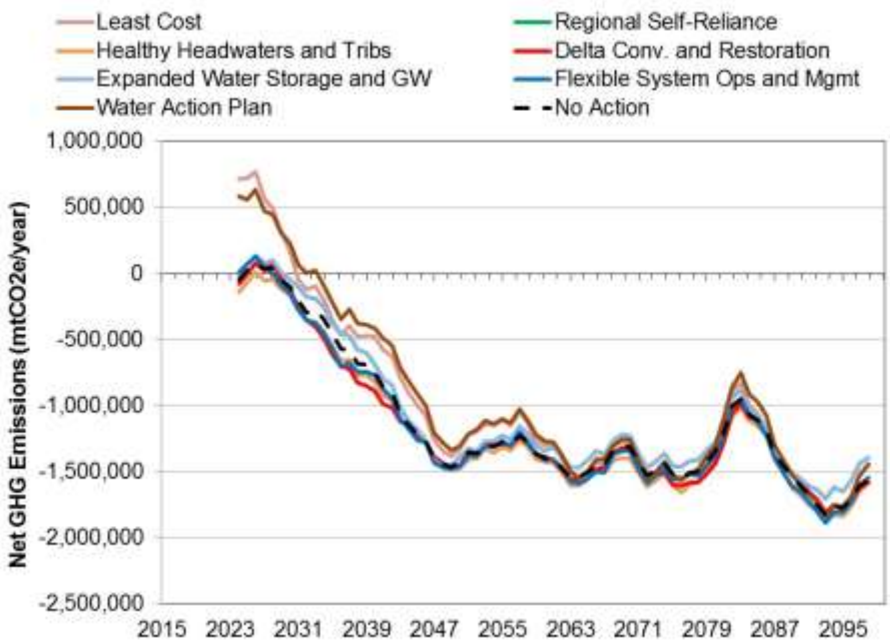

Figure 7-22a. 10-year moving average of annual GHG emissions or potential offsets for the combined **CVP and SWP systems** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

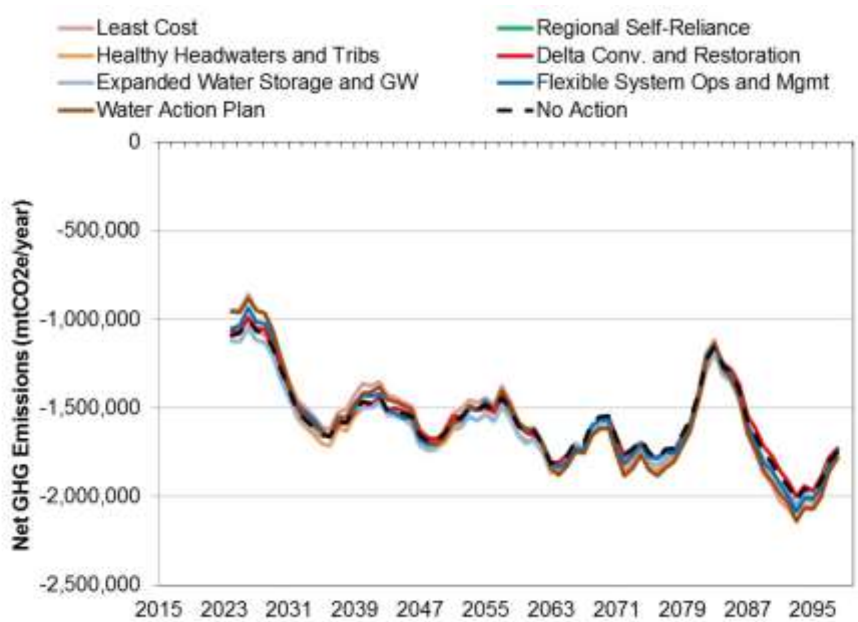

Figure 7-22b. 10-year moving average of annual GHG emissions or potential offsets for **the CVP system** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

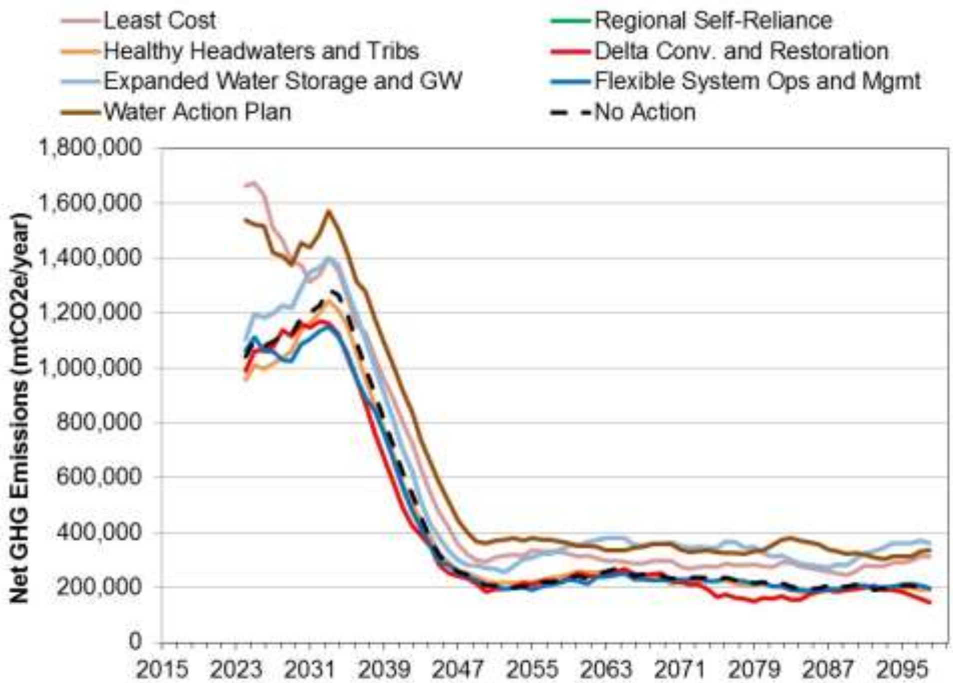

Figure 7-22c. 10-Year moving average of annual GHG emissions or potential offsets for the **SWP system** for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

Table 7-26. GHG Emissions: Adaptation Portfolio Comparison

Table 7-26a. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the Total **CVP and SWP System** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-464,884	-401,071	-426,742	-563,505	-609,686	-484,084
	2040-2069	-1,417,714	-1,165,866	-1,172,941	-1,738,745	-1,719,156	-1,445,489
	2070-2099	-1,347,426	-1,193,305	-1,184,005	-1,637,951	-1,658,398	-1,409,209
	2015-2099	**-1,067,842**	**-909,996**	**-918,617**	**-1,303,009**	**-1,318,042**	**-1,102,778**
Least Cost Portfolio	2015-2039	-59,542	-8,507	-4,404	-292,169	-337,384	-94,867
	2040-2069	-1,373,832	-1,022,931	-1,026,182	-1,750,737	-1,789,216	-1,396,692
	2070-2099	-1,288,620	-1,065,310	-1,069,632	-1,661,115	-1,713,087	-1,359,933
	2015-2099	**-894,728**	**-685,326**	**-686,357**	**-1,220,511**	**-1,265,331**	**-936,312**
Regional Self-Reliance Portfolio	2015-2039	-407,302	-321,916	-377,844	-516,548	-507,088	-430,569
	2040-2069	-1,357,580	-1,153,151	-1,187,333	-1,679,822	-1,669,852	-1,386,651
	2070-2099	-1,269,478	-1,092,534	-1,109,781	-1,545,086	-1,588,866	-1,310,393
	2015-2099	**-1,003,287**	**-848,136**	**-884,785**	**-1,238,115**	**-1,244,319**	**-1,033,879**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-567,658	-452,238	-515,819	-724,551	-629,294	-553,227
	2040-2069	-1,458,664	-1,223,306	-1,219,431	-1,782,419	-1,758,974	-1,500,811
	2070-2099	-1,420,214	-1,229,555	-1,220,473	-1,694,529	-1,721,752	-1,460,564
	2015-2099	**-1,139,611**	**-958,963**	**-976,827**	**-1,391,045**	**-1,357,887**	**-1,161,691**
Delta Conveyance and Restoration Portfolio	2015-2039	-546,536	-427,118	-447,105	-681,647	-600,476	-545,538
	2040-2069	-1,392,495	-1,187,486	-1,176,472	-1,758,534	-1,721,140	-1,461,471
	2070-2099	-1,336,498	-1,206,269	-1,169,224	-1,641,683	-1,648,577	-1,438,641
	2015-2099	**-1,083,772**	**-930,568**	**-922,510**	**-1,351,974**	**-1,312,648**	-1,138,461
Expanded Water Storage and Groundwater Portfolio	2015-2039	-407,302	-321,916	-377,844	-516,548	-507,088	-430,569
	2040-2069	-1,357,580	-1,153,151	-1,187,333	-1,679,822	-1,669,852	-1,386,651
	2070-2099	-1,269,478	-1,092,534	-1,109,781	-1,545,086	-1,588,866	-1,310,393
	2015-2099	**-1,003,287**	**-848,136**	**-884,785**	**-1,238,115**	**-1,244,319**	**-1,033,879**
Flexible System Operations and Mgmt Portfolio	2015-2039	-485,847	-318,662	-374,791	-593,777	-631,420	-513,424
	2040-2069	-1,434,619	-1,152,926	-1,126,179	-1,773,467	-1,786,846	-1,469,188
	2070-2099	-1,377,014	-1,188,084	-1,192,253	-1,661,239	-1,703,818	-1,427,696
	2015-2099	**-1,089,922**	**-875,370**	**-886,436**	**-1,332,792**	**-1,363,238**	**-1,126,873**
Water Action Plan Portfolio	2015-2039	-33,975	89,512	66,630	-256,748	-292,482	-77,976
	2040-2069	-1,355,093	-982,454	-971,088	-1,748,801	-1,779,488	-1,372,484
	2070-2099	-1,292,493	-1,047,574	-1,004,165	-1,672,133	-1,707,308	-1,320,936
	2015-2099	**-880,362**	**-631,751**	**-622,673**	**-1,210,870**	**-1,244,634**	**-910,229**

Note: negative values represent potential GHG offsets.

Table 7-26b. Average Annual GHG Emissions or Potential GHG Offsets (mTCO$_2$e/year) for the **CVP System** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	-1,403,968	-1,215,223	-1,190,523	-1,556,584	-1,591,734	-1,402,404
	2040-2069	-1,651,935	-1,379,699	-1,355,415	-1,975,203	-1,979,810	-1,676,280
	2070-2099	-1,590,259	-1,391,033	-1,331,824	-1,869,733	-1,914,005	-1,611,646
	2015-2099	**-1,547,971**	**-1,326,289**	**-1,291,467**	**-1,799,290**	**-1,826,247**	**-1,562,491**
Least Cost Portfolio	2015-2039	-1,310,685	-1,117,985	-1,088,157	-1,487,524	-1,539,926	-1,311,763
	2040-2069	-1,675,411	-1,346,658	-1,310,267	-2,023,013	-2,056,639	-1,693,108
	2070-2099	-1,597,453	-1,368,179	-1,332,935	-1,945,933	-2,002,823	-1,649,140
	2015-2099	**-1,526,292**	**-1,274,117**	**-1,240,333**	**-1,815,201**	**-1,862,233**	**-1,548,368**
Regional Self-Reliance Portfolio	2015-2039	-1,434,773	-1,245,090	-1,225,579	-1,588,695	-1,626,663	-1,427,491
	2040-2069	-1,697,921	-1,438,252	-1,417,465	-2,017,638	-2,015,299	-1,721,761
	2070-2099	-1,627,100	-1,406,582	-1,364,536	-1,902,959	-1,950,540	-1,636,562
	2015-2099	**-1,585,994**	**-1,362,140**	**-1,335,466**	**-1,835,420**	**-1,861,853**	**-1,594,811**
Healthy Headwaters and Tributaries Portfolio	2015-2039	-1,426,314	-1,235,085	-1,206,736	-1,613,772	-1,611,983	-1,426,968
	2040-2069	-1,702,574	-1,428,928	-1,395,095	-2,029,895	-2,021,967	-1,732,910
	2070-2099	-1,643,281	-1,424,908	-1,361,818	-1,920,416	-1,970,881	-1,655,251
	2015-2099	**-1,589,552**	**-1,360,810**	**-1,320,162**	**-1,853,650**	**-1,865,221**	**-1,604,174**
Delta Conveyance and Restoration Portfolio	2015-2039	-1,394,961	-1,193,579	-1,167,655	-1,573,193	-1,582,453	-1,392,253
	2040-2069	-1,641,177	-1,392,518	-1,360,385	-1,990,420	-1,972,406	-1,681,509
	2070-2099	-1,572,106	-1,382,006	-1,316,658	-1,859,262	-1,895,173	-1,598,714
	2015-2099	**-1,535,617**	**-1,320,708**	**-1,280,833**	**-1,807,342**	**-1,814,793**	**-1,557,005**
Expanded Water Storage and Groundwater Portfolio	2015-2039	-1,434,773	-1,245,090	-1,225,579	-1,588,695	-1,626,663	-1,427,491
	2040-2069	-1,697,921	-1,438,252	-1,417,465	-2,017,638	-2,015,299	-1,721,761
	2070-2099	-1,627,100	-1,406,582	-1,364,536	-1,902,959	-1,950,540	-1,636,562
	2015-2099	**-1,585,994**	**-1,362,140**	**-1,335,466**	**-1,835,420**	**-1,861,853**	**-1,594,811**
Flexible System Operations and Mgmt Portfolio	2015-2039	-1,385,722	-1,173,241	-1,152,063	-1,552,475	-1,603,783	-1,378,674
	2040-2069	-1,673,897	-1,366,081	-1,319,477	-2,005,319	-2,039,862	-1,691,208
	2070-2099	-1,606,438	-1,381,936	-1,346,914	-1,899,958	-1,947,034	-1,628,447
	2015-2099	**-1,554,331**	**-1,304,224**	**-1,269,845**	**-1,817,623**	**-1,861,684**	**-1,564,630**
Water Action Plan Portfolio	2015-2039	-1,340,825	-1,131,994	-1,106,102	-1,541,308	-1,574,888	-1,339,073
	2040-2069	-1,705,063	-1,365,548	-1,331,161	-2,065,078	-2,093,574	-1,721,612
	2070-2099	-1,638,747	-1,403,192	-1,348,719	-1,985,955	-2,022,671	-1,661,518
	2015-2099	**-1,559,577**	**-1,296,120**	**-1,258,688**	**-1,860,704**	**-1,893,402**	**-1,571,660**

Note: negative values represent potential GHG offsets.

Table 7-26c. Average Annual GHG Emissions or Potential GHG Offsets ($mTCO_2e$/year) for the **SWP System** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	939,084	814,152	763,781	993,080	982,049	918,319
	2040-2069	234,220	213,833	182,474	236,458	260,654	230,791
	2070-2099	242,834	197,728	147,819	231,781	255,607	202,437
	2015-2099	**480,129**	**416,293**	**372,849**	**496,281**	**508,205**	**459,713**
Least Cost Portfolio	2015-2039	1,251,143	1,109,478	1,083,753	1,195,356	1,202,542	1,216,896
	2040-2069	301,580	323,728	284,085	272,276	267,423	296,416
	2070-2099	308,834	302,869	263,303	284,818	289,735	289,208
	2015-2099	**631,564**	**588,791**	**553,976**	**594,691**	**596,902**	**612,055**
Regional Self-Reliance Portfolio	2015-2039	1,027,470	923,174	847,735	1,072,147	1,119,574	996,922
	2040-2069	340,340	285,101	230,132	337,816	345,446	335,111
	2070-2099	357,622	314,049	254,755	357,873	361,673	326,169
	2015-2099	**582,707**	**514,004**	**450,680**	**597,304**	**617,534**	**560,932**
Healthy Headwaters and Tributaries Portfolio	2015-2039	858,657	782,847	690,917	889,222	982,689	873,741
	2040-2069	243,910	205,622	175,664	247,476	262,993	232,099
	2070-2099	223,068	195,353	141,345	225,887	249,129	194,687
	2015-2099	**449,941**	**401,846**	**343,335**	**462,606**	**507,333**	**442,483**
Delta Conveyance and Restoration Portfolio	2015-2039	848,425	766,461	720,550	891,546	981,977	846,715
	2040-2069	248,682	205,032	183,913	231,886	251,266	220,038
	2070-2099	235,608	175,737	147,434	217,579	246,595	160,073
	2015-2099	**451,845**	**390,140**	**358,324**	**455,368**	**502,145**	**418,544**
Expanded Water Storage and Groundwater Portfolio	2015-2039	1,027,470	923,174	847,735	1,072,147	1,119,574	996,922
	2040-2069	340,340	285,101	230,132	337,816	345,446	335,111
	2070-2099	357,622	314,049	254,755	357,873	361,673	326,169
	2015-2099	**582,707**	**514,004**	**450,680**	**597,304**	**617,534**	**560,932**
Flexible System Operations and Mgmt Portfolio	2015-2039	899,876	854,579	777,272	958,698	972,363	865,250
	2040-2069	239,279	213,155	193,298	231,853	253,017	222,020
	2070-2099	229,425	193,852	154,661	238,720	243,216	200,751
	2015-2099	**464,409**	**428,854**	**383,409**	**484,831**	**498,446**	**437,757**
Water Action Plan Portfolio	2015-2039	1,306,850	1,221,506	1,172,732	1,284,560	1,282,407	1,261,097
	2040-2069	349,970	383,094	360,073	316,277	314,087	349,128
	2070-2099	346,253	355,618	344,554	313,822	315,363	340,581
	2015-2099	**679,215**	**664,368**	**636,015**	**649,835**	**648,767**	**661,431**

Note: negative values represent potential GHG offsets.

7.6. Flood Control

Two attributes of interest were used to characterize the flood control resource category. These attributes include the percentage of months when reservoir storage is within 10 TAF of the flood storage pool and the percentage of months that reservoir flow releases exceed hydropower penstock capacities. These performance metrics are applicable at major storage reservoirs during the flood control months from October to June.

7.6.1. Flood Control Storage Availability

The California Department of Water Resources 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. Reclamation is required to maintain reservoir storage levels below the flood conservation pool based on criteria established by the USACE. 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.

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. See Section 5.2.6.1. *Flood Control Storage.*

The Healthy Headwaters and Tributaries adaptation portfolio was the only portfolio that consistently had better performance than the 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.

More Flood Control Storage Available: The Least Cost and Regional Self-Reliance portfolios were the most likely to result in flood control conditions.

Less Flood Control Storage Available: The Expanded Water Storage and Groundwater portfolio was least likely to result in flood control conditions

The average change in flood control storage from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +6%
- Regional Self-Reliance portfolio: +6%
- Healthy Headwaters and Tributaries portfolio:-2%
- Delta Conveyance and Restoration portfolio: +0%
- Expanded Water Storage and Groundwater portfolio:-3%
- Flexible System Operations and Management portfolio: +1%
- Water Action Plan portfolio: +1%

7.6.1.1. 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 7-23). 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 adaptation portfolios all resulted in moderate increases in flood management risks, primarily because these portfolios operate to increase reservoir storage for later water deliveries.

Table 7-23 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

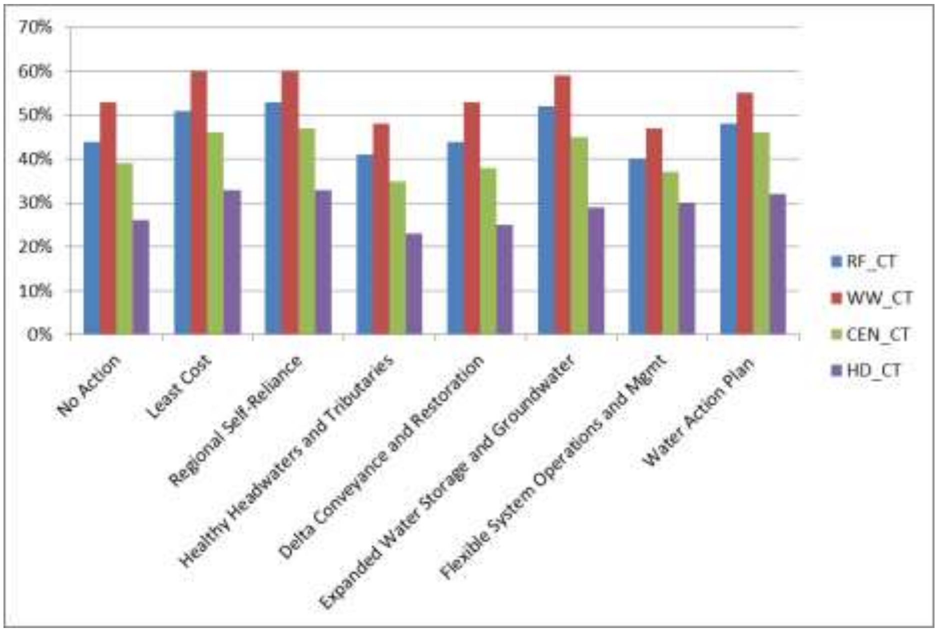

Figure 7-23. Folsom Lake storage: adaptation portfolio performance

Percentage of months from October through June that Folsom Lake storage is within 10 TAF of the flood conservation pool in each adaptation portfolio.[17] (Lower numbers indicate increased benefits).

Table 7-27. 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

[17] 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.

7.6.1.2. Adaptation Portfolio Climate Sensitivity

Table 7-28 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 7-28. 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

Table 7-29 shows the percentage of months from October through June that the reservoir storage in Shasta, Folsom, Oroville, New Bullards, New Melones, Millerton, New Don Pedro, McClure, and Pine Flat reservoirs are within 10 TAF of the flood conservation pool under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-29. Flood Control Storage: Adaptation Portfolio Comparison

Table 7-29a. Percentage of Months from October through June that **Lake Shasta** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	16%	10%	10%	23%	29%	13%
	2040-2069	43%	14%	10%	52%	61%	37%
	2070-2099	43%	25%	18%	59%	60%	38%
	2015-2099	**35%**	**17%**	**13%**	**46%**	**51%**	**30%**
Least Cost Portfolio	2015-2039	19%	12%	12%	23%	27%	16%
	2040-2069	54%	28%	20%	61%	69%	47%
	2070-2099	52%	36%	29%	66%	65%	49%
	2015-2099	**43%**	**26%**	**20%**	**52%**	**55%**	**39%**
Regional Self-Reliance Portfolio	2015-2039	22%	13%	12%	30%	32%	19%
	2040-2069	58%	30%	20%	71%	71%	53%
	2070-2099	59%	37%	28%	78%	72%	54%
	2015-2099	**48%**	**28%**	**20%**	**61%**	**60%**	**43%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	8%	5%	4%	13%	16%	7%
	2040-2069	22%	7%	6%	36%	37%	20%
	2070-2099	25%	17%	11%	44%	40%	23%
	2015-2099	**19%**	**10%**	**7%**	**32%**	**32%**	**17%**
Delta Conveyance and Restoration Portfolio	2015-2039	16%	11%	10%	23%	27%	13%
	2040-2069	43%	12%	10%	58%	61%	34%
	2070-2099	41%	23%	16%	63%	57%	35%
	2015-2099	**34%**	**16%**	**12%**	**49%**	**49%**	**28%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	12%	9%	10%	16%	24%	11%
	2040-2069	33%	9%	5%	51%	57%	26%
	2070-2099	37%	21%	12%	57%	54%	29%
	2015-2099	**28%**	**13%**	**9%**	**43%**	**46%**	**23%**
Flexible System Operations and Mgmt Portfolio	2015-2039	19%	13%	12%	22%	28%	17%
	2040-2069	43%	19%	16%	56%	61%	38%
	2070-2099	43%	29%	24%	62%	61%	42%
	2015-2099	**36%**	**21%**	**18%**	**48%**	**51%**	**33%**
Water Action Plan Portfolio	2015-2039	9%	4%	3%	12%	15%	8%
	2040-2069	24%	7%	4%	43%	51%	20%
	2070-2099	34%	20%	14%	55%	58%	33%
	2015-2099	**23%**	**11%**	**7%**	**38%**	**43%**	**21%**

Table 7-29b. Percentage of Months from October through June that **Folsom Lake** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	34%	27%	26%	42%	43%	33%
	2040-2069	48%	30%	25%	51%	59%	43%
	2070-2099	50%	33%	28%	48%	56%	41%
	2015-2099	44%	30%	26%	47%	53%	39%
Least Cost Portfolio	2015-2039	39%	28%	30%	47%	47%	35%
	2040-2069	58%	39%	36%	61%	67%	54%
	2070-2099	55%	41%	34%	59%	64%	49%
	2015-2099	51%	36%	33%	56%	60%	46%
Regional Self-Reliance Portfolio	2015-2039	39%	32%	31%	48%	47%	39%
	2040-2069	59%	43%	32%	63%	66%	54%
	2070-2099	58%	42%	34%	59%	66%	49%
	2015-2099	53%	39%	33%	57%	60%	47%
Healthy Headwaters and Tributaries Portfolio	2015-2039	31%	24%	24%	37%	39%	30%
	2040-2069	44%	27%	22%	44%	52%	38%
	2070-2099	45%	33%	24%	44%	51%	36%
	2015-2099	41%	28%	23%	42%	48%	35%
Delta Conveyance and Restoration Portfolio	2015-2039	32%	26%	25%	42%	42%	32%
	2040-2069	50%	27%	23%	53%	59%	43%
	2070-2099	49%	31%	27%	50%	56%	39%
	2015-2099	44%	28%	25%	49%	53%	38%
Expanded Water Storage and Groundwater Portfolio	2015-2039	41%	28%	28%	48%	48%	36%
	2040-2069	59%	36%	32%	59%	63%	50%
	2070-2099	53%	34%	27%	54%	62%	46%
	2015-2099	52%	33%	29%	54%	59%	45%
Flexible System Operations and Mgmt Portfolio	2015-2039	32%	31%	29%	40%	42%	32%
	2040-2069	44%	35%	33%	49%	50%	42%
	2070-2099	42%	29%	27%	44%	50%	36%
	2015-2099	40%	32%	30%	45%	47%	37%
Water Action Plan Portfolio	2015-2039	40%	28%	28%	47%	47%	37%
	2040-2069	54%	40%	32%	56%	60%	52%
	2070-2099	49%	39%	36%	57%	57%	46%
	2015-2099	48%	36%	32%	54%	55%	46%

Table 7-29c. Percentage of Months from October through June that **Lake Oroville** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	13%	8%	8%	19%	22%	14%
	2040-2069	26%	13%	12%	33%	43%	24%
	2070-2099	30%	20%	15%	37%	39%	24%
	2015-2099	**24%**	**14%**	**12%**	**30%**	**35%**	**21%**
Least Cost Portfolio	2015-2039	16%	10%	9%	24%	29%	12%
	2040-2069	47%	18%	12%	47%	57%	35%
	2070-2099	41%	27%	20%	50%	51%	38%
	2015-2099	**36%**	**19%**	**14%**	**42%**	**47%**	**29%**
Regional Self-Reliance Portfolio	2015-2039	20%	12%	11%	25%	25%	18%
	2040-2069	41%	17%	14%	47%	55%	34%
	2070-2099	36%	23%	18%	51%	53%	31%
	2015-2099	**33%**	**18%**	**15%**	**42%**	**45%**	**28%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	7%	3%	2%	12%	14%	7%
	2040-2069	15%	6%	7%	25%	27%	13%
	2070-2099	22%	14%	11%	30%	27%	18%
	2015-2099	**15%**	**8%**	**7%**	**23%**	**23%**	**13%**
Delta Conveyance and Restoration Portfolio	2015-2039	12%	4%	3%	14%	17%	8%
	2040-2069	21%	8%	9%	34%	41%	20%
	2070-2099	27%	14%	14%	39%	37%	20%
	2015-2099	**20%**	**9%**	**9%**	**30%**	**33%**	**17%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	11%	8%	8%	16%	16%	11%
	2040-2069	23%	7%	7%	34%	38%	21%
	2070-2099	26%	17%	13%	35%	34%	23%
	2015-2099	**21%**	**11%**	**9%**	**29%**	**30%**	**19%**
Flexible System Operations and Mgmt Portfolio	2015-2039	12%	9%	9%	19%	21%	13%
	2040-2069	26%	16%	16%	36%	41%	27%
	2070-2099	26%	19%	18%	41%	36%	26%
	2015-2099	**22%**	**15%**	**15%**	**33%**	**33%**	**22%**
Water Action Plan Portfolio	2015-2039	11%	8%	8%	12%	15%	8%
	2040-2069	26%	10%	10%	31%	37%	22%
	2070-2099	27%	17%	16%	37%	36%	24%
	2015-2099	**22%**	**12%**	**11%**	**27%**	**30%**	**19%**

Table 7-29d. Percentage of Months from October through June that **New Bullards Reservoir** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	18%	19%	34%	33%	26%
	2070-2099	24%	17%	15%	28%	33%	24%
	2015-2099	**23%**	**16%**	**16%**	**29%**	**30%**	**23%**
Least Cost Portfolio	2015-2039	20%	12%	13%	23%	24%	19%
	2040-2069	26%	19%	20%	35%	34%	28%
	2070-2099	27%	17%	17%	30%	34%	24%
	2015-2099	**24%**	**17%**	**17%**	**30%**	**31%**	**24%**
Regional Self-Reliance Portfolio	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	18%	19%	35%	34%	26%
	2070-2099	25%	17%	15%	29%	34%	24%
	2015-2099	**23%**	**16%**	**16%**	**29%**	**31%**	**23%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	20%	12%	13%	23%	24%	19%
	2040-2069	25%	19%	20%	35%	34%	27%
	2070-2099	25%	17%	16%	29%	34%	24%
	2015-2099	**24%**	**16%**	**16%**	**29%**	**31%**	**23%**
Delta Conveyance and Restoration Portfolio	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	18%	19%	34%	33%	26%
	2070-2099	24%	17%	15%	28%	33%	24%
	2015-2099	**23%**	**16%**	**16%**	**29%**	**30%**	**23%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	17%	19%	34%	33%	26%
	2070-2099	24%	16%	15%	28%	33%	24%
	2015-2099	**23%**	**15%**	**16%**	**29%**	**30%**	**23%**
Flexible System Operations and Mgmt Portfolio	2015-2039	20%	12%	13%	23%	24%	18%
	2040-2069	25%	18%	19%	34%	33%	26%
	2070-2099	24%	17%	15%	28%	33%	24%
	2015-2099	**23%**	**16%**	**16%**	**29%**	**30%**	**23%**
Water Action Plan Portfolio	2015-2039	20%	12%	13%	23%	24%	19%
	2040-2069	26%	19%	20%	35%	34%	28%
	2070-2099	26%	17%	17%	30%	34%	24%
	2015-2099	**24%**	**16%**	**17%**	**30%**	**31%**	**24%**

Table 7-29e. Percentage of Months from October through June that **New Melones Reservoir** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	4%	0%	0%	8%	9%	3%
	2040-2069	7%	0%	0%	17%	20%	8%
	2070-2099	10%	6%	4%	19%	22%	12%
	2015-2099	**7%**	**2%**	**2%**	**15%**	**17%**	**8%**
Least Cost Portfolio	2015-2039	4%	1%	1%	8%	8%	4%
	2040-2069	8%	1%	1%	20%	18%	11%
	2070-2099	10%	6%	6%	25%	23%	14%
	2015-2099	**7%**	**3%**	**3%**	**18%**	**17%**	**10%**
Regional Self-Reliance Portfolio	2015-2039	6%	1%	1%	10%	11%	6%
	2040-2069	14%	1%	1%	25%	29%	18%
	2070-2099	15%	8%	9%	25%	26%	15%
	2015-2099	**12%**	**4%**	**4%**	**21%**	**23%**	**13%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	4%	0%	0%	8%	9%	4%
	2040-2069	9%	1%	1%	18%	23%	11%
	2070-2099	10%	7%	7%	22%	23%	13%
	2015-2099	**8%**	**3%**	**3%**	**17%**	**19%**	**10%**
Delta Conveyance and Restoration Portfolio	2015-2039	4%	0%	0%	8%	9%	3%
	2040-2069	8%	0%	0%	18%	21%	10%
	2070-2099	10%	6%	6%	21%	22%	13%
	2015-2099	**7%**	**2%**	**2%**	**16%**	**18%**	**9%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	5%	0%	0%	8%	9%	3%
	2040-2069	8%	0%	0%	18%	21%	10%
	2070-2099	10%	6%	6%	21%	22%	13%
	2015-2099	**8%**	**2%**	**2%**	**16%**	**18%**	**9%**
Flexible System Operations and Mgmt Portfolio	2015-2039	4%	0%	0%	13%	11%	6%
	2040-2069	9%	0%	0%	26%	26%	13%
	2070-2099	13%	7%	7%	27%	26%	15%
	2015-2099	**9%**	**2%**	**3%**	**22%**	**22%**	**12%**
Water Action Plan Portfolio	2015-2039	7%	2%	2%	15%	14%	7%
	2040-2069	17%	1%	1%	32%	30%	22%
	2070-2099	20%	10%	11%	33%	33%	21%
	2015-2099	**15%**	**4%**	**5%**	**27%**	**27%**	**17%**

Table 7-29f. Percentage of Months from October through June that **Millerton Lake** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	37%	38%	27%
	2070-2099	25%	26%	30%	45%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**40%**	**39%**	**30%**
Least Cost Portfolio	2015-2039	24%	19%	25%	36%	32%	27%
	2040-2069	21%	14%	21%	36%	38%	25%
	2070-2099	23%	27%	30%	49%	45%	41%
	2015-2099	**23%**	**20%**	**25%**	**40%**	**39%**	**31%**
Regional Self-Reliance Portfolio	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	39%	38%	27%
	2070-2099	25%	26%	30%	49%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**42%**	**39%**	**30%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	24%	25%	27%	37%	35%	28%
	2040-2069	24%	15%	21%	40%	40%	29%
	2070-2099	28%	28%	31%	50%	46%	39%
	2015-2099	**25%**	**22%**	**26%**	**42%**	**41%**	**32%**
Delta Conveyance and Restoration Portfolio	2015-2039	24%	25%	26%	37%	35%	27%
	2040-2069	23%	13%	21%	39%	38%	27%
	2070-2099	25%	26%	30%	49%	43%	36%
	2015-2099	**24%**	**21%**	**26%**	**42%**	**39%**	**30%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	0%	0%	0%	1%	0%	0%
	2040-2069	0%	0%	1%	4%	3%	3%
	2070-2099	2%	2%	3%	9%	6%	4%
	2015-2099	**1%**	**1%**	**2%**	**5%**	**3%**	**2%**
Flexible System Operations and Mgmt Portfolio	2015-2039	25%	26%	27%	40%	36%	30%
	2040-2069	24%	14%	22%	38%	41%	28%
	2070-2099	25%	27%	32%	48%	45%	37%
	2015-2099	**25%**	**22%**	**27%**	**42%**	**41%**	**32%**
Water Action Plan Portfolio	2015-2039	0%	0%	0%	1%	0%	0%
	2040-2069	0%	0%	1%	4%	3%	3%
	2070-2099	3%	2%	3%	9%	6%	4%
	2015-2099	**1%**	**1%**	**1%**	**5%**	**3%**	**2%**

Table 7-29g. Percentage of Months from October through June that **New Don Pedro Reservoir** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	26%	14%	14%	32%	36%	24%
	2040-2069	35%	11%	6%	42%	54%	29%
	2070-2099	36%	24%	18%	45%	51%	32%
	2015-2099	**33%**	**16%**	**13%**	**40%**	**48%**	**28%**
Least Cost Portfolio	2015-2039	32%	20%	17%	39%	44%	29%
	2040-2069	49%	22%	16%	55%	65%	45%
	2070-2099	52%	39%	34%	61%	68%	48%
	2015-2099	**45%**	**27%**	**22%**	**53%**	**60%**	**41%**
Regional Self-Reliance Portfolio	2015-2039	32%	20%	17%	39%	44%	29%
	2040-2069	49%	21%	16%	54%	65%	45%
	2070-2099	51%	39%	35%	61%	65%	48%
	2015-2099	**45%**	**27%**	**23%**	**52%**	**59%**	**41%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	27%	15%	14%	32%	37%	25%
	2040-2069	38%	12%	7%	45%	56%	32%
	2070-2099	42%	25%	21%	50%	56%	36%
	2015-2099	**36%**	**17%**	**14%**	**43%**	**50%**	**31%**
Delta Conveyance and Restoration Portfolio	2015-2039	26%	14%	14%	32%	37%	24%
	2040-2069	37%	12%	7%	44%	55%	30%
	2070-2099	39%	25%	20%	48%	54%	34%
	2015-2099	**35%**	**17%**	**14%**	**42%**	**49%**	**30%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	26%	14%	14%	32%	37%	24%
	2040-2069	37%	12%	7%	44%	55%	30%
	2070-2099	39%	25%	20%	48%	54%	34%
	2015-2099	**35%**	**17%**	**14%**	**42%**	**49%**	**30%**
Flexible System Operations and Mgmt Portfolio	2015-2039	26%	14%	14%	32%	37%	24%
	2040-2069	37%	12%	7%	44%	55%	30%
	2070-2099	39%	25%	20%	48%	54%	34%
	2015-2099	**35%**	**17%**	**14%**	**42%**	**49%**	**30%**
Water Action Plan Portfolio	2015-2039	32%	20%	17%	40%	44%	30%
	2040-2069	49%	23%	16%	57%	66%	45%
	2070-2099	52%	39%	35%	62%	69%	50%
	2015-2099	**45%**	**28%**	**23%**	**54%**	**60%**	**42%**

Table 7-29h. Percentage of Months from October through June that **Lake McClure** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	15%	14%	47%	56%	36%
	2070-2099	35%	22%	20%	42%	52%	31%
	2015-2099	**37%**	**20%**	**18%**	**43%**	**52%**	**33%**
Least Cost Portfolio	2015-2039	35%	24%	23%	42%	47%	32%
	2040-2069	49%	22%	17%	51%	62%	40%
	2070-2099	41%	24%	24%	47%	60%	36%
	2015-2099	**42%**	**24%**	**21%**	**47%**	**57%**	**36%**
Regional Self-Reliance Portfolio	2015-2039	35%	24%	22%	42%	47%	32%
	2040-2069	47%	20%	17%	50%	61%	39%
	2070-2099	39%	24%	23%	46%	60%	35%
	2015-2099	**41%**	**23%**	**21%**	**46%**	**56%**	**35%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	35%	24%	22%	41%	46%	32%
	2040-2069	44%	16%	16%	48%	58%	37%
	2070-2099	36%	23%	20%	43%	53%	33%
	2015-2099	**39%**	**21%**	**19%**	**44%**	**53%**	**34%**
Delta Conveyance and Restoration Portfolio	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	15%	15%	47%	57%	36%
	2070-2099	35%	22%	20%	43%	53%	31%
	2015-2099	**38%**	**20%**	**18%**	**44%**	**52%**	**33%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	15%	15%	47%	57%	36%
	2070-2099	35%	22%	20%	43%	53%	31%
	2015-2099	**38%**	**20%**	**18%**	**44%**	**52%**	**33%**
Flexible System Operations and Mgmt Portfolio	2015-2039	34%	24%	21%	41%	46%	32%
	2040-2069	43%	15%	15%	47%	57%	36%
	2070-2099	35%	22%	20%	43%	53%	31%
	2015-2099	**38%**	**20%**	**18%**	**44%**	**52%**	**33%**
Water Action Plan Portfolio	2015-2039	35%	24%	23%	43%	47%	32%
	2040-2069	49%	22%	17%	51%	63%	40%
	2070-2099	41%	24%	24%	48%	60%	37%
	2015-2099	**42%**	**24%**	**21%**	**48%**	**57%**	**36%**

Table 7-29i. Percentage of Months from October through June that **Pine Flat Reservoir** Storage Is Within 10 TAF of the Flood Conservation Pool in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	17%	12%	12%	23%	27%	18%
	2040-2069	29%	14%	15%	33%	38%	25%
	2070-2099	27%	18%	17%	38%	43%	24%
	2015-2099	**24%**	**15%**	**15%**	**32%**	**36%**	**23%**
Least Cost Portfolio	2015-2039	26%	16%	16%	31%	33%	24%
	2040-2069	42%	25%	21%	44%	50%	37%
	2070-2099	42%	25%	21%	53%	61%	38%
	2015-2099	**38%**	**22%**	**19%**	**43%**	**49%**	**33%**
Regional Self-Reliance Portfolio	2015-2039	25%	16%	15%	29%	32%	22%
	2040-2069	40%	23%	19%	42%	49%	34%
	2070-2099	41%	22%	21%	52%	60%	36%
	2015-2099	**36%**	**21%**	**18%**	**42%**	**48%**	**31%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	17%	12%	12%	24%	28%	19%
	2040-2069	29%	16%	15%	34%	39%	26%
	2070-2099	27%	19%	18%	39%	44%	25%
	2015-2099	**25%**	**16%**	**15%**	**33%**	**37%**	**24%**
Delta Conveyance and Restoration Portfolio	2015-2039	17%	12%	12%	24%	28%	20%
	2040-2069	31%	16%	15%	35%	41%	26%
	2070-2099	28%	19%	18%	39%	44%	25%
	2015-2099	**26%**	**16%**	**15%**	**33%**	**38%**	**24%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	17%	12%	12%	25%	28%	20%
	2040-2069	31%	16%	15%	35%	41%	27%
	2070-2099	28%	19%	18%	39%	44%	25%
	2015-2099	**26%**	**16%**	**15%**	**34%**	**39%**	**24%**
Flexible System Operations and Mgmt Portfolio	2015-2039	17%	12%	12%	23%	27%	19%
	2040-2069	29%	14%	15%	34%	38%	26%
	2070-2099	27%	19%	17%	39%	43%	24%
	2015-2099	**25%**	**15%**	**15%**	**32%**	**36%**	**23%**
Water Action Plan Portfolio	2015-2039	26%	16%	16%	31%	33%	24%
	2040-2069	42%	26%	21%	44%	51%	37%
	2070-2099	44%	26%	22%	53%	61%	38%
	2015-2099	**38%**	**23%**	**20%**	**43%**	**49%**	**34%**

7.6.2. Frequency Releases Above Hydropower Penstock Capacities

Releasing water over the amount of water that can go through a penstock indicates increased potential of flood control measures. This is measured by the percentage of months from October through June in which releases are greater than the penstock capacities at Keswick (15,000 cfs), Thermalito (10,000 cfs), and Natoma (3,000 cfs). See Section 5.2.6.2. *Frequency Releases Above Hydropower Penstock Capacities*.

There are only minor differences in this metric across portfolios.

The average change in frequency releases from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +1%
- Regional Self-Reliance portfolio: +1%
- Healthy Headwaters and Tributaries portfolio: 0%
- Delta Conveyance and Restoration portfolio: 0%
- Expanded Water Storage and Groundwater portfolio: 0%
- Flexible System Operations and Management portfolio:-2%
- Water Action Plan portfolio: +2%

Table 7-30 shows the percentage of months from October through June that releases are greater than the penstock capacities at Keswick (15,000 cfs), Thermalito (10,000 cfs), and Natoma (3,000 cfs) under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-30. Frequency of Releases above Penstock Capacities: Adaptation Portfolio Comparison

Table 7-30a. Percentage of Months from October through June that **Keswick** Releases Exceed Penstock Capacities in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	92%	93%	94%	90%	89%	91%
	2040-2069	87%	91%	90%	79%	81%	85%
	2070-2099	86%	89%	90%	79%	81%	86%
	2015-2099	**88%**	**91%**	**91%**	**82%**	**84%**	**87%**
Least Cost Portfolio	2015-2039	94%	96%	96%	90%	88%	93%
	2040-2069	88%	92%	91%	77%	79%	86%
	2070-2099	84%	87%	87%	69%	69%	80%
	2015-2099	**88%**	**92%**	**91%**	**78%**	**78%**	**86%**
Regional Self-Reliance Portfolio	2015-2039	93%	93%	94%	91%	90%	93%
	2040-2069	88%	92%	91%	83%	83%	86%
	2070-2099	87%	91%	91%	82%	82%	87%
	2015-2099	**89%**	**92%**	**92%**	**85%**	**85%**	**88%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	92%	93%	92%	87%	87%	89%
	2040-2069	84%	90%	90%	76%	73%	83%
	2070-2099	84%	86%	87%	75%	74%	83%
	2015-2099	**86%**	**90%**	**89%**	**79%**	**78%**	**85%**
Delta Conveyance and Restoration Portfolio	2015-2039	92%	93%	93%	90%	89%	91%
	2040-2069	84%	91%	90%	79%	79%	83%
	2070-2099	86%	89%	90%	78%	79%	86%
	2015-2099	**87%**	**91%**	**91%**	**82%**	**82%**	**86%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	91%	94%	93%	88%	88%	91%
	2040-2069	84%	91%	89%	79%	79%	84%
	2070-2099	86%	90%	90%	78%	77%	84%
	2015-2099	**87%**	**91%**	**90%**	**82%**	**81%**	**86%**
Flexible System Operations and Mgmt Portfolio	2015-2039	94%	97%	96%	92%	91%	95%
	2040-2069	90%	96%	95%	84%	81%	91%
	2070-2099	86%	90%	91%	79%	75%	85%
	2015-2099	**90%**	**94%**	**94%**	**84%**	**82%**	**90%**
Water Action Plan Portfolio	2015-2039	93%	94%	95%	87%	87%	92%
	2040-2069	84%	91%	90%	71%	73%	80%
	2070-2099	81%	86%	86%	65%	67%	79%
	2015-2099	**85%**	**90%**	**90%**	**74%**	**75%**	**83%**

Table 7-30b. Percentage of Months from October through June that **Thermalito Releases** Exceed Penstock Capacities in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	97%	99%	99%	96%	95%	97%
	2040-2069	96%	98%	98%	91%	90%	94%
	2070-2099	93%	97%	97%	88%	88%	92%
	2015-2099	**96%**	**98%**	**98%**	**91%**	**91%**	**94%**
Least Cost Portfolio	2015-2039	98%	100%	99%	96%	96%	97%
	2040-2069	96%	98%	99%	90%	91%	94%
	2070-2099	92%	96%	96%	89%	87%	92%
	2015-2099	**95%**	**98%**	**98%**	**91%**	**91%**	**94%**
Regional Self-Reliance Portfolio	2015-2039	97%	99%	98%	94%	95%	97%
	2040-2069	95%	97%	97%	89%	89%	93%
	2070-2099	92%	96%	96%	86%	87%	91%
	2015-2099	**95%**	**97%**	**97%**	**89%**	**90%**	**93%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	98%	99%	99%	96%	96%	98%
	2040-2069	97%	98%	97%	91%	90%	95%
	2070-2099	93%	97%	96%	87%	88%	92%
	2015-2099	**96%**	**98%**	**97%**	**91%**	**91%**	**95%**
Delta Conveyance and Restoration Portfolio	2015-2039	97%	99%	99%	96%	96%	98%
	2040-2069	97%	99%	98%	91%	90%	96%
	2070-2099	94%	97%	97%	88%	89%	92%
	2015-2099	**96%**	**98%**	**98%**	**91%**	**92%**	**95%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	97%	99%	99%	96%	96%	97%
	2040-2069	96%	99%	98%	91%	90%	96%
	2070-2099	94%	97%	97%	89%	88%	92%
	2015-2099	**96%**	**98%**	**98%**	**92%**	**91%**	**95%**
Flexible System Operations and Mgmt Portfolio	2015-2039	98%	100%	99%	96%	95%	98%
	2040-2069	97%	99%	99%	92%	91%	96%
	2070-2099	94%	97%	96%	90%	89%	93%
	2015-2099	**96%**	**99%**	**98%**	**92%**	**91%**	**95%**
Water Action Plan Portfolio	2015-2039	98%	100%	100%	96%	96%	97%
	2040-2069	97%	99%	99%	91%	91%	94%
	2070-2099	92%	96%	96%	88%	87%	92%
	2015-2099	**96%**	**98%**	**98%**	**91%**	**91%**	**94%**

Table 7-30c. Percentage of Months from October through June that **Natoma Releases** Exceed Penstock Capacities in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	80%	87%	86%	77%	78%	83%
	2040-2069	79%	86%	87%	76%	73%	81%
	2070-2099	79%	84%	85%	73%	70%	80%
	2015-2099	**79%**	**86%**	**86%**	**75%**	**73%**	**81%**
Least Cost Portfolio	2015-2039	81%	88%	87%	79%	79%	84%
	2040-2069	78%	84%	84%	73%	71%	79%
	2070-2099	76%	80%	84%	72%	67%	77%
	2015-2099	**78%**	**84%**	**85%**	**74%**	**72%**	**80%**
Regional Self-Reliance Portfolio	2015-2039	80%	85%	85%	79%	77%	83%
	2040-2069	77%	85%	86%	74%	72%	79%
	2070-2099	78%	82%	84%	72%	66%	77%
	2015-2099	**78%**	**84%**	**85%**	**75%**	**72%**	**79%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	80%	88%	87%	79%	79%	83%
	2040-2069	77%	86%	85%	76%	72%	81%
	2070-2099	78%	84%	86%	73%	68%	81%
	2015-2099	**78%**	**86%**	**86%**	**76%**	**73%**	**81%**
Delta Conveyance and Restoration Portfolio	2015-2039	80%	86%	86%	78%	78%	82%
	2040-2069	79%	86%	86%	75%	73%	80%
	2070-2099	79%	84%	85%	73%	69%	81%
	2015-2099	**79%**	**85%**	**86%**	**75%**	**73%**	**81%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	80%	86%	85%	80%	78%	83%
	2040-2069	80%	86%	86%	74%	73%	80%
	2070-2099	80%	85%	86%	74%	69%	80%
	2015-2099	**80%**	**85%**	**86%**	**76%**	**73%**	**81%**
Flexible System Operations and Mgmt Portfolio	2015-2039	82%	90%	88%	80%	80%	84%
	2040-2069	79%	87%	86%	75%	74%	81%
	2070-2099	78%	83%	85%	74%	70%	80%
	2015-2099	**79%**	**86%**	**87%**	**76%**	**74%**	**82%**
Water Action Plan Portfolio	2015-2039	83%	89%	88%	80%	80%	84%
	2040-2069	79%	84%	85%	74%	71%	79%
	2070-2099	78%	81%	85%	74%	67%	78%
	2015-2099	**80%**	**85%**	**86%**	**76%**	**73%**	**80%**

7.7. Recreation

Reduced reservoir storage decreases the reservoir's water surface area, which in turn reduces potential recreational uses.

	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. This metric is applied in at all major CVP, SWP and non-project reservoirs in the Central Valley hydrologic basins. *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. See Section 5.2.7. *Recreation.*

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.

More Reservoir Surface Area: The Least Cost, Regional Self-Reliance and Water Action Plan portfolios provide the greatest recreation benefit,

Less Reservoir Surface Area: The Healthy Headwaters and Tributaries portfolio results in the greatest reduction in recreation benefit.

The percentage change in reservoir surface area from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-17%
- Regional Self-Reliance portfolio:-13%
- Healthy Headwaters and Tributaries portfolio: +5%
- Delta Conveyance and Restoration portfolio: +1%
- Expanded Water Storage and Groundwater portfolio:-1%
- Flexible System Operations and Management portfolio:-7%
- Water Action Plan portfolio:-11%

7.7.1. Adaptation Portfolio Performance

The Least Cost and Regional Self-Reliance adaptation portfolios consistently had improvements relative to the No Action alternative as a result of water management actions that increased water storage and improved water use efficiency (Figure 7-24). Moderate to significant decreases in performance were associated with the other portfolios.

Table 7-31 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

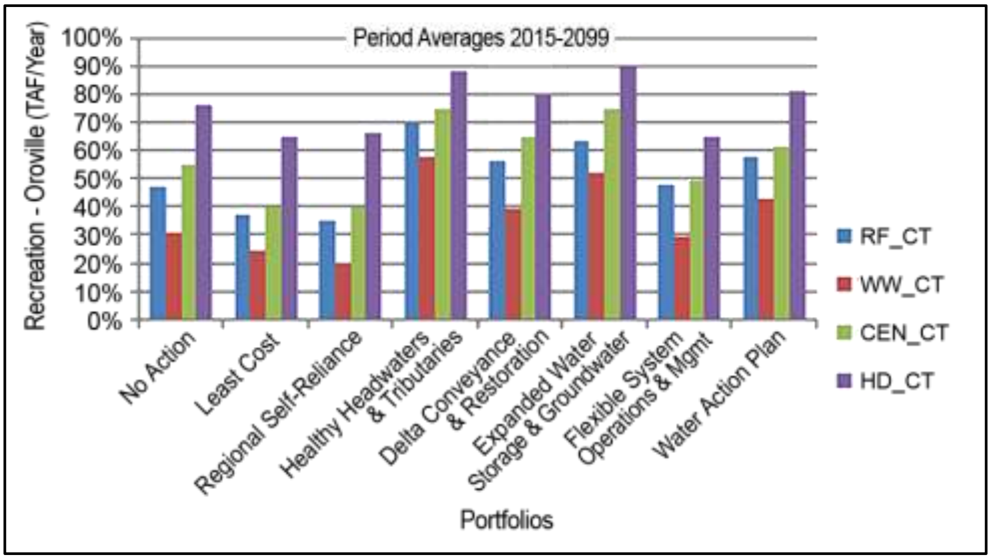

Figure 7-24. Lake Oroville surface area: adaptation portfolio performance

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[18] (Lower numbers indicate increased benefits).

Table 7-31. Lake Oroville Surface Area: Adaptation Portfolio Performance

(Percent Change Compared to No Action) (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

[18] 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.

7.7.2. Adaptation Portfolio Climate Sensitivity

Table 7-32 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 7-32. 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
Expanded Water Storage and Groundwater	-17	19	43
Flexible System Operations and Mgmt	-40	2	35
Water Action Plan	-26	5	40

Table 7-33 shows the percentage of months from May through September that the reservoir surface areas in Shasta, Folsom, Oroville, New Bullards Bar, New Melones, New Don Pedro, McClure, Millerton, and Pine Flat reservoirs are less than the performance metric under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-33. Reservoir Surface Area: Adaptation Portfolio Comparison

Table 7-33a. Percentage of Months from May through September that **Lake Shasta** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	78%	85%	85%	73%	56%	81%
	2040-2069	30%	72%	95%	31%	12%	55%
	2070-2099	41%	63%	83%	17%	17%	52%
	2015-2099	**48%**	**72%**	**88%**	**38%**	**27%**	**61%**
Least Cost Portfolio	2015-2039	44%	62%	66%	46%	34%	53%
	2040-2069	3%	17%	34%	4%	3%	4%
	2070-2099	7%	22%	34%	1%	1%	12%
	2015-2099	**16%**	**32%**	**44%**	**16%**	**12%**	**21%**
Regional Self-Reliance Portfolio	2015-2039	68%	79%	84%	49%	43%	69%
	2040-2069	10%	41%	69%	5%	7%	17%
	2070-2099	10%	36%	65%	0%	1%	21%
	2015-2099	**27%**	**51%**	**72%**	**16%**	**15%**	**34%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	89%	97%	98%	80%	81%	92%
	2040-2069	75%	99%	99%	59%	59%	86%
	2070-2099	57%	83%	90%	26%	38%	72%
	2015-2099	**73%**	**93%**	**96%**	**53%**	**58%**	**83%**
Delta Conveyance and Restoration Portfolio	2015-2039	74%	86%	86%	69%	62%	82%
	2040-2069	31%	78%	95%	19%	15%	59%
	2070-2099	43%	67%	83%	9%	25%	54%
	2015-2099	**48%**	**76%**	**88%**	**30%**	**32%**	**64%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	74%	82%	83%	48%	46%	75%
	2040-2069	16%	66%	82%	5%	9%	29%
	2070-2099	26%	55%	71%	1%	8%	39%
	2015-2099	**37%**	**67%**	**78%**	**16%**	**19%**	**46%**
Flexible System Operations and Mgmt Portfolio	2015-2039	61%	74%	78%	54%	45%	63%
	2040-2069	19%	49%	67%	17%	9%	28%
	2070-2099	24%	58%	61%	7%	8%	32%
	2015-2099	**33%**	**60%**	**68%**	**24%**	**19%**	**40%**
Water Action Plan Portfolio	2015-2039	72%	84%	84%	58%	54%	78%
	2040-2069	14%	65%	77%	7%	5%	30%
	2070-2099	24%	35%	55%	7%	5%	29%
	2015-2099	**35%**	**60%**	**71%**	**22%**	**20%**	**44%**

Table 7-33b. Percentage of Months from May through September that **Folsom Lake** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	62%	77%	82%	63%	51%	75%
	2040-2069	29%	61%	84%	38%	24%	48%
	2070-2099	29%	61%	79%	37%	27%	52%
	2015-2099	**39%**	**66%**	**82%**	**45%**	**33%**	**57%**
Least Cost Portfolio	2015-2039	25%	47%	58%	33%	23%	38%
	2040-2069	9%	17%	35%	16%	11%	18%
	2070-2099	11%	30%	43%	17%	11%	21%
	2015-2099	**14%**	**31%**	**44%**	**21%**	**15%**	**25%**
Regional Self-Reliance Portfolio	2015-2039	38%	56%	70%	47%	35%	53%
	2040-2069	14%	28%	48%	22%	15%	25%
	2070-2099	14%	35%	63%	29%	20%	28%
	2015-2099	**21%**	**39%**	**60%**	**32%**	**23%**	**34%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	70%	86%	90%	65%	65%	80%
	2040-2069	49%	74%	89%	50%	37%	69%
	2070-2099	47%	70%	82%	43%	40%	67%
	2015-2099	**55%**	**76%**	**87%**	**52%**	**46%**	**72%**
Delta Conveyance and Restoration Portfolio	2015-2039	66%	78%	84%	57%	54%	76%
	2040-2069	29%	61%	83%	37%	27%	47%
	2070-2099	31%	64%	79%	37%	30%	55%
	2015-2099	**40%**	**67%**	**82%**	**43%**	**36%**	**58%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	51%	74%	86%	50%	42%	64%
	2040-2069	21%	50%	68%	30%	23%	41%
	2070-2099	28%	62%	77%	35%	28%	50%
	2015-2099	**32%**	**61%**	**76%**	**38%**	**30%**	**51%**
Flexible System Operations and Mgmt Portfolio	2015-2039	42%	58%	64%	38%	30%	53%
	2040-2069	16%	32%	51%	19%	13%	21%
	2070-2099	18%	43%	61%	17%	13%	32%
	2015-2099	**24%**	**44%**	**58%**	**24%**	**18%**	**34%**
Water Action Plan Portfolio	2015-2039	43%	65%	73%	41%	30%	48%
	2040-2069	15%	44%	56%	23%	16%	30%
	2070-2099	23%	47%	55%	28%	19%	36%
	2015-2099	**26%**	**51%**	**60%**	**30%**	**21%**	**37%**

Table 7-33c. Percentage of Months from May through September that **Lake Oroville** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference -CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	63%	80%	80%	54%	49%	68%
	2040-2069	37%	53%	74%	26%	12%	47%
	2070-2099	43%	59%	76%	29%	35%	52%
	2015-2099	**47%**	**63%**	**76%**	**35%**	**31%**	**55%**
Least Cost Portfolio	2015-2039	69%	82%	80%	46%	46%	69%
	2040-2069	18%	42%	59%	11%	10%	26%
	2070-2099	31%	49%	59%	13%	21%	31%
	2015-2099	**37%**	**56%**	**65%**	**22%**	**24%**	**40%**
Regional Self-Reliance Portfolio	2015-2039	58%	70%	75%	34%	49%	58%
	2040-2069	17%	43%	58%	3%	5%	20%
	2070-2099	34%	53%	67%	10%	9%	46%
	2015-2099	**35%**	**55%**	**66%**	**15%**	**19%**	**40%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	86%	92%	93%	71%	78%	87%
	2040-2069	63%	87%	95%	49%	44%	70%
	2070-2099	64%	75%	77%	45%	55%	71%
	2015-2099	**70%**	**84%**	**88%**	**54%**	**58%**	**75%**
Delta Conveyance and Restoration Portfolio	2015-2039	77%	79%	86%	58%	62%	82%
	2040-2069	42%	71%	79%	26%	24%	54%
	2070-2099	51%	67%	75%	25%	35%	61%
	2015-2099	**56%**	**72%**	**80%**	**35%**	**39%**	**65%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	82%	86%	90%	70%	66%	84%
	2040-2069	54%	87%	93%	51%	43%	69%
	2070-2099	56%	76%	87%	40%	49%	73%
	2015-2099	**63%**	**83%**	**90%**	**53%**	**52%**	**75%**
Flexible System Operations and Mgmt Portfolio	2015-2039	63%	68%	76%	49%	46%	69%
	2040-2069	31%	50%	60%	15%	13%	37%
	2070-2099	51%	57%	60%	17%	31%	44%
	2015-2099	**48%**	**58%**	**65%**	**26%**	**29%**	**49%**
Water Action Plan Portfolio	2015-2039	82%	88%	90%	77%	70%	85%
	2040-2069	51%	72%	83%	38%	36%	56%
	2070-2099	45%	65%	72%	27%	29%	47%
	2015-2099	**58%**	**74%**	**81%**	**46%**	**43%**	**61%**

Table 7-33d. Percentage of Months from May through September that **New Bullards Reservoir** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	70%	88%	86%	74%	59%	78%
	2040-2069	59%	78%	89%	68%	54%	71%
	2070-2099	57%	71%	80%	73%	54%	70%
	2015-2099	**62%**	**78%**	**85%**	**72%**	**56%**	**73%**
Least Cost Portfolio	2015-2039	70%	87%	86%	74%	60%	75%
	2040-2069	59%	74%	90%	65%	54%	69%
	2070-2099	53%	68%	79%	69%	53%	68%
	2015-2099	**60%**	**76%**	**85%**	**69%**	**56%**	**71%**
Regional Self-Reliance Portfolio	2015-2039	70%	88%	86%	74%	59%	78%
	2040-2069	60%	77%	89%	68%	54%	71%
	2070-2099	57%	70%	81%	73%	55%	71%
	2015-2099	**62%**	**78%**	**86%**	**72%**	**56%**	**73%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	70%	87%	86%	74%	60%	75%
	2040-2069	59%	75%	89%	66%	54%	70%
	2070-2099	56%	70%	81%	71%	53%	69%
	2015-2099	**61%**	**77%**	**85%**	**70%**	**56%**	**71%**
Delta Conveyance and Restoration Portfolio	2015-2039	70%	88%	86%	74%	59%	78%
	2040-2069	59%	78%	89%	68%	54%	71%
	2070-2099	57%	71%	80%	73%	54%	70%
	2015-2099	**62%**	**78%**	**85%**	**72%**	**56%**	**73%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	72%	88%	86%	74%	60%	78%
	2040-2069	59%	79%	89%	69%	55%	71%
	2070-2099	57%	71%	83%	74%	54%	72%
	2015-2099	**62%**	**79%**	**86%**	**72%**	**56%**	**73%**
Flexible System Operations and Mgmt Portfolio	2015-2039	70%	88%	86%	74%	59%	78%
	2040-2069	59%	78%	89%	68%	54%	71%
	2070-2099	57%	71%	80%	73%	54%	70%
	2015-2099	**62%**	**78%**	**85%**	**72%**	**56%**	**73%**
Water Action Plan Portfolio	2015-2039	70%	87%	86%	74%	60%	75%
	2040-2069	59%	75%	90%	66%	54%	69%
	2070-2099	55%	69%	81%	71%	55%	69%
	2015-2099	**61%**	**76%**	**86%**	**70%**	**56%**	**71%**

Table 7-33e. Percentage of Months from May through September that **New Melones Reservoir** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	73%	88%	92%	63%	54%	75%
	2040-2069	35%	97%	98%	25%	22%	47%
	2070-2099	49%	73%	71%	30%	30%	61%
	2015-2099	**51%**	**86%**	**87%**	**38%**	**34%**	**60%**
Least Cost Portfolio	2015-2039	64%	79%	82%	44%	40%	65%
	2040-2069	25%	67%	77%	12%	15%	24%
	2070-2099	35%	53%	51%	20%	18%	27%
	2015-2099	**40%**	**66%**	**69%**	**24%**	**23%**	**37%**
Regional Self-Reliance Portfolio	2015-2039	61%	84%	81%	42%	36%	68%
	2040-2069	24%	73%	85%	13%	14%	27%
	2070-2099	37%	60%	57%	23%	23%	44%
	2015-2099	**39%**	**72%**	**74%**	**25%**	**24%**	**45%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	72%	87%	86%	58%	45%	76%
	2040-2069	32%	90%	93%	20%	18%	39%
	2070-2099	45%	67%	67%	28%	27%	58%
	2015-2099	**48%**	**81%**	**82%**	**34%**	**29%**	**57%**
Delta Conveyance and Restoration Portfolio	2015-2039	72%	87%	89%	61%	49%	76%
	2040-2069	35%	95%	93%	21%	19%	47%
	2070-2099	49%	73%	70%	28%	27%	60%
	2015-2099	**51%**	**85%**	**84%**	**35%**	**31%**	**60%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	72%	88%	92%	60%	46%	75%
	2040-2069	35%	100%	98%	21%	19%	46%
	2070-2099	49%	73%	71%	28%	27%	60%
	2015-2099	**51%**	**87%**	**87%**	**35%**	**30%**	**60%**
Flexible System Operations and Mgmt Portfolio	2015-2039	68%	88%	92%	50%	42%	68%
	2040-2069	36%	93%	94%	20%	21%	41%
	2070-2099	51%	67%	67%	23%	23%	53%
	2015-2099	**51%**	**83%**	**84%**	**30%**	**28%**	**53%**
Water Action Plan Portfolio	2015-2039	63%	77%	82%	44%	41%	64%
	2040-2069	25%	70%	82%	10%	14%	23%
	2070-2099	33%	55%	51%	15%	17%	27%
	2015-2099	**39%**	**67%**	**71%**	**22%**	**23%**	**37%**

Table 7-33f. Percentage of Months from May through September that **New Don Pedro Reservoir** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	54%	68%	72%	40%	43%	54%
	2040-2069	49%	77%	84%	31%	28%	55%
	2070-2099	52%	59%	59%	28%	24%	55%
	2015-2099	**52%**	**68%**	**72%**	**33%**	**31%**	**55%**
Least Cost Portfolio	2015-2039	46%	58%	66%	35%	33%	43%
	2040-2069	33%	59%	71%	21%	14%	41%
	2070-2099	35%	52%	39%	13%	11%	29%
	2015-2099	**38%**	**56%**	**58%**	**22%**	**18%**	**37%**
Regional Self-Reliance Portfolio	2015-2039	47%	58%	66%	35%	33%	43%
	2040-2069	33%	60%	72%	21%	14%	42%
	2070-2099	37%	53%	39%	13%	12%	31%
	2015-2099	**39%**	**57%**	**59%**	**22%**	**19%**	**38%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	50%	68%	72%	39%	42%	50%
	2040-2069	47%	69%	83%	29%	27%	54%
	2070-2099	52%	59%	58%	27%	22%	51%
	2015-2099	**50%**	**65%**	**71%**	**31%**	**30%**	**52%**
Delta Conveyance and Restoration Portfolio	2015-2039	50%	68%	72%	39%	42%	50%
	2040-2069	49%	75%	84%	31%	28%	54%
	2070-2099	52%	59%	59%	27%	23%	54%
	2015-2099	**50%**	**67%**	**72%**	**32%**	**30%**	**53%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	50%	68%	72%	39%	42%	50%
	2040-2069	49%	75%	84%	31%	28%	54%
	2070-2099	52%	59%	59%	27%	23%	54%
	2015-2099	**50%**	**67%**	**72%**	**32%**	**30%**	**53%**
Flexible System Operations and Mgmt Portfolio	2015-2039	50%	68%	72%	39%	42%	50%
	2040-2069	49%	75%	84%	31%	28%	54%
	2070-2099	52%	59%	59%	27%	23%	54%
	2015-2099	**50%**	**67%**	**72%**	**32%**	**30%**	**53%**
Water Action Plan Portfolio	2015-2039	46%	58%	66%	34%	31%	43%
	2040-2069	33%	58%	70%	20%	13%	41%
	2070-2099	34%	51%	38%	13%	10%	29%
	2015-2099	**37%**	**56%**	**58%**	**22%**	**17%**	**37%**

Table 7-33g. Percentage of Months from May through September that **Lake McClure** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	73%	79%	52%	36%	59%
	2070-2099	55%	73%	80%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Least Cost Portfolio	2015-2039	49%	64%	74%	43%	38%	58%
	2040-2069	44%	65%	76%	43%	30%	54%
	2070-2099	49%	70%	74%	59%	41%	63%
	2015-2099	**47%**	**67%**	**75%**	**48%**	**36%**	**58%**
Regional Self-Reliance Portfolio	2015-2039	49%	64%	75%	44%	38%	59%
	2040-2069	44%	65%	76%	44%	30%	55%
	2070-2099	49%	71%	75%	59%	41%	63%
	2015-2099	**47%**	**67%**	**75%**	**49%**	**36%**	**59%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	49%	64%	76%	46%	39%	60%
	2040-2069	44%	68%	78%	47%	35%	59%
	2070-2099	54%	72%	79%	69%	47%	70%
	2015-2099	**49%**	**68%**	**78%**	**55%**	**40%**	**63%**
Delta Conveyance and Restoration Portfolio	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	72%	79%	52%	36%	59%
	2070-2099	55%	73%	79%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	72%	79%	52%	36%	59%
	2070-2099	55%	73%	79%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Flexible System Operations and Mgmt Portfolio	2015-2039	49%	66%	76%	48%	40%	60%
	2040-2069	44%	72%	79%	52%	36%	59%
	2070-2099	55%	73%	79%	69%	48%	71%
	2015-2099	**49%**	**71%**	**78%**	**57%**	**41%**	**64%**
Water Action Plan Portfolio	2015-2039	49%	64%	74%	43%	38%	58%
	2040-2069	43%	65%	76%	42%	30%	54%
	2070-2099	49%	70%	74%	58%	40%	63%
	2015-2099	**47%**	**67%**	**75%**	**48%**	**36%**	**58%**

Table 7-33h. Percentage of Months from May through September that **Millerton Lake** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	54%	66%	71%	56%	46%	60%
	2040-2069	45%	64%	80%	76%	45%	64%
	2070-2099	54%	69%	77%	75%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**70%**	**51%**	**66%**
Least Cost Portfolio	2015-2039	48%	62%	69%	56%	46%	54%
	2040-2069	43%	57%	76%	71%	38%	60%
	2070-2099	43%	63%	71%	73%	57%	71%
	2015-2099	**44%**	**61%**	**72%**	**67%**	**47%**	**62%**
Regional Self-Reliance Portfolio	2015-2039	54%	66%	71%	58%	46%	60%
	2040-2069	45%	64%	80%	73%	45%	64%
	2070-2099	54%	69%	77%	76%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**69%**	**51%**	**66%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	47%	62%	69%	57%	44%	55%
	2040-2069	43%	56%	76%	69%	40%	60%
	2070-2099	45%	63%	69%	74%	55%	70%
	2015-2099	**45%**	**60%**	**72%**	**67%**	**47%**	**62%**
Delta Conveyance and Restoration Portfolio	2015-2039	54%	66%	71%	58%	46%	60%
	2040-2069	45%	64%	80%	73%	45%	64%
	2070-2099	54%	69%	77%	76%	61%	74%
	2015-2099	**51%**	**66%**	**76%**	**69%**	**51%**	**66%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	60%	60%	60%	60%	60%	60%
	2040-2069	59%	60%	60%	60%	59%	60%
	2070-2099	58%	60%	60%	60%	58%	60%
	2015-2099	**59%**	**60%**	**60%**	**60%**	**59%**	**60%**
Flexible System Operations and Mgmt Portfolio	2015-2039	54%	66%	71%	56%	49%	60%
	2040-2069	45%	63%	81%	75%	43%	65%
	2070-2099	53%	69%	77%	76%	61%	74%
	2015-2099	**50%**	**66%**	**77%**	**70%**	**51%**	**67%**
Water Action Plan Portfolio	2015-2039	60%	60%	60%	60%	60%	60%
	2040-2069	59%	60%	60%	60%	59%	60%
	2070-2099	58%	60%	60%	60%	58%	60%
	2015-2099	**59%**	**60%**	**60%**	**60%**	**59%**	**60%**

Table 7-33i. Percentage of Months from May through September that **Pine Flat Reservoir** Surface Area Is Less than the Monthly Median in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	34%	49%	50%	26%	22%	49%
	2040-2069	25%	45%	53%	26%	10%	31%
	2070-2099	32%	53%	55%	15%	1%	36%
	2015-2099	**30%**	**49%**	**53%**	**22%**	**11%**	**38%**
Least Cost Portfolio	2015-2039	19%	39%	46%	18%	14%	26%
	2040-2069	14%	27%	39%	8%	7%	19%
	2070-2099	7%	42%	47%	0%	0%	16%
	2015-2099	**13%**	**36%**	**44%**	**8%**	**6%**	**20%**
Regional Self-Reliance Portfolio	2015-2039	21%	42%	46%	18%	14%	28%
	2040-2069	15%	29%	39%	9%	7%	21%
	2070-2099	7%	43%	51%	1%	0%	19%
	2015-2099	**14%**	**38%**	**45%**	**9%**	**7%**	**22%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	33%	49%	50%	23%	22%	49%
	2040-2069	24%	43%	52%	23%	9%	29%
	2070-2099	29%	53%	54%	13%	0%	31%
	2015-2099	**28%**	**48%**	**52%**	**20%**	**10%**	**36%**
Delta Conveyance and Restoration Portfolio	2015-2039	33%	49%	50%	23%	22%	49%
	2040-2069	24%	43%	51%	23%	9%	29%
	2070-2099	29%	53%	54%	11%	0%	31%
	2015-2099	**28%**	**48%**	**52%**	**19%**	**10%**	**36%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	30%	49%	50%	22%	22%	49%
	2040-2069	23%	43%	51%	21%	8%	29%
	2070-2099	29%	53%	54%	9%	0%	30%
	2015-2099	**27%**	**48%**	**52%**	**17%**	**9%**	**35%**
Flexible System Operations and Mgmt Portfolio	2015-2039	33%	49%	50%	24%	22%	49%
	2040-2069	25%	45%	52%	25%	9%	31%
	2070-2099	31%	53%	54%	14%	1%	35%
	2015-2099	**29%**	**49%**	**52%**	**21%**	**10%**	**37%**
Water Action Plan Portfolio	2015-2039	19%	39%	46%	18%	14%	26%
	2040-2069	13%	27%	37%	8%	7%	19%
	2070-2099	7%	39%	45%	0%	0%	16%
	2015-2099	**13%**	**35%**	**42%**	**8%**	**6%**	**20%**

7.8. Ecological Resources

The attributes of interest selected as indicators of ecological resources were selected primarily to address concerns with respect to endangered aquatic species and their habitats in the Central Valley of California watersheds. These attributes include reservoir cold water pool and floodplain processes in the Sacramento River and pelagic species habitat, adult salmon migration, and food web productivity in the Delta. The performance metrics for these attributes are described in more detail in the following sections.

7.8.1. Storage for Cold Water Pool Management

Storage levels in Shasta Reservoir at the end of April and September are useful measures of the availability of cold water for managing water temperatures needed by salmonid species for survival. When storage in Lake Shasta levels is below 2,200 TAF at the end of September or below 3,800 TAF at the end of April, management of water temperatures in the Sacramento River during the warm season months becomes increasingly difficult. Note that this indicator was not discussed in the Summary Report. See Section 5.2.8.1. *Storage for Cold Water Pool Management* for a discussion of impacts under the No Action alternative.

PORTFOLIOS

Better Cold Pool Storage: The Least Cost and Regional Self-Reliance portfolios reduces the amount of time that storage is less than the minimum, thereby benefitting cold water pool storage.

Worse Cold Pool Storage: The Healthy Headwaters and Tributaries portfolio increase the amount of time that storage is less than the minimum, reducing the benefit for cold water pool storage.

The percentage change in cold pool storage from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-22% to-12%
- Regional Self-Reliance portfolio:-19% to-6%
- Healthy Headwaters and Tributaries portfolio:+22% to +51%
- Delta Conveyance and Restoration portfolio: +0% to +1%
- Expanded Water Storage and Groundwater portfolio: +0% to +6%
- Flexible System Operations and Management portfolio:-12% to +0% i
- Water Action Plan portfolio: 2% to +7%

Table 7-34 shows the percentage of years that Lake Shasta storage is less than 2,200 TAF at the end of September and the percentage of years that Lake Shasta storage is less than 3,800 TAF/year at the end of April under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-34. End-of-September Storage: Adaptation Portfolio Comparison

Table 7-34a. Percentage of Months that **Lake Shasta Storage Is Less than 2,200 TAF** in September in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	56%	80%	80%	44%	32%	56%
	2040-2069	10%	43%	73%	3%	3%	17%
	2070-2099	10%	50%	70%	0%	0%	30%
	2015-2099	**24%**	**56%**	**74%**	**14%**	**11%**	**33%**
Least Cost Portfolio	2015-2039	32%	44%	48%	24%	24%	36%
	2040-2069	0%	7%	20%	3%	3%	0%
	2070-2099	3%	17%	20%	0%	0%	0%
	2015-2099	**11%**	**21%**	**28%**	**8%**	**8%**	**11%**
Regional Self-Reliance Portfolio	2015-2039	36%	52%	68%	36%	24%	44%
	2040-2069	3%	3%	17%	3%	0%	3%
	2070-2099	3%	17%	37%	0%	0%	0%
	2015-2099	**13%**	**22%**	**39%**	**12%**	**7%**	**14%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	68%	84%	84%	64%	48%	80%
	2040-2069	23%	73%	87%	7%	3%	43%
	2070-2099	23%	57%	70%	3%	10%	47%
	2015-2099	**36%**	**71%**	**80%**	**22%**	**19%**	**55%**
Delta Conveyance and Restoration Portfolio	2015-2039	56%	68%	80%	36%	32%	64%
	2040-2069	3%	40%	73%	3%	3%	13%
	2070-2099	13%	50%	67%	0%	3%	30%
	2015-2099	**22%**	**52%**	**73%**	**12%**	**12%**	**34%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	64%	76%	76%	40%	28%	64%
	2040-2069	10%	53%	70%	3%	3%	27%
	2070-2099	23%	57%	60%	0%	3%	30%
	2015-2099	**31%**	**61%**	**68%**	**13%**	**11%**	**39%**
Flexible System Operations and Mgmt Portfolio	2015-2039	48%	56%	64%	36%	24%	52%
	2040-2069	3%	23%	57%	3%	3%	3%
	2070-2099	10%	33%	50%	7%	7%	13%
	2015-2099	**19%**	**36%**	**56%**	**14%**	**11%**	**21%**
Water Action Plan Portfolio	2015-2039	64%	76%	80%	56%	36%	64%
	2040-2069	7%	40%	60%	3%	3%	13%
	2070-2099	10%	33%	37%	3%	3%	20%
	2015-2099	**25%**	**48%**	**58%**	**19%**	**13%**	**31%**

Table 7-34b. Percentage of Months that **Lake Shasta Storage Is Less than 3,800 TAF** in September in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	48%	68%	64%	44%	32%	52%
	2040-2069	7%	40%	60%	3%	3%	7%
	2070-2099	13%	40%	57%	0%	0%	20%
	2015-2099	**21%**	**48%**	**60%**	**14%**	**11%**	**25%**
Least Cost Portfolio	2015-2039	32%	56%	56%	28%	20%	32%
	2040-2069	3%	7%	20%	3%	3%	3%
	2070-2099	7%	20%	30%	3%	3%	7%
	2015-2099	**13%**	**26%**	**34%**	**11%**	**8%**	**13%**
Regional Self-Reliance Portfolio	2015-2039	36%	64%	64%	32%	28%	48%
	2040-2069	3%	10%	27%	3%	3%	7%
	2070-2099	3%	23%	40%	0%	0%	7%
	2015-2099	**13%**	**31%**	**42%**	**11%**	**9%**	**19%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	92%	96%	96%	68%	64%	92%
	2040-2069	70%	100%	100%	37%	40%	80%
	2070-2099	63%	77%	80%	10%	17%	60%
	2015-2099	**74%**	**91%**	**92%**	**36%**	**39%**	**76%**
Delta Conveyance and Restoration Portfolio	2015-2039	44%	68%	64%	36%	28%	48%
	2040-2069	7%	47%	60%	3%	3%	10%
	2070-2099	20%	47%	57%	0%	0%	20%
	2015-2099	**22%**	**53%**	**60%**	**12%**	**9%**	**25%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	48%	60%	68%	32%	28%	52%
	2040-2069	3%	47%	60%	0%	3%	7%
	2070-2099	20%	40%	57%	0%	3%	20%
	2015-2099	**22%**	**48%**	**61%**	**9%**	**11%**	**25%**
Flexible System Operations and Mgmt Portfolio	2015-2039	48%	64%	64%	36%	28%	52%
	2040-2069	3%	30%	50%	3%	3%	7%
	2070-2099	10%	33%	50%	7%	7%	20%
	2015-2099	**19%**	**41%**	**54%**	**14%**	**12%**	**25%**
Water Action Plan Portfolio	2015-2039	60%	76%	80%	44%	44%	64%
	2040-2069	10%	53%	63%	3%	3%	13%
	2070-2099	17%	33%	40%	7%	7%	23%
	2015-2099	**27%**	**53%**	**60%**	**16%**	**16%**	**32%**

7.8.2. River Temperature

River temperatures are important for critical life stages of fish species such as the Chinook salmon and steelhead. The Sacramento and San Joaquin water temperature models were simulated for each portfolio with Central Tendency climate/Current Trends socioeconomic scenarios for the following key locations:

- Sacramento River at Keswick
- Sacramento River at Jelly's Ferry
- American River below Nimbus
- San Joaquin River at Gravelly Ford
- San Joaquin River at Vernalis

See Section 5.2.8.2. *River Temperature* for a discussion of impacts under the No Action alternative.

PORTFOLIOS

Sacramento River

Increased Temperature Management: The Least Cost, Flexible System Operations and Management, Expanded Water Storage and Groundwater and Water Action Plan portfolios, which all include either the enlarged Shasta or flexible system operations actions that allow for higher storage levels in the summer and fall, appear to provide the greatest benefit for Sacramento River temperature.

Reduced Temperature Management: The Healthy Headwaters and Tributaries portfolio has lower storage levels due to the tributary environmental flow action, and thus results in the greatest reduction in benefit for river temperature on the Sacramento River.

The change in mean temperature in the Sacramento River from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios ranges from:

- Least Cost portfolio: –0.8 to-0.9 °F
- Regional Self-Reliance portfolio:-0.2 to-0.5 °F
- Healthy Headwaters and Tributaries portfolio: +0.9 to +1.0 °F
- Delta Conveyance and Restoration portfolio: +0.2 to +0.3 °F
- Expanded Water Storage and Groundwater portfolio:-0.3 to-0.4 °F
- Flexible System Operations and Management portfolio: -0.5 to-0.7 °F
- Water Action Plan portfolio: -0.3 to-0.3 °F

American River

Increased Temperature Management: The Flexible System Operations and Management portfolio appears to provide the greatest benefit for American River temperature.

Reduced Temperature Management: The Healthy Headwaters and Tributaries portfolio results in the greatest reduction in benefit for river temperature on the American River.

The change in mean temperature in the American River from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio: +0.2 °F
- Regional Self-Reliance portfolio: +0.3 °F
- Healthy Headwaters and Tributaries portfolio: +0.4 °F
- Delta Conveyance and Restoration portfolio: +0.1 °F
- Expanded Water Storage and Groundwater portfolio: +0.3 °F
- Flexible System Operations and Management portfolio:-0.2 °F
- Water Action Plan portfolio: 0.2 °F

San Joaquin River:

All of the portfolios result in only minor changes in river temperatures on the San Joaquin River.

The change in mean temperature in the American River from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios ranges from:

- Least Cost portfolio: 0.0 to 0.0 °F
- Regional Self-Reliance portfolio: 0.0 to +0.3 °F
- Healthy Headwaters and Tributaries portfolio:-0.2 to 0.0 °F
- Delta Conveyance and Restoration portfolio: 0.0 to-0.1 °F
- Expanded Water Storage and Groundwater portfolio: 0.0 to 0.0 °F
- Flexible System Operations and Management portfolio: 0.0 to-0.1 °F
- Water Action Plan portfolio: 0.0 to 0.0 °F

Figure 7-25 shows exceedance plots of daily water temperatures from July through September for each portfolio in the Sacramento River at Keswick and at Jelly's Ferry and on the American River below Nimbus as well as the San Joaquin River at Lost Lake and Vernalis from August through November.

Figure 7-25. River temperature exceedences.

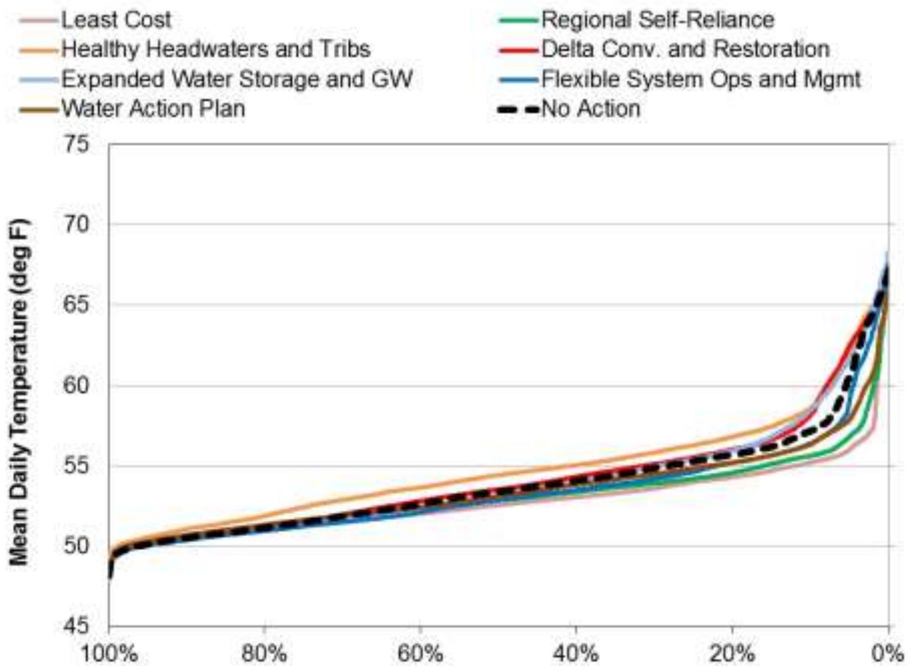

Figure 7-25a. Exceedance of average temperature on **Sacramento River at Keswick** from July to September for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

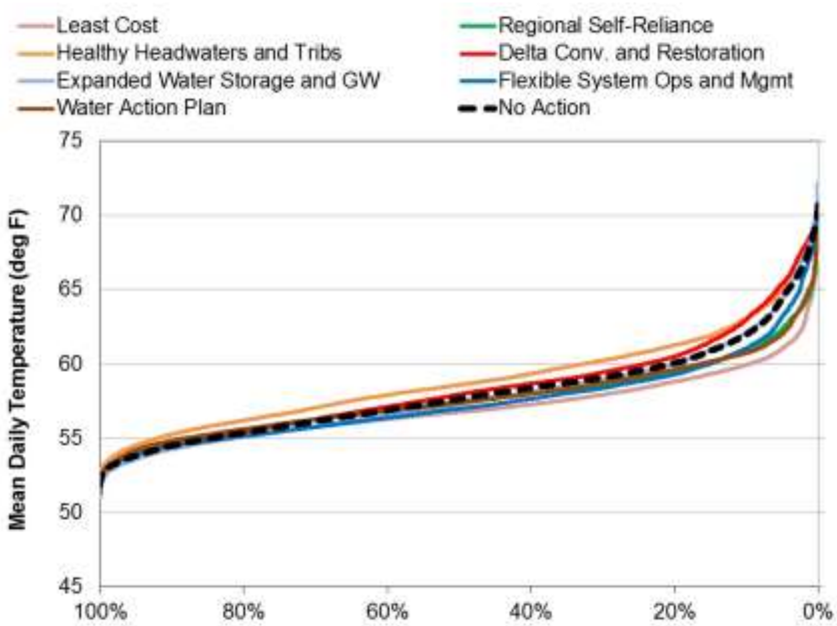

Figure 7-25b. Exceedance of average temperature on **Sacramento River at Jelly's Ferry** from July to September for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

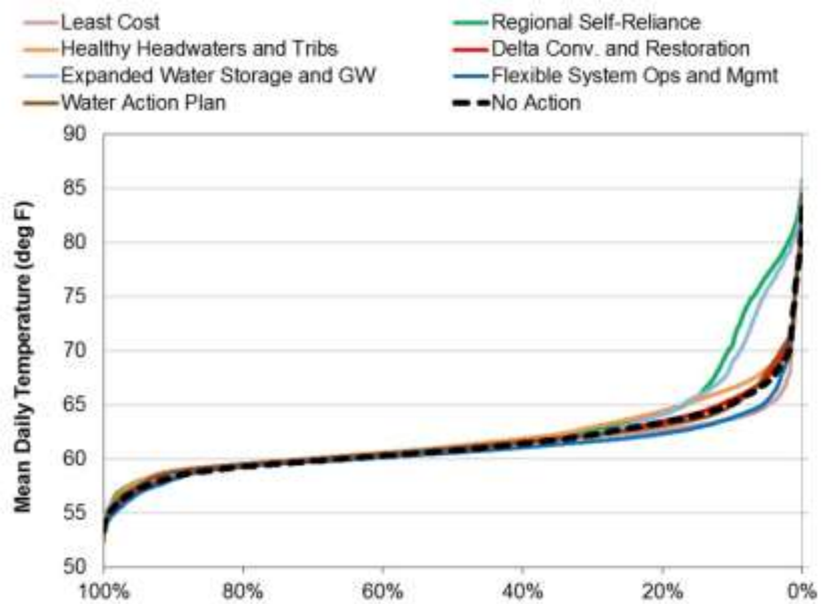

Figure 7-25c. Exceedance of average temperature on **American River below Nimbus** from July to September for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

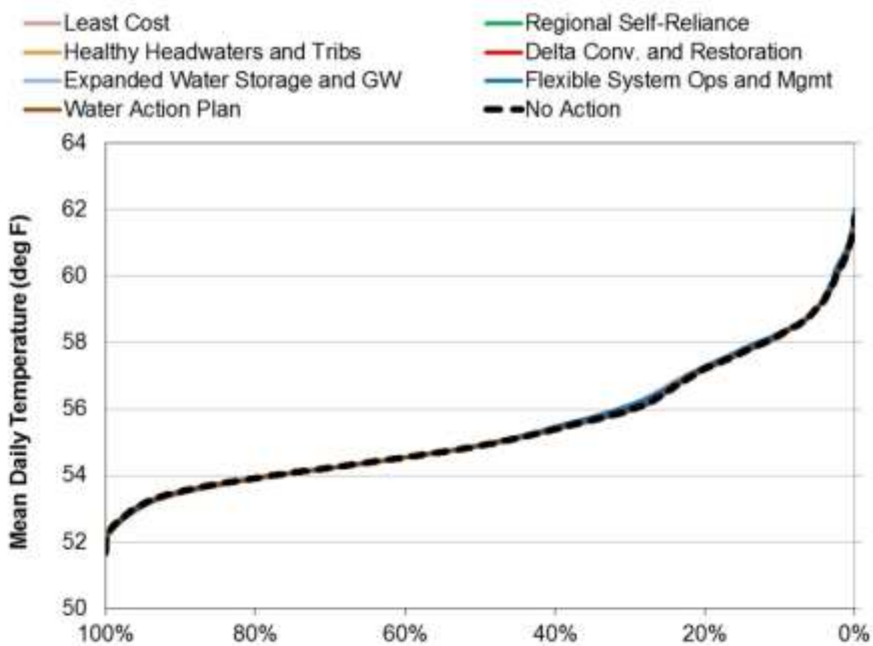

Figure 7-25d. Exceedance of average temperature on **San Joaquin River at Lost Lake** from July to September for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

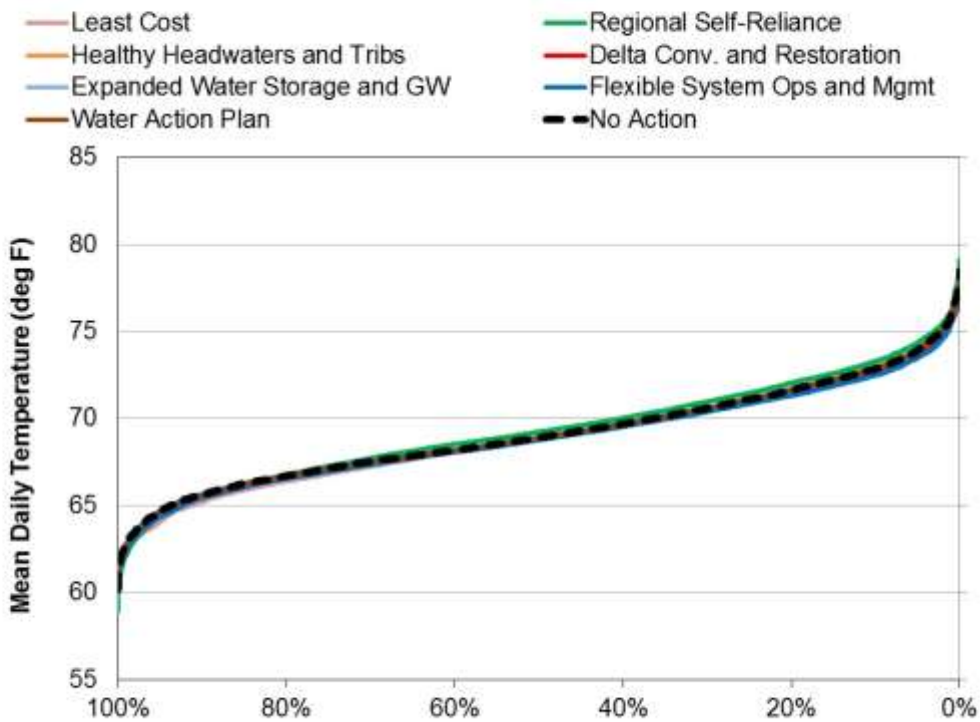

Figure 7-25e. Exceedance of average temperature on San Joaquin River at Vernalis from July to September for each adaptation portfolio in the Central Tendency climate/Current Trends socioeconomic scenarios.

7.8.3. Floodplain Processes: Instream Flows for Channel Maintenance and Habitat Creation

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.

This indicator also measures flows:

- Sacramento River at Keswick Reservoir over 15,000 cfs.
- At the mouth of Feather River: flows over at 10,000 cfs
- American River flows at Natoma: flows over 3,000 cfs

Flows above these rates 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. See Section 5.2.8.3. *Floodplain Processes*.

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.

More Instream Flows: The Healthy Headwaters and Tributaries and Water Action Plan portfolios provide the greatest benefit to instream flows for channel maintenance and habitat creation, reflecting the effects of the tributary environmental flows action.

Fewer Instream Flows: The Regional Self-Reliance and Flexible System Operations and Management portfolios result in the greatest reduction in benefit.

The percentage change in from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-2%
- Regional Self-Reliance portfolio: +3%
- Healthy Headwaters and Tributaries portfolio:-9%
- Delta Conveyance and Restoration portfolio:-3%
- Expanded Water Storage and Groundwater portfolio:-4%
- Flexible System Operations and Management portfolio: +4%
- Water Action Plan portfolio:-9%

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 7-26). 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. Table 7-35 shows details of the performance of each of the ortfolios relative to the No Action alternative in four climate scenarios.

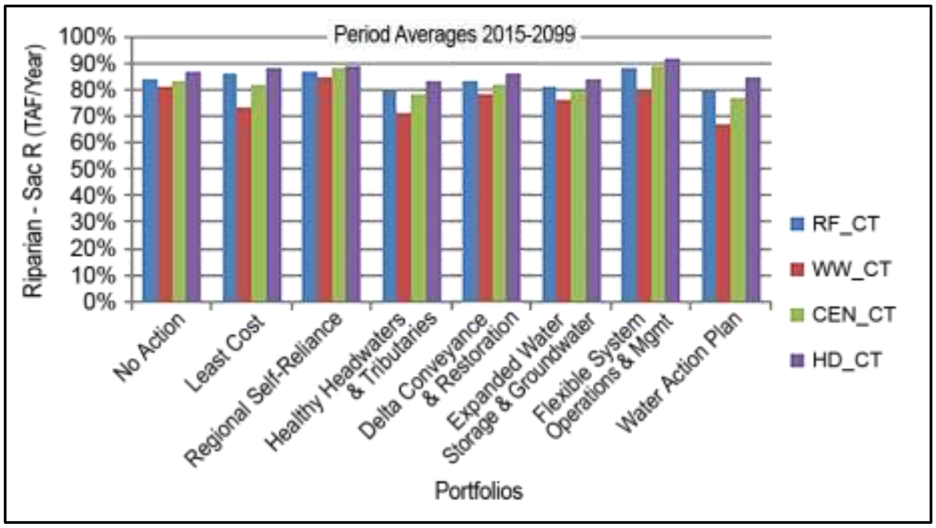

Figure 7-26. Keswick flows: adaptation portfolio performance Percentage of months from February through June that flows on the Sacramento River at Keswick are less than the 15,000 cfs in each adaptation portfolio.[19] (Lower numbers indicate increased benefits).

[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.

Table 7-35. Keswick Flows: 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	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

7.8.3.2. Adaptation Portfolio Climate Sensitivity

Table 7-36 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 7-36. 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

Table 7-37 shows the percentage of months from February through June that Sacramento River flows at Keswick, Feather River at the mouth, and American River flows at Natoma are less than the performance indicator values under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-37. Instream Flows: Adaptation Portfolio Comparison

Table 7-37a. Percentage of Months from February through June that Flows on the **Sacramento River at Keswick are Less than 15,000 cfs** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	88%	89%	90%	86%	86%	87%
	2040-2069	84%	87%	84%	77%	80%	81%
	2070-2099	81%	84%	86%	77%	79%	82%
	2015-2099	**84%**	**86%**	**87%**	**80%**	**81%**	**83%**
Least Cost Portfolio	2015-2039	91%	94%	94%	86%	84%	89%
	2040-2069	87%	89%	87%	73%	78%	83%
	2070-2099	80%	85%	83%	62%	59%	75%
	2015-2099	**86%**	**89%**	**88%**	**73%**	**73%**	**82%**
Regional Self-Reliance Portfolio	2015-2039	90%	90%	91%	89%	87%	91%
	2040-2069	88%	93%	88%	86%	86%	88%
	2070-2099	84%	90%	88%	82%	82%	87%
	2015-2099	**87%**	**91%**	**89%**	**85%**	**85%**	**88%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	86%	88%	86%	80%	80%	83%
	2040-2069	77%	87%	83%	70%	67%	75%
	2070-2099	77%	77%	79%	70%	67%	75%
	2015-2099	**80%**	**84%**	**83%**	**73%**	**71%**	**78%**
Delta Conveyance and Restoration Portfolio	2015-2039	89%	90%	89%	86%	86%	86%
	2040-2069	80%	88%	84%	77%	76%	78%
	2070-2099	80%	83%	85%	75%	73%	81%
	2015-2099	**83%**	**87%**	**86%**	**79%**	**78%**	**82%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	85%	90%	88%	84%	83%	86%
	2040-2069	78%	86%	82%	75%	76%	77%
	2070-2099	80%	85%	83%	74%	71%	78%
	2015-2099	**81%**	**87%**	**84%**	**77%**	**76%**	**80%**
Flexible System Operations and Mgmt Portfolio	2015-2039	92%	96%	95%	91%	90%	93%
	2040-2069	89%	96%	95%	85%	83%	92%
	2070-2099	83%	89%	88%	76%	70%	83%
	2015-2099	**88%**	**94%**	**92%**	**84%**	**80%**	**89%**
Water Action Plan Portfolio	2015-2039	89%	90%	92%	82%	81%	87%
	2040-2069	79%	85%	84%	62%	67%	73%
	2070-2099	74%	81%	81%	54%	55%	72%
	2015-2099	**80%**	**85%**	**85%**	**65%**	**67%**	**77%**

Table 7-37b. Percentage of Months from February through June that Flows on the **Feather River at the Mouth are Less than 10,000 cfs** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	80%	86%	84%	75%	72%	82%
	2040-2069	72%	86%	87%	64%	57%	77%
	2070-2099	71%	77%	80%	65%	63%	72%
	2015-2099	**74%**	**83%**	**84%**	**68%**	**64%**	**76%**
Least Cost Portfolio	2015-2039	71%	82%	81%	60%	59%	77%
	2040-2069	59%	73%	75%	51%	41%	65%
	2070-2099	58%	73%	75%	57%	53%	67%
	2015-2099	**62%**	**76%**	**77%**	**56%**	**50%**	**69%**
Regional Self-Reliance Portfolio	2015-2039	79%	87%	86%	72%	72%	82%
	2040-2069	70%	84%	86%	61%	56%	73%
	2070-2099	70%	77%	81%	60%	62%	73%
	2015-2099	**73%**	**83%**	**84%**	**64%**	**63%**	76%
Healthy Headwaters and Tributaries Portfolio	2015-2039	74%	82%	81%	65%	62%	75%
	2040-2069	62%	75%	78%	54%	51%	67%
	2070-2099	63%	71%	76%	54%	55%	65%
	2015-2099	**66%**	**76%**	**78%**	**57%**	**56%**	**69%**
Delta Conveyance and Restoration Portfolio	2015-2039	77%	86%	83%	74%	69%	78%
	2040-2069	64%	75%	75%	55%	47%	65%
	2070-2099	63%	73%	76%	61%	57%	65%
	2015-2099	**68%**	**78%**	**78%**	**63%**	**57%**	**69%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	70%	78%	76%	63%	62%	74%
	2040-2069	55%	71%	71%	49%	43%	59%
	2070-2099	59%	70%	69%	58%	55%	65%
	2015-2099	**61%**	**73%**	**72%**	**56%**	**53%**	**65%**
Flexible System Operations and Mgmt Portfolio	2015-2039	78%	87%	86%	74%	72%	80%
	2040-2069	75%	85%	86%	61%	55%	75%
	2070-2099	71%	78%	80%	63%	63%	71%
	2015-2099	**75%**	**83%**	**84%**	**66%**	**63%**	**75%**
Water Action Plan Portfolio	2015-2039	64%	74%	76%	52%	49%	70%
	2040-2069	49%	65%	66%	41%	35%	57%
	2070-2099	53%	69%	70%	51%	49%	61%
	2015-2099	**55%**	**69%**	**70%**	**48%**	**44%**	**62%**

Table 7-37c. Percentage of Months from February through June that Flows on the American River at Natoma are Less than 3,000 cfs in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	60%	46%	50%	54%	58%	51%
	2040-2069	53%	41%	40%	39%	52%	44%
	2070-2099	48%	32%	32%	32%	46%	37%
	2015-2099	**53%**	**39%**	**40%**	**41%**	**52%**	**44%**
Least Cost Portfolio	2015-2039	53%	42%	35%	48%	51%	47%
	2040-2069	51%	37%	30%	43%	54%	42%
	2070-2099	48%	29%	27%	37%	52%	35%
	2015-2099	**50%**	**36%**	**31%**	**42%**	**52%**	**41%**
Regional Self-Reliance Portfolio	2015-2039	54%	42%	45%	50%	54%	51%
	2040-2069	49%	37%	37%	35%	49%	38%
	2070-2099	44%	29%	27%	33%	47%	33%
	2015-2099	**48%**	**36%**	**36%**	**39%**	**50%**	**40%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	67%	60%	61%	63%	68%	66%
	2040-2069	65%	54%	50%	57%	67%	61%
	2070-2099	59%	43%	38%	42%	59%	49%
	2015-2099	**64%**	**52%**	**49%**	**53%**	**64%**	**58%**
Delta Conveyance and Restoration Portfolio	2015-2039	58%	43%	47%	54%	61%	50%
	2040-2069	57%	41%	39%	39%	53%	44%
	2070-2099	50%	33%	35%	34%	47%	39%
	2015-2099	**55%**	**39%**	**40%**	**42%**	**53%**	**44%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	56%	47%	51%	51%	58%	52%
	2040-2069	50%	37%	35%	35%	51%	40%
	2070-2099	45%	36%	31%	32%	45%	37%
	2015-2099	**50%**	**40%**	**39%**	**39%**	**51%**	**42%**
Flexible System Operations and Mgmt Portfolio	2015-2039	50%	37%	39%	48%	48%	46%
	2040-2069	50%	31%	29%	38%	52%	35%
	2070-2099	45%	31%	25%	32%	44%	30%
	2015-2099	**48%**	**33%**	**30%**	**39%**	**48%**	**36%**
Water Action Plan Portfolio	2015-2039	65%	54%	52%	59%	64%	56%
	2040-2069	61%	52%	45%	54%	61%	55%
	2070-2099	55%	41%	32%	45%	57%	43%
	2015-2099	**60%**	**48%**	**42%**	**52%**	**61%**	**51%**

7.8.4. Pelagic Species Habitat

Pelagic species are fish that live and spawn in open water in the estuaries of the Bay-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. See Section 5.8.4. Pelagic Species Habitat for description.

7.8.4.1. Spring Delta Outflows

See Section 5.2.8.4.1. *Spring Delta Outflows* for a discussion of impacts under the No Action alternative.

More Outflows: The Healthy Headwaters and Tributaries and Water Action Plan portfolios provide the greatest benefit in flows for pelagic species habitat, reflecting the effects of the tributary environmental flows action.

Fewer Outflows: The Expanded Water Storage and Groundwater portfolio results in the greatest reduction in benefit.

The percent change in outflows from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios ranges from:

- Least Cost portfolio:-1% to +3%
- Regional Self-Reliance portfolio:-1% to-3%
- Healthy Headwaters and Tributaries portfolio:-11% to-6%
- Delta Conveyance and Restoration portfolio: +1% to +4%
- Expanded Water Storage and Groundwater portfolio: +5% to +10%
- Flexible System Operations and Management portfolio:-1% to-3%
- Water Action Plan portfolio: 6% to-5%

Table 7-38 show the percentage of months from March through May that the Delta outflow is less than 28,000 cfs and that it is less than 44,000 cfs under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-38. March – May Delta Outflow Flow: Adaptation Portfolio Comparison

Table 7-38a. Percentage in Months that the March-through-May **Delta Outflow Flow is less than 28,000 cfs** in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	69%	81%	84%	64%	57%	71%
	2040-2069	54%	80%	80%	49%	43%	63%
	2070-2099	72%	81%	82%	54%	50%	70%
	2015-2099	**65%**	**81%**	**82%**	**55%**	**50%**	**68%**
Least Cost Portfolio	2015-2039	76%	79%	81%	61%	60%	76%
	2040-2069	58%	81%	84%	49%	43%	63%
	2070-2099	71%	82%	86%	56%	51%	73%
	2015-2099	**68%**	**81%**	**84%**	**55%**	**51%**	**71%**
Regional Self-Reliance Portfolio	2015-2039	68%	81%	83%	64%	59%	68%
	2040-2069	53%	73%	76%	48%	41%	60%
	2070-2099	67%	80%	81%	54%	48%	68%
	2015-2099	**62%**	**78%**	**80%**	**55%**	**49%**	**65%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	64%	73%	75%	51%	45%	63%
	2040-2069	42%	61%	72%	41%	37%	49%
	2070-2099	59%	73%	77%	47%	41%	61%
	2015-2099	**55%**	**69%**	**75%**	**46%**	**41%**	**57%**
Delta Conveyance and Restoration Portfolio	2015-2039	72%	85%	85%	65%	61%	77%
	2040-2069	63%	81%	83%	56%	46%	69%
	2070-2099	76%	84%	86%	61%	57%	71%
	2015-2099	**70%**	**84%**	**85%**	**60%**	**54%**	**72%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	79%	87%	88%	69%	65%	81%
	2040-2069	71%	89%	89%	58%	48%	76%
	2070-2099	79%	86%	86%	61%	59%	79%
	2015-2099	**76%**	**87%**	**87%**	**62%**	**57%**	**78%**
Flexible System Operations and Mgmt Portfolio	2015-2039	68%	77%	77%	59%	53%	69%
	2040-2069	56%	74%	84%	44%	39%	59%
	2070-2099	66%	79%	80%	48%	47%	69%
	2015-2099	**63%**	**77%**	**81%**	**50%**	**46%**	**65%**
Water Action Plan Portfolio	2015-2039	72%	80%	83%	60%	56%	73%
	2040-2069	47%	73%	80%	42%	39%	52%
	2070-2099	61%	79%	81%	52%	47%	62%
	2015-2099	**59%**	**77%**	**81%**	**51%**	**47%**	**62%**

Table 7-38b. Percentage in Months that the March-through-May **Delta Outflow Flow is less than 44,000 cfs** in the Reference-No-Climate-Change and Ensemble Climate Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	83%	93%	93%	80%	73%	87%
	2040-2069	81%	91%	91%	72%	64%	84%
	2070-2099	83%	92%	96%	76%	72%	88%
	2015-2099	**82%**	**92%**	**93%**	**76%**	**70%**	**86%**
Least Cost Portfolio	2015-2039	85%	93%	93%	80%	76%	88%
	2040-2069	80%	93%	91%	71%	59%	82%
	2070-2099	82%	90%	94%	76%	72%	87%
	2015-2099	**82%**	**92%**	**93%**	**75%**	**69%**	**85%**
Regional Self-Reliance Portfolio	2015-2039	83%	93%	92%	79%	72%	87%
	2040-2069	81%	90%	90%	71%	61%	82%
	2070-2099	83%	91%	96%	73%	69%	87%
	2015-2099	**82%**	**91%**	**93%**	**74%**	**67%**	**85%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	81%	89%	87%	75%	68%	83%
	2040-2069	70%	86%	88%	62%	57%	77%
	2070-2099	79%	86%	92%	62%	61%	80%
	2015-2099	**76%**	**87%**	**89%**	**66%**	**62%**	**80%**
Delta Conveyance and Restoration Portfolio	2015-2039	88%	92%	92%	80%	79%	89%
	2040-2069	84%	91%	91%	73%	71%	86%
	2070-2099	84%	94%	96%	77%	73%	88%
	2015-2099	**85%**	**93%**	**93%**	**76%**	**74%**	**87%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	91%	96%	96%	87%	84%	91%
	2040-2069	88%	94%	96%	76%	74%	90%
	2070-2099	86%	97%	99%	78%	77%	92%
	2015-2099	**88%**	**96%**	**97%**	**80%**	**78%**	**91%**
Flexible System Operations and Mgmt Portfolio	2015-2039	83%	92%	93%	76%	72%	83%
	2040-2069	76%	93%	91%	68%	56%	84%
	2070-2099	80%	91%	93%	71%	70%	87%
	2015-2099	**79%**	**92%**	**93%**	**71%**	**65%**	**85%**
Water Action Plan Portfolio	2015-2039	84%	93%	93%	77%	73%	84%
	2040-2069	74%	89%	91%	62%	56%	78%
	2070-2099	80%	89%	93%	67%	61%	81%
	2015-2099	**79%**	**90%**	**93%**	**68%**	**63%**	**81%**

7.8.4.2. Delta Low Salinity Zone

X2 is defined as the distance measured in kilometers (km) from the Golden Gate Bridge to the location of the 2 parts per thousand salinity concentration isohaline in the Delta. The X2 position is a function of both the freshwater Delta outflow and sea level which affects tidal saltwater mixing in the Delta. Higher X2 positions indicate that salinity has moved farther eastward into the Delta. See Section 5.2.8.4.2. *Delta Low Salinity Zone*.

7.8.4.2.1. Delta Salinity Levels from February through June

Maintaining X2 positions of less than 74 km in spring months (from February through June) 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. See Section 5.2.8.4.2.1. *Delta Salinity Levels from February through June* for a discussion of impacts under the No Action alternative.

The changes in X2 position results are minor between the different portfolios. The Healthy Headwaters and Tributaries adaptation portfolio has the lowest X2 position results, while the Expanded Water Storage and Groundwater portfolio has the highest X2 position results.

The Healthy Headwaters and Tributaries portfolio provides the least amount of salinity and therefore the greatest benefit for pelagic species habitat. The Expanded Water Storage and Groundwater portfolio results in more salinity and therefore the greatest impact to pelagic species habitat. The percentage change in in average annual GHG offset for the CVP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios ranges from:

- Least Cost portfolio: +0% to +7%
- Regional Self-Reliance portfolio:-2% to +0%
- Healthy Headwaters and Tributaries portfolio:-3% to-1%
- Delta Conveyance and Restoration portfolio: +0% to +3%
- Expanded Water Storage and Groundwater portfolio: +1% to +12%
- Flexible System Operations and Management portfolio: +1% to +2%
- Water Action Plan portfolio: +0% to +4%

Figure 7-27 shows the exceedance of the X2 position from February through June for each of the portfolios in the central tendency climate – current trends socioeconomic scenario.

Table 7-39 shows the percentage of months from February through June that the average distance measured from the Golden Gate Bridge to the X2 (2 parts per thousand salinity concentration) position is greater than 74 km and the percentage of months from February through June that X2 position is greater than 81 km under the

Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

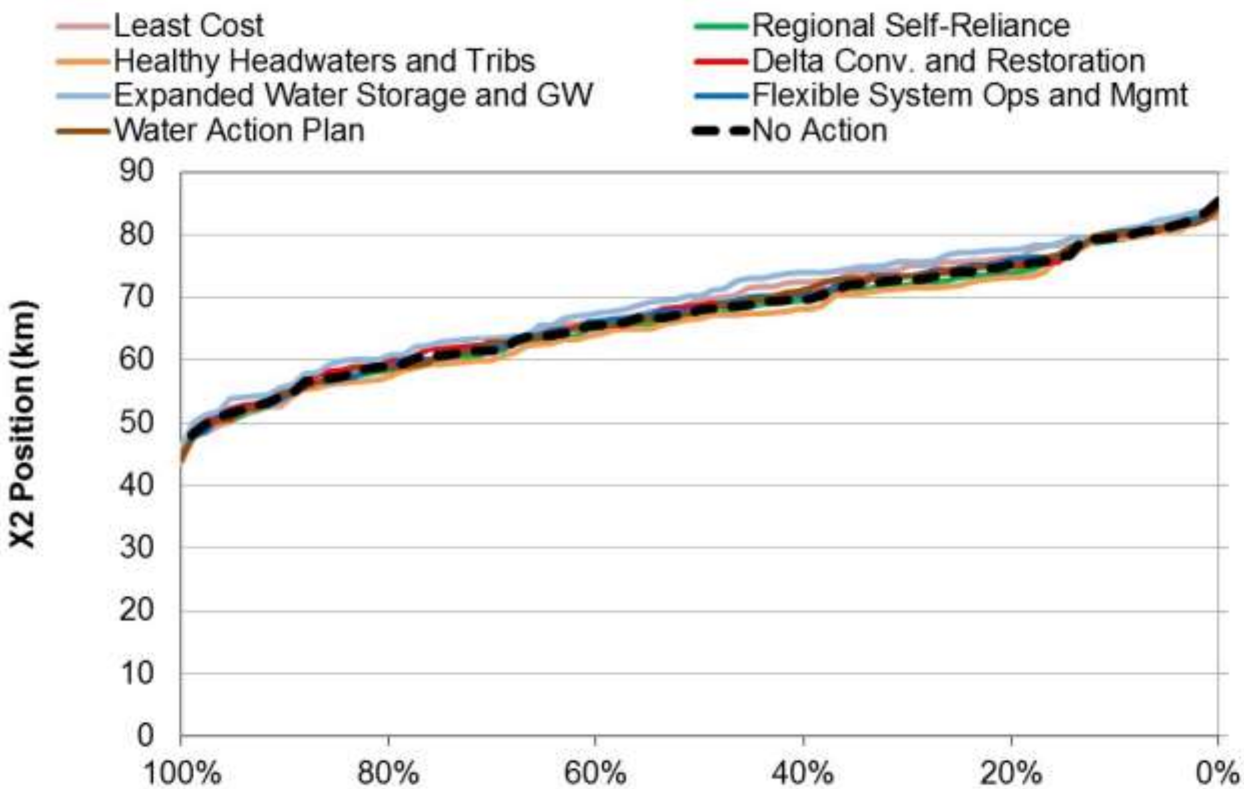

Figure 7-27. February-to-June X2 position: Exceedance of average position in each portfolio.

Table 7-39. February – June X2 Positions: Adaptation Portfolio Comparison

Table 7-39a. Percentage of Months that the February-to-June X2 Position Is **Greater than 74 km** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	30%	45%	49%	26%	22%	37%
	2040-2069	19%	35%	44%	25%	15%	25%
	2070-2099	22%	50%	65%	28%	17%	35%
	2015-2099	**24%**	**43%**	**53%**	**26%**	**18%**	**32%**
Least Cost Portfolio	2015-2039	40%	57%	61%	34%	27%	46%
	2040-2069	20%	44%	54%	24%	13%	33%
	2070-2099	25%	53%	65%	28%	15%	39%
	2015-2099	**28%**	**51%**	**60%**	**28%**	**18%**	**39%**
Regional Self-Reliance Portfolio	2015-2039	30%	47%	48%	30%	24%	37%
	2040-2069	17%	35%	43%	19%	13%	25%
	2070-2099	21%	48%	60%	22%	13%	33%
	2015-2099	**22%**	**43%**	**50%**	**23%**	**16%**	**32%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	27%	42%	45%	28%	20%	34%
	2040-2069	15%	34%	42%	19%	12%	24%
	2070-2099	17%	45%	58%	23%	15%	31%
	2015-2099	**20%**	**40%**	**48%**	**23%**	**16%**	**29%**
Delta Conveyance and Restoration Portfolio	2015-2039	37%	51%	54%	30%	26%	38%
	2040-2069	21%	37%	47%	25%	15%	27%
	2070-2099	21%	51%	63%	28%	19%	39%
	2015-2099	**26%**	**46%**	**55%**	**28%**	**20%**	**35%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	39%	62%	63%	38%	32%	47%
	2040-2069	25%	51%	58%	25%	17%	35%
	2070-2099	28%	63%	69%	31%	20%	51%
	2015-2099	**30%**	**58%**	**63%**	**31%**	**22%**	**44%**
Flexible System Operations and Mgmt Portfolio	2015-2039	31%	51%	52%	29%	23%	37%
	2040-2069	19%	40%	49%	25%	13%	27%
	2070-2099	21%	51%	64%	29%	17%	37%
	2015-2099	**23%**	**47%**	**55%**	**27%**	**17%**	**34%**
Water Action Plan Portfolio	2015-2039	35%	55%	59%	31%	27%	41%
	2040-2069	19%	42%	51%	22%	12%	30%
	2070-2099	21%	49%	63%	26%	14%	39%
	2015-2099	**25%**	**48%**	**58%**	**26%**	**17%**	**36%**

Table 7-39b. Percentage of Months that the February-to-June X2 Position Is **Greater than 81 km** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	7%	13%	15%	4%	5%	9%
	2040-2069	5%	8%	12%	6%	3%	8%
	2070-2099	5%	13%	19%	10%	3%	13%
	2015-2099	**6%**	**11%**	**16%**	**7%**	**4%**	**10%**
Least Cost Portfolio	2015-2039	7%	14%	18%	5%	5%	10%
	2040-2069	3%	13%	21%	4%	1%	6%
	2070-2099	3%	18%	34%	11%	2%	15%
	2015-2099	**4%**	**15%**	**25%**	**7%**	**3%**	**10%**
Regional Self-Reliance Portfolio	2015-2039	8%	13%	18%	8%	6%	10%
	2040-2069	3%	9%	14%	3%	3%	6%
	2070-2099	3%	12%	19%	4%	1%	10%
	2015-2099	**5%**	**11%**	**17%**	**5%**	**3%**	**8%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	7%	14%	14%	6%	4%	9%
	2040-2069	5%	7%	11%	5%	3%	7%
	2070-2099	4%	13%	19%	7%	1%	12%
	2015-2099	**5%**	**11%**	**15%**	**6%**	**3%**	**9%**
Delta Conveyance and Restoration Portfolio	2015-2039	7%	11%	10%	6%	6%	9%
	2040-2069	5%	7%	11%	5%	3%	8%
	2070-2099	6%	12%	19%	9%	4%	13%
	2015-2099	**6%**	**10%**	**14%**	**7%**	**4%**	**10%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	8%	13%	17%	7%	6%	9%
	2040-2069	3%	11%	13%	7%	3%	9%
	2070-2099	6%	15%	30%	9%	4%	15%
	2015-2099	**6%**	**13%**	**20%**	**8%**	**4%**	**11%**
Flexible System Operations and Mgmt Portfolio	2015-2039	7%	16%	19%	5%	4%	9%
	2040-2069	5%	14%	22%	8%	1%	10%
	2070-2099	5%	19%	29%	11%	3%	15%
	2015-2099	**6%**	**16%**	**24%**	**8%**	**3%**	**11%**
Water Action Plan Portfolio	2015-2039	8%	16%	22%	5%	4%	9%
	2040-2069	3%	11%	20%	4%	1%	7%
	2070-2099	3%	17%	32%	9%	1%	13%
	2015-2099	**4%**	**15%**	**25%**	**6%**	**2%**	**10%**

7.8.4.2.2. Delta Salinity Levels from September through November

Maintaining X2 positions of less than 74 km in fall months (from September through November) is through June) 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. See Section 5.2.8.4.2.2. *Delta Salinity Levels from September through November*.

The Delta Conveyance and Restoration adaptation portfolio provides the least amount of salinity and therefore the greatest benefit in salinity for pelagic species habitat. No adaptation portfolio results in a significant increase in salinity. Under the Central Tendency climate scenario from 2015-2099, the change in this indicator from the No Action alternative ranges from:

- Least Cost portfolio:-2% to-1%
- Regional Self-Reliance portfolio:-2% to-2%
- Healthy Headwaters and Tributaries portfolio: +0% to +2%
- Delta Conveyance and Restoration portfolio:-7% to-2%
- Expanded Water Storage and Groundwater portfolio:-2% to-2%
- Flexible System Operations and Management portfolio:-2% to +0%
- Water Action Plan portfolio:-3% to-3%

Table 7-40 shows the percentage of months from September through November that the average X2 position is greater than 74 km and the percentage of months from September through November that X2 position is greater than 81 km under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-40.September-November X2 Position: Adaptation Portfolio Comparison

Table 7-40a. Percentage of Months that the **September-to-November** X2 Position Is Greater than **74 km** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	96%	96%	96%	95%	93%	96%
	2040-2069	96%	98%	97%	94%	91%	97%
	2070-2099	89%	96%	99%	91%	86%	93%
	2015-2099	**93%**	**96%**	**97%**	**93%**	**90%**	**95%**
Least Cost Portfolio	2015-2039	95%	95%	95%	93%	91%	96%
	2040-2069	96%	98%	99%	93%	87%	97%
	2070-2099	87%	91%	98%	87%	82%	90%
	2015-2099	**92%**	**95%**	**97%**	**91%**	**86%**	**94%**
Regional Self-Reliance Portfolio	2015-2039	95%	96%	96%	93%	89%	95%
	2040-2069	93%	97%	97%	87%	80%	97%
	2070-2099	83%	90%	98%	84%	76%	89%
	2015-2099	**90%**	**94%**	**97%**	**88%**	**81%**	**93%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	96%	96%	96%	96%	93%	96%
	2040-2069	96%	98%	98%	94%	91%	97%
	2070-2099	89%	96%	99%	89%	87%	93%
	2015-2099	**93%**	**96%**	**98%**	**93%**	**90%**	**95%**
Delta Conveyance and Restoration Portfolio	2015-2039	95%	93%	96%	93%	93%	92%
	2040-2069	96%	97%	96%	94%	93%	96%
	2070-2099	89%	94%	99%	89%	86%	92%
	2015-2099	**93%**	**95%**	**97%**	**92%**	**91%**	**93%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	91%	92%	92%	95%	91%	92%
	2040-2069	91%	94%	97%	92%	92%	94%
	2070-2099	83%	94%	99%	89%	86%	92%
	2015-2099	**88%**	**94%**	**96%**	**92%**	**89%**	**93%**
Flexible System Operations and Mgmt Portfolio	2015-2039	96%	96%	96%	96%	93%	96%
	2040-2069	97%	97%	98%	93%	91%	97%
	2070-2099	89%	96%	99%	91%	86%	91%
	2015-2099	**94%**	**96%**	**98%**	**93%**	**90%**	**95%**
Water Action Plan Portfolio	2015-2039	91%	92%	89%	93%	89%	92%
	2040-2069	92%	98%	90%	93%	83%	96%
	2070-2099	81%	84%	98%	87%	74%	88%
	2015-2099	**88%**	**91%**	**93%**	**91%**	**82%**	**92%**

Table 7-40b. Percentage of Months that the **September-to-November** X2 Position Is Greater than **81 km** in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	87%	91%	91%	89%	81%	91%
	2040-2069	83%	92%	91%	81%	71%	87%
	2070-2099	78%	84%	94%	82%	68%	83%
	2015-2099	**82%**	**89%**	**92%**	**84%**	**73%**	**87%**
Least Cost Portfolio	2015-2039	85%	85%	88%	81%	76%	92%
	2040-2069	78%	92%	92%	74%	59%	84%
	2070-2099	71%	82%	82%	69%	54%	81%
	2015-2099	**78%**	**87%**	**87%**	**75%**	**62%**	**85%**
Regional Self-Reliance Portfolio	2015-2039	84%	92%	95%	83%	76%	91%
	2040-2069	69%	92%	97%	68%	56%	82%
	2070-2099	62%	83%	93%	56%	50%	84%
	2015-2099	**71%**	**89%**	**95%**	**68%**	**60%**	**85%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	85%	93%	89%	91%	84%	93%
	2040-2069	86%	92%	89%	80%	73%	89%
	2070-2099	79%	91%	96%	73%	66%	86%
	2015-2099	**83%**	**92%**	**91%**	**81%**	**74%**	**89%**
Delta Conveyance and Restoration Portfolio	2015-2039	81%	81%	83%	85%	76%	77%
	2040-2069	84%	86%	83%	80%	71%	83%
	2070-2099	73%	78%	86%	76%	67%	79%
	2015-2099	**80%**	**82%**	**84%**	**80%**	**71%**	**80%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	85%	81%	84%	88%	79%	87%
	2040-2069	78%	83%	76%	83%	73%	86%
	2070-2099	64%	77%	89%	73%	64%	82%
	2015-2099	**75%**	**80%**	**83%**	**81%**	**72%**	**85%**
Flexible System Operations and Mgmt Portfolio	2015-2039	85%	91%	92%	85%	75%	87%
	2040-2069	87%	93%	93%	79%	76%	87%
	2070-2099	80%	84%	96%	79%	60%	82%
	2015-2099	**84%**	**89%**	**94%**	**81%**	**70%**	**85%**
Water Action Plan Portfolio	2015-2039	80%	79%	79%	80%	75%	85%
	2040-2069	76%	90%	77%	72%	57%	84%
	2070-2099	60%	73%	86%	67%	47%	82%
	2015-2099	**71%**	**81%**	**80%**	**73%**	**58%**	**84%**

7.8.4.3. Frequency of Reverse Flows in the Old and Middle Rivers

7.8.4.3.1. For Delta Smelt:-3,500 cfs OMR Reverse Flows from March through June

The entrainment of Delta smelt in the south Delta channels leading to the Banks and Jones pumping plants is negatively correlated with the frequency of reverse Old and Middle River channels of the San Joaquin River (OMR) flows greater than -3,500 cfs. More negative flows result in greater amounts of Delta smelt entrainment and loss. See Section 5.2.8.4.3.1. *For Delta Smelt:-3,500 cfs OMR Reverse Flows from March through June*.

The Least Cost, Delta Conveyance and Restoration, Expanded Water Storage and Groundwater and Water Action Plan portfolios all provide significant improvements in OMR flows. No portfolios result in a significant reduction in benefit. With the central tendency climate scenario from 2015-2099, the change in this indicator from the No Action alternative is:

The percentage change in in average annual GHG offset for the CVP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-17%
- Regional Self-Reliance portfolio:-1%
- Healthy Headwaters and Tributaries portfolio: +0%
- Conveyance and Restoration portfolio:-29%
- Expanded Water Storage and Groundwater portfolio:-15%
- Flexible System Operations and Management portfolio: +1%
- Water Action Plan portfolio:-17%

Table 7-41 shows the percentage of months from March through June that OMR flow is less (more negative) than-3,500 cfs under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-41.March – June OMR-3,500 cfs: Adaptation Portfolio Comparison

Percentage of Months in Each Portfolio that March-through-June OMR Flow is Less (more negative) than 3,500 cfs in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	30%	18%	16%	32%	33%	27%
	2040-2069	41%	37%	33%	40%	42%	42%
	2070-2099	33%	23%	23%	38%	34%	33%
	2015-2099	**35%**	**26%**	**24%**	**37%**	**36%**	**34%**
Least Cost Portfolio	2015-2039	16%	5%	7%	18%	13%	14%
	2040-2069	12%	21%	20%	19%	12%	20%
	2070-2099	11%	13%	11%	16%	15%	17%
	2015-2099	**13%**	**13%**	**13%**	**18%**	**13%**	**17%**
Regional Self-Reliance Portfolio	2015-2039	31%	17%	15%	25%	32%	26%
	2040-2069	40%	37%	33%	36%	41%	40%
	2070-2099	32%	22%	22%	33%	34%	33%
	2015-2099	**34%**	**26%**	**24%**	**31%**	**36%**	**33%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	31%	18%	17%	25%	32%	29%
	2040-2069	43%	36%	32%	37%	40%	42%
	2070-2099	30%	25%	23%	33%	34%	31%
	2015-2099	**35%**	**27%**	**24%**	**32%**	**36%**	**34%**
Delta Conveyance and Restoration Portfolio	2015-2039	3%	1%	1%	5%	4%	4%
	2040-2069	6%	4%	2%	13%	7%	7%
	2070-2099	6%	3%	2%	8%	9%	3%
	2015-2099	**5%**	**3%**	**1%**	**9%**	**7%**	**5%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	14%	6%	7%	12%	14%	16%
	2040-2069	17%	20%	12%	18%	13%	20%
	2070-2099	17%	12%	10%	13%	15%	19%
	2015-2099	**16%**	**13%**	**10%**	**14%**	**14%**	**19%**
Flexible System Operations and Mgmt Portfolio	2015-2039	32%	20%	16%	30%	31%	30%
	2040-2069	40%	36%	33%	41%	44%	42%
	2070-2099	32%	23%	23%	37%	33%	33%
	2015-2099	**35%**	**27%**	**25%**	**36%**	**36%**	**35%**
Water Action Plan Portfolio	2015-2039	14%	6%	7%	16%	12%	16%
	2040-2069	11%	19%	20%	20%	13%	19%
	2070-2099	10%	10%	10%	17%	16%	17%
	2015-2099	**11%**	**12%**	**13%**	**18%**	**14%**	**17%**

7.8.4.3.2. For Adult San Joaquin Salmonid Migration:-5,000 cfs OMR Reverse Flows from October through December

Adult salmon migration is included in the ESA Species resource category. Increased entrainment of adult salmonids migrating to spawning habitat in the San Joaquin River watershed is highly correlated with the frequency of flows more negative than-5,000 cfs in these channels during the months of October through December. 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. See Section 5.2.8.5.2. *For Adult San Joaquin Salmonid Migration:-5,000 cfs OMR Reverse Flows from October through December.*

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

No portfolios result in a significantly more reverse flows. With the central tendency climate scenario from 2015-2099, the change in this indicator from the No Action alternative is:

The percentage change in in average annual GHG offset for the CVP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios is:

- Least Cost portfolio:-54%
- Regional Self-Reliance portfolio: +2%
- Healthy Headwaters and Tributaries portfolio:-1%
- Delta Conveyance and Restoration portfolio:-53%
- Expanded Water Storage and Groundwater portfolio:-46%
- Flexible System Operations and Management portfolio: +1%
- Water Action Plan portfolio: 62%

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 7-28). 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 7-42 shows details of the performance of each of the portfolios relative to the No Action alternative in four climate scenarios.

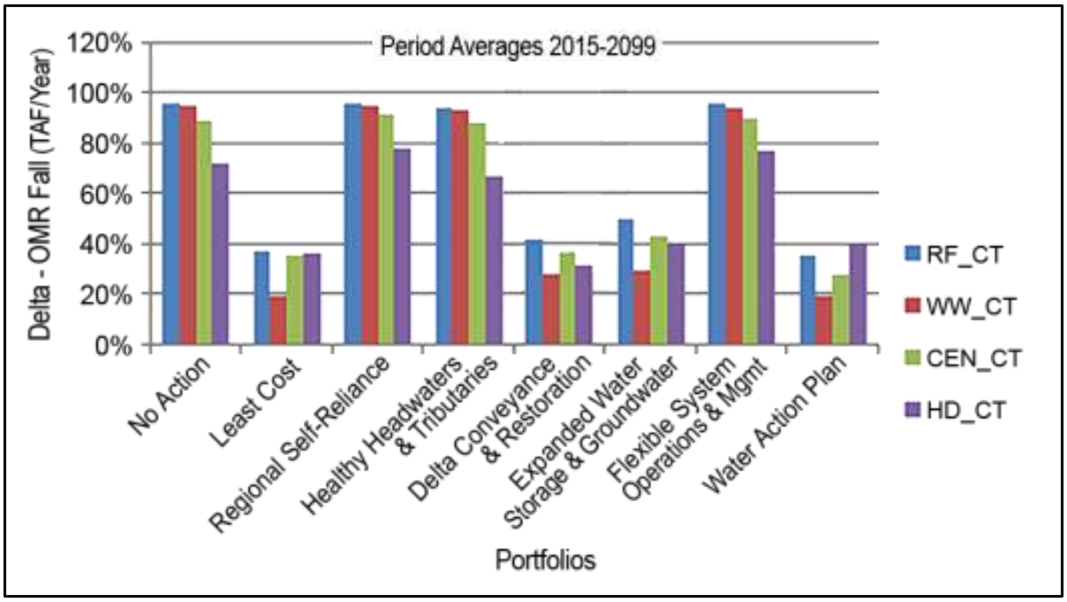

Figure 7-28. October-through-December OMR flow: adaptation portfolio performance

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 7-42. 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

Adaptation Portfolio Climate Sensitivity

Table 7-43 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 7-43. October-through-December OMR Flow: Climate Scenario

(% 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
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

Table 7-44 shows the percentage of months from October through December that OMR flow is less (more negative) than-5,000 cfs under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-44. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than -5,000 cfs in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	89%	85%	71%	89%	92%	85%
	2040-2069	100%	91%	77%	93%	98%	94%
	2070-2099	98%	82%	68%	91%	93%	87%
	2015-2099	**96%**	**86%**	**72%**	**91%**	**95%**	**89%**
Least Cost Portfolio	2015-2039	51%	55%	45%	35%	37%	59%
	2040-2069	29%	54%	42%	9%	19%	28%
	2070-2099	34%	44%	23%	3%	4%	21%
	2015-2099	**37%**	**51%**	**36%**	**15%**	**19%**	**35%**
Regional Self-Reliance Portfolio	2015-2039	91%	85%	76%	87%	95%	88%
	2040-2069	98%	96%	86%	98%	97%	97%
	2070-2099	98%	90%	71%	92%	94%	89%
	2015-2099	96%	91%	78%	93%	95%	91%
Healthy Headwaters and Tributaries Portfolio	2015-2039	85%	80%	67%	91%	93%	81%
	2040-2069	99%	89%	76%	96%	98%	94%
	2070-2099	97%	82%	60%	90%	89%	87%
	2015-2099	**94%**	**84%**	**67%**	**92%**	**93%**	**88%**
Delta Conveyance and Restoration Portfolio	2015-2039	45%	36%	43%	36%	40%	41%
	2040-2069	34%	52%	32%	24%	23%	38%
	2070-2099	44%	33%	19%	13%	20%	30%
	2015-2099	**41%**	**41%**	**31%**	**24%**	**27%**	**36%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	59%	49%	49%	60%	47%	53%
	2040-2069	49%	60%	43%	23%	19%	47%
	2070-2099	43%	51%	28%	17%	23%	30%
	2015-2099	**50%**	**54%**	**40%**	**32%**	**29%**	**43%**
Flexible System Operations and Mgmt Portfolio	2015-2039	89%	88%	79%	92%	92%	83%
	2040-2069	99%	96%	84%	92%	98%	97%
	2070-2099	98%	82%	69%	93%	91%	90%
	2015-2099	**96%**	**89%**	**77%**	**93%**	**94%**	**90%**
Water Action Plan Portfolio	2015-2039	55%	57%	53%	47%	47%	51%
	2040-2069	24%	58%	48%	3%	9%	21%
	2070-2099	29%	31%	21%	1%	6%	14%
	2015-2099	**35%**	**48%**	**40%**	**15%**	**19%**	**27%**

7.8.4.3.3. For Food Web Productivity:-5,000 cfs OMR Reverse Flows from July through September

The more frequent reverse flows above -5,000 cfs in the channels, the more food web productivity is affected.

See Section 5.2.8.46. *Delta Flows-Food Web Productivity:-5,000 cfs OMR Reverse Flows from July through September* for a discussion of impacts under the No Action alternative.

The Least Cost, Delta Conveyance and Restoration, Expanded Water Storage and Groundwater and Water Action Plan portfolios all provide significant improvements in OMR flows. The Regional Self-Reliance portfolio results in the most increase in reverse flows, impacting the food web. The percentage change in in average annual GHG offset for the CVP system from the No Action alternative from 2015-2099 in the Central Tendency climate/Current Trends socioeconomic scenarios ranges from:

- Least Cost portfolio:-55%
- Regional Self-Reliance portfolio: +18%
- Healthy Headwaters and Tributaries portfolio:-4%
- Delta Conveyance and Restoration portfolio:-59%
- Expanded Water Storage and Groundwater portfolio:-52%
- Flexible System Operations and Management portfolio: +7%
- Water Action Plan portfolio:-54%

Table 7-45 shows the percentage of months from July through September that OMR flow is less (more negative) than-5,000 cfs under the Current Trends socioeconomic scenario in the Reference-No-Climate-Change and ensemble climate scenarios for the No Action alternative and adaptation portfolios.

Table 7-45. Percentage of Months that July-through-September OMR Flow Is Less (more negative) than-5,000 cfs in the Reference-No-Climate-Change and Ensemble Scenarios for the Current Trends Socioeconomic Scenario for Each Adaptation Portfolio

Location	Period	Reference-CT	Warm-Dry-CT	Hot-Dry-CT	Hot-Wet-CT	Warm-Wet-CT	Central-CT
No Action alternative	2015-2039	64%	45%	41%	69%	72%	60%
	2040-2069	88%	64%	47%	89%	91%	82%
	2070-2099	72%	52%	43%	80%	88%	61%
	2015-2099	**75%**	**55%**	**44%**	**80%**	**84%**	**68%**
Least Cost Portfolio	2015-2039	13%	12%	11%	19%	15%	20%
	2040-2069	7%	19%	11%	8%	8%	11%
	2070-2099	11%	12%	7%	6%	3%	9%
	2015-2099	**10%**	**15%**	**9%**	**10%**	**8%**	**13%**
Regional Self-Reliance Portfolio	2015-2039	68%	60%	55%	80%	83%	73%
	2040-2069	94%	87%	68%	97%	99%	94%
	2070-2099	90%	74%	67%	97%	97%	88%
	2015-2099	**85%**	**75%**	**64%**	**92%**	**93%**	**86%**
Healthy Headwaters and Tributaries Portfolio	2015-2039	57%	37%	28%	63%	69%	51%
	2040-2069	82%	54%	44%	90%	90%	79%
	2070-2099	68%	50%	46%	80%	89%	60%
	2015-2099	**70%**	**48%**	**40%**	**78%**	**84%**	**64%**
Delta Conveyance and Restoration Portfolio	2015-2039	16%	8%	7%	19%	13%	13%
	2040-2069	10%	3%	1%	13%	13%	11%
	2070-2099	9%	3%	4%	10%	9%	4%
	2015-2099	**11%**	**5%**	**4%**	**14%**	**12%**	**9%**
Expanded Water Storage and Groundwater Portfolio	2015-2039	20%	12%	9%	24%	17%	19%
	2040-2069	22%	8%	4%	17%	16%	23%
	2070-2099	12%	7%	6%	8%	9%	7%
	2015-2099	**18%**	**9%**	**6%**	**16%**	**14%**	**16%**
Flexible System Operations and Mgmt Portfolio	2015-2039	69%	59%	55%	75%	79%	65%
	2040-2069	89%	74%	71%	93%	92%	87%
	2070-2099	74%	66%	53%	90%	91%	71%
	2015-2099	**78%**	**67%**	**60%**	**87%**	**88%**	**75%**
Water Action Plan Portfolio	2015-2039	20%	20%	16%	20%	16%	20%
	2040-2069	11%	18%	10%	6%	8%	16%
	2070-2099	10%	16%	11%	3%	3%	8%
	2015-2099	**13%**	**18%**	**12%**	**9%**	**9%**	**14%**

7.9. Summary of Portfolio Results

Based on the evaluations presented above for each of the metrics, several summary observations about the performances of the portfolios can be made:

- All of the portfolios considered in this Basins Study reduce Central Valley unmet demand. The Water Action Plan, Least Cost, and Regional Self-Reliance portfolios reduce the unmet demands by nearly half, but cannot fully eliminate the unmet demands in the San Joaquin and Tulare Lake Basins.

- The portfolios take different approaches toward addressing the reliability challenges in the Basins. Delta exports are substantially increased in the Least Cost, Expanded Water Storage, and Water Action Plan portfolios as these include significant conveyance and storage actions. Increases in local alternative water supplies in the Regional Self-Reliance portfolio, results in reduced export demand and thus lower simulated exports. The Healthy Headwaters and Tributaries portfolio results in significantly lower exports as higher river flows in the spring result in increased outflow.

- Portfolios that include substantial demand reductions as part of water use efficiency actions (e.g., such as Least Cost, Regional Self-Reliance, Water Action Plan, and Flexible System Operations) improve reservoir storage conditions. Shasta end-of-September storage below 1.9 MAF is reduced to less than 5% of the years in the Least Cost portfolio as compared to nearly 14% of the years in the No Action portfolio.

- While the spring delta pelagic habitat will certainly be altered due to climate change, most portfolios do not substantially change the condition beyond the No Action. However, Healthy Headwaters and Tributaries, Regional Self-Reliance, and Water Action Plan portfolios show small improvements in this metric, partially attenuating the changes due to future climate and sea level changes.

To understand how well an adaptation portfolio might improve or worsen conditions for a particular resource category under a particular climate-socioeconomic scenario, Figure 7-29 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.[20]

- 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 7-29 in a decision making context. The first column in in Figure 7-29 compares the impacts under No Action 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 addresses this impact in a significant way. 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.)

It is important to remember that these results do depend on the criteria used for the groupings and on the climate-socioeconomic scenario employed in the analysis. Therefore, it would be essential to clearly define such factors in greater detail through a collaborative process that engages with stakeholders across the range of resource categories prior to making any decision about implementation of any of the portfolios.

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

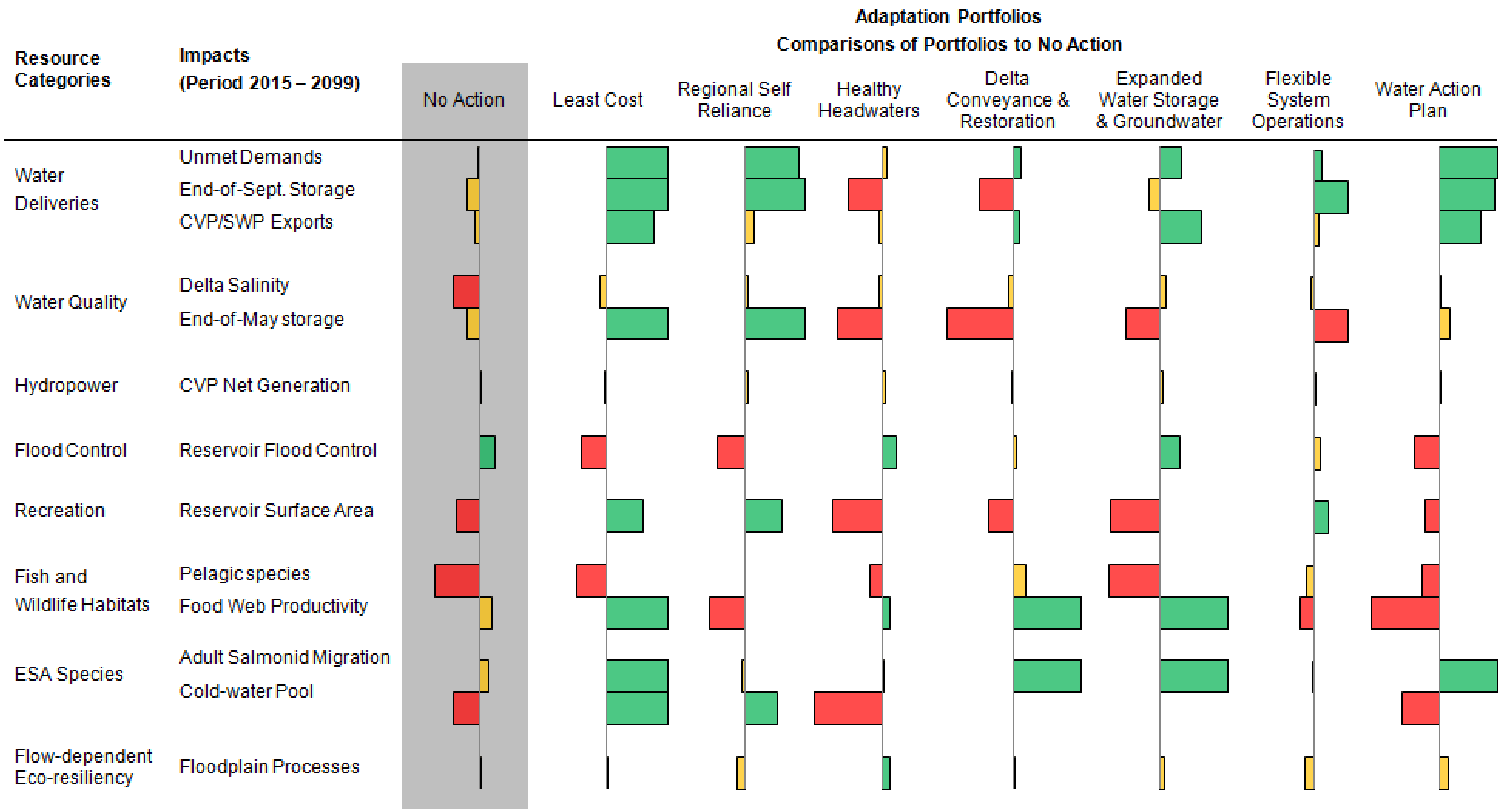

Figure 7-29. Summary Comparisons of Adaptation Portfolios to the No Action Alternative.

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