RECLAMATION

*Managing Water in the West*

## Technical Appendix

# Sacramento and San Joaquin Basins Climate Impact Assessment

U.S. Department of the Interior
Bureau of Reclamation

October 2014

# Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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.

## Technical Appendix

# Sacramento and San Joaquin Basins Climate Impact Assessment

Prepared for Reclamation by CH2M HILL under
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**Bureau of Reclamation**

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# Abbreviations and Acronyms

| | |
|---|---|
| °C | degrees Centigrade |
| °F | degrees Fahrenheit |
| µS/cm | microSiemens per centimeter |
| AET | actual evapotranspiration |
| AMJ | April, May, and June |
| AMO | Atlantic Multi-decadal Oscillation |
| ANN | artificial neural network |
| AR4 | Fourth Assessment Report (IPCC's 2007 Climate Change 2007: The Physical Science Basis) |
| Banks PP | Harvey O. Banks Pumping Plant |
| Bay-Delta | San Francisco Bay–Sacramento-San Joaquin Delta Commission |
| BDCP | Bay Delta Conservation Plan |
| BiOp | biological opinion |
| CAT | California Climate Action Team |
| CCSM | Community Climate System Model |
| CDEC | California Data Exchange Center |
| CDF | cumulative distribution function |
| cfs | cubic feet per second |
| cm | centimeter |
| CMIP3 | Coupled Model Intercomparison Project Phase 3 |
| CMIP5 | Coupled Model Intercomparison Project Phase 5 |
| CNRM | National Centre for Meteorological Research (transposition from French) |
| CO2 | carbon dioxide |
| CT | Current Trends |
| CT_noCC | Current Trends NoCC |
| CT_Q5 | Current Trends – central tendency |
| CVP | Central Valley Project |
| CVP IRP | Central Valley Project Integrated Resource Plan |
| CVP IRP CalLite | CVP IRP Central Valley Water Management Screening Model |
| CWP | California Water Plan Update 2009 |
| D1641 | Decision 1641 |
| Delta | Sacramento-San Joaquin Delta |
| DOF | California Department of Finance |
| DRMS | Delta Risk Management Strategy |

| | |
|---|---|
| DWR | California Department of Water Resources |
| EC | electroconductivity |
| EG | Expansive Growth |
| EG-Q2 | Expansive Growth – warmer and drier |
| EI5 | five ensemble-informed |
| ENSO | El Nino Southern Oscillation |
| ET | evapotranspiration |
| GCM | global climate model |
| GHG | greenhouse gas |
| GWh/year | gigawatt hours per year |
| Impact Assessment | West-wide Climate Risk Assessment for the Sacramento and San Joaquin Basins |
| IPCC | Intergovernmental Panel on Climate Change |
| JAS | July-August-September |
| JFM | January-February-March |
| Jones PP | C. W. Jones Pumping Plant |
| km | kilometer |
| MAF | million acre-feet |
| MPI | Max Planck Institute for Meteorology |
| $mTCO_2e$ | metric tons of CO2 equivalents |
| $mTCO_2e$/GWH | metric tons of CO2 equivalents per gigawatt hour |
| NCAR | National Center for Atmospheric Research |
| NOAA | National Oceanographic and Atmospheric Administration |
| NoCC | No Climate Change scenario |
| NRC | National Research Council |
| OMR | Old and Middle Rivers |
| OND | October-November-December |
| PCM | Parallel Climate Model |
| PDO | Pacific Decadal Oscillation |
| Q1 | drier, less warming |
| Q2 | drier, more warming |
| Q3 | wetter, more warming |
| Q4 | wetter, less warming |
| Q5 | ensemble median |

| | |
|---|---|
| Reclamation | Bureau of Reclamation |
| SG | Slow Growth |
| SG-Q4 | Slow Growth – less warming and wetter |
| SRES | Special Report on Emission Scenarios |
| SSJBS | Sacramento and San Joaquin Basins Study |
| SWE | snow water equivalent |
| SWP | State Water Project |
| SWRCB | State Water Resources Control Board |
| TAF | thousand acre-feet |
| TAF/year | thousand acre-feet per year |
| USACE | U.S. Army Corps of Engineers |
| USFWS | U.S. Fish and Wildlife Service |
| VIC | Variable Infiltration Capacity |
| WCRP | World Climate Research Program |
| WEAP-CV | Water Evaluation and Planning model of the Central Valley |
| WWCRA | West-wide Climate Risk Assessment |
| X2 | 2 parts per thousand salinity concentration |

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# Preface

This Technical Appendix to the Sacramento and San Joaquin Basins Climate Impact Assessment provides greater detail regarding the technical approach employed including assumptions, methodologies and results which were not presented in the Impact Assessment report. This appendix is not a stand-alone document. For information related to the purpose of study, objectives of the analyses as well as other relevant background information, the reader should refer to the Sacramento and San Joaquin Basins Climate Impact Assessment report. Figure 1 below presents the geographic area which is addressed in the Sacramento and San Joaquin Basins Climate Impact Assessment.

Figure P-1. Impact Assessment Study Area

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# 1.0 Technical Approach

The technical approach employed in this SSJIA 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) and include assumptions about the effects of urban growth on agricultural lands. These socioeconomic projections are embedded in the 2009 California Water Plan. Additional information related to how the socioeconomic and climate projections were developed is provided in Chapter 5 of this report.

The modeling approach and tools employed in the SSJIA are shown on Figure 1-1 below. The modeling approach and tools were developed as part of CVP IRP, 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)[1].

In the Critical Uncertainties and Scenario Development task (left side of figure), a current trends socioeconomic projection was combined with multiple GCM-based climate projections to form 18 future scenarios representing a wide range of potential 21st century socioeconomic-climate uncertainties. The scenarios were developed using data from climate projections used in the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report (AR4) (IPCC 2007) and the World Climate Research Program's (WCRP) CMIP3.

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[1] The CVP IRP report can be downloaded from the SSJBS website at http://www.usbr.gov/mp/SSJBasinStudy/documents.html

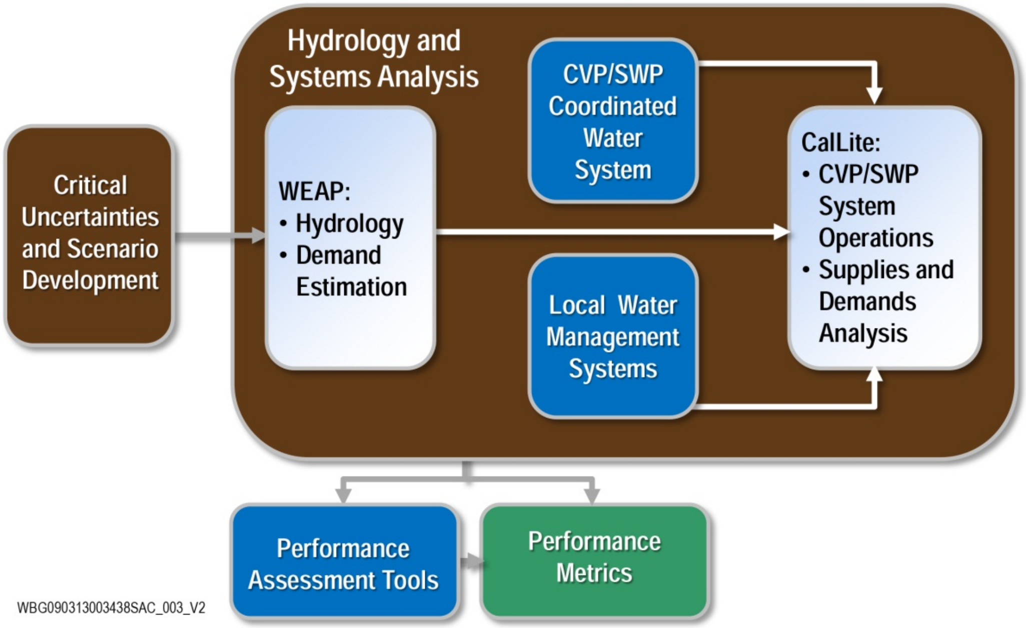


Figure 1-1. Impact Assessment Technical Approach

The socioeconomic-climate scenarios developed for the SSJIA were used as inputs to the Water Evaluation and Planning model of the Central Valley (WEAP-CV) 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 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 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 final 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. More detailed descriptions of the technical approach and assessment results are provided in the following sections for each resource category.

# 2.0 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 water supplies. Changes in temperature and 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 (Reclamation 2013); 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

A scenario planning process was used to guide the development of scenarios for providing a broad range of projections of future water supply and demand. Each scenario reflects factors related to a particular socioeconomic future and a particular climate future, resulting in eighteen 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

Scenarios are not predictions or forecasts of the future. Rather, 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.

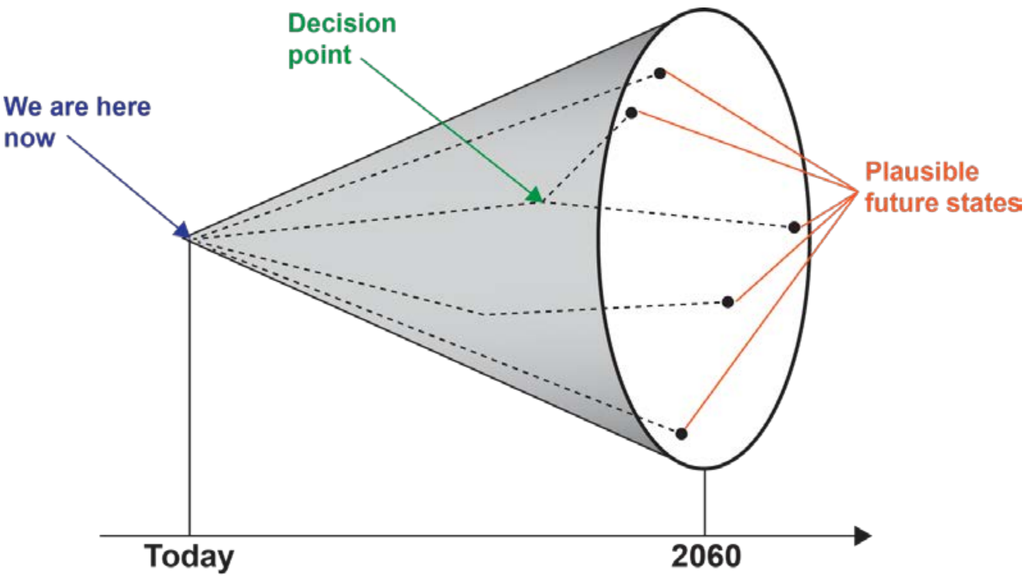


Figure 2-1. Conceptual Representation of the Uncertain Future of a System, also Known as “The Scenario Funnel” Adapted from Timpe and Scheepers 2003

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 Scenario Summary

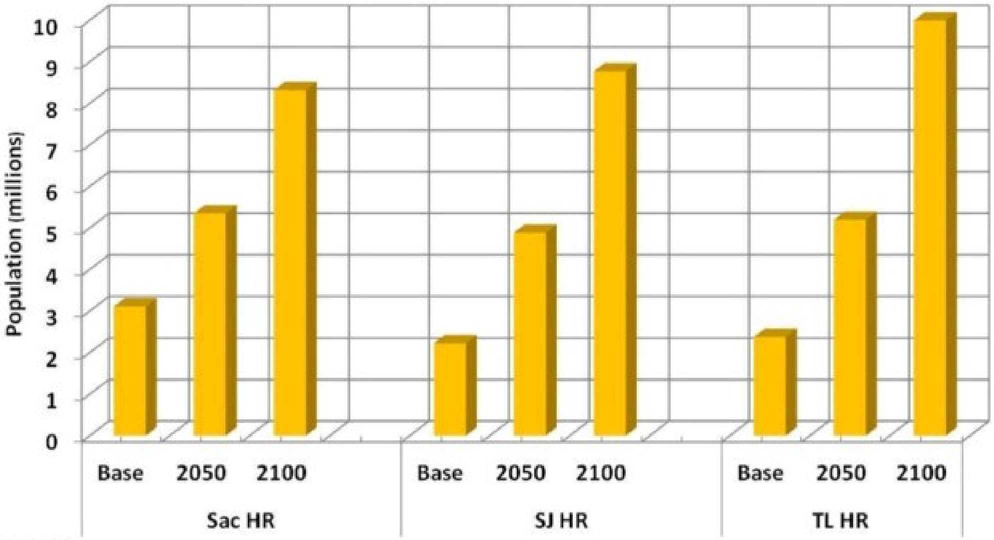
To account for a range of uncertainty in future conditions, a suite of scenarios was developed to reflect a range of future conditions.  Each of these scenarios reflected a combination of a socioeconomic future and a climate future.

Eighteen future scenarios were developed, each of which was analyzed for the period from October 2011 to September 2099 using a transient approach in which the climate and socioeconomic factors gradually change as the simulation moves through time. The following sections describe the socioeconomic and climate futures that were used for each future scenario for the Impact Assessment.

### *Socioeconomic Futures*

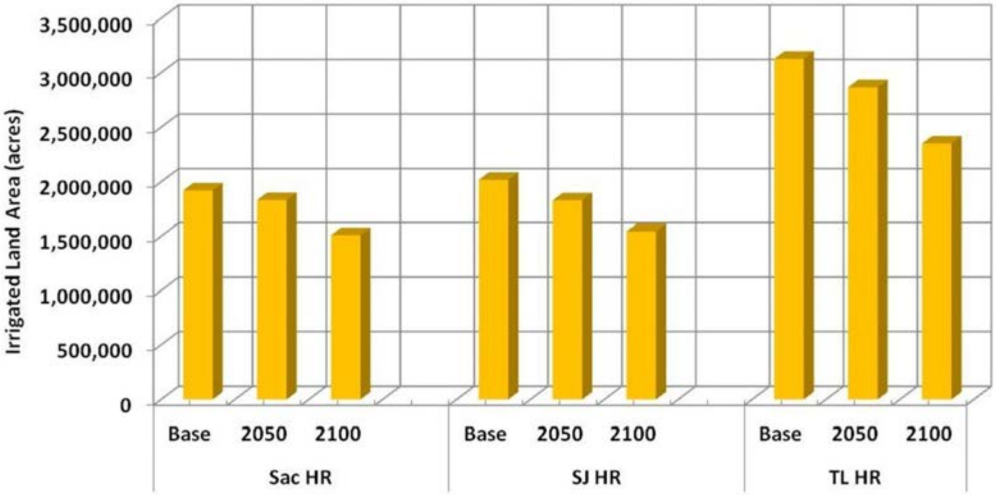
Because the focus of this report is on climate impact assessment, only a Current Trends (CT) projection of future socioeconomic conditions was used to represent changes in population and land use during the 21st century. This scenario was based on information developed by the California Water Plan Update 2009 (CWP) (DWR, 2009) and the CVP IRP. The CT projection was selected for use in the SSJIA because it represented an estimate of central tendency of future socioeconomic conditions which in combination with the 18 climate projections used, provided a reasonably wide range of future socioeconomic-climate uncertainties.

Figures 2-2 and 2-3 show the CT population and irrigated land projections for the Sacramento, San Joaquin and Tulare Lake hydrologic basins in the years 2005 (Base), 2050 and 2100. For the CT projection, the CWP and CVP IRP developed projections for each California county by using data from 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). 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.



Notes:
Sac HR = Sacramento Hydrologic Region
SJ HR = San Joaquin Hydrologic Region
TL HR = Tulare Lake Hydrologic Region

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



Notes: Sac HR = Sacramento Hydrologic Region
SJ HR = San Joaquin Hydrologic Region
TL HR = Tulare Lake Hydrologic Region

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

### *Climate Futures*

A total of 18 climate projections were used to characterize a wide range of future hydroclimate uncertainties. The following projections were included in the SSJIA:

- No Climate Change (NoCC) Scenario, which included simulations of hydroclimatic conditions under historical climate.
- Future Climate – Ensemble-Informed (EI) Scenario utilized five ensemble-informed (EI5) scenarios that were developed by the CVP IRP based on downscaled GCM projections.
- Future Climate – Downscaled Climate Projections utilized the 12 specific GCM projections identified by the State of California's Climate Action Team (CAT) for use in climate studies performed by DWR for the CWP (i.e., 12 CAT Scenarios).

Table 2-1 summarizes the 18 climate scenarios: one reflecting no climate change (NoCC), 5 EI scenarios (Q1 through Q5) and 12 CAT scenarios. For each scenario, temperature and precipitation projections were developed for the period from 2011 through 2099. The methods used to develop each climate scenario are described below.

Table 2-1. Climate Scenarios Used in the Impact Assessment

| Scenario | Description | Emmission Scenarios |
|---|---|---|
| NoCC | No Climate Change | Not applicable |
| Q1 | Drier and less warming | Derived from mixtures of SRES A1B, A2, and B1 |
| Q2 | Drier and more warming | Derived from mixtures of SRES A1B, A2, and B1 |
| Q3 | Wetter and more warming | Derived from mixtures of SRES A1B, A2, and B1 |
| Q4 | Wetter and less warming | Derived from mixtures of SRES A1B, A2, and B1 |
| Q5 | Central tending climate scenario | Derived from mixtures of SRES A1B, A2, and B1 |
| A2_cnrmcm3 | Climate simulation derived from CNRM-CM3 | SRES A2 |
| A2_gfdlcm21 | Climate simulation derived from GFDL-CM2.1 | SRES A2 |
| A2_miroc32med | Climate simulation derived from MIROC3.2 (medium resolution) | SRES A2 |
| A2_mpiecham5 | Climate simulation derived from ECHAM5/ MPI-OM | SRES A2 |
| A2_ncarccsm3 | Climate simulation derived from CCSM3 GCM | SRES A2 |
| A2_ncarpcm1 | Climate simulation derived from PCM | SRES A2 |
| B1_cnrmcm3 | Climate simulation derived from CNRM-CM3 | SRES B1 |
| B1_gfdlcm21 | Climate simulation derived from GFDL-CM2.1 | SRES B1 |

| Scenario | Description | Emmission Scenarios |
|---|---|---|
| B1_miroc32med | Climate simulation derived from MIROC3.2 (medium resolution) | SRES B1 |
| B1_mpiecham5 | Climate simulation derived from ECHAM5/ MPI-OM | SRES B1 |
| B1_ncarccsm3 | Climate simulation derived from CCSM3 GCM | SRES B1 |
| B1_ncarpcm1 | Climate simulation derived from PCM | SRES B1 |

For each of these 18 scenarios, temperature and precipitation projections were developed for the future period of 2011 through 2099. The NoCC scenario was developed by using the unadjusted historical climate sequence from 1915 through 2003 (Hamlet and Lettenmaier 2005) to simulate the same future period as the other 17 climate projections.

The EI climate projections were developed from 112 GCM simulations which had been bias-corrected spatially downscaled (BCSD) by Reclamation and others (Maurer et al., 2007). Using statistical techniques, the wide range of future temperature and precipitation uncertainties expressed in the full ensemble of 112 projections were represented in EI5 projections. Details of the methodology can be found in Reclamation (2013). One of the five EI projections include a central tendency projection (Q5) that is based on the BCSD projections near the median of changes in temperature and precipitation. The remaining four EI projections are based on ensembles of BCSD projections that differ from the central tendency by being drier with less warming (Q1); drier with more warming (Q2); wetter with more warming (Q3); and wetter with less warming than Q5. In addition, atmospheric carbon dioxide concentrations for each of the five climate projections were computed from the IPCC (IPCC 2000) emission’s scenarios associated with the individual GCM projections included in the ensemble.

The 12 CAT scenarios were developed as part of a series of reports released by California’s CAT in 2009 that serve as a summary update of the latest climate change science and response options for decision makers in California (Cayan et al. 2008a, 2008b, and 2008c). This document included 12 CAT climate change scenarios (6 GCMs x 2 emission scenarios). The Special Report on Emission Scenarios (SRES) A2 (higher) and B1 (lower) emission scenarios was selected to represent a range of possible future global conditions (IPCC 2000). Approximately 80 percent of the range of emissions are between the A2 (higher emissions) and B1 (lower emissions). It should also be noted that the current GHG trajectory has been more closely following the A1F1 scenario.

The Six GCMs that were selected for use in the 2008–2009 update include:

- National Center for Atmospheric Research's (NCAR) Parallel Climate Model (PCM)
- National Oceanographic and Atmospheric Administration's (NOAA) GFDL version 2.1
- NCAR Community Climate System Model (CCSM)
- Max Planck Institute for Meteorology's (MPI) MPI ECHAM5
- MIROC 3.2 medium resolution model
- National Centre for Meteorological Research (CNRM) models used in the IPCC's AR4 and the WCRP's CMIP3

These GCM's were selected by the State's CAT 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 Nino Southern Oscillation. To bracket the range of future climatic uncertainties, high and low GHG emissions scenarios were simulated by each of the six models yielding the 12 CAT projections.

Figure 2-4 presents an example of projected temperatures and precipitations for each of the eighteen scenarios for a representative grid cell in the American River Basin. The observed historical temperature and precipitation (dashed line) is also shown for comparison. Figure 2-5 shows the transient projected temperature and precipitation departures over time for the EI5 scenarios.

All of the EI5 and CAT projections were consistent in the direction of the temperature change relative to the NoCC scenario, but varied in terms of climate sensitivity. Trends in the precipitation projections were less apparent because of naturally occurring decadal and multi-decadal precipitation variations.

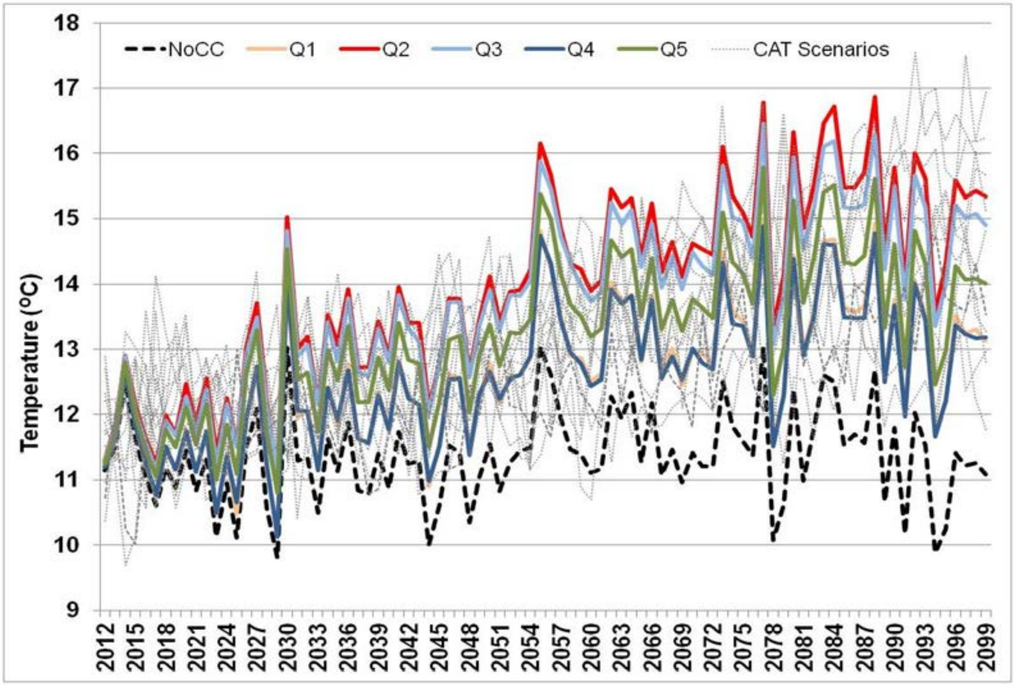


Figure 2-4a. Temperature Projections under Each Climate Scenario for a Representative Grid Cell in the American River Basin

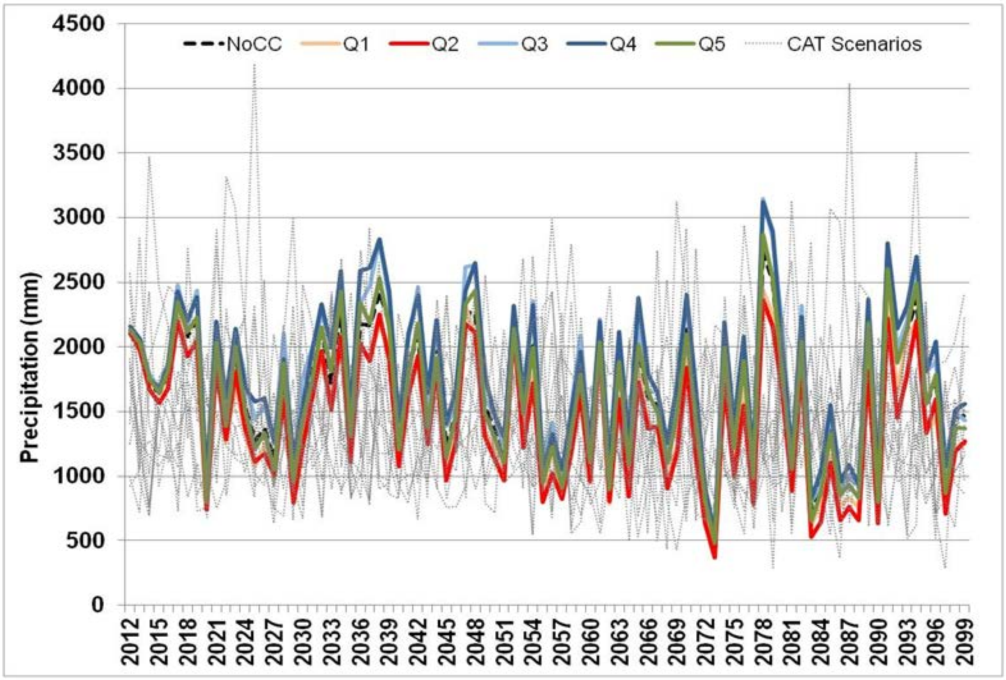


Figure 2-4b. Precipitation Projections under Each Climate Scenario for a Representative Grid Cell in the American River Basin

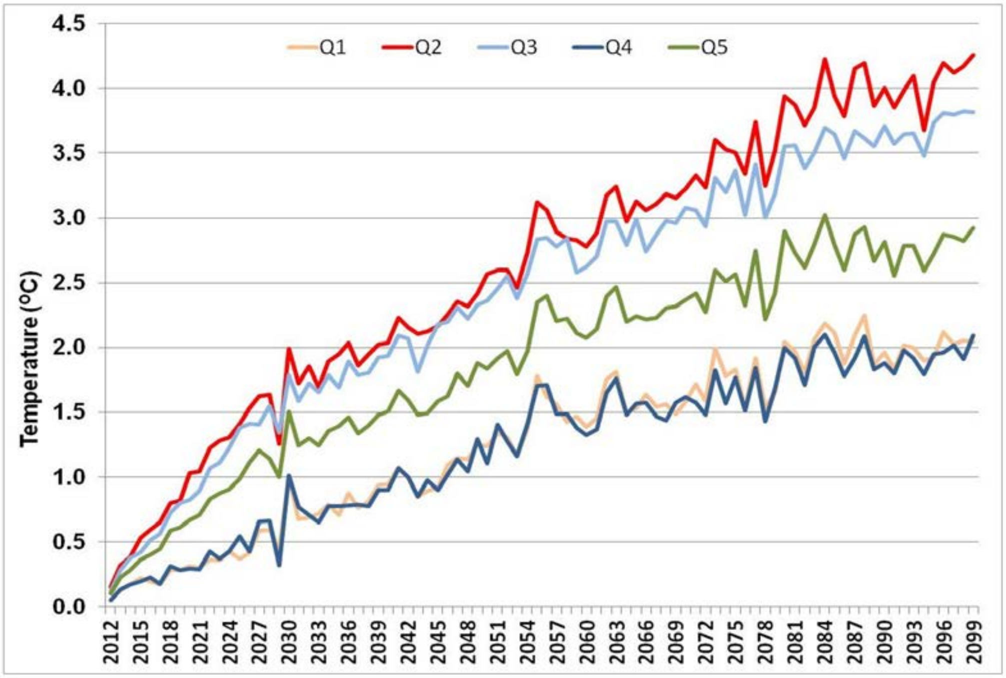


Figure 2-5a. Projected Changes in Temperature Ensemble-informed Transient Climate Scenarios for a Representative Grid Cell in the American River Basin (Example)

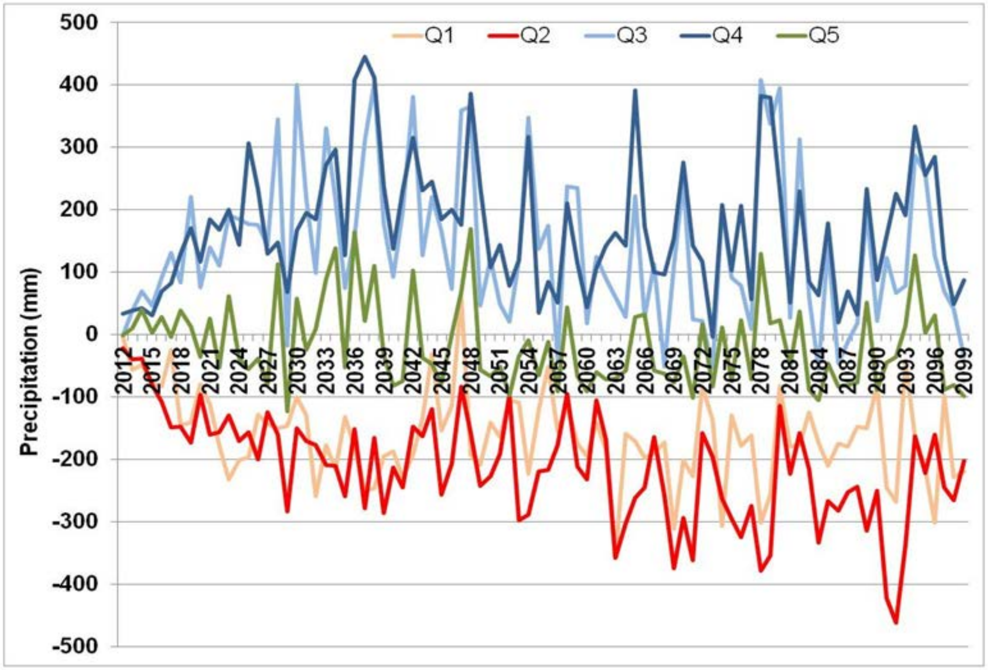


Figure 2-5b. Projected Changes in Precipitation Ensemble-informed Transient Climate Scenarios for a Representative Grid Cell in the American River Basin (Example)

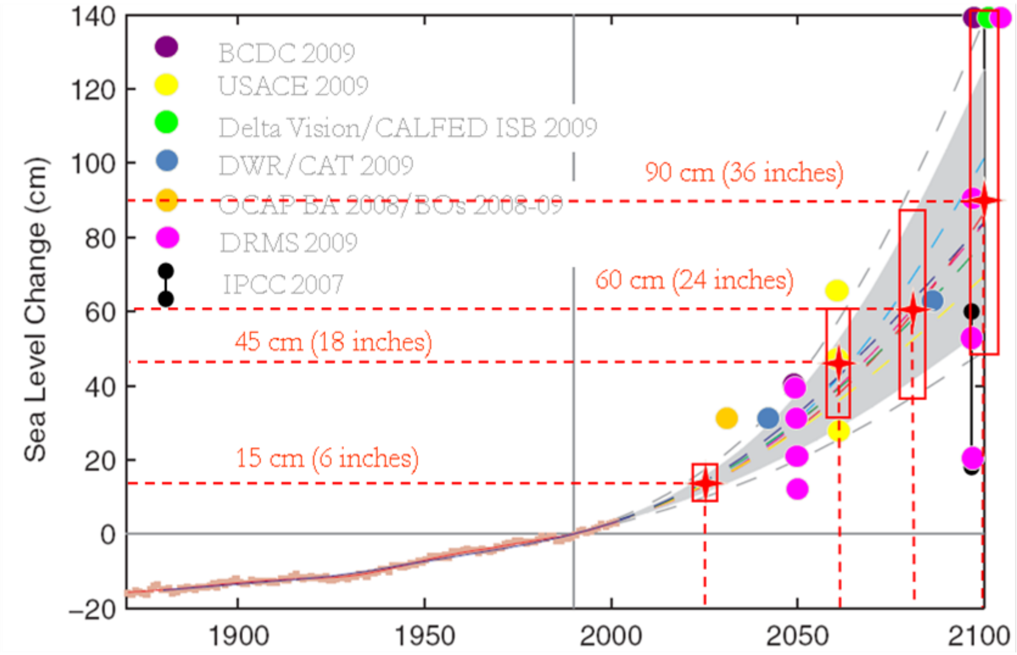
### *Sea Level Changes*

Global and regional sea levels have been increasing steadily over the past century and are expected to continue to increase throughout this century. 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 (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.

Other estimates by Rahmstorf (2007), Vermeer and Rahmstorf (2009), and others suggests that the sea level rise may be substantially greater than the IPCC projections. 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).

The CALFED Science Program, National Research Council (NRC), and others have made assessments of the range of potential future sea level rise throughout the twenty-first century (Healey 2007, 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. Figure 2-6 shows various projected ranges of potential sea level change in the Bay-Delta through the year 2100. Most State and federal planning processes in the Central Valley (such as the BDCP) 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.

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 (2007) and Vermeer and Rahmstorf (2009).



Note: Complete reference information for citations on this figure is provided in Section 9, References, Table 9-1.

Figure 2-6. Range of Future Mean Sea Level Based on Global Mean Temperature Projections and Sea Level Rise Values

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 CAT as guidance for incorporating sea level rise projections into planning and decision making for projects in California.

As part of the Impact Assessment 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 NRC report 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 2-2. The sea level rise by 2100 ranges between approximately 42 cm through 166 cm, with a mean of about 90 cm sea level rise.

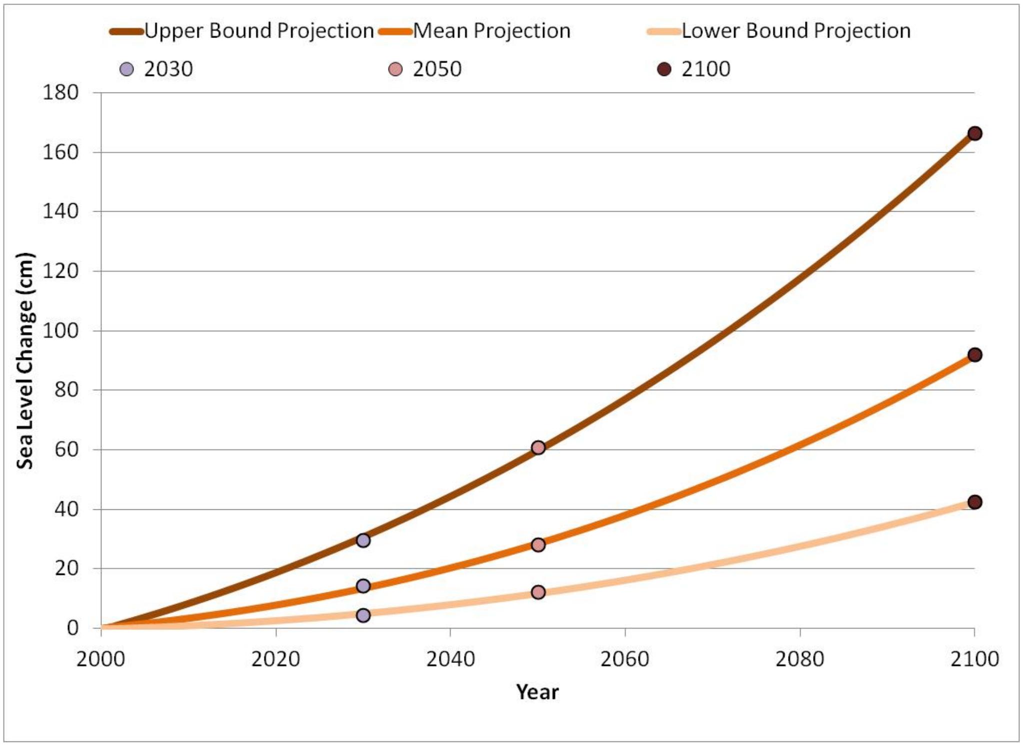
Table 2-2. Sea Level Rise Projections Relative to 2000 in San Francisco

| 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 |

These projections were fit to polynomial equations to obtain transient annual sea level rise projections over the period 2000 through 2100 (Figure 2-7). For the Impact Assessment, the mean sea level projection was employed in all the simulations.

In the Impact Assessment 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 CVP IRP CalLite 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 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.



Source: NRC 2012
Note: Mean projection is used in the Impact Assessment

Figure 2-7. Projected Sea Level Rise Values Based on the NRC Study

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# 3.0 Water Supply Assessment

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

## 3.1 Objective and Approach

The objective of the Water Supply Assessment was to characterize and quantify 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 had depletions and reservoir regulation 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 or SWE), and soil moisture. The climate teleconnection indicators included El Nino Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Atlantic Multi-decadal Oscillation (AMO) indices. Finally, streamflow indicators are natural flows at selected key locations in the Central Valley basins.

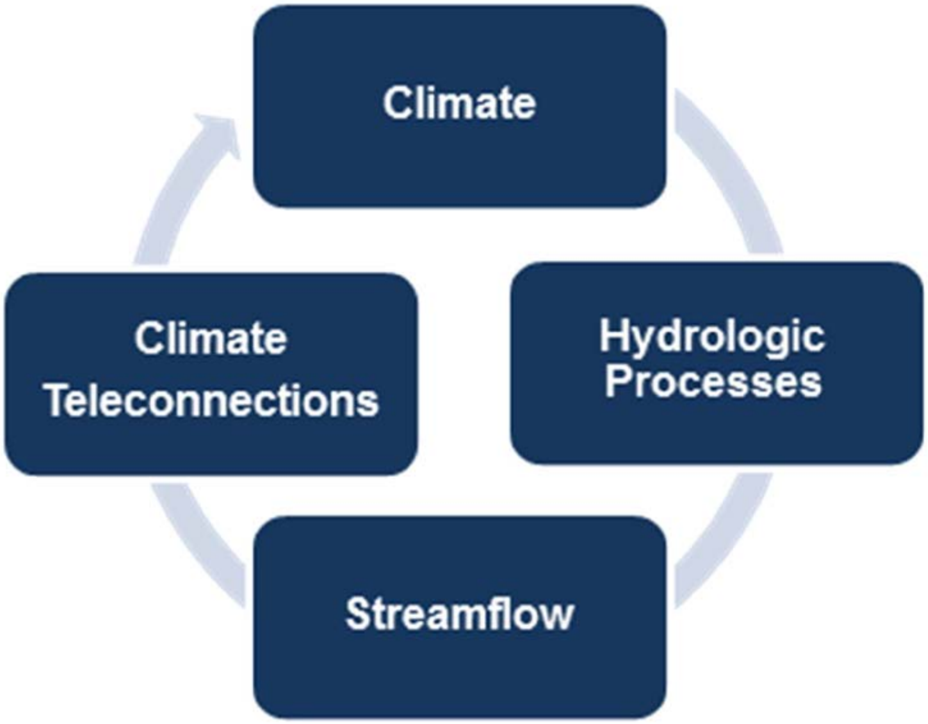


Figure 3-1. Types of Water Supply Indicators Used in the Study

### 3.1.1 Assessment of Historical Supply

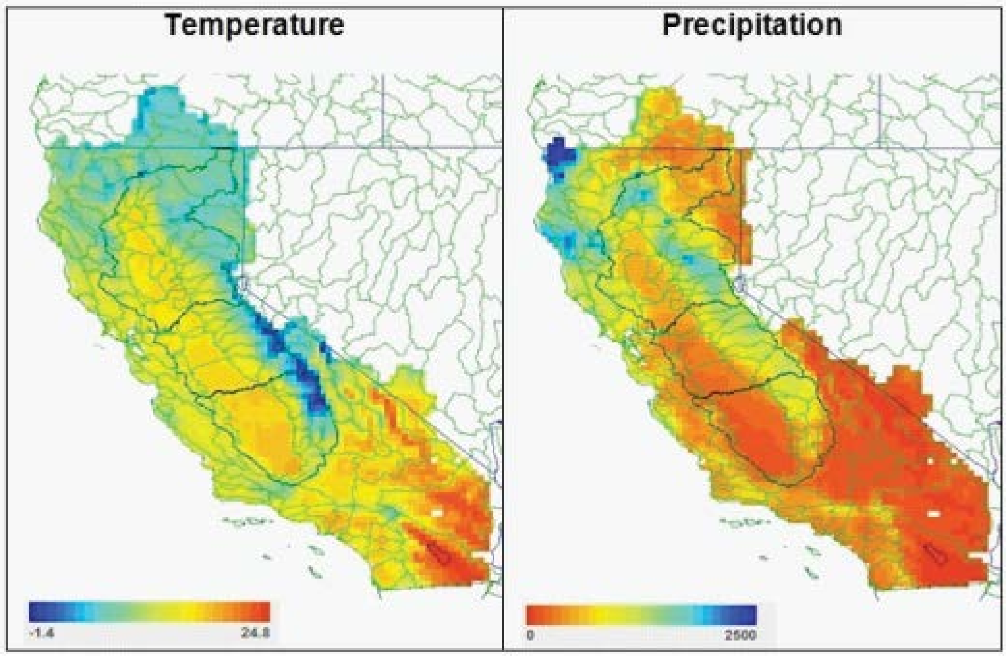
***Climate and Trends***

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 incorporates the longer historical time period represented in the Hamlet and Lettenmaier (2005) dataset. 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 has been defined as current climate normal by NOAA. 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).

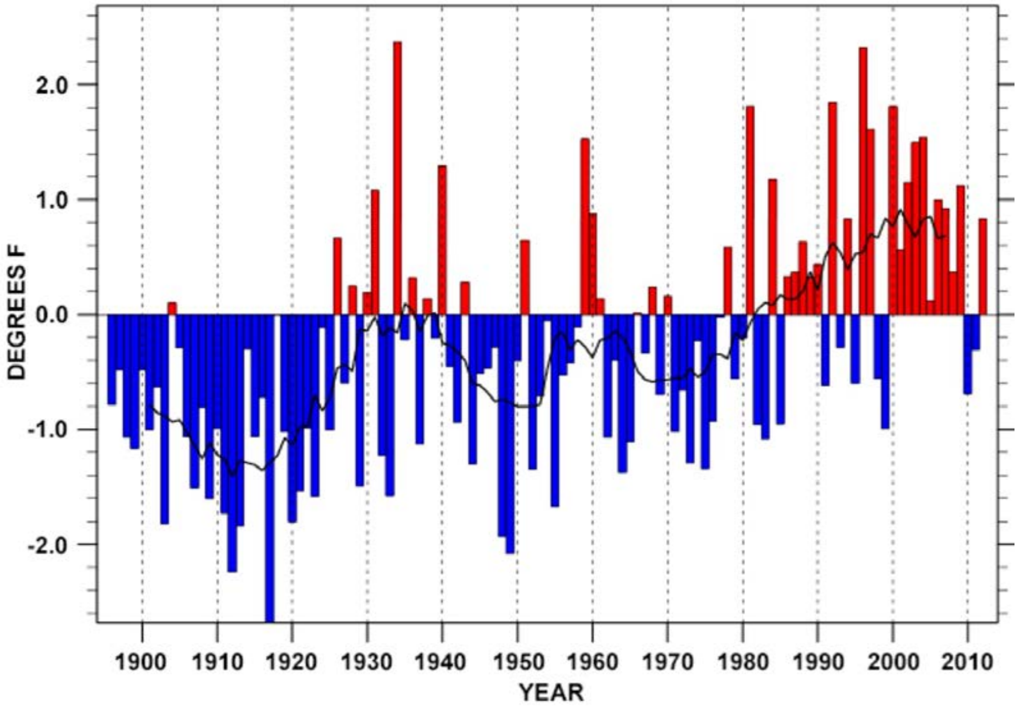
Precipitation in most of California is dominated by extreme variability, both spatially and temporally. The northern part of the Central Valley receives greater precipitation than the semi-desert southern part (Figure 3-2). Average temperatures vary considerably by location and elevation. Warmest temperatures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



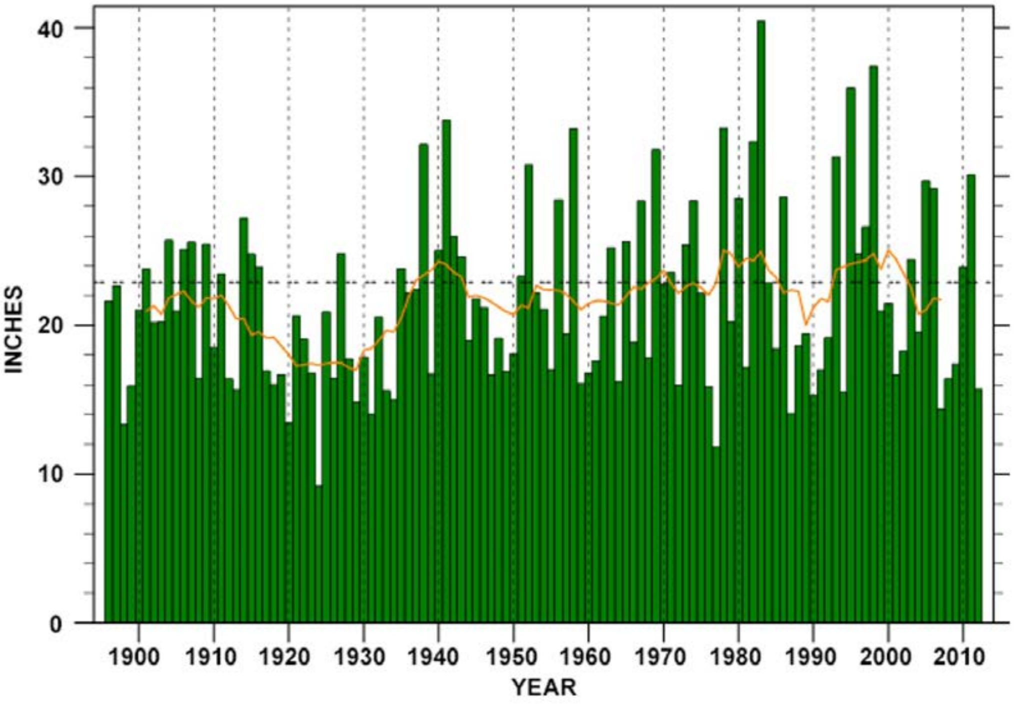
Source: Derived from Livneh et al., 2013

Figure 3-2. Average Annual Temperature (°C) and Average Annual Precipitation for 1981 to 2010 (in millimeters)

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 1985, 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 is likely a response to the increases in greenhouse gas (GHG) during this time.



Notes: Departure of annual water year average surface air temperature, 1896-2012. Bars: annual values; solid curve: 11-year running mean. Source: Western Regional Climate Center 2013



Notes: Annual water year average precipitation for the entire state. Departure for temperature is computed for 1949-2005. Bars: annual values; solid curve: 11-year running mean. Source: Western Regional Climate Center 2013

Figure 3-3. California Statewide Mean Temperature Departure (Oct-Sep) (top) and California Statewide Precipitation (Oct-Sep) (bottom)

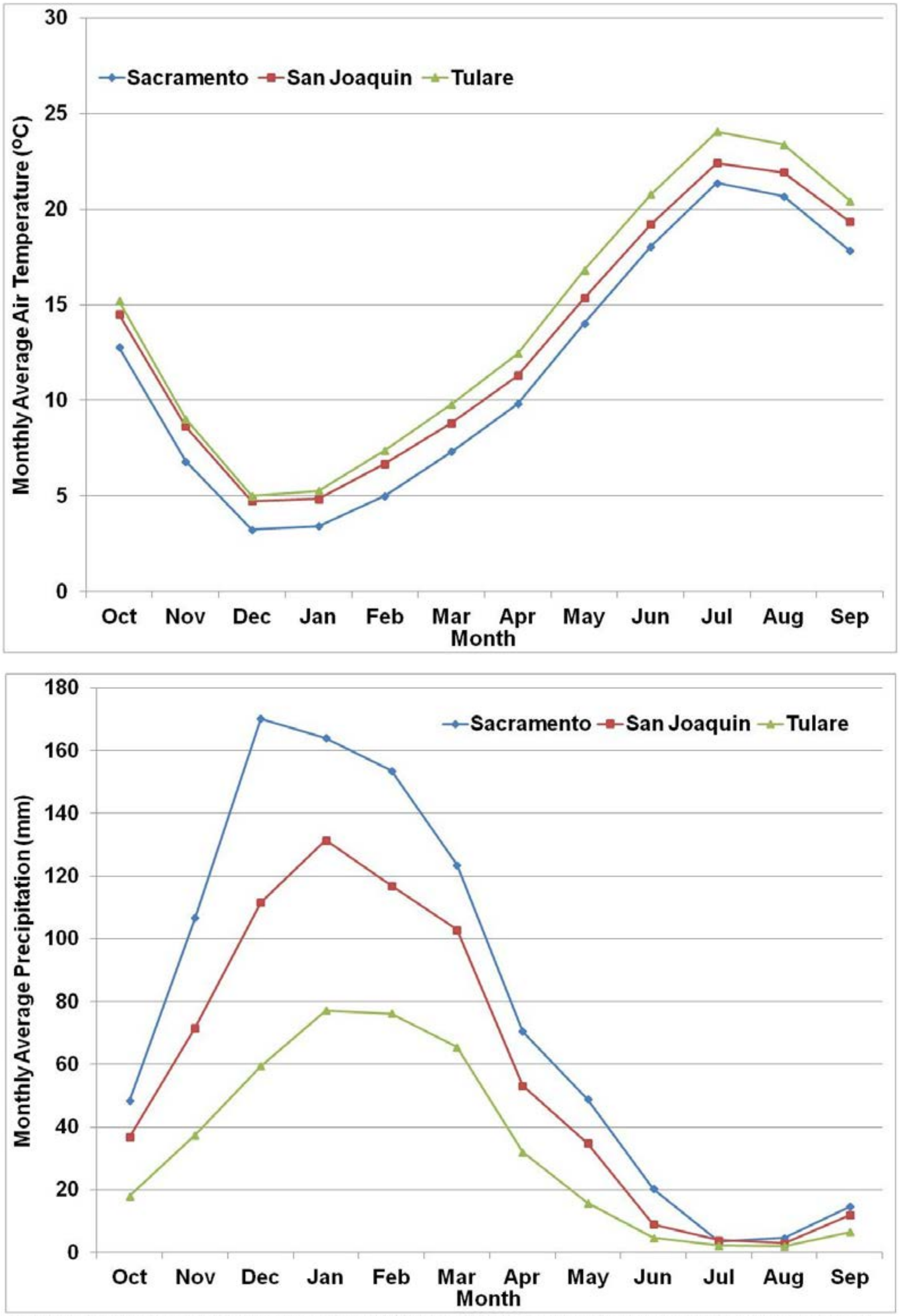
Annual precipitation shows substantial variability and periods of dry and wet spells. Most notable in the precipitation record is the lack of a significant long term annual trend, yet the annual variability appears to be increasing. More years with larger than long-term annual precipitation seem to appear in the most recent 30-year record.

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.

### *Streamflow and Trends*

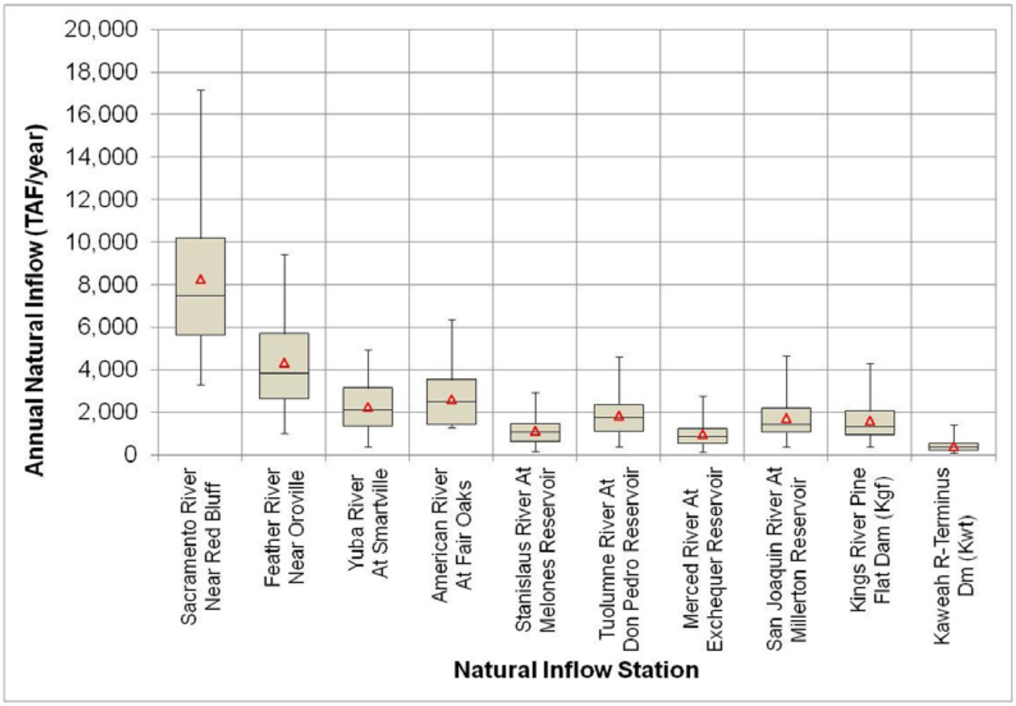
Streamflow assessments provide an understanding of the cumulative effect of various climatic-hydrologic processes. Monthly and annual observed natural (also known as "unimpaired") streamflows from the major tributary watersheds in the Central Valley (Sacramento, San Joaquin, and Tulare River basins) 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 (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.



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



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

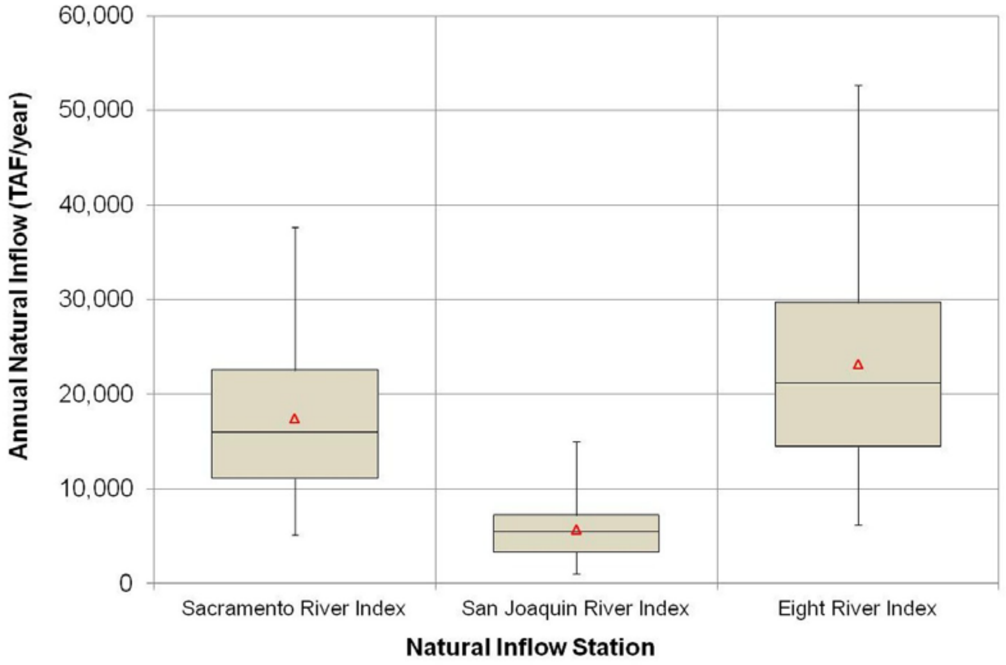
Figure 3-5. Average Annual Total Natural Flows for Major Locations

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) |

Note: MAF = million acre-feet

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



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 Rivers Index

above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and 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, and San Joaquin River inflow to Millerton Lake. The Sacramento-San Joaquin 8 Index is the sum of all of the rivers included in the Sacramento and San Jaoquin 4 Rivers Indices.

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 approximately 5.7 MAF, but ranged from 1.1 MAF (1977) to 15.0 MAF (1983). The mean annual flow of the Sacramento and San Jaoquin 8 Rivers Index is approximately 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.

### *Drought Analysis*

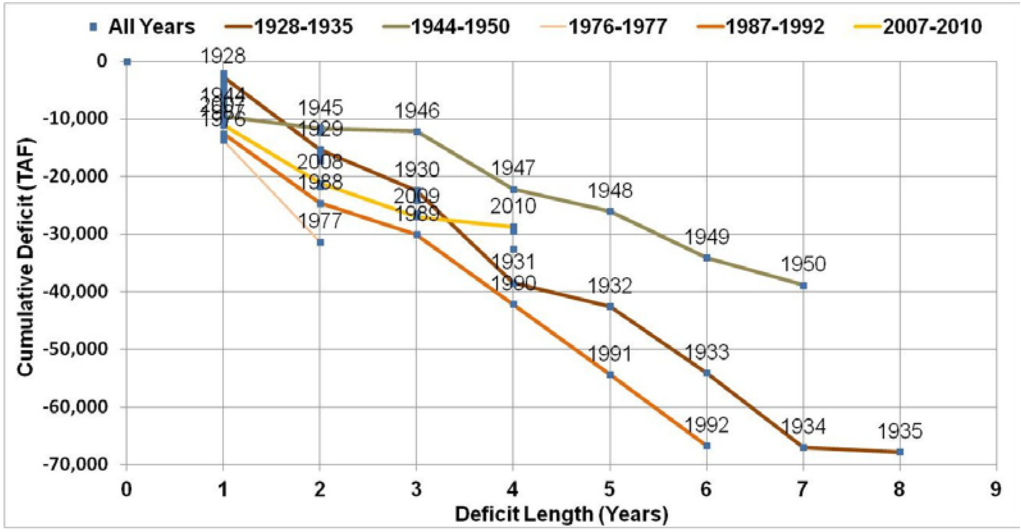
Drought has played an important role in shaping California’s water supply history. Multiple large-scale drought sequences in California since 1900 include 1918 1920, 1923-1926, 1928-1935, 1947-1950, 1959-1962, 1976-1977, 1987-1992, 2000-2002, and 2007-2009. These periods of significant drought provide 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 precipitation-, soil moisture-, and streamflow-based indices. Only streamflow-based indices are included in this discussion because appropriate precipitation- and soil moisture-based indices are still being identified.

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. 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 2012 period.

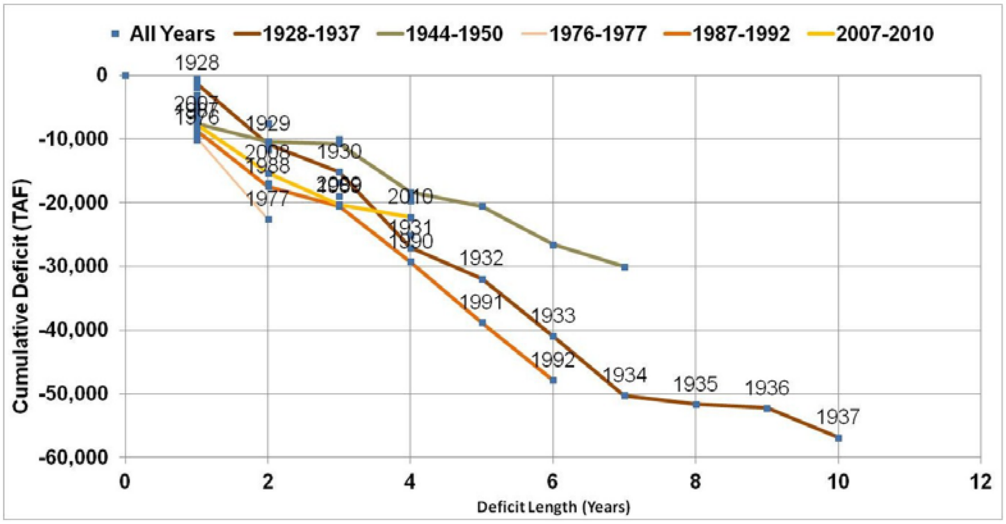
Figures 3-7 through 3-10 present the drought summaries for the following indices which were previously defined: Sacramento and San Joaquin 8 River Index, Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index. The Tulare 2 Rivers Index was also included. The Tulare 2 Rivers Index is the sum of streamflows 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 Rivers Index. For each year of the 1906 to 2012 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. Three significant deficit spells that occurred in the observed period beginning in 1928 (8-year deficit), 1944 (7-year deficit), 1976 (2-year deficit), 1987 (6-year deficit), and 2007 (4-year deficit) are shown on the figure. 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 65 MAF. The recent period deficit that began in 2007 accumulated a 4-year



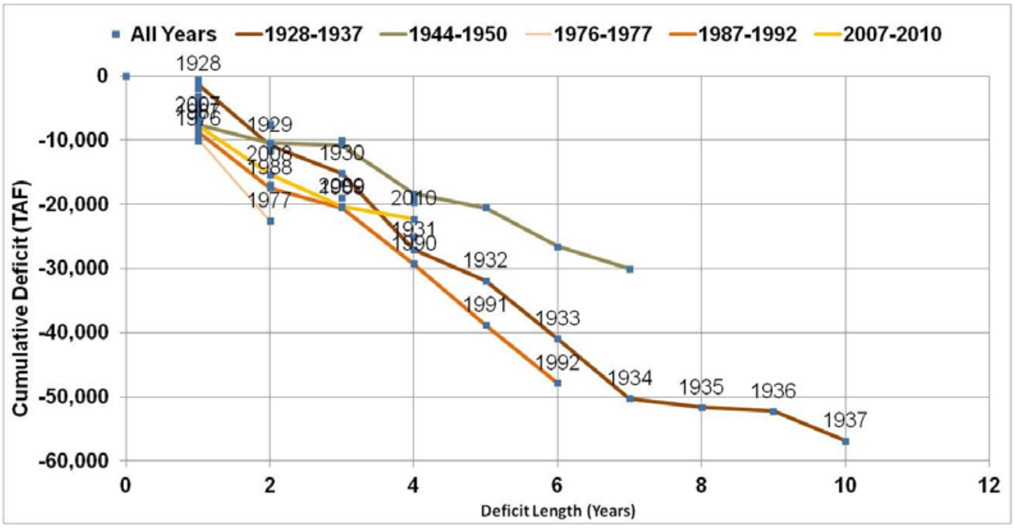
Notes:
Deficit defined as 1-year mean below long-term mean.
The 8 River Index is the sum of streamflows of Sacramento River at Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro Reservoir, Merced River inflow to Lake McClure, and San Joaquin River inflow to Millerton Lake.

Figure 3-7. Cumulative Streamflow Deficits in Observed Natural Flow Records for the Sacramento and San Joaquin 8 Rivers Index (1906-2012)



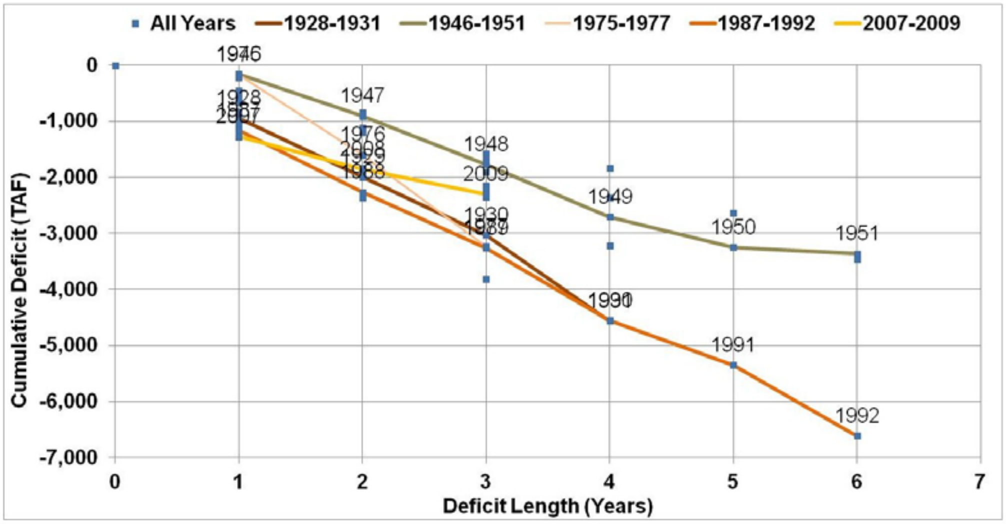
Notes:
Deficit defined as 1-year mean below long-term mean.The Sacramento 4 Rivers Index is the sum of streamflows of Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.

Figure 3-8. Cumulative Streamflow Deficits in Observed Natural Flow Records for the Sacramento 4 Rivers Index (1906-2012)



Notes:
Deficit defined as 1-year mean below long-term mean.The Sacramento 4 Rivers Index is the sum of streamflows of Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake.

Figure 3-9. Cumulative Streamflow Deficits in Observed Natural Flow Records for the San Joaquin 4 Rivers Index (1906-2012)



Notes:
Deficit defined as 1-year mean below long-term mean.
The Tulare 2 Rivers Index is the sum of streamflows of Kings River inflow to Pine Flat and Kaweah River inflow to Terminus Dam.

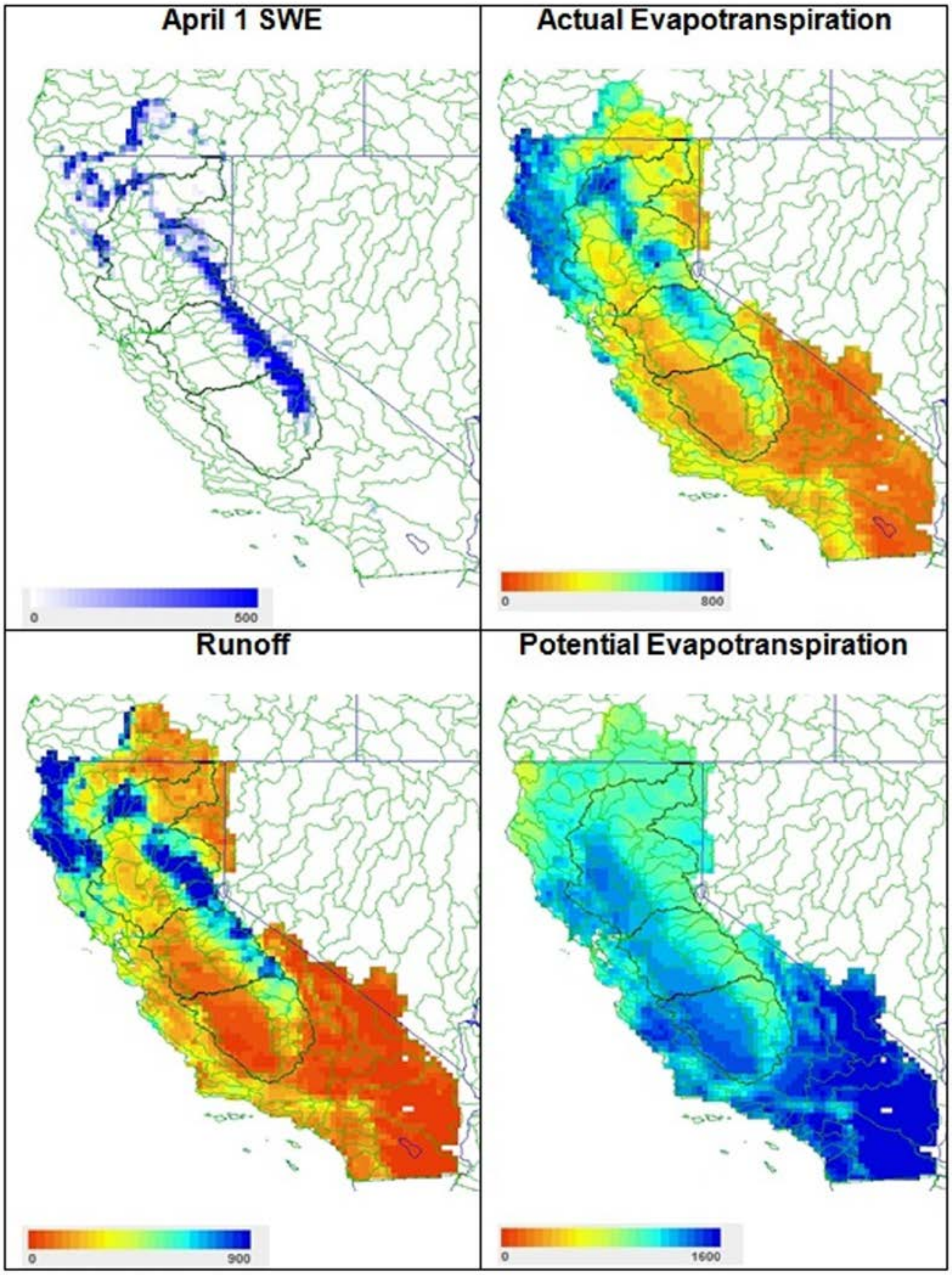
Figure 3-10. Cumulative Streamflow Deficits in Observed Natural Flow Records for the Tulare 2 Rivers Index (1906-2012) deficit of more than 28 MAF. The 1976-1977 drought was the most severe 2-year period in record.

### *Other Hydrologic Processes and Trends*

The purpose of using dynamic hydrologic modeling is 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, 2011a).

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 3-11 provides an estimate of the average spatially distributed April 1 SWE, actual and potential ET as well as 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 3-11, 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.



April 1 SWE

Actual Evapotranspiration

Runoff

Potential Evapotranspiration

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

Figure 3-11. Estimated Average April 1 SWE, Average Annual ET, and Runoff (1981 to 2010, in mm)

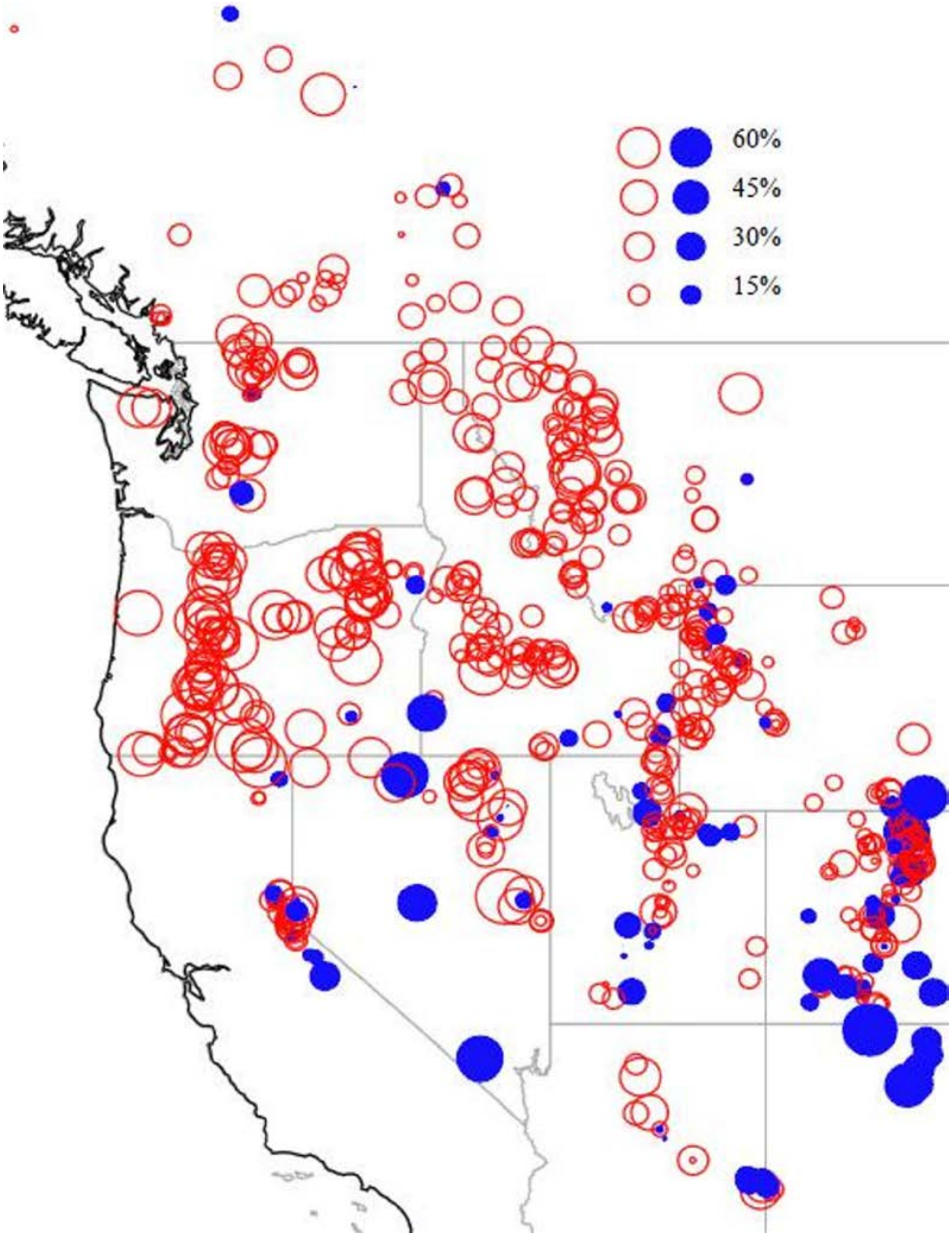
Water retained in the snowpack from winter storms forms an important part of the hydrological cycle and water supply in California. Previously published research was used to assess observed snowpack trends in the Central Valley. Research by Mote (2003), Mote et al. (2008), Cayan et al. (2001), Pierce et al. (2008), and Pederson et al. (2011) indicate a general decline in April 1 SWE for Pacific Northwest and northern Sierra locations, and increases in parts of the southern Sierra (Figure 3-12a).

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 plotted April 1 SWE trends (1950 to 2000) against elevation of snow course (Figure 3-12b). 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, declined since mid-century.

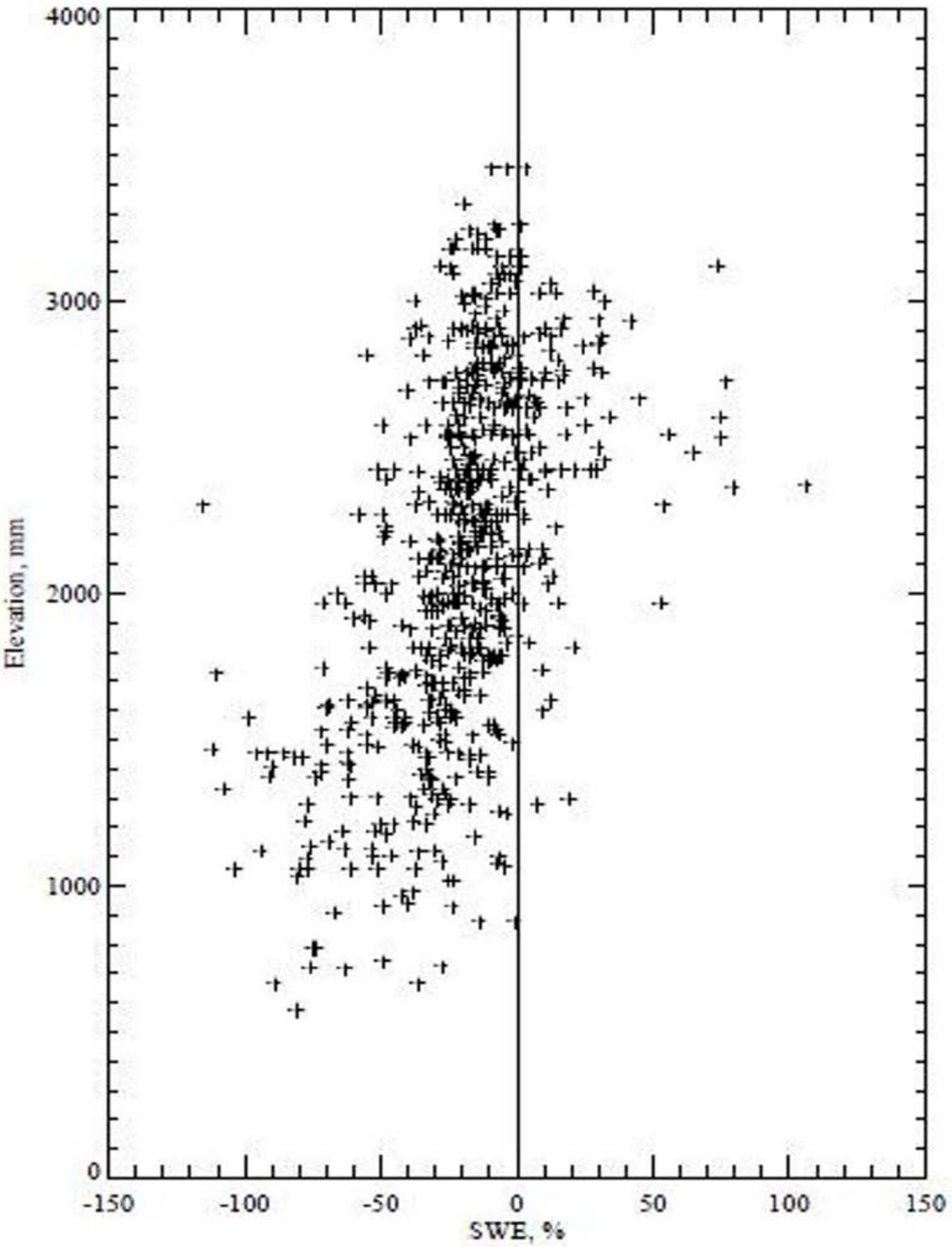
### *Teleconnection Analysis and Trends*

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. Other teleconnections, such as the AMO and the Madden-Jullian 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, and combined, describe ENSO.



Note: Negative trends are shown by open red circles, positive by solid blue circles (Mote et al. 2008)

Figure 3-12a. Linear Trends in April 1 SWE at 594 Locations in the Western United States and Canada (1950 to 2000) (Mote et al. 2008)



Source: Mote et al. 2008

Figure 3-12b. April 1 SWE Trends Plotted Against Elevation of Snow Course (1950 to 2000)

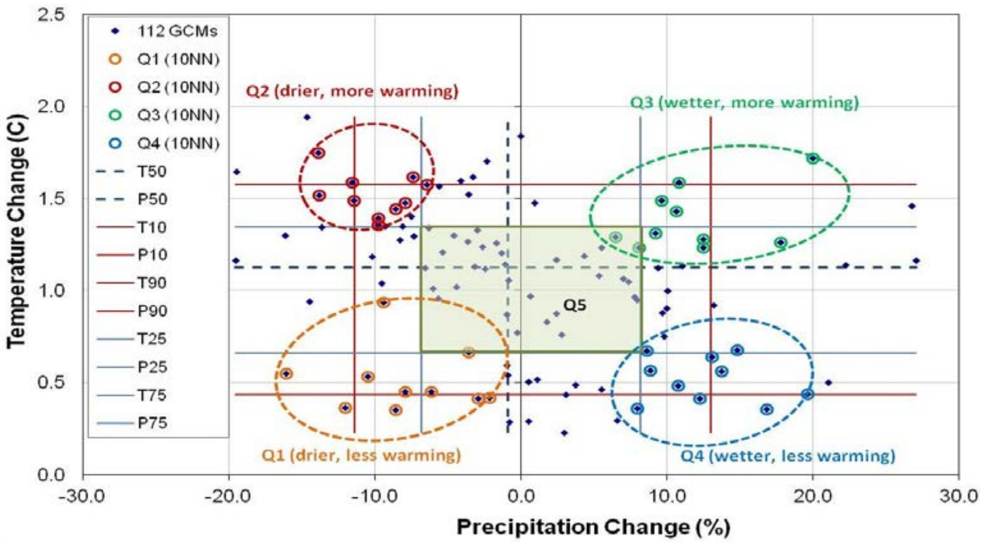
### 3.1.2 Assessment of Future Water Supply

***Projected Climate and Trends***

Future projections of climate are typically drawn from GCMs forced by a range of plausible atmospheric conditions. The climate projections used in this study were based on the CMIP3 archives developed by Reclamation and others (Reclamation 2011B). The ensembles of downscaled GCM projections (EI5, as described previously) and individual downscaled GCM projections (12 CAT scenarios). The 12 CAT scenarios were obtained from Scripps Institution of Oceanography.

The EI5 climate sequences were developed using statistical techniques similar to those used to develop climate scenarios for the BDCP and CVP IRP. These techniques considered the full range of the 112 bias-corrected spatially downscaled climate projections (Maurer et al. 2007) to develop the five statistically representative climate scenarios employed in this study. These 112 climate projections used in the IPCC's AR4 and the WCRP CMIP3 have been bias-corrected and spatially downscaled (Maurer et al. 2007) 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 projections was broken into regions representing future climate uncertainties: (Q1) drier, less warming; (Q2) drier, more warming; (Q3) wetter, more warming; and (Q4) wetter, less warming scenarios than captured by the ensemble median (Q5). These regions are labeled Q1 through Q4 on Figure 3-13. The ensemble "consensus" region (Q5) 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 projections, consisting of those bounded by the region were identified. For Q5, all of the projections in the bounded region were included. For the Q1 through Q4 regions, the subset consisted of the 10 nearest neighbors to the 10–90 percentile points (Figure 5-13). This approach was employed to sample the range of climate projection uncertainty present in the complete ensemble of the 112 projections, but to allow a smaller representative set of scenarios to be included in the analysis.

In the transient climate change scenario approach used in this Impact Assessment, the climate change as projected to occur through the GCM simulations of temperature and precipitation is mapped to historical time series (Livneh et al. 2013). The historical cumulative distribution function (CDF) was developed using a 30-year period centered around 1985 (1971-2000). 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 (1915-2003) and the projected climate change. The method applies the change for any particular year by interpolating from

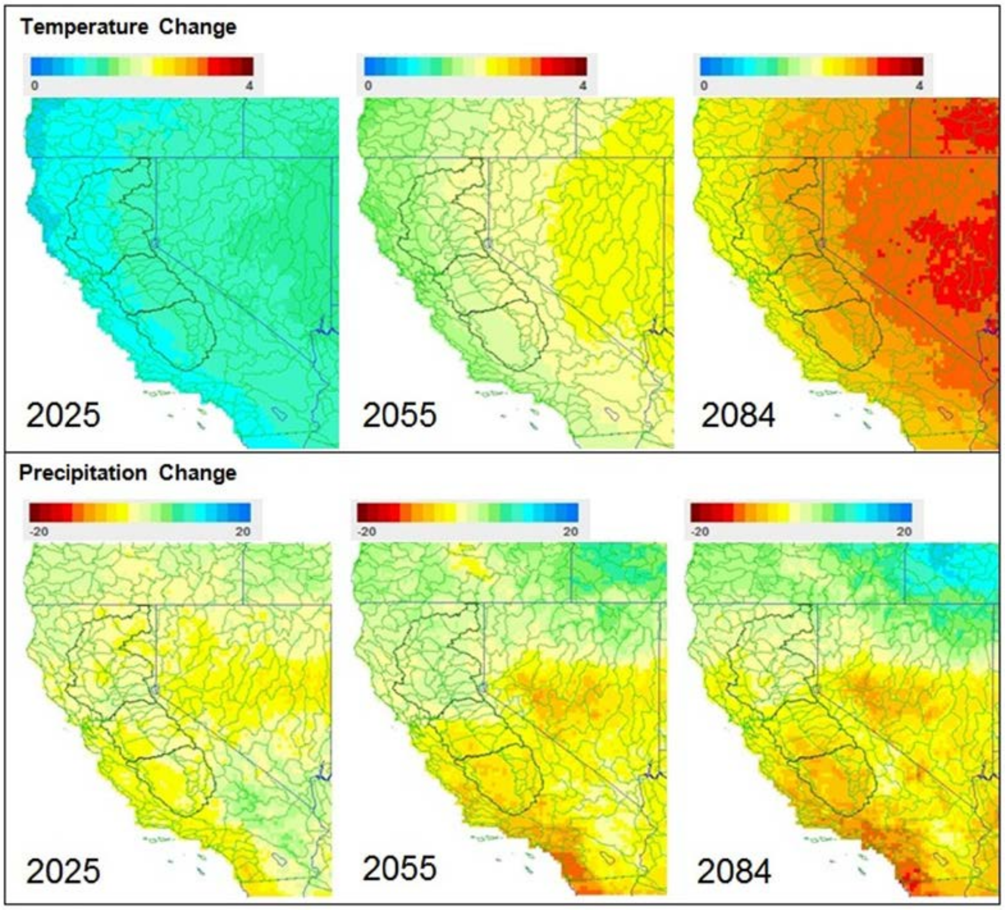


Notes:
The Q5 scenario is bounded by the 25th and 75th percentile joint temperature-precipitation change. Scenarios Q1-Q4 are selected to reflect the results of the 10 projections nearest each of 10th and 90th joint temperature-precipitation change bounds. Representative gridcell at American River Basin used as example; 10 NN Method.

Figure 3-13. Relationship between Changes in Mean Annual Temperature and Precipitation Scenarios

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.

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 median climate projection (Q5). Q5 is a composite of the individual projections that are closest to the median change, and, thus, reflect the "consensus" of projections. Figure 3-14 shows the annual mean temperature and precipitation changes for California and Nevada derived from the central quadrant (Q5). Projected changes for the future periods 2011-2040 (2025), 2041-2070 (2055), and 2070-2099 (2084) are compared to the historical climatological period of 1971-2000. The Q5 scenario indicates substantial warming by 2050. Warming is projected to be generally higher farther away from the coast, reflecting a continued ocean cooling influence. 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 slightly greater precipitation, while the San Joaquin Valley may experience 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).

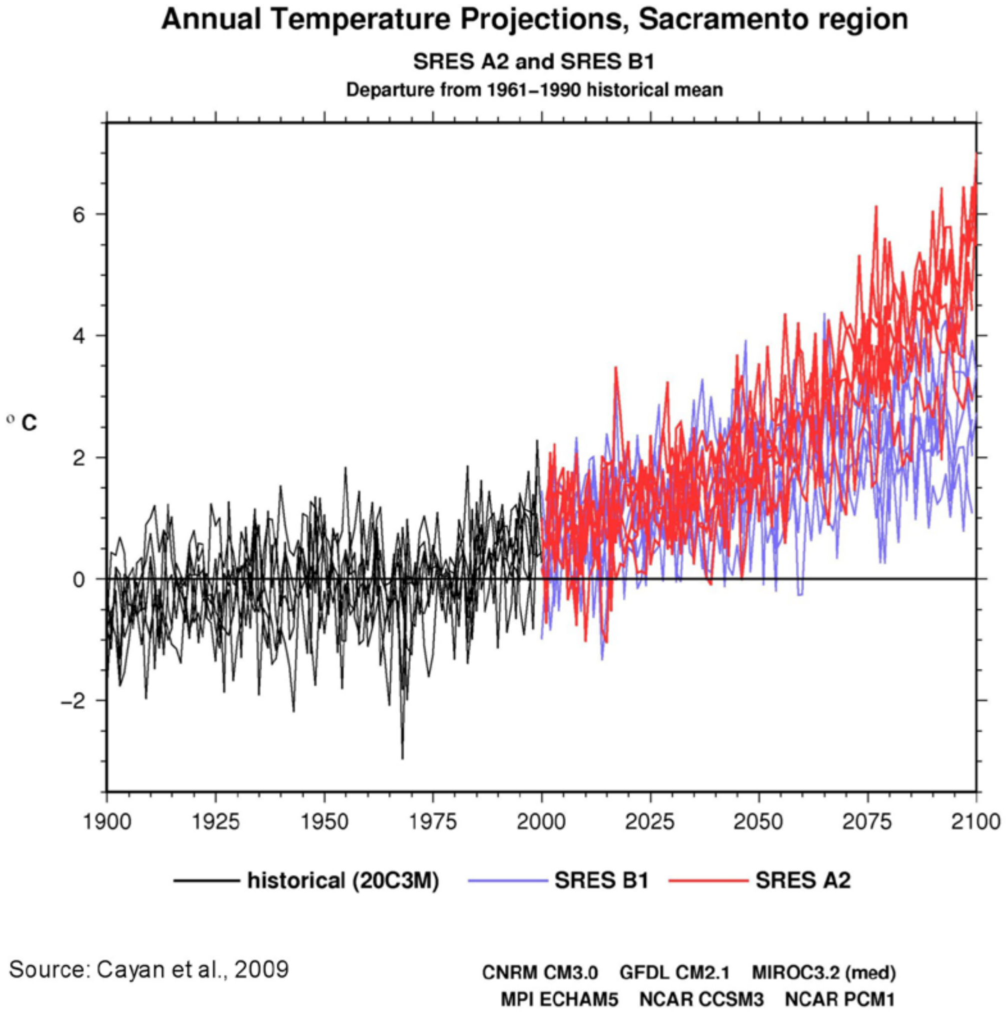


Notes:

Figures show change as compared to the 1971-2000 model simulated historical period.
Top panel shows °C. Bottom panel shows percent change.

Figure 3-14. Projected Changes in Annual Mean Temperature and Precipitation for 2011-2040 (2025), 2041-2070 (2055) and 2070-2099 (2084)

Historical simulations with GCMs exhibit a similar response providing a basis for our understanding of causal mechanisms. The current suite of GCMs, when simulated under future GHG emission scenarios and current atmospheric GHGs, exhibit warming globally and regionally over California (Figure 3-15). In the early part of the twenty-first century, the amount of warming produced by the higher emission A2 scenario is not very different from the lower emission B1 scenario, but becomes increasingly larger through the middle and especially the latter part of the century. Six GCMs selected by the CAT for the 2009 scenarios project a mid-century temperature increase of about 1°C to 3°C (1.8° Fahrenheit [F] to 5.4°F) and an end-of-century increase from about 2°C to 5°C (3.6°F to 9°F). The upper part of this range is a considerably greater warming rate than the historical rates estimated from observed temperature records in California (Bonfils et al. 2008).



Source: Cayan et al., 2009

Figure 3-15. Change in Simulated Future Annual Temperature Projections (Departure from 1961-1990 Historical Mean) for the Sacramento Region

The GCM simulations of historical climate capture the historical range of variability reasonably well (Cayan et al. 2009), but historical trends are not well captured in these models. Projections of future precipitation are much more uncertain than those for temperature. Although it is difficult to discern strong trends from the full range of climate projections, the six GCMs that were selected for the California study demonstrate a drying trend in the twenty-first century (Figure 3-16). The precipitation projection uncertainty is largest in the northern part of the state, with a stronger tendency toward drying in the southern part of the state.

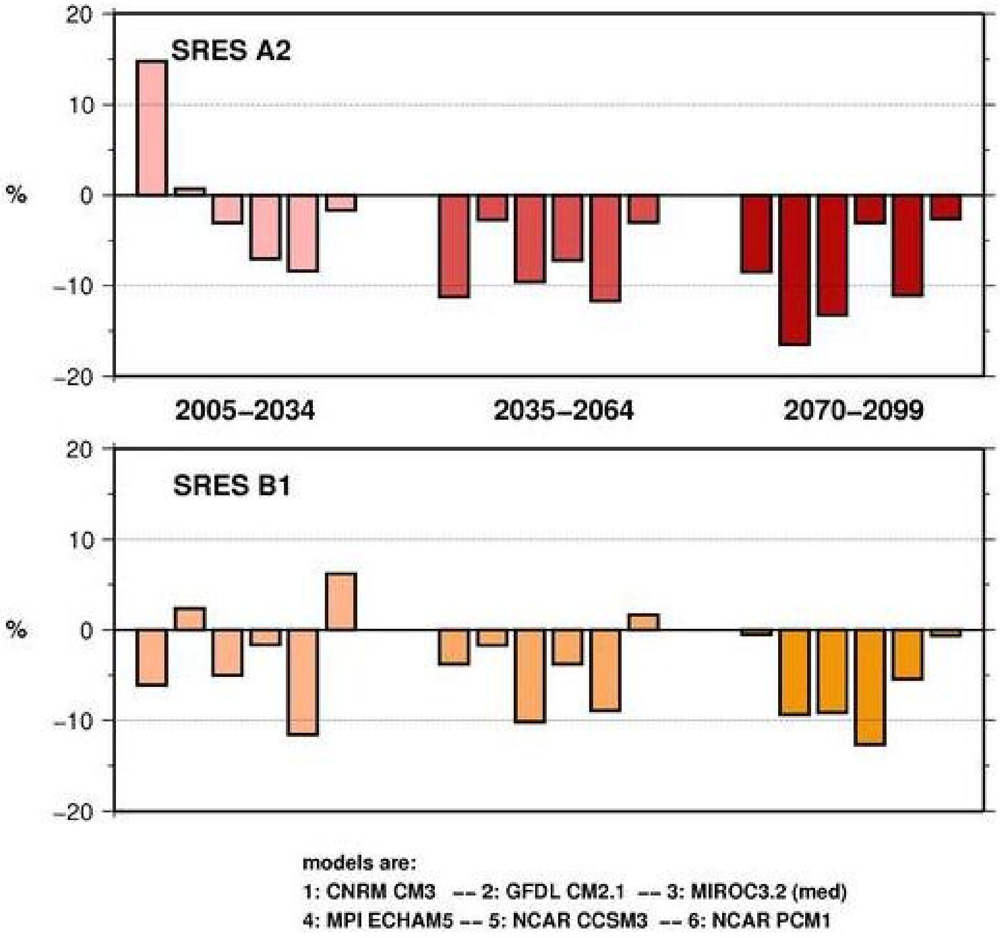


Figure 3-16. Simulated Future Percentage Change in Precipitation for IPCC's SRES A2 and B1 Scenarios for the Sacramento Region

Figures 3-17 through 3-19 show 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-informed transient climate scenarios capture most of the considerable range of future uncertainty represented by the 12 CAT climate projections.

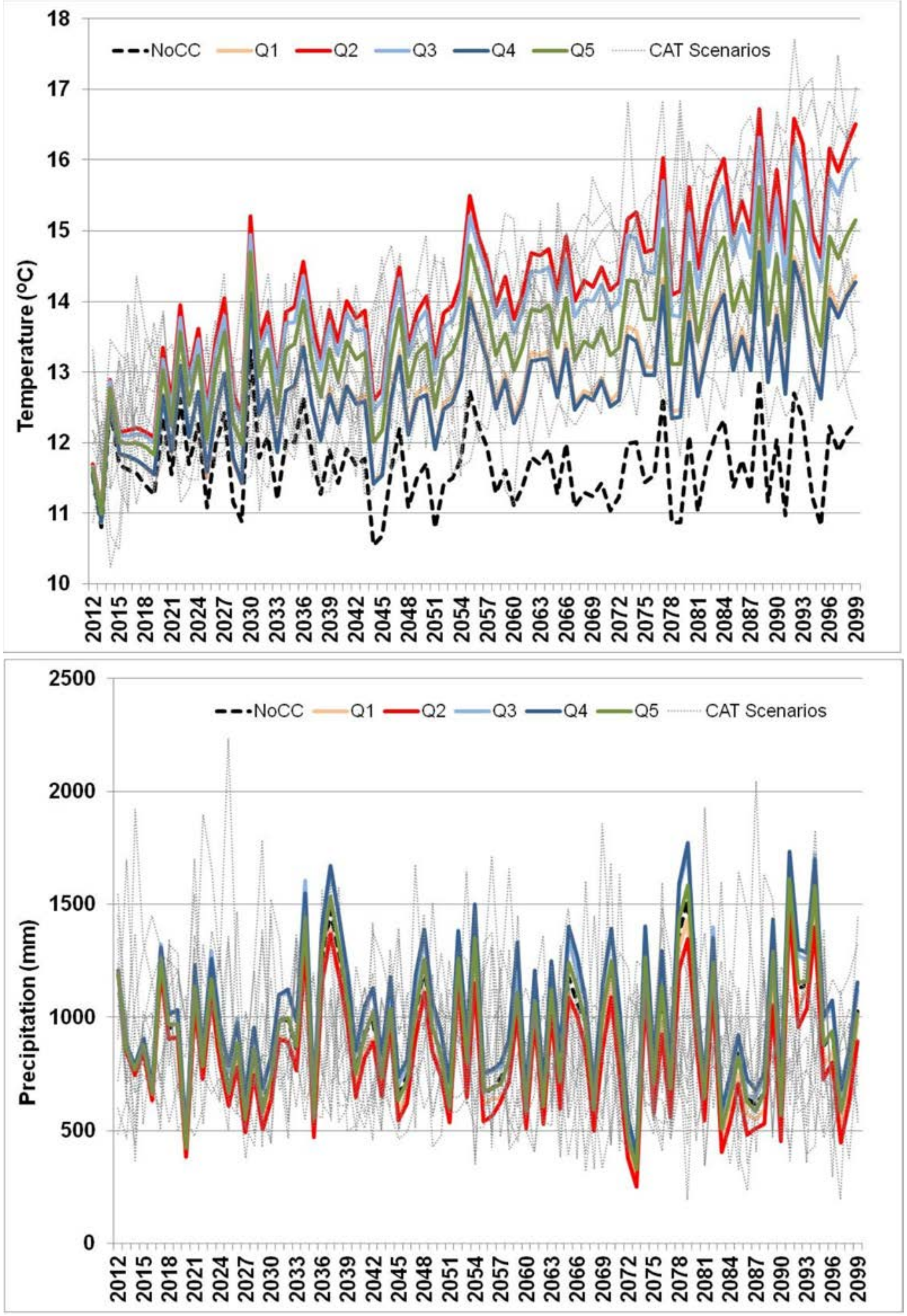


Figure 3-17. Annual Average Temperature (top) and Annual Total Precipitation (bottom) for Sacramento River Hydrologic Region in Each Climate Scenario

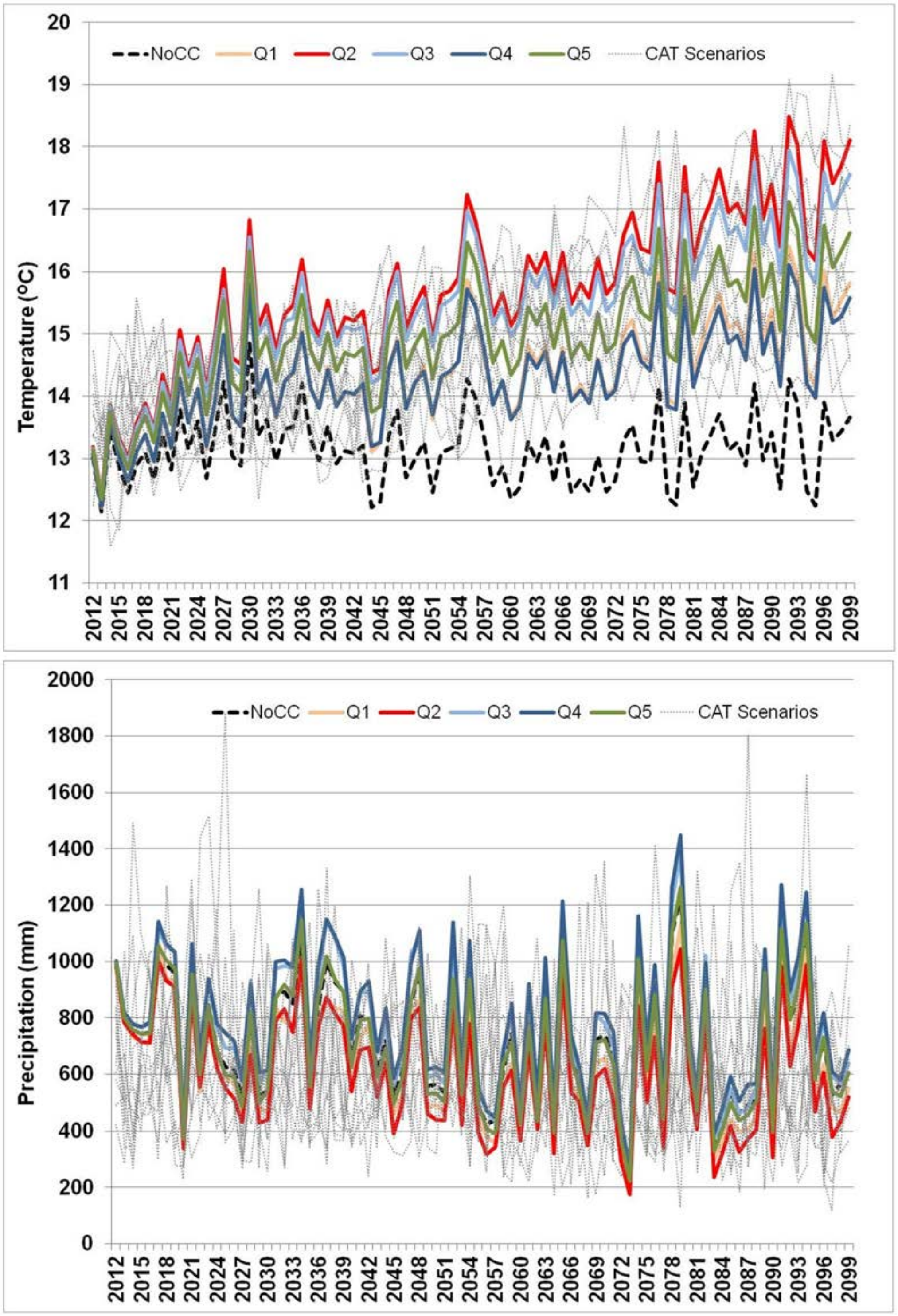


Figure 3-18. Annual Average Temperature (top) and Annual Total Precipitation (bottom) for San Joaquin River Hydrologic Region in Each Climate Scenario

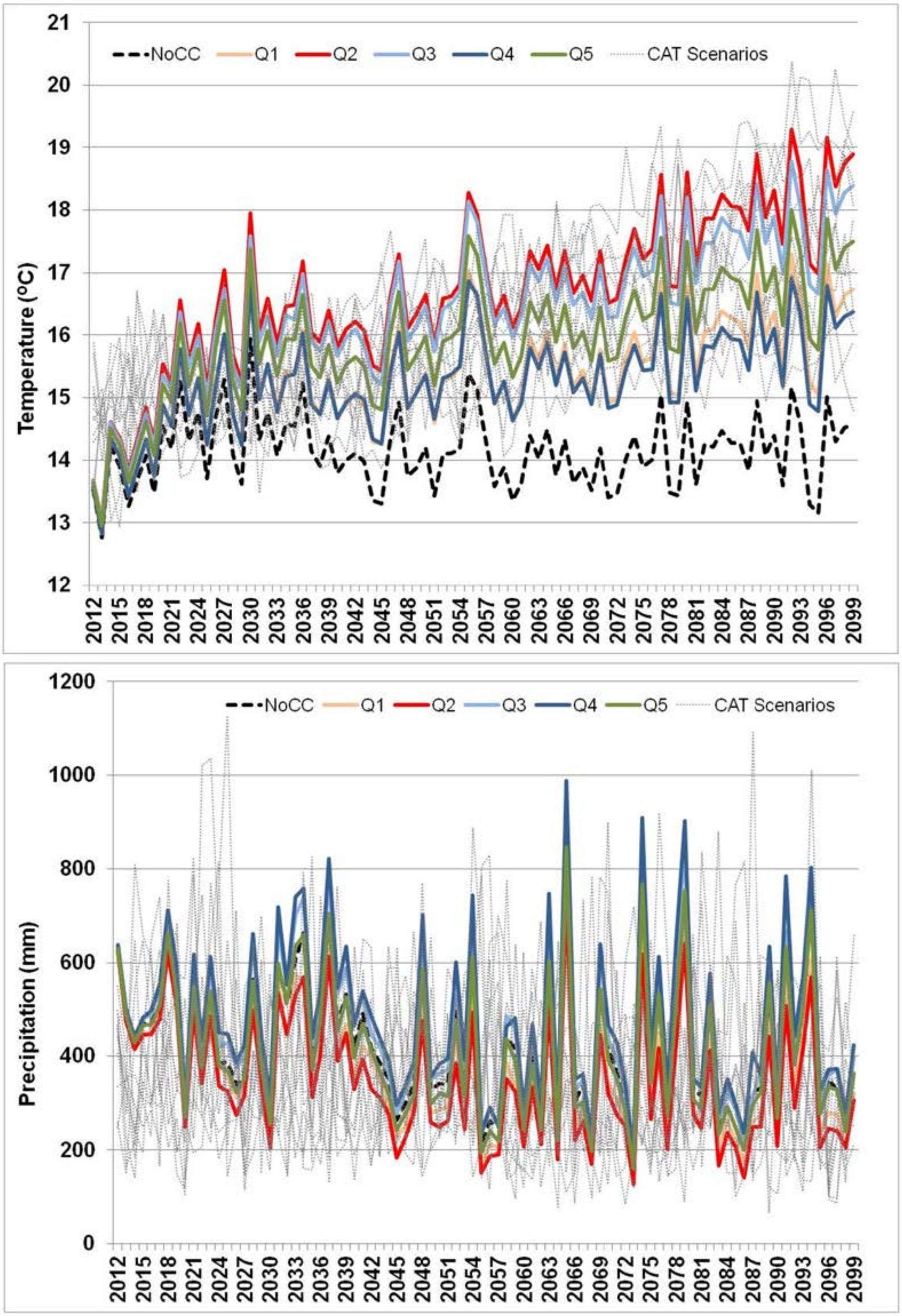


Figure 3-19. Annual Average Temperature (top) and Annual Total Precipitation (bottom) for Tulare Lake Hydrologic Region in Each Climate Scenario

Tables 3-2 and 3-3 summarize projected changes in mean annual temperature and precipitation in the Sacramento River, San Joaquin River, and Tulare Lake hydrologic regions in each climate scenario. Projected changes in annual precipitation and temperature were computed for three periods (2012-2040, 2041-2070, and 2071-2099) relative to the NoCC scenario developed based on Livneh et al. (2013) historical observed climate data. All projections 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 0.7 (12 CAT mean) to 0.9°C (Q5), with projections ranging from 0.1 to 1.3°C during the period of 2012-2040, from 1.8 (12 CAT mean) to 1.9°C (Q5), with projections ranging from 0.7 to 2.6°C during the period of 2041-2070 and from 2.5 (Q5) to 2.8°C (CAT mean), with projections ranging from 1.2 to 4.2°C during the period of 2071 2099. The projected temperature changes are similar in the San Joaquin River and Tulare Lake hydrologic regions with slightly higher projected warming.

The central tendency of projected precipitation change in the Sacramento River hydrologic region ranges from -1.8% (12 CAT mean) to +0.9% (Q5), with projections ranging from -12.8% to +17.1% during the period of 2012-2040; from -4.9% (12 CAT mean) to +0.5% (Q5), with projections ranging from -18.1% to 13.6% during the period of 2041-2070; and from -7.4% (12 CAT mean) to +0.7% (Q5), with projections ranging from -27.5% to +12.5% during the period of 2071 2099. The range of projections indicates considerable uncertainty around these mean values. The central tendency of projected precipitation change in the San Joaquin River hydrologic region ranges from -16.9% (12 CAT mean) to +0.3% (Q5) during 2012 2040, from -8.8% (12 CAT mean) to -2.6% (Q5) during 2041 2070, and from 1.5% (Q5) to -14.2% (12 CAT mean) during 2071-2099.

The central tendency of projected precipitation change in the Tulare Lake hydrologic region ranges from -19.4% (12 CAT mean) to -0.7% (Q5), with projections ranging from -30.1% to +12.6% during the period of 2012-2040; from -8.9% (12 CAT mean) to -5.2% (Q5), with projections ranging from -33.4% to +13.5% during the period of 2041-2070; and from -16.7% (12 CAT mean) to -4.4% (Q5), with projections ranging from -34.8% to +12.7% during the period of 2071 2099. In all regions, the 12 CAT scenarios represent a greater degree of drying that those represented in the EI ensemble median scenario (Q5), reflecting a dry bias in the 12 CAT subset.

Table 3-2. Annual Temperature change (in degrees C) in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions in Each Climate Scenario (2012–2040, 2041–2070, and 2071-2099)

| | **Ensemble-Informed Scenarios** | | | | | |
|---|---|---|---|---|---|---|
| | **NoCC Average** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Sacramento River Hydrologic Region** | | | | | | |
| 2012-2040 | 11.8 | 0.5 | 1.3 | 1.2 | 0.5 | 0.9 |
| 2041-2070 | 11.5 | 1.2 | 2.6 | 2.4 | 1.2 | 1.9 |
| 2071-2099 | 11.7 | 1.8 | 3.6 | 3.2 | 1.7 | 2.5 |
| **San Joaquin River Hydrologic Region** | | | | | | |
| 2012-2040 | 13.3 | 0.5 | 1.3 | 1.2 | 0.5 | 1.0 |
| 2041-2070 | 13.0 | 1.3 | 2.7 | 2.5 | 1.3 | 1.9 |
| 2071-2099 | 13.2 | 1.9 | 3.8 | 3.4 | 1.7 | 2.6 |
| **Tulare Lake Hydrologic Region** | | | | | | |
| 2012-2040 | 14.2 | 0.5 | 1.3 | 1.2 | 0.5 | 1.0 |
| 2041-2070 | 14.0 | 1.3 | 2.6 | 2.5 | 1.3 | 1.9 |
| 2071-2099 | 14.2 | 1.9 | 3.7 | 3.3 | 1.6 | 2.6 |

| | **CAT Scenarios** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A2_cnrmcm3** | **A2_gfdlcm21** | **A2_miroc32med** | **A2_mpiecham5** | **A2_ncarccsm3** | **A2_ncarpcm1** | **B1_cnrmcm3** | **B1_gfdlcm21** | **B1_miroc32med** | **B1_mpiecham5** | **B1_ncarccsm3** | **B1_ncarpcm1** |
| **Sacramento River Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | 0.6 | 1.0 | 1.0 | 0.6 | 1.1 | 0.1 | 0.8 | 0.9 | 0.9 | 0.4 | 1.3 | 0.1 |
| 2041-2070 | 1.8 | 2.3 | 2.6 | 2.0 | 2.6 | 1.2 | 1.4 | 1.7 | 2.2 | 1.8 | 2.0 | 0.7 |
| 2071-2099 | 3.3 | 3.8 | 4.2 | 3.6 | 4.1 | 2.2 | 1.6 | 2.0 | 2.9 | 2.6 | 2.2 | 1.2 |
| **San Joaquin River Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | 0.4 | 0.8 | 1.1 | 0.6 | 0.9 | 0.0 | 0.7 | 0.8 | 0.9 | 0.4 | 1.1 | 0.0 |
| 2041-2070 | 1.5 | 2.1 | 2.7 | 2.0 | 2.5 | 1.0 | 1.2 | 1.6 | 2.3 | 1.8 | 1.8 | 0.5 |
| 2071-2099 | 3.1 | 3.6 | 4.4 | 3.4 | 3.9 | 2.0 | 1.4 | 1.9 | 2.9 | 2.5 | 2.0 | 1.1 |
| **Tulare Lake Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | 0.6 | 1.0 | 1.2 | 0.8 | 1.0 | 0.2 | 0.9 | 1.0 | 1.0 | 0.6 | 1.2 | 0.2 |
| 2041-2070 | 1.7 | 2.3 | 2.8 | 2.2 | 2.5 | 1.3 | 1.4 | 1.8 | 2.3 | 2.0 | 1.8 | 0.8 |
| 2071-2099 | 3.4 | 3.8 | 4.6 | 3.7 | 4.0 | 2.3 | 1.7 | 2.2 | 3.1 | 2.8 | 2.1 | 1.4 |

Note: Changes are computed with respect to NoCC scenario.

Table 3-3. Annual Precipitation (in mm) for the NoCC Scenario and Percent Change in Each Climate Scenario in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions (2012–2040, 2041–2070, and 2071-2099)

| | Ensemble-Informed Scenarios | | | | | |
|---|---|---|---|---|---|---|
| | **NoCC Average** | **Q1** | **Q2** | **Q3** | **Q4** | **Q5** |
| **Sacramento Hydrologic Region** | | | | | | |
| 2012-2040 | 923 | -6.4 | -7.6 | 9.6 | 9.9 | 0.9 |
| 2041-2070 | 910 | -8.8 | -11.8 | 10.1 | 13.6 | 0.5 |
| 2071-2099 | 916 | -7.6 | -14.8 | 10.7 | 13.3 | 0.7 |
| **San Joaquin Hydrologic Region** | | | | | | |
| 2012-2040 | 783 | -6.6 | -9.2 | 9.5 | 11.3 | 0.3 |
| 2041-2070 | 664 | -10.7 | -15.7 | 9.0 | 12.5 | -2.6 |
| 2071-2099 | 683 | -11.9 | -18.8 | 7.3 | 12.2 | -1.5 |
| **Tulare Hydrologic Region** | | | | | | |
| 2012-2040 | 432 | -7.3 | -10.8 | 9.0 | 12.6 | -0.7 |
| 2041-2070 | 390 | -14.2 | -21.4 | 8.4 | 13.5 | -5.2 |
| 2071-2099 | 407 | -17.1 | -23.3 | 6.8 | 12.7 | -4.4 |

| | CAT Scenarios | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **A2_cnrmcm3** | **A2_gfdlcm21** | **A2_miroc32med** | **A2_mpiecham5** | **A2_ncarccsm3** | **A2_ncarpcm1** | **B1_cnrmcm3** | **B1_gfdlcm21** | **B1_miroc32med** | **B1_mpiecham5** | **B1_ncarccsm3** | **B1_ncarpcm1** |
| **Sacramento Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | 13.1 | -6.9 | -11.7 | -6.2 | -12.8 | -0.7 | 5.5 | 1.6 | -11.1 | 1.0 | -9.9 | 17.1 |
| 2041-2070 | -17.4 | -4.7 | -16.0 | 0.9 | -7.0 | 2.6 | -0.2 | -2.3 | -18.1 | 2.6 | -4.0 | 4.9 |
| 2071-2099 | -5.5 | -20.2 | -16.4 | 3.6 | -8.1 | 2.2 | -9.6 | -10.0 | -14.3 | -12.1 | -1.9 | 2.9 |
| **San Joaquin Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | -4.7 | -20.6 | -27.3 | -23.4 | -24.5 | -13.4 | -10.1 | -13.3 | -26.6 | -14.5 | -23.1 | -0.9 |
| 2041-2070 | -27.5 | -4.7 | -24.1 | -5.1 | -8.8 | 3.8 | -6.0 | -5.2 | -22.1 | -0.5 | -4.3 | -1.0 |
| 2071-2099 | -17.5 | -28.3 | -27.9 | -1.0 | -12.9 | 2.0 | -20.1 | -20.1 | -25.3 | -18.9 | -0.5 | -0.2 |
| **Tulare Hydrologic Region** | | | | | | | | | | | | |
| 2012-2040 | -7.9 | -23.1 | -30.1 | -27.3 | -25.5 | -15.7 | -14.2 | -17.6 | -28.9 | -16.3 | -23.4 | -3.2 |
| 2041-2070 | -33.4 | -6.4 | -27.5 | -5.5 | -7.4 | 8.3 | -7.0 | -7.5 | -23.8 | 2.5 | 0.9 | 0.6 |
| 2071-2099 | -20.0 | -31.7 | -34.8 | -1.8 | -12.9 | 5.6 | -26.8 | -24.7 | -31.9 | -21.7 | 1.0 | -0.3 |

Note: Changes are computed with respect to NoCC scenario.

The precipitation and average temperature from the EI5 and 12 CAT climate scenarios described above were used in the WEAP-CV hydrology model for each of the future periods. The WEAP model obtains this climate data at the discrete nodes shown on Figure 3-20.

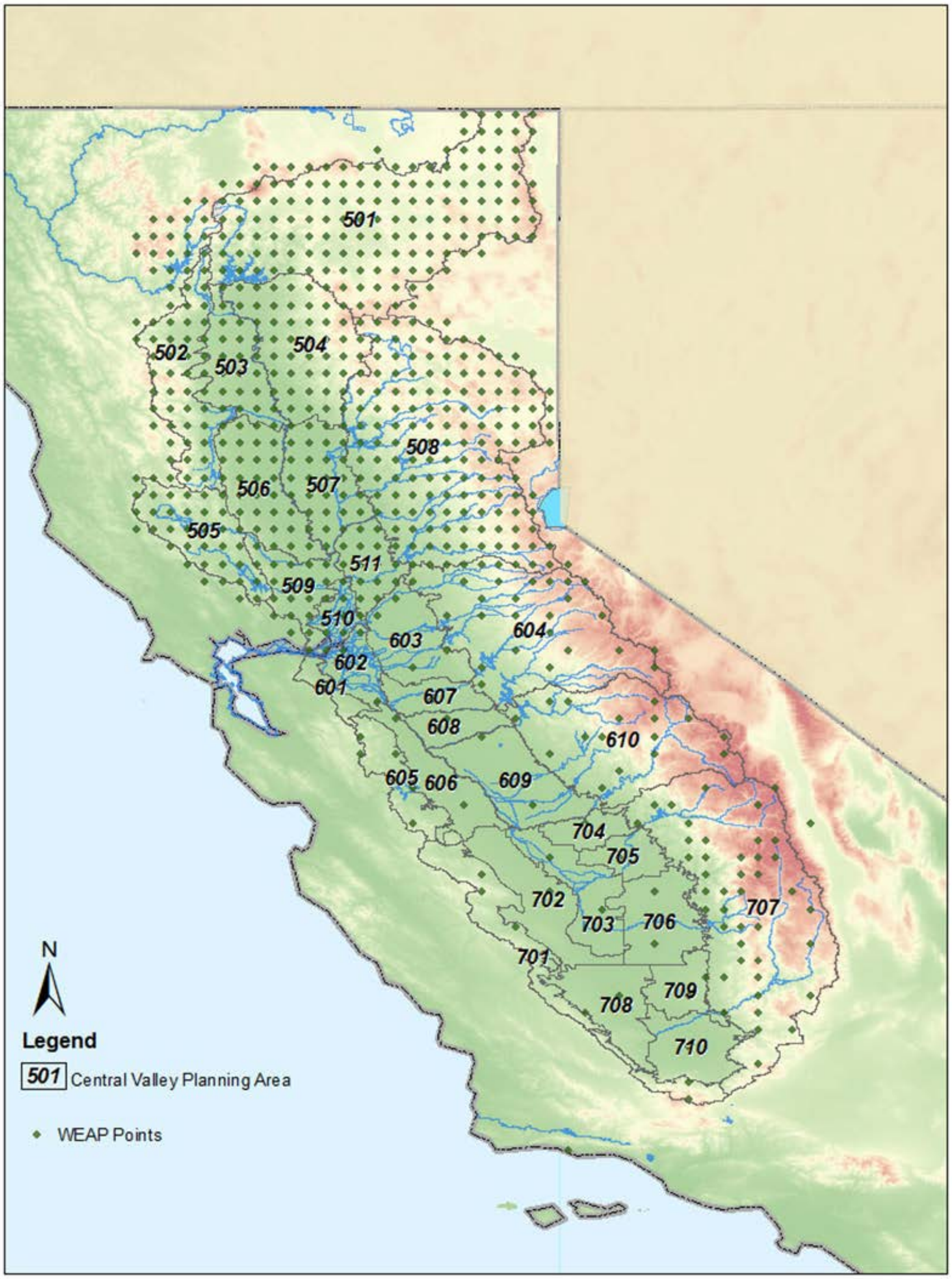


Figure 3-20. Climate Input Locations Used in the WEAP-CV Hydrologic Modeling

### *Projected Hydrologic Processes and Trends*

Consistent with the evaluation of 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.

### *Projected Streamflow*

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

- Observed Scenario, which included simulations of hydrologic conditions under historical climate.
- Future Climate – Ensemble-Informed Scenario utilized EI5 scenarios that are based on downscaled GCM projections included in the CMIP3 archives.
- Future Climate – Downscaled Climate Projections utilized 12 specific GCM projections (12 CAT) that are being used in the CWP.

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.

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, 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 method was applied to seventeen major river locations in the upper watersheds using the results of the historical WEAP-CV simulation from 1970-2003 and then applied for the NoCC scenario 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 CVP IRP CalLite 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 Supply

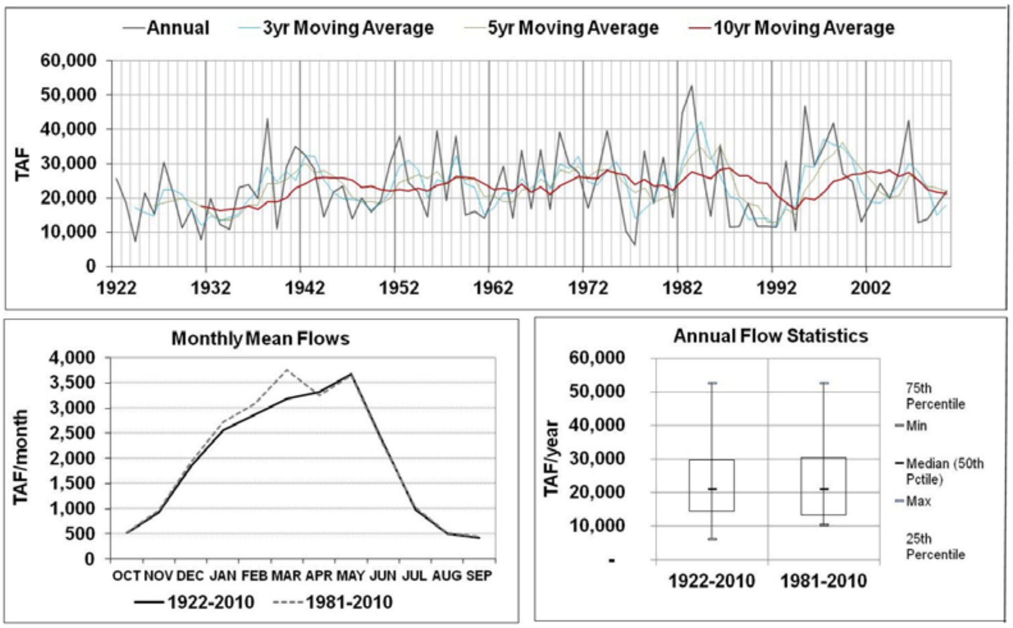
Streamflow analysis summaries (snapshots) were prepared for selected major natural flow locations in the Central Valley to evaluate the trends and variability of flows (See Section 5.1.1 subsection Streanflow and Trends). Four snapshot summaries are presented in this report for the Sacramento and San Joaquin 8 River Index, Sacramento 4 Rivers Index, San Joaquin 4 Rivers Index, and Tulare 2 Rivers Index.

The snapshot results were developed from the natural flows dataset using data for water years 1922 to 2010 (Figures 3-21 to 3-24). 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.

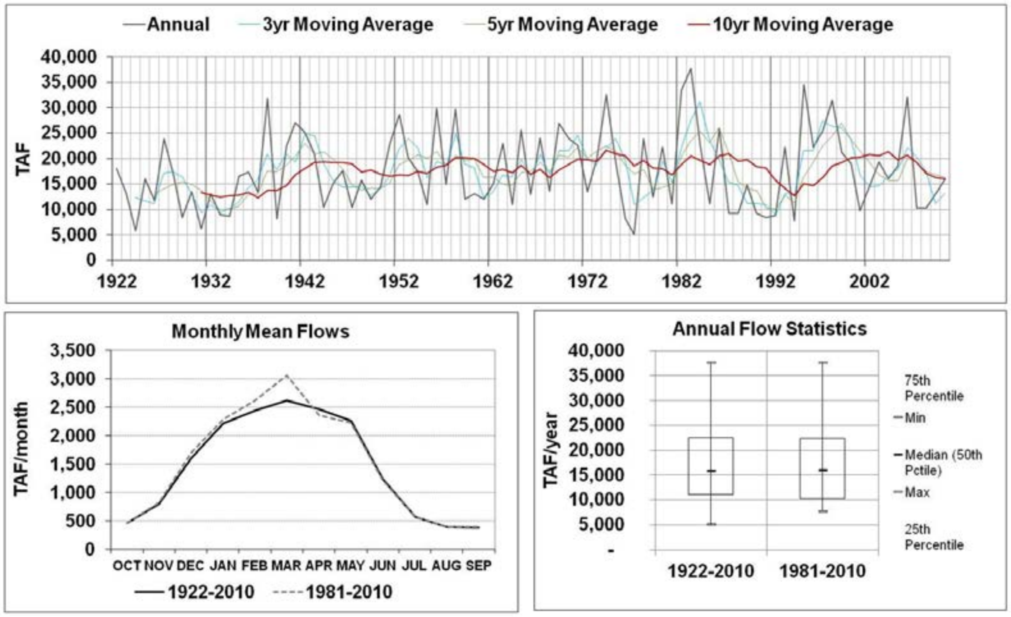
The bottom left plot shows a two-period comparison of monthly average streamflow. The first period spans 1922 to 2010, and the second period captures the more recent 30-year period (1981 to 2010). For 1981 to 2010, all selected locations exhibit slight increases in winter streamflows when compared to 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 3-21) 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.



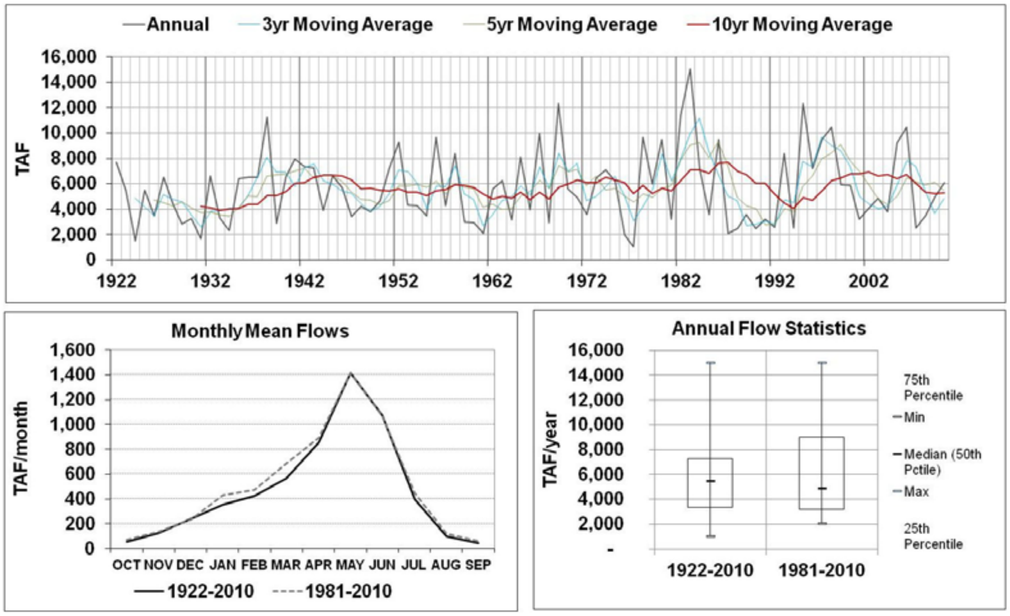
Note: The Sacramento and San Joaquin 8 River Index is the sum of streamflows of Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, American River inflow to Folsom Lake, Stanislaus River inflow to New Melones Lake, Tuolumne River inflow to New Don Pedro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

Figure 3-21. Sacramento and San Joaquin 8 River Index Natural Streamflow Snapshot Analysis



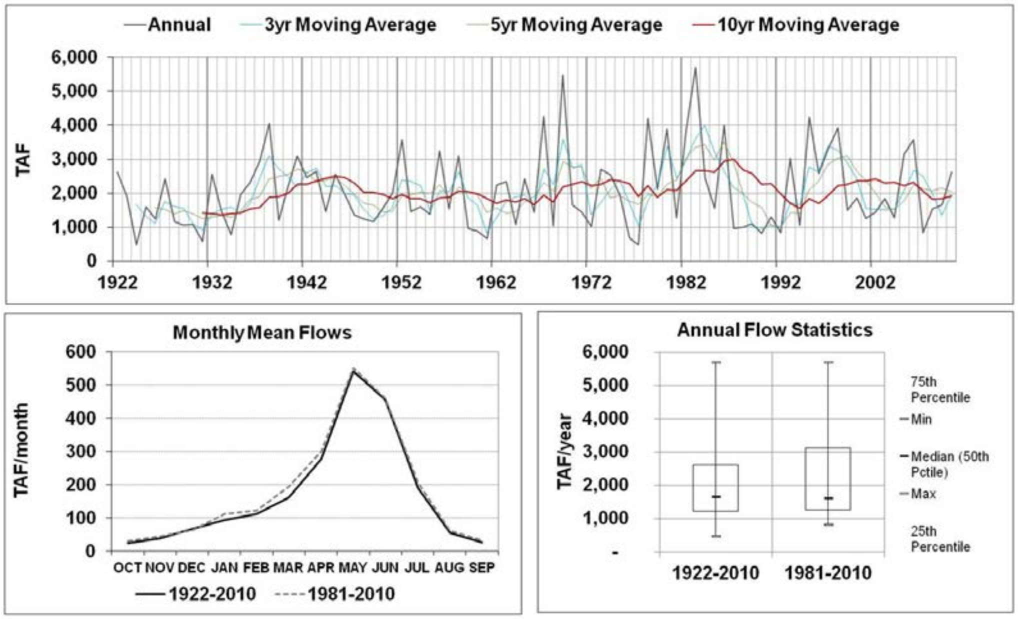
Note: The Sacramento 4 River Index is the sum of streamflows of the Sacramento River above Bend Bridge, Feather River inflow to Lake Oroville, Yuba River at Smartville, and American River inflow to Folsom Lake

Figure 3-22. 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 3-23. 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 3-24. Tulare 2 Rivers Index Natural Streamflow Snapshot Analysis

Table 3-4 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 3-4. Natural Flows Key Statistics 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 |
| **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 |

### 3.2.2 Future Projected Supply

Figures 3-25 through 3-28 show the average annual runoff 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 2012 through 2099.

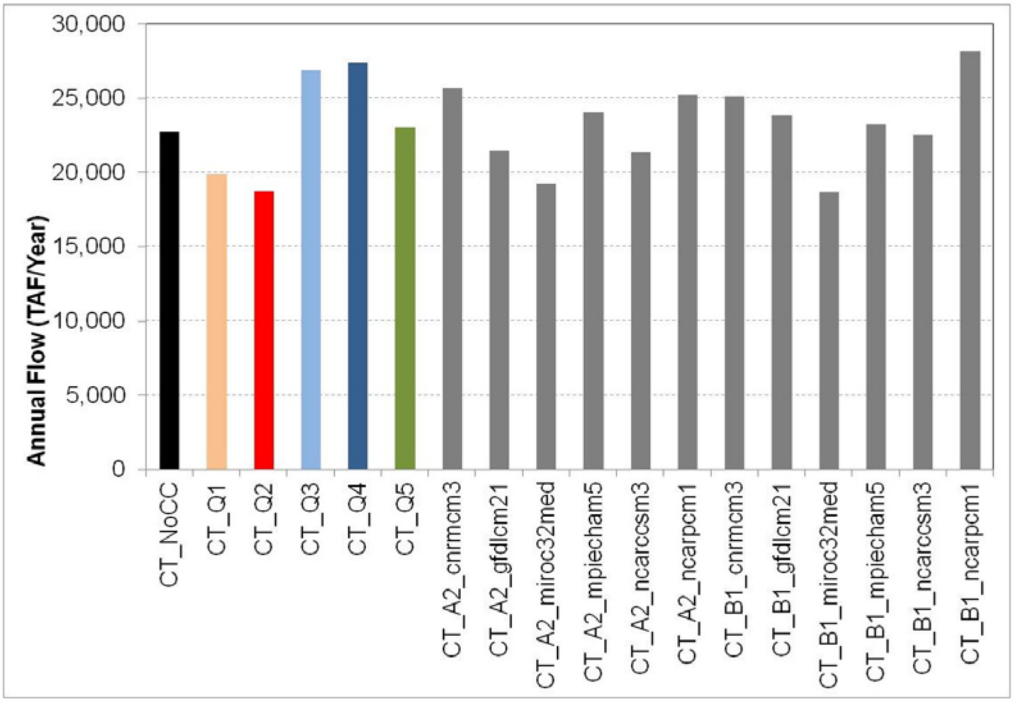


Figure 3-25. Projected Average Annual Runoff in the Sacramento River System in Each Scenario (Water Years 2012 – 2099)

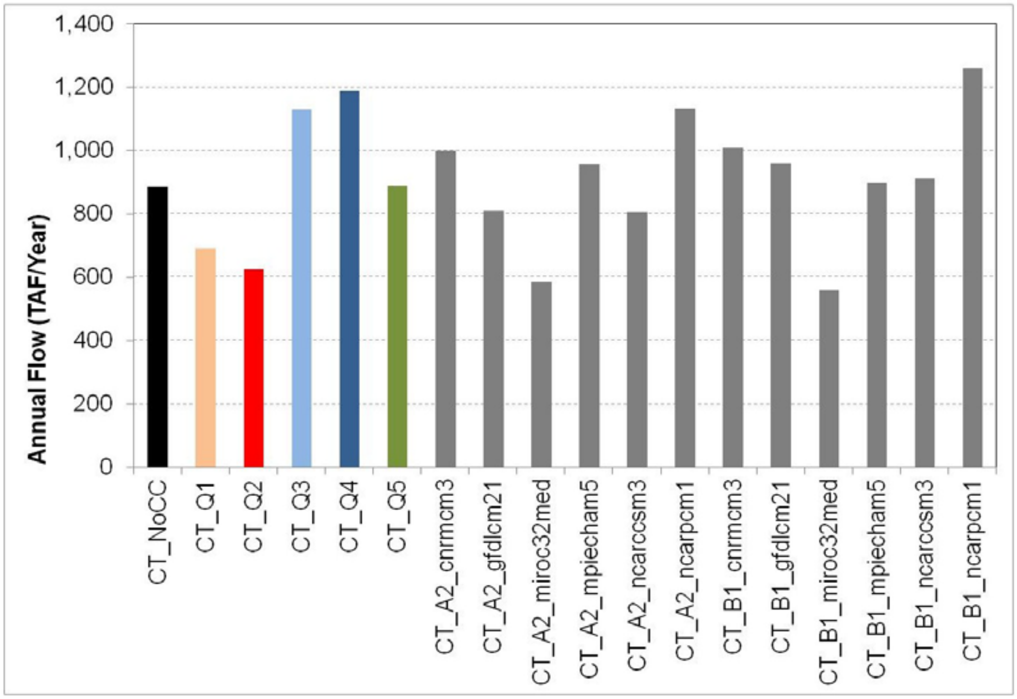


Figure 3-26. Projected Average Annual Runoff in the East Side Streams and Delta in Each Scenario (Water Years 2012 – 2099)

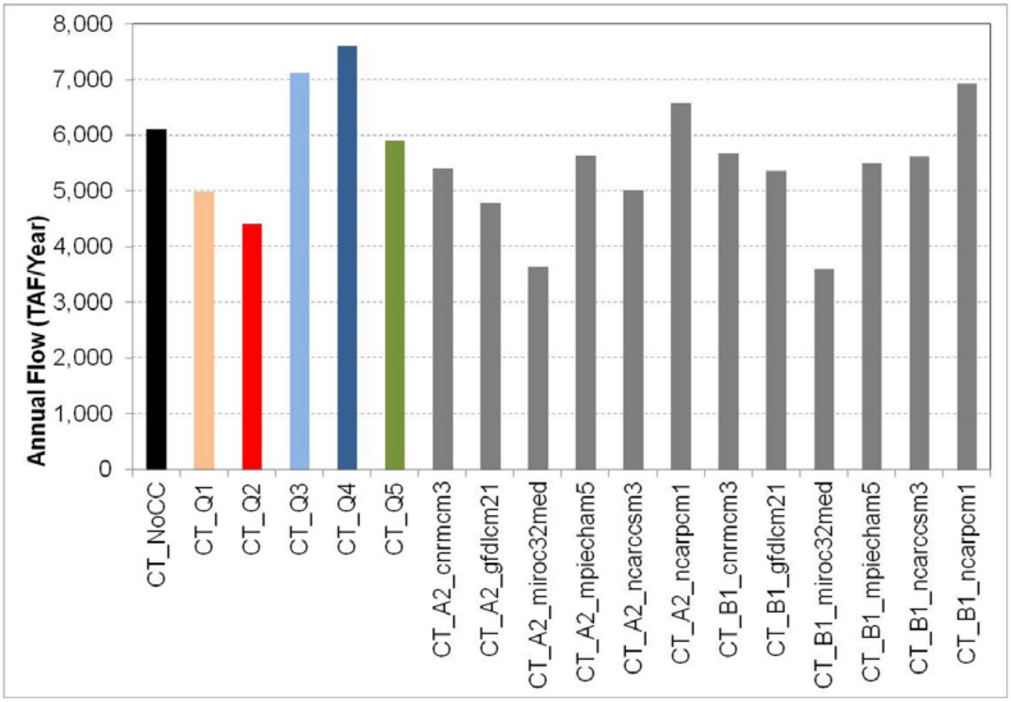


Figure 3-27. Projected Average Annual Runoff in the San Joaquin River System in Each Scenario (Water Years 2012 – 2099)

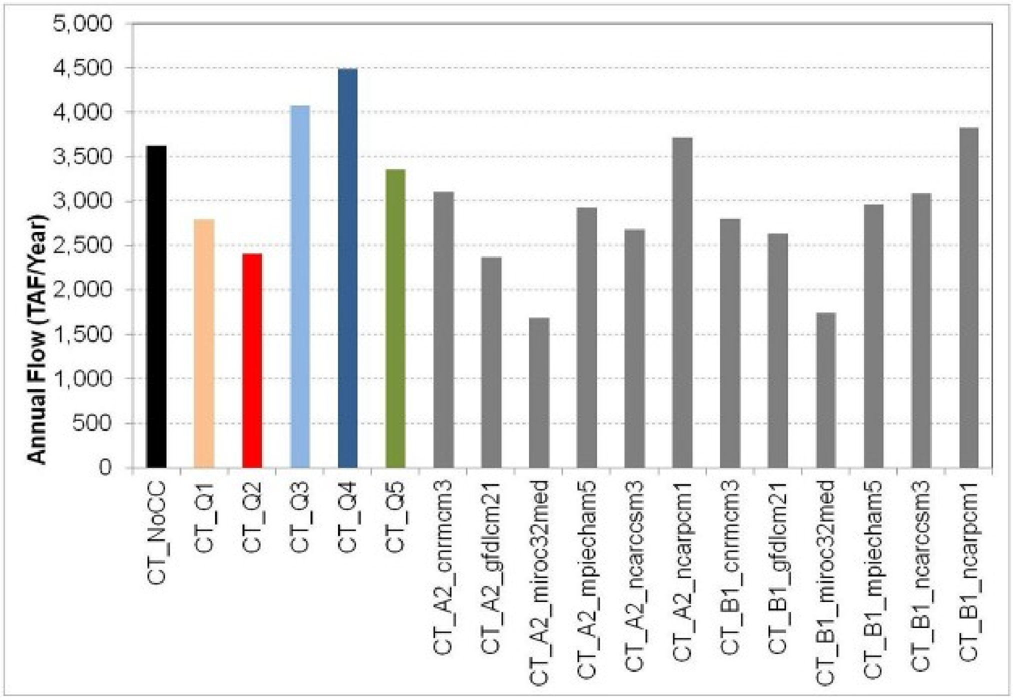


Figure 3-28. Projected Average Annual Runoff in the Tulare Lake Region in Each Scenario (Water Years 2012 – 2099)

Under the NoCC scenario, average annual runoff was about 22,739 TAF/year in the Sacramento River system; 886 TAF/year in the East Side streams and the Delta; 6,112 TAF/year in the San Joaquin River system; and 3,625 TAF/year in the Tulare Lake region, for a total of 33,364 TAF/year.

The projected central tendencies of average annual runoff in the Sacramento River system ranged from 23,050 (Q5) to 23,230 (12 CAT mean) TAF/year. The range over all 18 projected scenarios was 18,715 to 28,190 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was only slightly higher than the NoCC scenario. However, the drier climate scenarios (Q1 and Q2) had average annual runoff that was substantially lower (ranging from 13 to 18 percent) than the NoCC scenario, and the wetter climate scenarios (Q3 and Q4) had average runoff that was substantially higher (ranging from 18 to 20 percent) than the NoCC scenario. Across the range of all climate scenarios, average annual runoff ranged from 17,993 to 31,899 TAF/year for 2012-2040; 16,989 to 29,129 TAF/year for 2041-2070; and 18,372 to 28,695 TAF/year for 2071-2099.

The projected central tendencies of average annual runoff in the East Side streams and the Delta River system ranged from 888 (Q5) to 907 (12 CAT mean) TAF/year. The range over all 18 projected scenarios was 558 to 1,260 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was only slightly higher than the NoCC scenario. However, the drier climate scenarios (Q1 and Q2) had average annual runoff that was substantially lower (ranging from 22 to 30 percent) than the NoCC scenario, and the wetter climate scenarios (Q3 and Q4) had average runoff that was substantially higher (ranging from 28 to 34 percent) than the NoCC scenario. Across the range of all climate scenarios, average annual runoff ranged from 557 to 1,540 TAF/year for 2012-2040; 500 to 1,270 TAF/year for 2041-2070; and 488 to 1,355 TAF/year for 2071-2099.

The projected central tendencies of average annual runoff in the San Joaquin River system ranged from 5,899 (Q5) to 5,312 (12CAT mean) TAF/year. The range over all 18 projected scenarios was 3,604 to 7,609 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was about 4 percent lower than the NoCC scenario. However, the drier climate scenarios (Q1 and Q2) had average annual runoff that was substantially lower (ranging from 18 to 28 percent) than the NoCC scenario, and the wetter climate scenarios (Q3 and Q4) had average runoff that was substantially higher (ranging from 16.5 to 24.5 percent) than the NoCC scenario. Across the range of all climate scenarios, average annual runoff ranged from 4,370 to 8,109 TAF/year for 2012-2040; 3,196 to 7,539 TAF/year for 2041-2070; and 3,104 to 7,863 TAF/year for 2071-2099.

The projected central tendencies of average annual runoff in the Tulare Lake system ranged from 3,358 (Q5) to 2,796 (CAT mean) TAF/year. The range over all 18 projected scenarios was 1,683 to 4,487 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was about 7.4 percent lower than the NoCC scenario. However, the drier climate scenarios (Q1 and Q2) had average annual runoff that was substantially lower (ranging from 23 to 33 percent) than the NoCC scenario, and the wetter climate scenarios (Q3 and Q4) had average runoff that was substantially higher (ranging from 12 to 24 percent) than the NoCC scenario. Across the range of all climate scenarios, average annual runoff ranged from 2,356 to 4,803 TAF/year for 2012-2040; 1,496 to 4,252 TAF/year for 2041-2070; and 1,203 to 4,414 TAF/year for 2071-2099.

Figures 3-29 through 3-34 show the projected monthly pattern of inflow to the major reservoirs in the study area for the 2012-2040, 2041-2070 and 2071-2099 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 NoCC scenario, but with a shift in runoff 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.

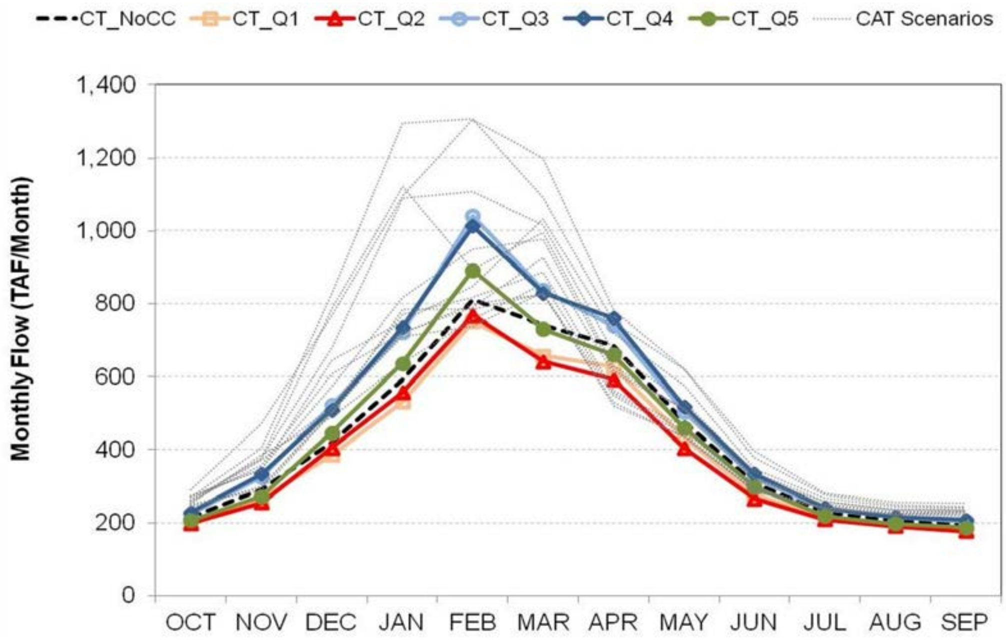


Figure 3-29a. Projected Average Runoff in Each Month into Lake Shasta in Each Climate Scenario (Long-term Average Over Water Years 2012 through 2040)

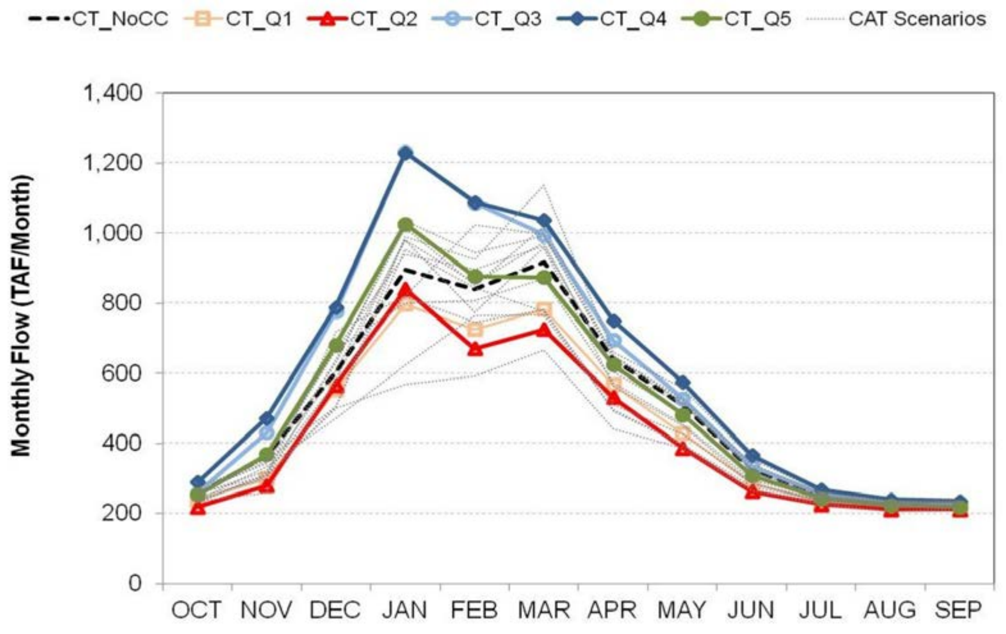


Figure 3-29b. Projected Average Runoff in Each Month into Lake Shasta in Each Climate Scenario (Long-term Average Over Water Years 2041 through 2070)

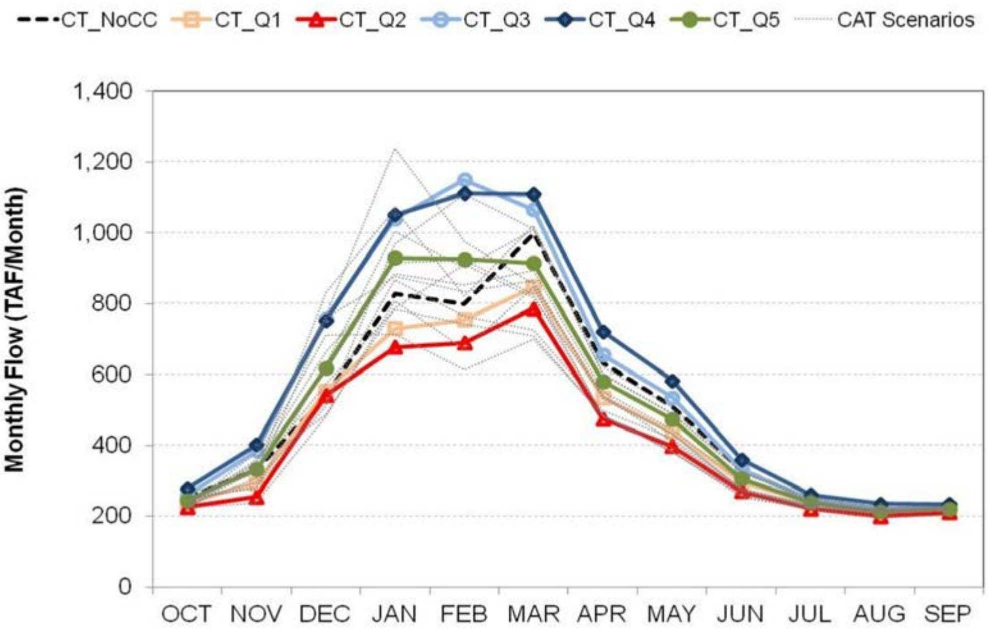


Figure 3-29c. Projected Average Runoff in Each Month into Lake Shasta in Each Climate Scenario (Long-term Average Over Water Years 2071 through 2099)

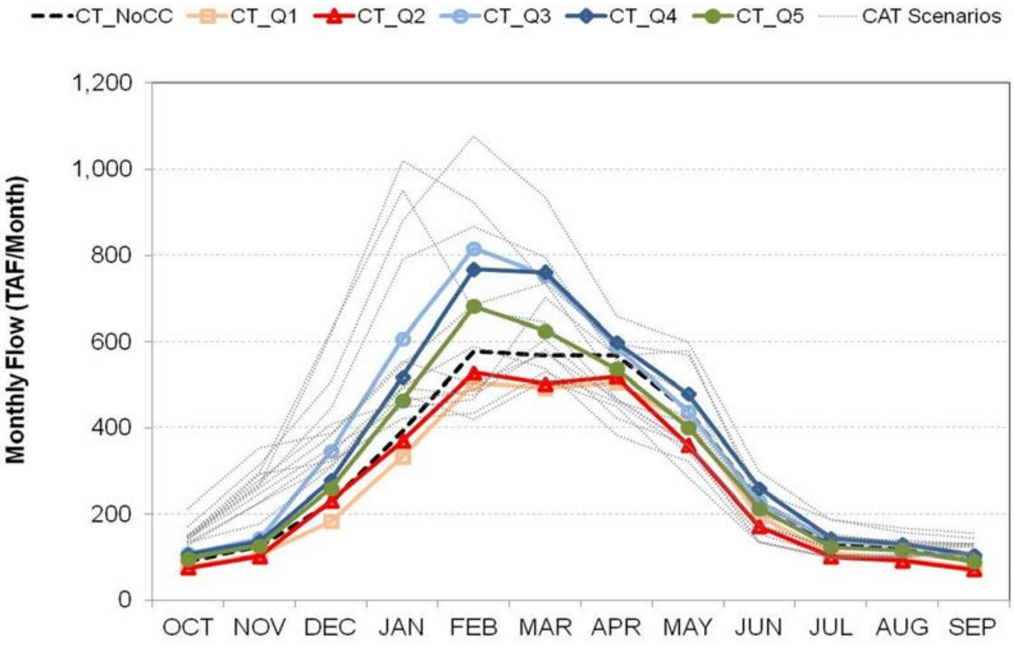


Figure 3-30a. Projected Average Runoff in Each Month into Lake Oroville in Each Climate Scenario (Long-term Average Over Water Years 2012 through 2040)

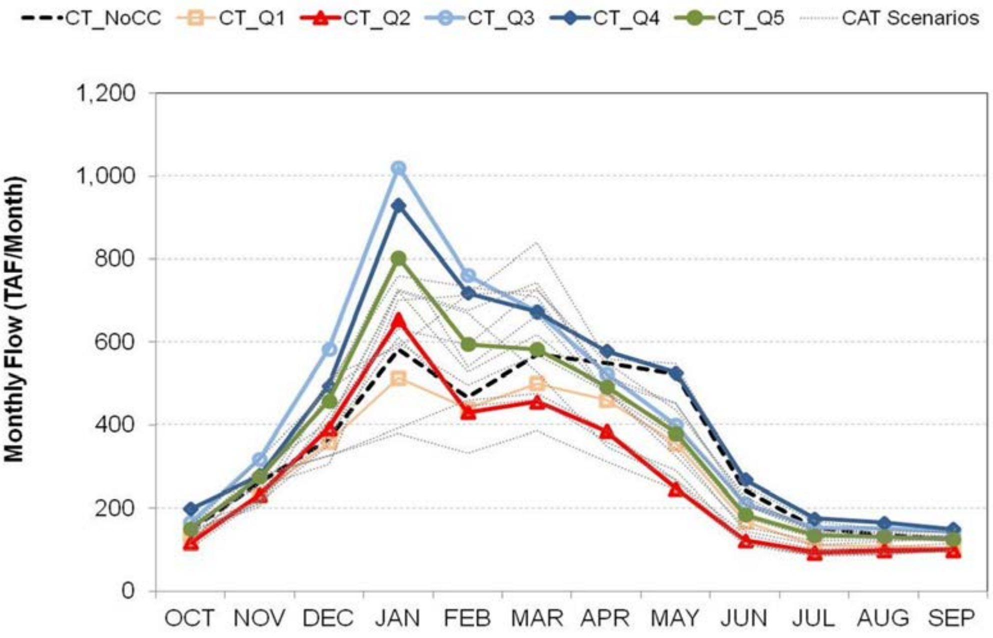


Figure 3-30b. Projected Average Runoff in Each Month into Lake Oroville in Each Climate Scenario (Long-term Average Over Water Years 2041 through 2070)

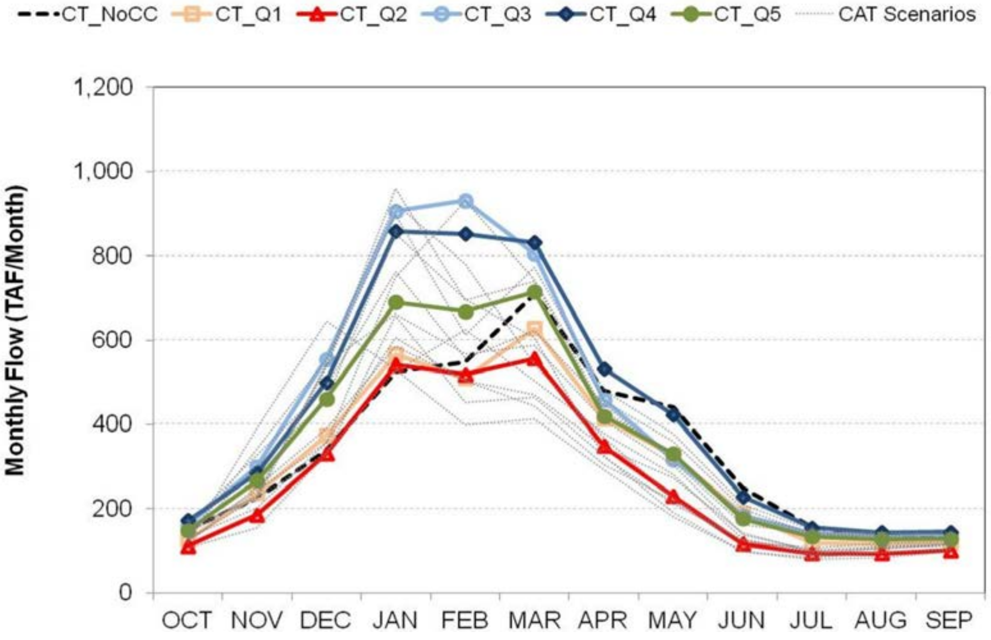


Figure 3-30c. Projected Average Runoff in Each Month into Lake Oroville in Each Climate Scenario (Long-term Average Over Water Years 2071 through 2099)

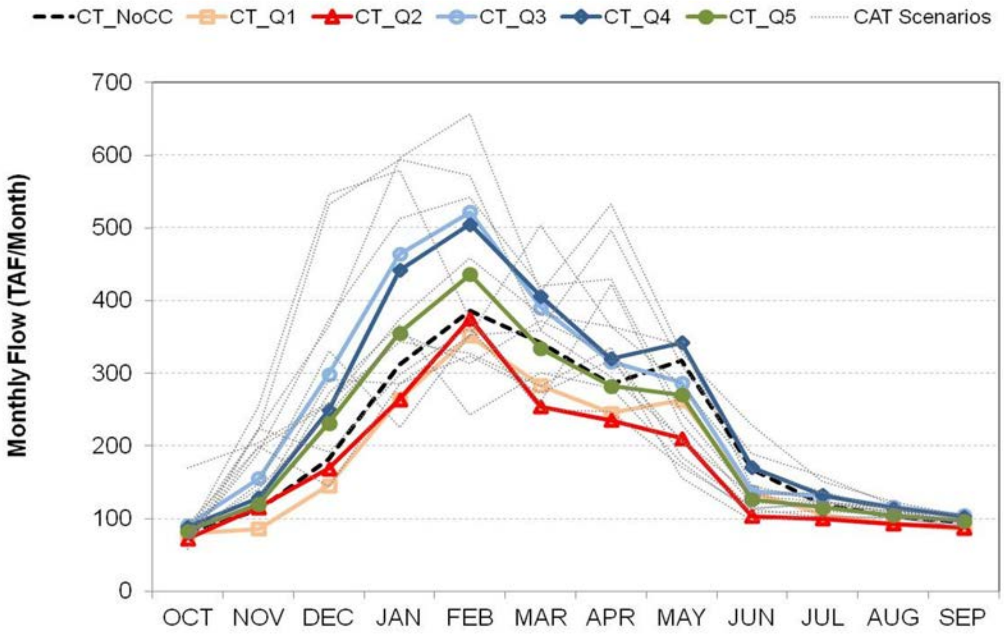


Figure 3-31a. Projected Average Runoff in Each Month into Folsom Lake in Each Climate Scenario (Long-term Average Over Water Years 2012 through 2040)

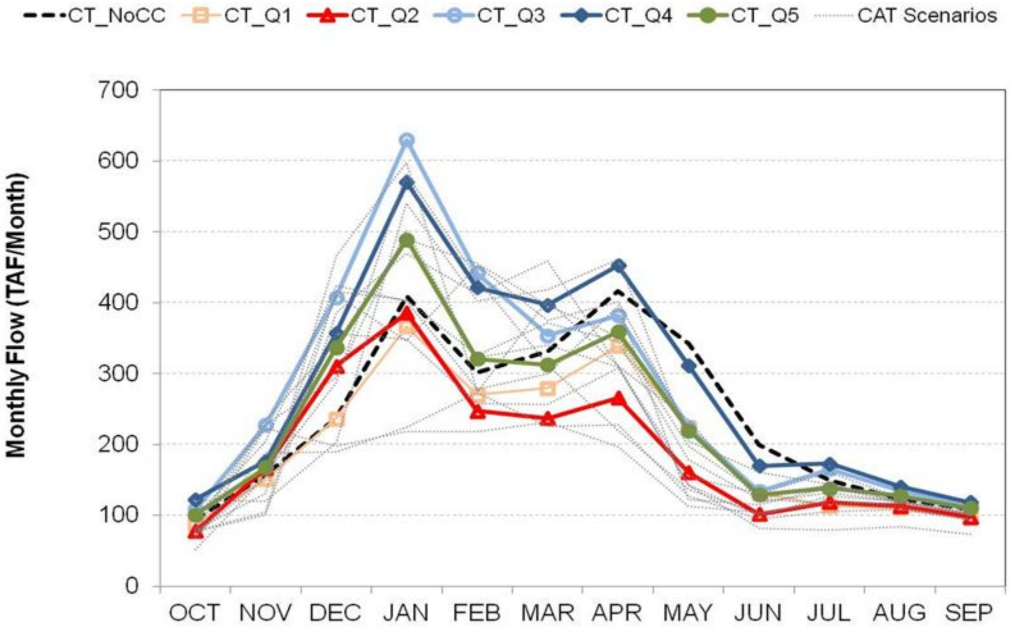


Figure 3-31b. Projected Average Runoff in Each Month into Folsom Lake in Each Climate Scenario (Long-term Average Over Water Years 2041 through 2070)

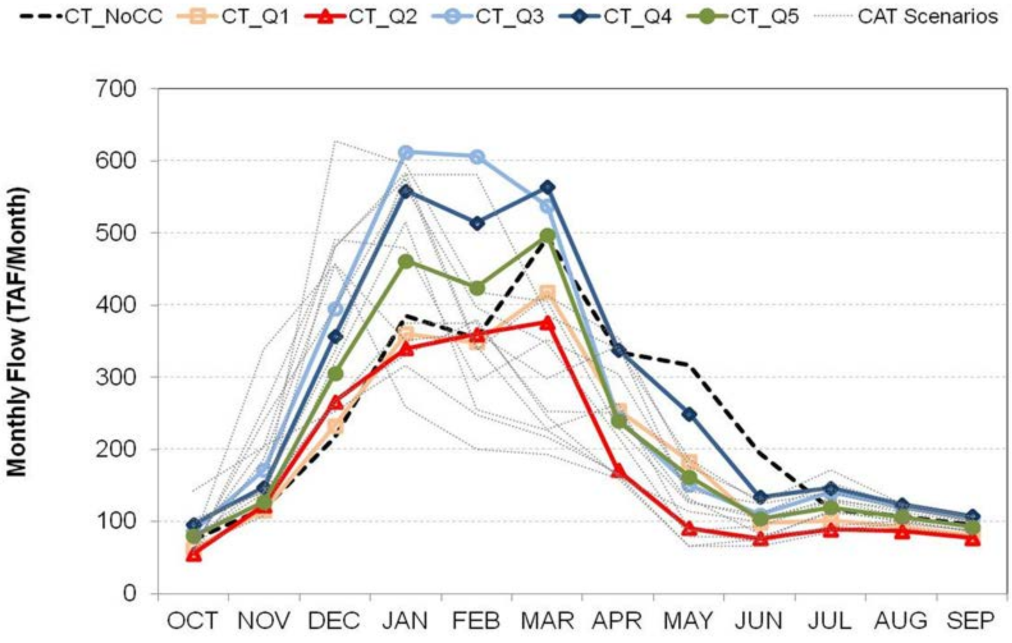


Figure 3-31c. Projected Average Runoff in Each Month into Folsom Lake in Each Climate Scenario (Long-term Average Over Water Years 2071 through 2099)

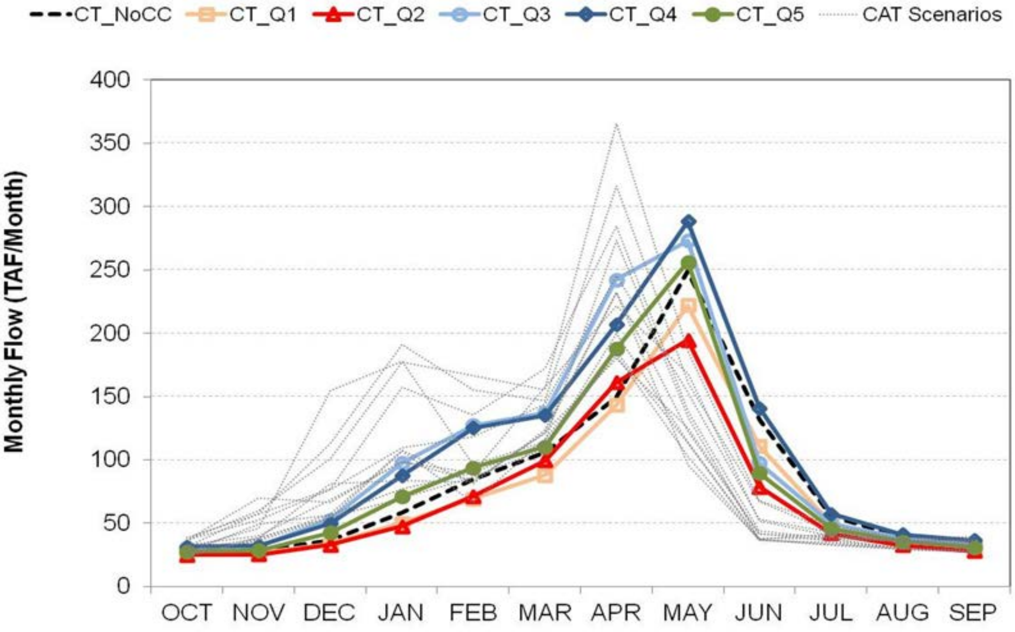


Figure 3-32a. Projected Average Runoff in Each Month into New Melones Reservoir in Each Climate Scenario (Long-term Average Over Water Years 2012 through 2040)

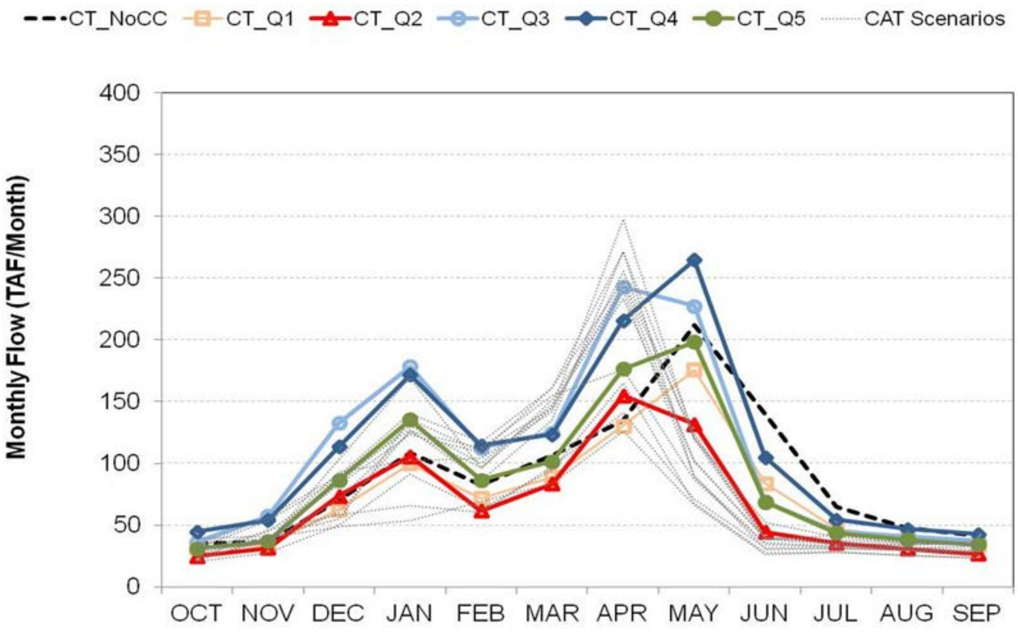


Figure 3-32b. Projected Average Runoff in Each Month into New Melones Reservoir in Each Climate Scenario (Long-term Average Over Water Years 2041-2070)

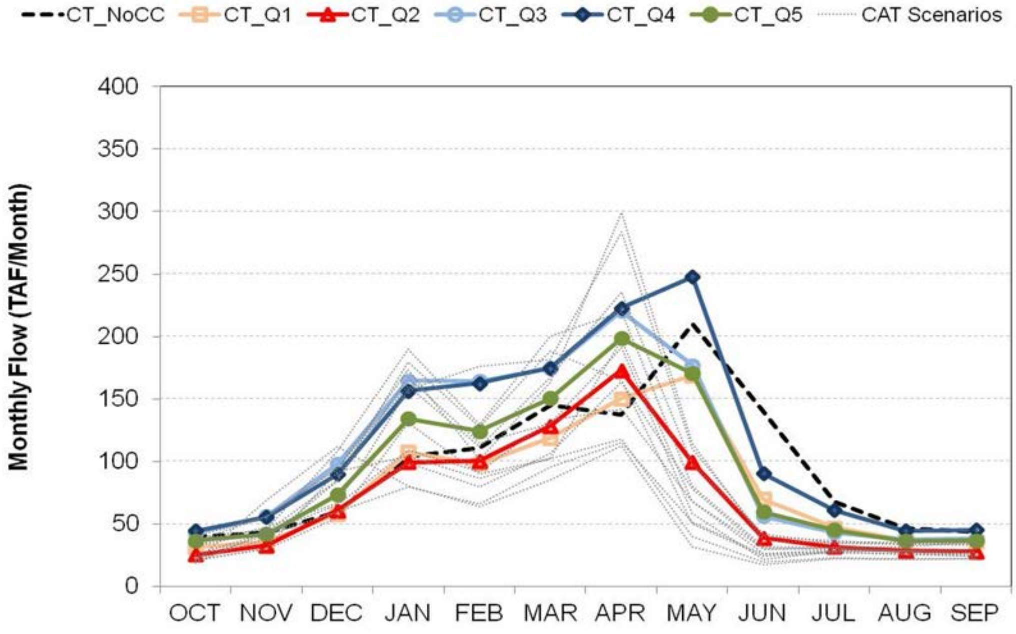


Figure 3-32c. Projected Average Runoff in Each Month into New Melones Reservoir in Each Climate Scenario (Long-term Average Over Water Years 2071-2099)

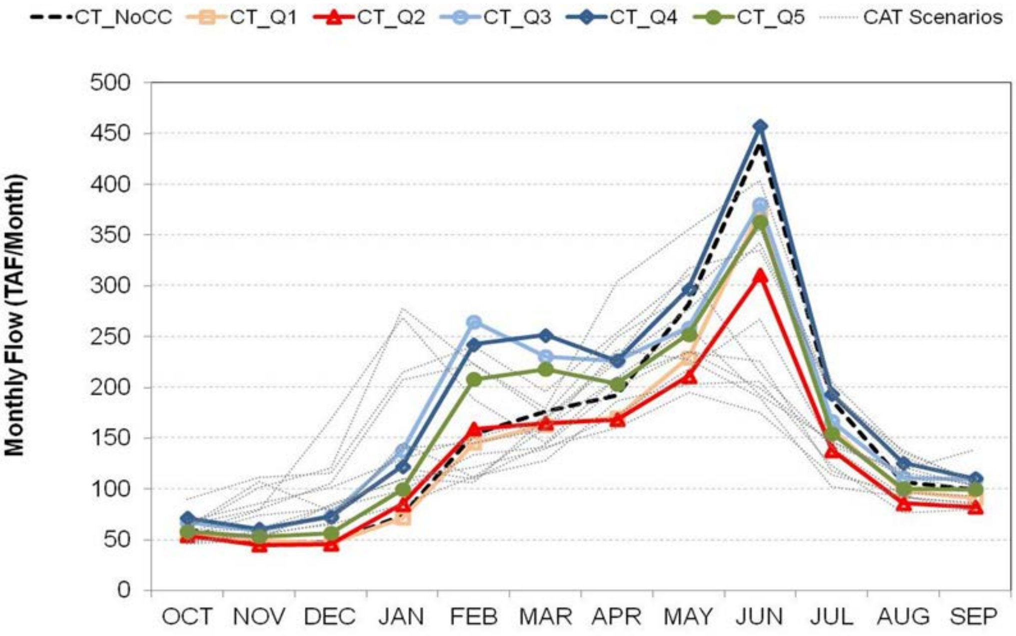


Figure 3-33a. Projected Average Runoff in Each Month into Millerton Lake in Each Climate Scenario (Long-term Average Over Water Years 2012-2040)

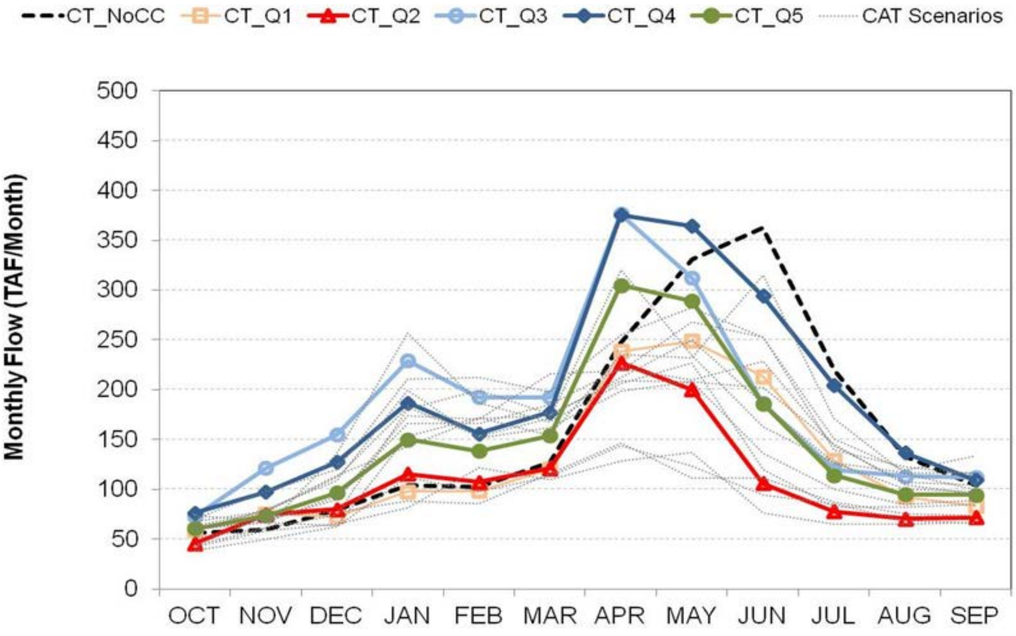


Figure 3-33b. Projected Average Runoff in Each Month into Millerton Lake in Each Climate Scenario (Long-term Average Over Water Years 2041-2070)

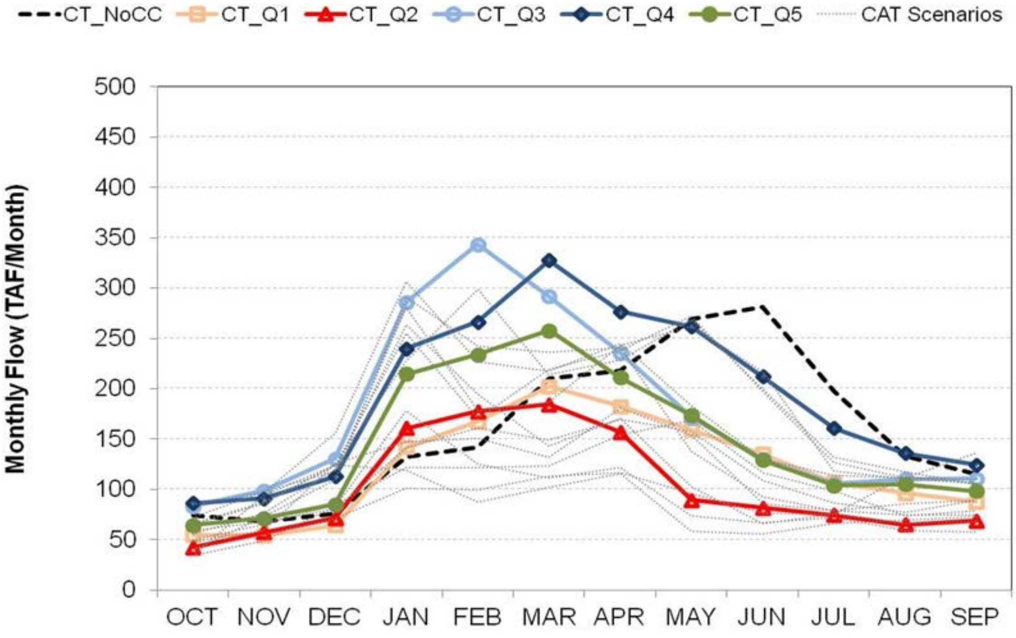


Figure 3-33c. Projected Average Runoff in Each Month into Millerton Lake in Each Climate Scenario (Long-term Average Over Water Years 2071-2099)

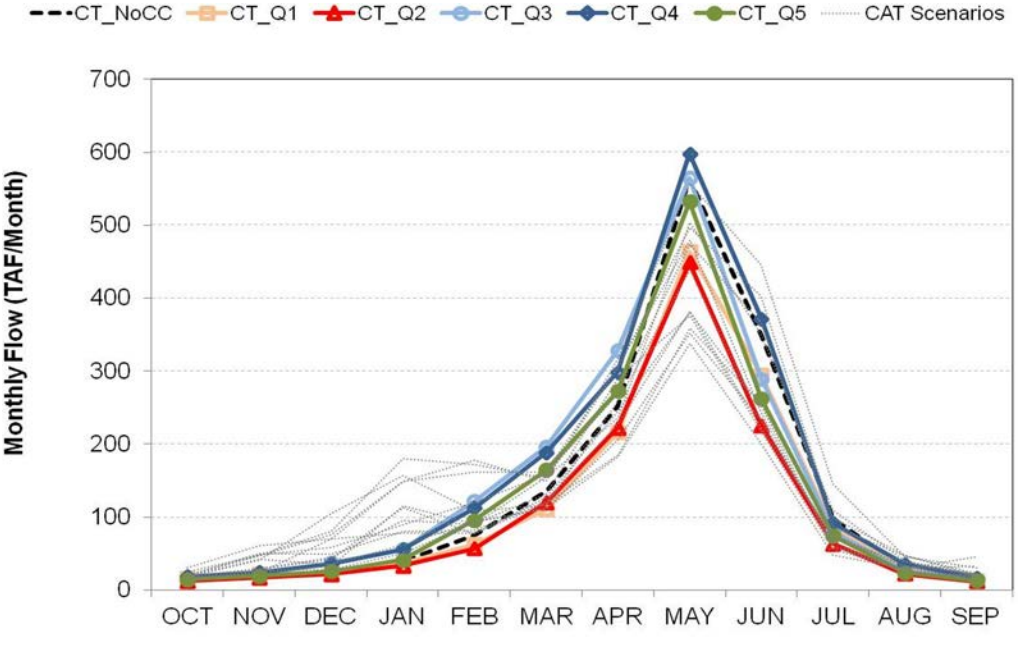


Figure 3-34a. Projected Average Runoff in Each Month into Pine Flat in Each Climate Scenario (Long-term Average Over Water Years 2012-2040)

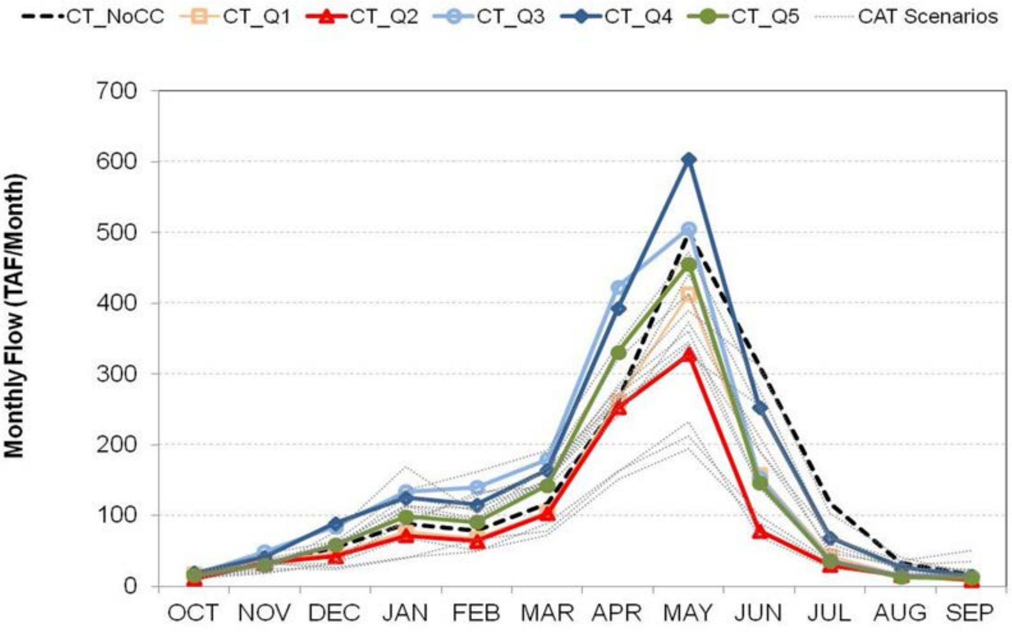


Figure 3-34b. Projected Average Runoff in Each Month into Pine Flat in Each Climate Scenario (Long-term Average Over Water Years 2041-2070)

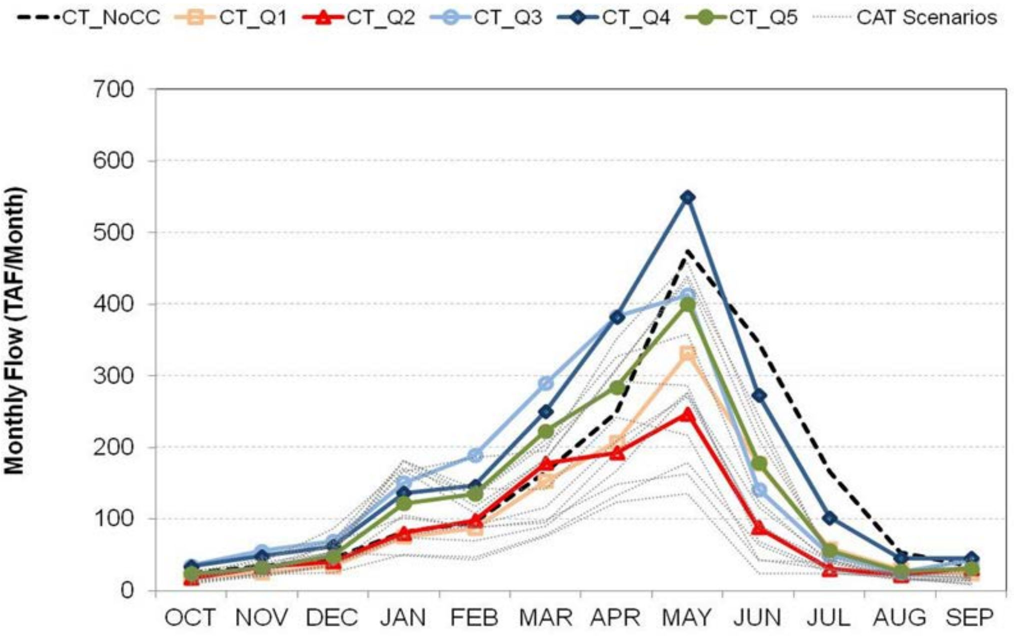


Figure 3-34c. Projected Average Runoff in Each Month into Pine Flat in Each Climate Scenario (Long-term Average Over Water Years 2071-2090)

Figures 3-35 through 3-38 show the projected annual time series of runoff in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region under each of Current Trends scenarios in water years 2012 through 2099. The EI future time series 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 runoff values from 2025 to 2030 (corresponding to the 1929–1934 dry period) and from 2083 to 2088 (corresponding to the 1987–1992 drought), and a very substantial dry period from 2072 to 2073 (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 CAT scenarios, the inter-annual variability is not constrained by the historic climate variability. For these projections, climate variability results from the representation of physical characteristics of the land surface, ocean and atmospheric processes and initial conditions, GHG emissions scenarios and computational methods used for the individual GCM simulations.

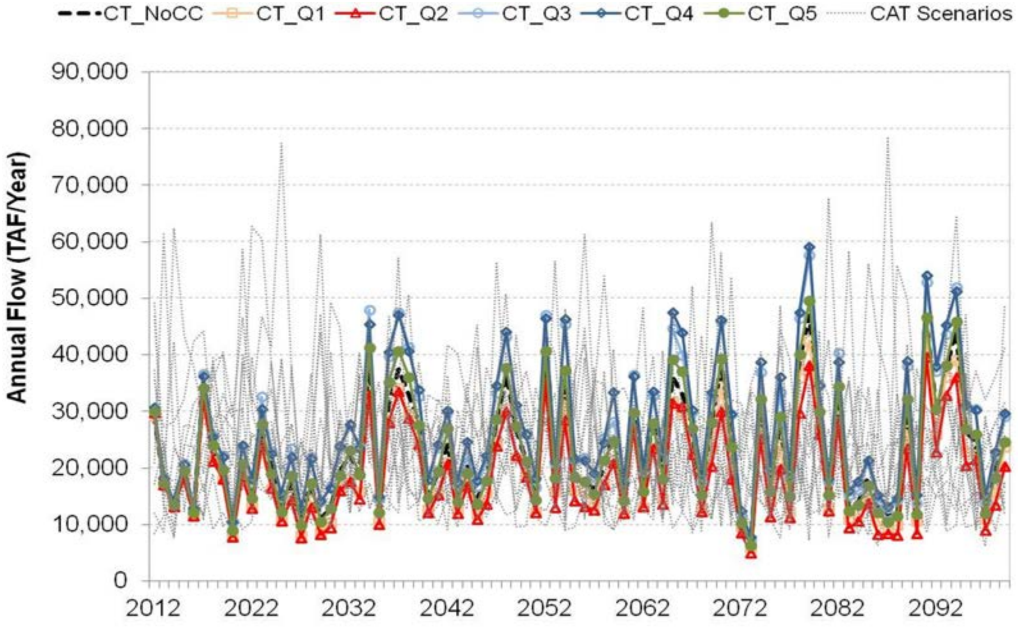


Figure 3-35. Annual Time Series of Runoff in the Sacramento River System in Each Climate Scenario

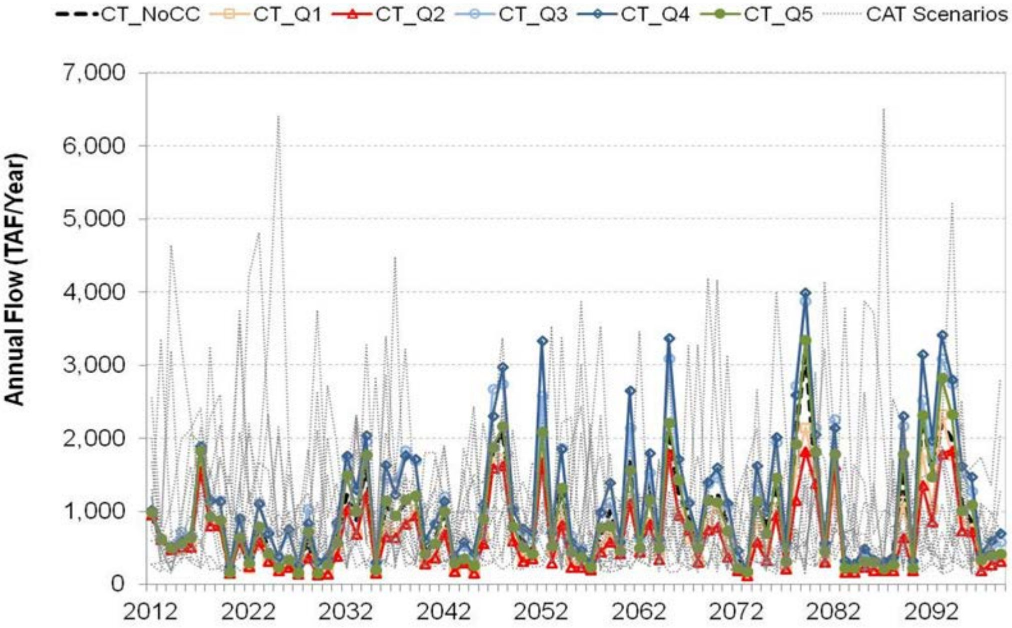


Figure 3-36. Projected Annual Time Series of Runoff in the East Side Streams and Delta in Each Climate Scenario

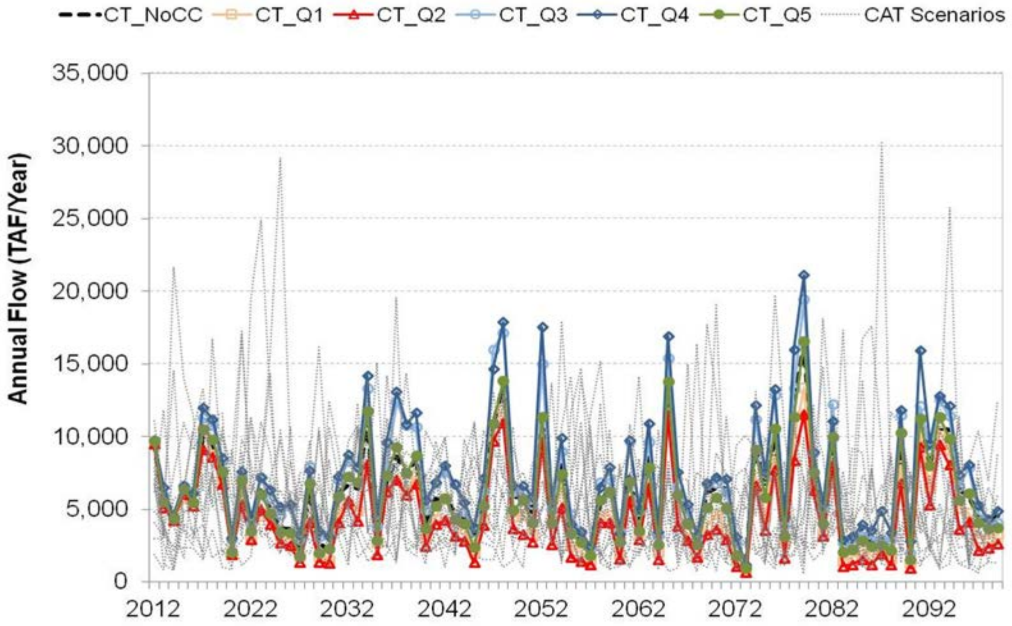


Figure 3-37. Projected Annual Time Series of Runoff in the San Joaquin River System in Each Climate Scenario

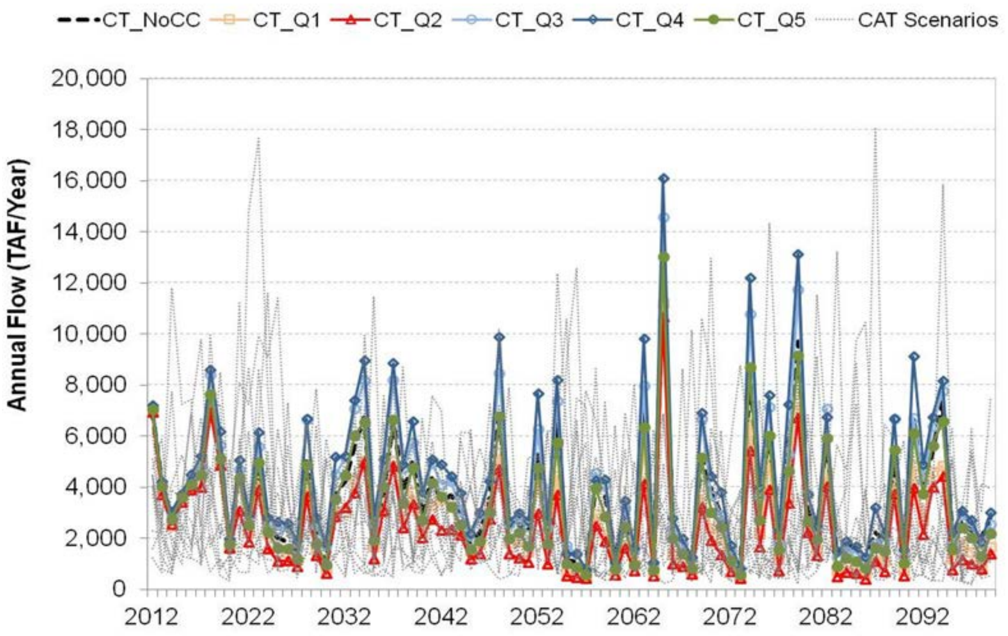


Figure 3-38. Projected Annual Time Series of Runoff in the Tulare Lake Region in Each Climate Scenario

Table 3-5 summarizes 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 (2012-2040, 2041-2070, 2071-2099, and 2012-2099) relative to the simulated no climate change (NoCC) scenario based on Livneh et al. (2013) historical observed climate data.

Table 3-5. Summary of Annual Streamflow Changes (%) in the Sacramento River System, Eastside Streams and Delta, San Joaquin River System, and Tulare Lake Region (2012–2040, 2041–2070, 2071-2099, and 2012–2099)

| | Q1 | Q2 | Q3 | Q4 | Q5 |
|---|---|---|---|---|---|
| **Sacramento River System** | | | | | |
| 2012-2040 | -11.4 | -12.7 | 18.6 | 17.8 | 2.3 |
| 2041-2070 | -14.6 | -18.2 | 18.2 | 21.9 | 1.2 |
| 2071-2099 | -11.8 | -21.3 | 17.9 | 21.2 | 0.8 |
| 2012-2099 | -12.7 | -17.6 | 18.2 | 20.4 | 1.4 |
| **Eastside Streams and Delta** | | | | | |
| 2012-2040 | -18.2 | -20.7 | 33.1 | 33.2 | 3.8 |
| 2041-2070 | -24.1 | -30.3 | 26.0 | 35.0 | -3.7 |
| 2071-2099 | -22.8 | -35.1 | 24.9 | 33.5 | 1.6 |
| 2012-2099 | -22.1 | -29.6 | 27.5 | 34.0 | 0.2 |
| **San Joaquin River System** | | | | | |
| 2012-2040 | -13.3 | -18.8 | 19.4 | 25.7 | 1.2 |
| 2041-2070 | -19.7 | -31.2 | 18.6 | 25.1 | -6.0 |
| 2071-2099 | -21.6 | -33.0 | 11.7 | 22.8 | -5.3 |
| 2012-2099 | -18.4 | -27.9 | 16.5 | 24.5 | -3.5 |
| **Tulare Lake Region** | | | | | |
| 2012-2040 | -14.9 | -21.3 | 15.4 | 23.0 | -2.0 |
| 2041-2070 | -24.2 | -38.2 | 13.3 | 25.0 | -10.4 |
| 2071-2099 | -30.5 | -42.0 | 8.3 | 23.4 | -10.3 |
| 2012-2099 | -22.9 | -33.4 | 12.4 | 23.8 | -7.4 |

| | A2_cnrm cm3 | A2_gfdl cm21 | A2_miroc32 med | A2_mpie cham5 | A2_ncarc csm3 | A2_ncarp cm1 |
|---|---|---|---|---|---|---|
| **Sacramento River System** | | | | | | |
| 2012-2040 | 52.4 | 8.8 | -2.2 | 7.7 | -5.1 | 17.5 |
| 2041-2070 | -11.4 | -1.8 | -23.0 | 3.0 | -8.7 | 6.6 |
| 2071-2099 | 4.6 | -22.4 | -18.7 | 7.3 | -4.2 | 9.7 |
| 2012-2099 | 13.1 | -5.7 | -15.3 | 5.9 | -6.1 | 10.9 |
| **Eastside Streams and Delta** | | | | | | |
| 2012-2040 | 111.6 | 23.2 | -1.7 | 12.9 | -0.1 | 53.6 |
| 2041-2070 | -30.3 | 4.9 | -44.7 | -1.6 | -11.3 | 20.4 |
| 2071-2099 | -14.7 | -44.2 | -46.2 | 13.5 | -12.9 | 17.3 |
| 2012-2099 | 12.6 | -8.8 | -34.1 | 7.9 | -9.0 | 27.9 |
| **San Joaquin River System** | | | | | | |
| 2012-2040 | 31.1 | -11.1 | -25.0 | -17.7 | -20.3 | 6.8 |
| 2041-2070 | -40.6 | -5.8 | -46.9 | -7.2 | -17.2 | 9.9 |
| 2071-2099 | -23.0 | -47.1 | -48.3 | 0.8 | -16.5 | 6.5 |
| 2012-2099 | -11.7 | -21.7 | -40.4 | -7.8 | -17.9 | 7.7 |

| | A2_cnrm cm3 | A2_gfdl cm21 | A2_miroc32 med | A2_mpie cham5 | A2_ncarc csm3 | A2_ncarp cm1 |
|---|---|---|---|---|---|---|
| **Tulare Lake Region** | | | | | | |
| 2012-2040 | 13.8 | -30.2 | -39.7 | -32.9 | -31.3 | -10.0 |
| 2041-2070 | -36.7 | -17.5 | -56.0 | -15.0 | -22.6 | 10.7 |
| 2071-2099 | -23.1 | -55.8 | -66.3 | -8.9 | -23.9 | 7.7 |
| 2012-2099 | -14.3 | -34.4 | -53.6 | -19.4 | -26.1 | 2.4 |

| | B1_cnrm cm3 | B1_gfdl cm21 | B1_miroc 32med | B1_mpie cham5 | B1_ncarc csm3 | B1_ncarp cm1 |
|---|---|---|---|---|---|---|
| **Sacramento River System** | | | | | | |
| 2012-2040 | 32.6 | 29.3 | -1.9 | 18.3 | 0.1 | 54.8 |
| 2041-2070 | 6.8 | 0.0 | -28.9 | 6.9 | -4.4 | 10.9 |
| 2071-2099 | -4.8 | -11.7 | -19.7 | -16.1 | 1.9 | 10.8 |
| 2012-2099 | 10.5 | 4.7 | -17.7 | 2.4 | -0.9 | 24.0 |
| **Eastside Streams and Delta** | | | | | | |
| 2012-2040 | 76.5 | 76.5 | -2.1 | 39.8 | 7.1 | 119.5 |
| 2041-2070 | 5.5 | 1.4 | -46.9 | 13.8 | -0.2 | 14.4 |
| 2071-2099 | -21.4 | -32.3 | -51.9 | -36.9 | 2.9 | 15.1 |
| 2012-2099 | 13.9 | 8.3 | -37.1 | 1.4 | 2.9 | 42.1 |
| **San Joaquin River System** | | | | | | |
| 2012-2040 | 17.0 | 11.0 | -26.1 | 2.5 | -17.8 | 37.2 |
| 2041-2070 | -5.2 | -8.0 | -44.4 | 2.1 | -5.6 | 0.8 |
| 2071-2099 | -31.1 | -37.7 | -51.5 | -33.9 | -1.8 | 3.4 |
| 2012-2099 | -7.1 | -12.2 | -41.0 | -10.2 | -8.2 | 13.3 |
| **Tulare Lake Region** | | | | | | |
| 2012-2040 | -9.0 | -13.1 | -37.8 | -9.4 | -27.6 | 18.5 |
| 2041-2070 | -16.7 | -20.1 | -54.6 | -2.0 | -7.8 | -0.8 |
| 2071-2099 | -43.0 | -49.6 | -64.9 | -44.1 | -7.5 | -2.1 |
| 2012-2099 | -22.5 | -27.2 | -52.0 | -18.3 | -14.7 | 5.6 |

# 4.0 Water Demand Assessment

The water demand assessment was performed for the eighteen socioeconomic-climate scenarios developed using the scenario planning approach are described in Section 4. This section provides a quantitative evaluation of recent historical and projected future agricultural and urban demands for the eighteen socioeconomic-climate scenarios 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 the historical years of 1998 through 2005. This information had already been incorporated into the WEAP-CV and CVP IRP CalLite models during previous Reclamation projects. For the Impact Assessment, the information was reviewed and a WEAP-CV simulation was performed for water years 1950 through 2003, reflecting current population and land use and historical hydrology to assess the variability of recent historical demands in the Central Valley.

Additionally, historical water use and trends, geographic and sector-based demand trends, and trends in water use efficiency and urban and agricultural footprints were assessed.

### 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. Following are some 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

The development of scenarios that reasonably bracket a range of potential future water demands had been addressed in previous planning studies. For the Impact Assessment, the water demand scenario was selected from the three scenarios that Reclamation and DWR developed for the CVP IRP (Reclamation 2013) and CWP (California Department of Water Resources 2009). These projects used three socioeconomic future scenarios:

- **Current Trends**, which assumes that recent trends will to continue into the future
- **Slow Growth**, which assumes that future development is less resource intensive than under recent conditions
- **Expansive Growth**, which assumes that future development is more resource intensive than under recent conditions

A review of the CVP IRP results showed limited sensitivity of agricultural water demands to different socioeconomic scenarios. In contrast, urban water demands show limited sensitivity to climate projections. Therefore, the Impact Assessment used the Current Trends scenario to reflect the mid-range of future changes in population and land use changes in combination with the eighteen future climate projections to characterize a reasonably wide range of future water demands.

The WEAP-CV model was used to develop climate-based demand estimates for the Bay-Delta, Sacramento, San Joaquin, and Tulare Lake hydrologic regions. The model includes a plant growth module that incorporates climatic inputs into the computation of agricultural demands. The WEAP-CV model was run one time for each of the socioeconomic-climate scenarios for water years 2012 through 2099. Each scenario was simulated using a transient approach in which the climate and socioeconomic factors gradually change as the simulation progresses through time. As previously described in Section 3, the climate-based demand results produced by WEAP-CV are used as inputs to the CVP IRP CalLite model to perform the system risk and reliability assessment presented in Section 7.

## 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 2005. In the Central Valley, agricultural demand ranged from 18,752 to 26,221 TAF/year during this period, while urban demand ranged from 1,794 TAF/year to 2,351 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)

| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|---|---|
| **Sacramento River Hydrologic Region** | | | | | | | | |
| Agricultural | 5,841 | 7,828 | 7,927 | 7,782 | 8,020 | 7,078 | 8,503 | 6,968 |
| Urban | 718 | 763 | 851 | 869 | 906 | 882 | 915 | 803 |
| Total | 6,559 | 8,591 | 8,778 | 8,650 | 8,926 | 7,960 | 9,418 | 7,771 |
| **San Joaquin River Hydrologic Region** | | | | | | | | |
| Agricultural | 5,079 | 7,069 | 6,556 | 6,794 | 7,139 | 6,568 | 7,059 | 6,123 |
| Urban | 541 | 580 | 583 | 609 | 574 | 596 | 617 | 631 |
| Total | 5,620 | 7,649 | 7,139 | 7,403 | 7,713 | 7,163 | 7,675 | 6,755 |
| **Tulare Lake Hydrologic Region** | | | | | | | | |
| Agricultural | 7,831 | 10,138 | 10,006 | 9,976 | 10,514 | 9,969 | 10,659 | 9,298 |
| Urban | 535 | 592 | 638 | 664 | 683 | 770 | 819 | 704 |
| Total | 8,367 | 10,730 | 10,643 | 10,640 | 11,197 | 10,739 | 11,479 | 10,002 |
| **Total Central Valley** | | | | | | | | |
| Agricultural | 18,752 | 25,036 | 24,489 | 24,552 | 25,673 | 23,615 | 26,221 | 22,390 |
| Urban | 1,794 | 1,935 | 2,072 | 2,141 | 2,162 | 2,248 | 2,351 | 2,138 |
| Total | 20,545 | 26,970 | 26,561 | 26,693 | 27,836 | 25,862 | 28,572 | 24,528 |

Source: DWR, 2009

The time varying trend of recent historical demands in the Central Valley were estimated using the results of a WEAP-CV simulation that was performed for October 1949 through September 2003, reflecting current population and land use and historical hydrology. The WEAP-CV simulation was performed with historical hydrology for that period, but with year 2005 levels of population and land use in each DWR Planning Area. Table 4-2 shows the average annual agricultural and urban demand in each region. The total Central Valley agricultural demand ranged from 16,000 TAF/year to 33,000 TAF/year, reflecting year-to-year variability in precipitation and temperature over the historical period. The urban demand was fairly consistent at about 2,000 TAF/year.

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

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

Figures 4-1 through 4-5 show the annual time series of 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 for the historical period of water years from 1950 through 2003. Because population and land use do not change over time in this particular historical period simulation, the year-to-year variability in demand was due to changes in annual temperature, precipitation, temperature, and other meteorological conditions affecting evapotranspiration (ET) in the historical record. 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.

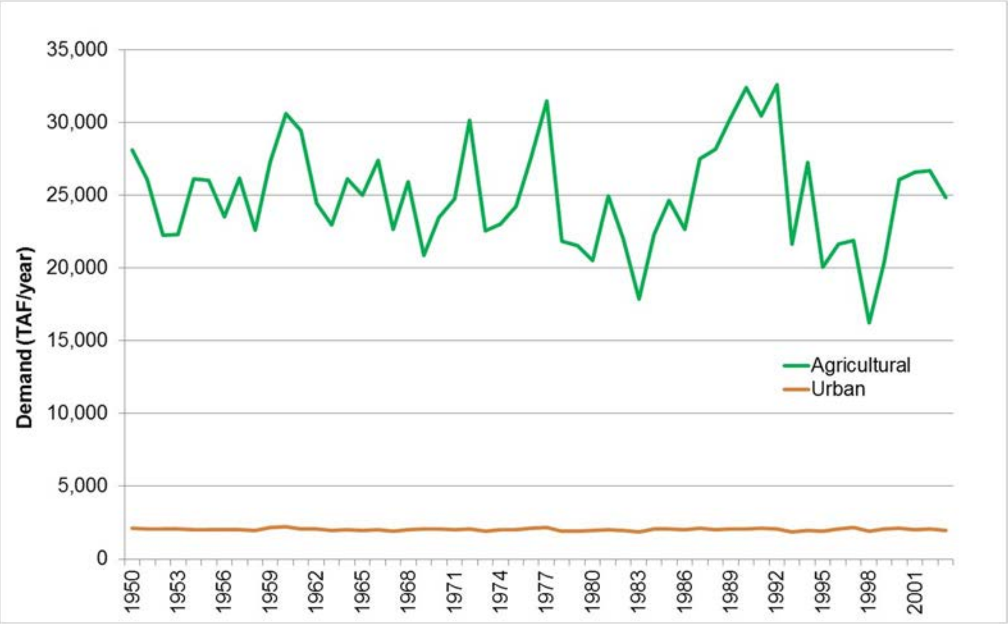


Figure 4-1. Annual Time Series of Simulated Recent Historical Agricultural and Urban Applied Water Demand with Historical Climate and Hydrology in the Central Valley

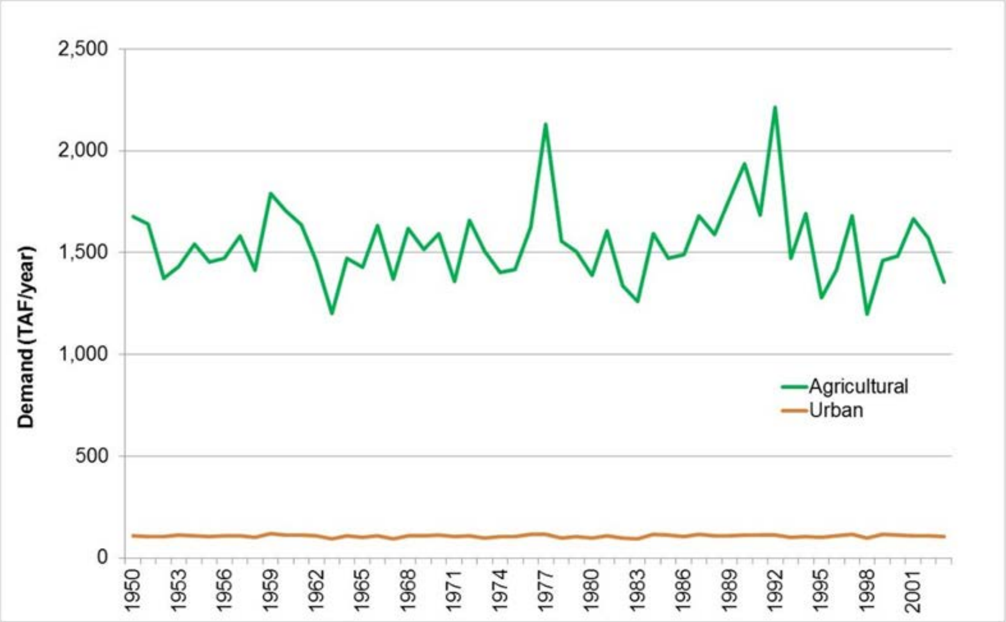


Figure 4-2. Annual Time Series of Simulated Recent Historical Agricultural and Urban Applied Water Demand with Historical Climate and Hydrology in the Sacramento River System

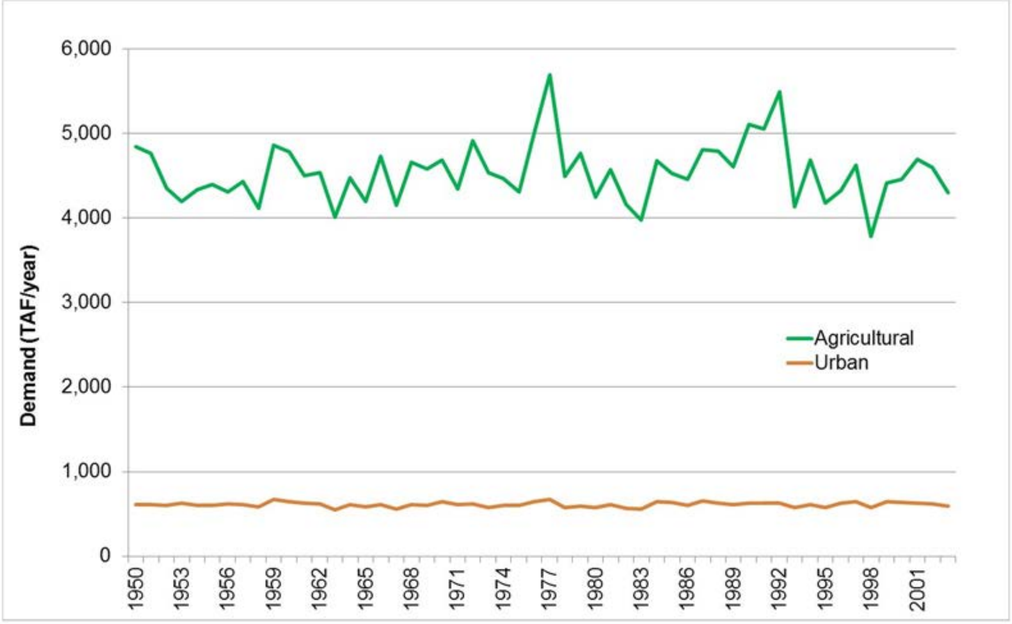


Figure 4-3. Annual Time Series of Simulated Recent Historical Agricultural and Urban Applied Water Demand with Historical Climate and Hydrology in the East Side Streams and Delta

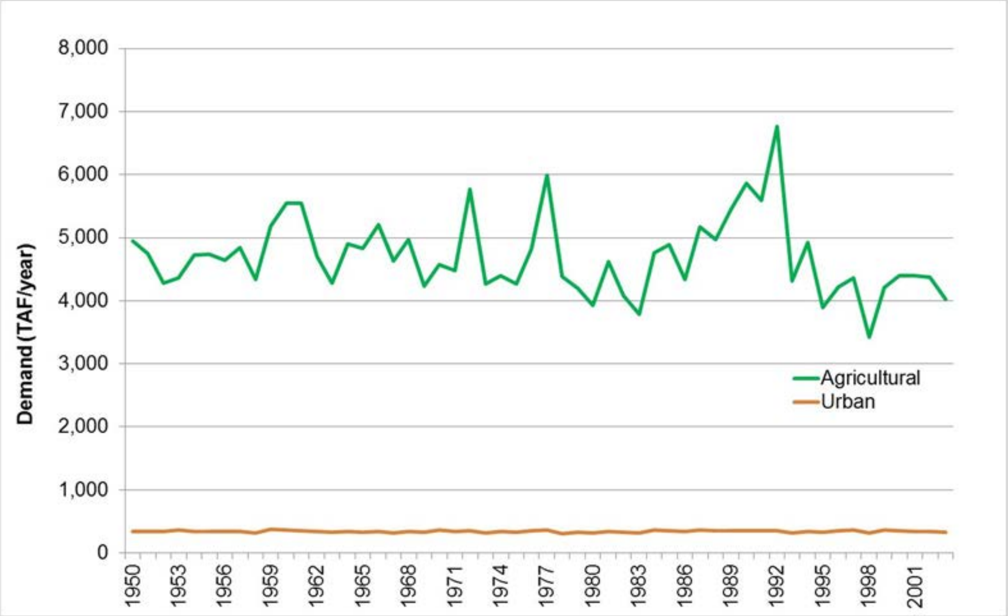


Figure 4-4. Annual Time Series of Simulated Recent Historical Agricultural and Urban Applied Water Demand with Historical Climate and Hydrology in the San Joaquin River System

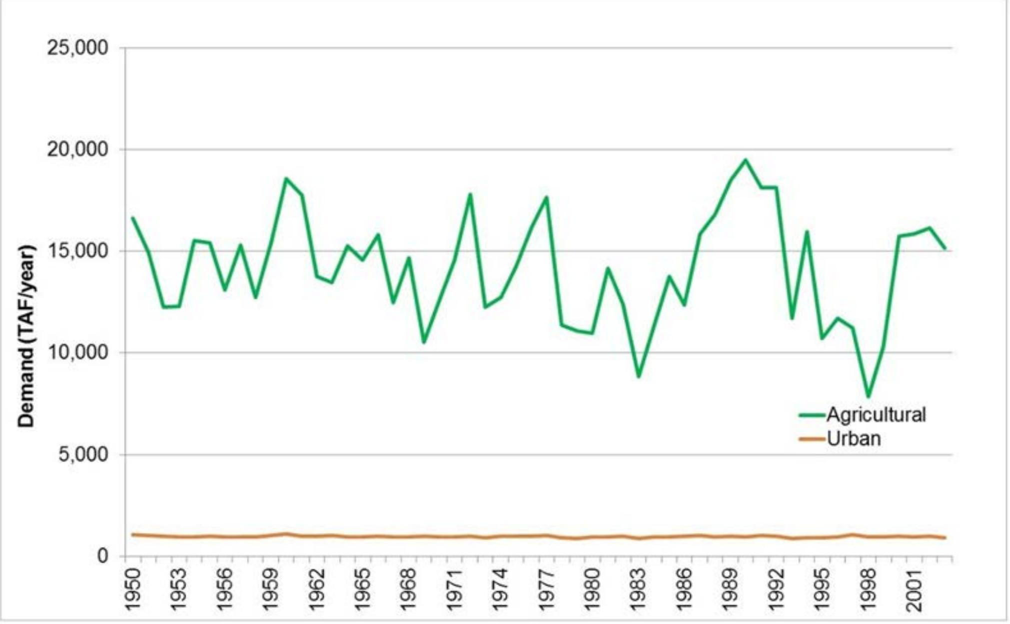


Figure 4-5. Annual Time Series of Simulated Recent Historical Agricultural and Urban Applied Water Demand with Historical Climate and Hydrology in the Tulare Lake Region

### 4.2.2 Future Projected Demand

Tables 4-3 and 4-4 show the average annual agricultural and urban 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 socioeconomic-climate scenarios over the projected period of water years from 2012 through 2099 and for the multi-decadal periods of 2012-2040, 2041-2070, and 2071-2099.

Total agricultural and urban water demands varied across the range of climate scenarios. In all basins, agricultural demands showed a strong relationship with the climate scenarios over the course of the twenty-first century. Although the magnitudes differed among basins because of differences in crops and acreages, the overall relationship between precipitation and agricultural demand was similar in all basins.

In the no climate change (NoCC) scenario, the average annual total Central Valley agricultural demand was 21,656 TAF/year from 2012 to 2099 and ranged from 21,603 TAF/year from 2012 to 2040; 23,553 TAF/year from 2041 to 2070; and 19,748 TAF/year from 2071 to 2099.

Across the range of all climate scenarios, average annual agricultural demand in the Central Valley was 21,553 TAF/year and ranged from 18,500 to 25,823 TAF/year for 2012 to 2099; 19,712 to 26,172 TAF/year for 2012-2040; 19,353 to 27,290 TAF/year for 2041-2070; and 14,090 to 23,965 TAF/year for 2071-2099.

For the EI scenarios, the median climate scenario (Q5) had demands that were similar to the NoCC scenario, the drier climate scenarios (Q1 and Q2) had average demands that were higher than the NoCC scenario, and the wetter climate scenarios (Q3 and Q4) had average demands that were less than the NoCC scenario.

Table 4-3. Average Annual Agricultural Applied Water Demand in Each Scenario (in TAF/year)

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 21,603 | 22,188 | 23,605 | 20,496 | 19,712 | 21,693 |
| | 2041–2070 | 23,553 | 23,909 | 25,691 | 21,006 | 20,355 | 23,037 |
| | 2071–2099 | 19,748 | 19,474 | 19,725 | 15,234 | 15,605 | 17,277 |
| | 2012–2099 | 21,656 | 21,880 | 23,037 | 18,936 | 18,577 | 20,696 |
| Sacramento River System | 2012–2040 | 4,995 | 5,042 | 5,271 | 4,943 | 4,839 | 5,037 |
| | 2041–2070 | 4,455 | 4,305 | 4,517 | 4,290 | 4,228 | 4,333 |
| | 2071–2099 | 3,942 | 3,773 | 3,827 | 3,447 | 3,551 | 3,586 |
| | 2012–2099 | 4,464 | 4,373 | 4,538 | 4,227 | 4,206 | 4,319 |
| Delta and Eastside Streams | 2012–2040 | 1,542 | 1,558 | 1,652 | 1,551 | 1,497 | 1,564 |
| | 2041–2070 | 1,388 | 1,324 | 1,433 | 1,316 | 1,282 | 1,342 |
| | 2071–2099 | 1,260 | 1,153 | 1,151 | 993 | 1,057 | 1,068 |
| | 2012–2099 | 1,397 | 1,345 | 1,412 | 1,287 | 1,279 | 1,325 |
| San Joaquin River System | 2012–2040 | 4,578 | 4,592 | 4,845 | 4,436 | 4,337 | 4,561 |
| | 2041–2070 | 4,580 | 4,487 | 4,959 | 4,048 | 4,019 | 4,364 |
| | 2071–2099 | 3,884 | 3,736 | 3,813 | 2,932 | 3,127 | 3,266 |
| | 2012–2099 | 4,350 | 4,274 | 4,544 | 3,808 | 3,830 | 4,067 |
| Tulare Lake Region | 2012–2040 | 10,488 | 10,995 | 11,836 | 9,566 | 9,038 | 10,531 |
| | 2041–2070 | 13,130 | 13,793 | 14,783 | 11,352 | 10,826 | 12,997 |
| | 2071–2099 | 10,663 | 10,812 | 10,933 | 7,863 | 7,870 | 9,356 |
| | 2012–2099 | 11,446 | 11,888 | 12,543 | 9,614 | 9,263 | 10,985 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 21,603 | 21,800 | 24,382 | 26,172 | 24,387 | 24,387 | 22,029 |
| | 2041–2070 | 23,553 | 26,851 | 21,947 | 26,581 | 22,180 | 22,180 | 19,353 |
| | 2071–2099 | 19,748 | 17,787 | 20,208 | 20,118 | 15,285 | 15,285 | 14,090 |
| | 2012–2099 | 21,656 | 22,199 | 22,176 | 24,316 | 20,635 | 20,635 | 18,500 |
| Sacramento River System | 2012–2040 | 4,995 | 4,574 | 4,700 | 4,722 | 4,611 | 4,611 | 4,533 |
| | 2041–2070 | 4,455 | 4,580 | 4,298 | 4,496 | 4,224 | 4,224 | 4,121 |
| | 2071–2099 | 3,942 | 3,567 | 3,717 | 3,663 | 3,423 | 3,423 | 3,299 |
| | 2012–2099 | 4,464 | 4,245 | 4,239 | 4,296 | 4,088 | 4,088 | 3,986 |
| Delta and Eastside Streams | 2012–2040 | 1,542 | 1,378 | 1,439 | 1,521 | 1,397 | 1,397 | 1,345 |
| | 2041–2070 | 1,388 | 1,435 | 1,276 | 1,456 | 1,234 | 1,234 | 1,161 |
| | 2071–2099 | 1,260 | 1,021 | 1,053 | 1,079 | 945 | 945 | 866 |
| | 2012–2099 | 1,397 | 1,280 | 1,257 | 1,353 | 1,192 | 1,192 | 1,124 |
| San Joaquin River System | 2012–2040 | 4,578 | 4,578 | 4,912 | 5,422 | 4,924 | 4,924 | 4,472 |
| | 2041–2070 | 4,580 | 5,542 | 4,162 | 5,585 | 4,216 | 4,216 | 3,758 |
| | 2071–2099 | 3,884 | 3,506 | 4,001 | 3,913 | 2,931 | 2,931 | 2,792 |
| | 2012–2099 | 4,350 | 4,553 | 4,356 | 4,980 | 4,026 | 4,026 | 3,675 |
| Tulare Lake Region | 2012–2040 | 10,488 | 11,270 | 13,330 | 14,508 | 13,455 | 13,455 | 11,679 |
| | 2041–2070 | 13,130 | 15,293 | 12,211 | 15,044 | 12,507 | 12,507 | 10,313 |
| | 2071–2099 | 10,663 | 9,693 | 11,437 | 11,463 | 7,986 | 7,986 | 7,133 |
| | 2012–2099 | 11,446 | 12,122 | 12,325 | 13,687 | 11,330 | 11,330 | 9,715 |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 21,603 | 22,820 | 24,092 | 26,162 | 22,768 | 25,925 | 20,659 |
| | 2041–2070 | 23,553 | 22,173 | 23,059 | 27,290 | 21,799 | 22,489 | 21,304 |
| | 2071–2099 | 19,748 | 21,097 | 21,029 | 23,965 | 21,041 | 18,004 | 18,361 |
| | 2012–2099 | 21,656 | 22,032 | 22,730 | 25,823 | 21,868 | 22,143 | 20,122 |
| Sacramento River System | 2012–2040 | 4,995 | 4,686 | 4,714 | 4,817 | 4,548 | 4,853 | 4,516 |
| | 2041–2070 | 4,455 | 4,356 | 4,360 | 4,711 | 4,376 | 4,351 | 4,240 |
| | 2071–2099 | 3,942 | 3,900 | 3,842 | 4,049 | 3,875 | 3,831 | 3,828 |
| | 2012–2099 | 4,464 | 4,314 | 4,306 | 4,528 | 4,267 | 4,345 | 4,195 |
| Delta and Eastside Streams | 2012–2040 | 1,542 | 1,418 | 1,434 | 1,523 | 1,352 | 1,512 | 1,325 |
| | 2041–2070 | 1,388 | 1,309 | 1,328 | 1,524 | 1,327 | 1,316 | 1,226 |
| | 2071–2099 | 1,260 | 1,210 | 1,198 | 1,341 | 1,217 | 1,163 | 1,167 |
| | 2012–2099 | 1,397 | 1,312 | 1,320 | 1,464 | 1,299 | 1,330 | 1,239 |
| San Joaquin River System | 2012–2040 | 4,578 | 4,650 | 4,840 | 5,382 | 4,625 | 5,348 | 4,350 |
| | 2041–2070 | 4,580 | 4,286 | 4,396 | 5,553 | 4,308 | 4,304 | 4,160 |
| | 2071–2099 | 3,884 | 4,088 | 4,000 | 4,884 | 4,003 | 3,479 | 3,724 |
| | 2012–2099 | 4,350 | 4,341 | 4,412 | 5,276 | 4,312 | 4,376 | 4,079 |
| Tulare Lake Region | 2012–2040 | 10,488 | 12,066 | 13,104 | 14,440 | 12,243 | 14,212 | 10,469 |
| | 2041–2070 | 13,130 | 12,221 | 12,976 | 15,502 | 11,788 | 12,517 | 11,678 |
| | 2071–2099 | 10,663 | 11,899 | 11,988 | 13,691 | 11,946 | 9,532 | 9,642 |
| | 2012–2099 | 11,446 | 12,064 | 12,693 | 14,555 | 11,990 | 12,092 | 10,609 |

In the no climate change scenario (NoCC), the total Central Valley urban demand averaged 3,480 from 2012 to 2099; 2,385 TAF/year from 2012 to 2040; 3,679 TAF/year from 2041 to 2070; and 4,368 TAF/year from 2071 to 2099.

Across the range of all climate scenarios, the average annual total urban demand in the Central Valley was 3,652 TAF/year and ranged from 3,464 to 3,877 TAF/year for 2012 to 2099; 2,352 to 2,630 TAF/year for 2012-2040; 3,679 to 4,774 TAF/year for 2041-2070; and 4,325 to 4,883 TAF/year for 2071-2099.

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

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 2,385 | 2,431 | 2,481 | 2,396 | 2,352 | 2,417 |
| | 2041–2070 | 3,679 | 3,843 | 3,948 | 3,763 | 3,706 | 3,816 |
| | 2071–2099 | 4,368 | 4,586 | 4,734 | 4,445 | 4,325 | 4,501 |
| | 2012–2099 | 3,480 | 3,623 | 3,723 | 3,537 | 3,464 | 3,580 |
| Sacramento River System | 2012–2040 | 813 | 824 | 834 | 824 | 816 | 821 |
| | 2041–2070 | 1,127 | 1,156 | 1,171 | 1,156 | 1,146 | 1,155 |
| | 2071–2099 | 1,304 | 1,344 | 1,381 | 1,344 | 1,318 | 1,339 |
| | 2012–2099 | 1,082 | 1,108 | 1,129 | 1,109 | 1,094 | 1,106 |
| Delta and Eastside Streams | 2012–2040 | 148 | 151 | 153 | 150 | 149 | 150 |
| | 2041–2070 | 217 | 223 | 227 | 224 | 221 | 223 |
| | 2071–2099 | 261 | 269 | 275 | 270 | 264 | 269 |
| | 2012–2099 | 209 | 214 | 218 | 215 | 211 | 214 |
| San Joaquin River System | 2012–2040 | 507 | 515 | 524 | 513 | 507 | 514 |
| | 2041–2070 | 751 | 776 | 798 | 775 | 765 | 776 |
| | 2071–2099 | 876 | 918 | 961 | 909 | 884 | 910 |
| | 2012–2099 | 712 | 737 | 761 | 733 | 719 | 734 |
| Tulare Lake Region | 2012–2040 | 916 | 942 | 970 | 909 | 880 | 931 |
| | 2041–2070 | 1,584 | 1,687 | 1,752 | 1,608 | 1,573 | 1,661 |
| | 2071–2099 | 1,927 | 2,055 | 2,117 | 1,922 | 1,859 | 1,983 |
| | 2012–2099 | 1,477 | 1,563 | 1,614 | 1,481 | 1,439 | 1,527 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 2,385 | 2,549 | 2,570 | 2,630 | 2,596 | 2,596 | 2,541 |
| | 2041–2070 | 3,679 | 4,111 | 3,850 | 4,109 | 3,880 | 3,880 | 3,738 |
| | 2071–2099 | 4,368 | 4,701 | 4,840 | 4,883 | 4,487 | 4,487 | 4,440 |
| | 2012–2099 | 3,480 | 3,791 | 3,754 | 3,877 | 3,657 | 3,657 | 3,575 |
| Sacramento River System | 2012–2040 | 813 | 828 | 825 | 832 | 825 | 825 | 822 |
| | 2041–2070 | 1,127 | 1,183 | 1,152 | 1,177 | 1,152 | 1,152 | 1,137 |
| | 2071–2099 | 1,304 | 1,353 | 1,364 | 1,374 | 1,320 | 1,320 | 1,319 |
| | 2012–2099 | 1,082 | 1,122 | 1,114 | 1,128 | 1,099 | 1,099 | 1,093 |
| Delta and Eastside Streams | 2012–2040 | 148 | 151 | 151 | 153 | 151 | 151 | 150 |
| | 2041–2070 | 217 | 229 | 223 | 230 | 224 | 224 | 220 |
| | 2071–2099 | 261 | 273 | 274 | 277 | 266 | 266 | 265 |
| | 2012–2099 | 209 | 218 | 216 | 220 | 214 | 214 | 212 |
| San Joaquin River System | 2012–2040 | 507 | 533 | 533 | 542 | 536 | 536 | 529 |
| | 2041–2070 | 751 | 834 | 777 | 845 | 785 | 785 | 763 |
| | 2071–2099 | 876 | 948 | 985 | 995 | 906 | 906 | 900 |
| | 2012–2099 | 712 | 772 | 765 | 795 | 743 | 743 | 731 |
| Tulare Lake Region | 2012–2040 | 916 | 1,037 | 1,061 | 1,103 | 1,084 | 1,084 | 1,040 |
| | 2041–2070 | 1,584 | 1,865 | 1,697 | 1,858 | 1,720 | 1,720 | 1,618 |
| | 2071–2099 | 1,927 | 2,127 | 2,216 | 2,237 | 1,995 | 1,995 | 1,955 |
| | 2012–2099 | 1,477 | 1,678 | 1,659 | 1,734 | 1,601 | 1,601 | 1,539 |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 2,385 | 2,558 | 2,578 | 2,619 | 2,544 | 2,611 | 2,522 |
| | 2041–2070 | 3,679 | 3,836 | 3,819 | 3,960 | 3,824 | 3,781 | 3,790 |
| | 2071–2099 | 4,368 | 4,662 | 4,638 | 4,774 | 4,649 | 4,402 | 4,462 |
| | 2012–2099 | 3,480 | 3,687 | 3,680 | 3,786 | 3,674 | 3,600 | 3,594 |
| Sacramento River System | 2012–2040 | 813 | 827 | 832 | 828 | 820 | 831 | 825 |
| | 2041–2070 | 1,127 | 1,148 | 1,135 | 1,150 | 1,152 | 1,140 | 1,133 |
| | 2071–2099 | 1,304 | 1,325 | 1,317 | 1,331 | 1,325 | 1,297 | 1,311 |
| | 2012–2099 | 1,082 | 1,100 | 1,095 | 1,104 | 1,100 | 1,090 | 1,090 |
| Delta and Eastside Streams | 2012–2040 | 148 | 151 | 152 | 152 | 150 | 152 | 151 |
| | 2041–2070 | 217 | 222 | 220 | 224 | 223 | 220 | 220 |
| | 2071–2099 | 261 | 266 | 266 | 268 | 267 | 259 | 262 |
| | 2012–2099 | 209 | 213 | 213 | 215 | 214 | 211 | 211 |
| San Joaquin River System | 2012–2040 | 507 | 533 | 536 | 539 | 529 | 539 | 529 |
| | 2041–2070 | 751 | 778 | 769 | 796 | 776 | 767 | 764 |
| | 2071–2099 | 876 | 924 | 917 | 960 | 92 | 881 | 898 |
| | 2012–2099 | 712 | 745 | 741 | 765 | 742 | 730 | 731 |
| Tulare Lake Region | 2012–2040 | 916 | 1,047 | 1,058 | 1,099 | 1,045 | 1,088 | 1,017 |
| | 2041–2070 | 1,584 | 1,689 | 1,695 | 1,789 | 1,673 | 1,654 | 1,672 |
| | 2071–2099 | 1,927 | 2,147 | 2,139 | 2,215 | 2,135 | 1,965 | 1,991 |
| | 2012–2099 | 1,477 | 1,628 | 1,631 | 1,702 | 1,619 | 1,570 | 1,561 |

Figures 4-6 through 4-10 present annual time series from 2012 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 eighteen socioeconomic-climate scenarios.

For the agricultural demands, it was assumed that there were no changes in the types of crops being grown and that changes in acreage were associated only with changes in urban growth. It was also assumed that as irrigated land decreased higher value permanent crops such as orchards would be less impacted.

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. The longer-term trends include a period of increasing demands primarily related to climate during the early twenty-first century followed by declining demands in the latter half of the century due principally to reducing irrigated land. These trends occurred in all the future socioeconomic-climate scenarios.

Overall agricultural demands were projected to increase in the early to middle twenty-first century primarily because of rising temperatures and increasing vapor pressure deficits causing increases in ET. However, in the latter half of the twenty-first century, as projected solar radiation continues to decrease and carbon dioxide (CO2) concentrations continue to increase, ET of many agricultural crops currently being grown in the Central Valley was projected to decline despite the rising temperatures and increasing vapor pressure deficits.

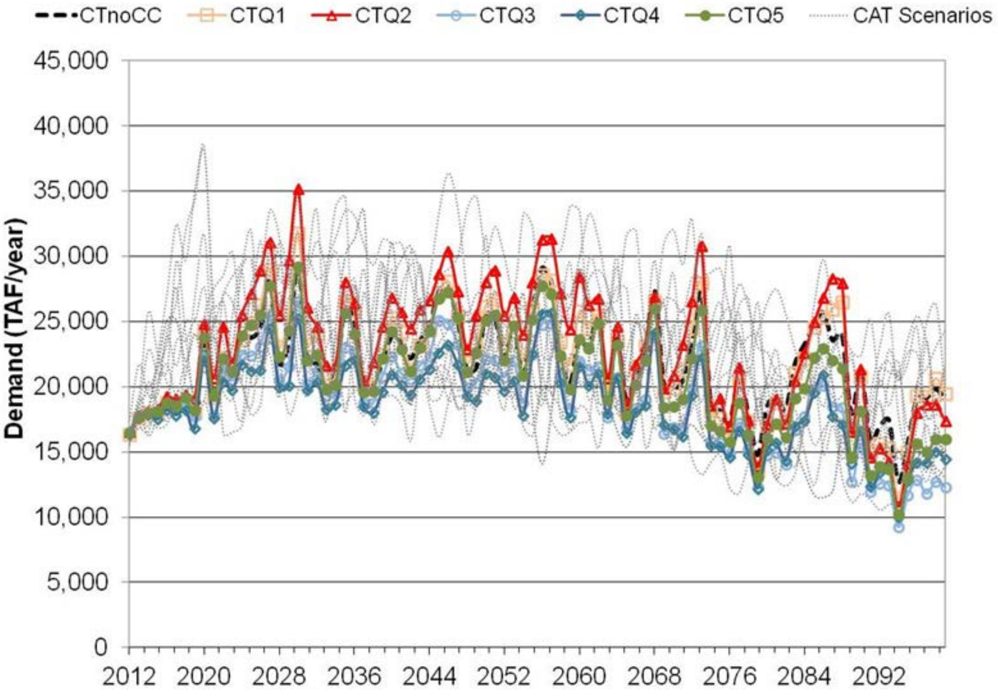


Figure 4-6. Annual Time Series of Agricultural Applied Water Demand in the Central Valley in Each Scenario

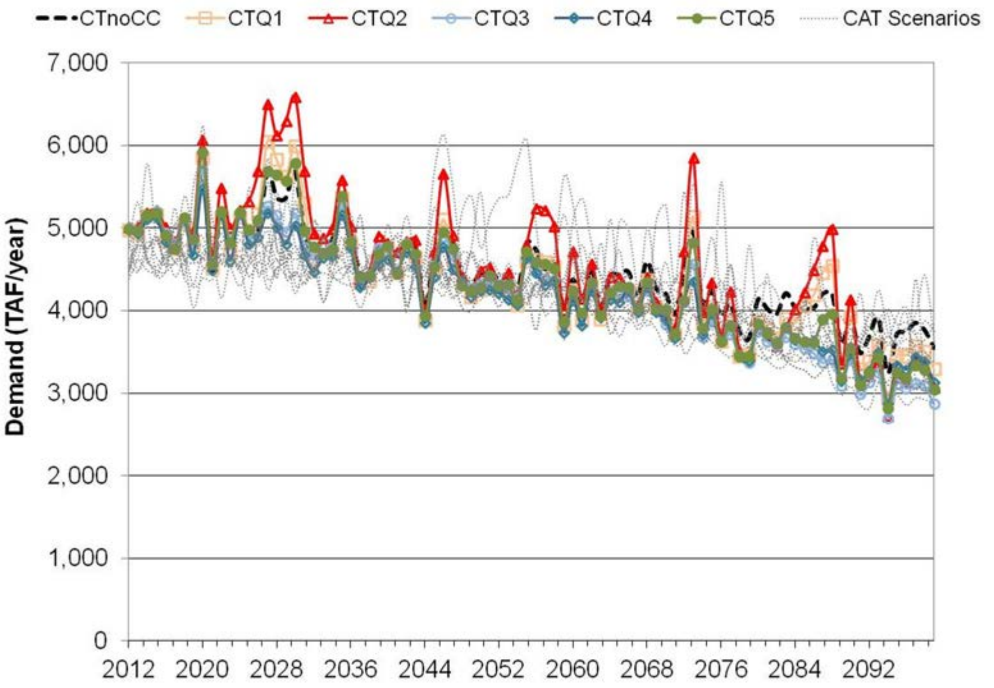


Figure 4-7. Annual Time Series of Agricultural Applied Water Demand in the Sacramento River System in Each Scenario

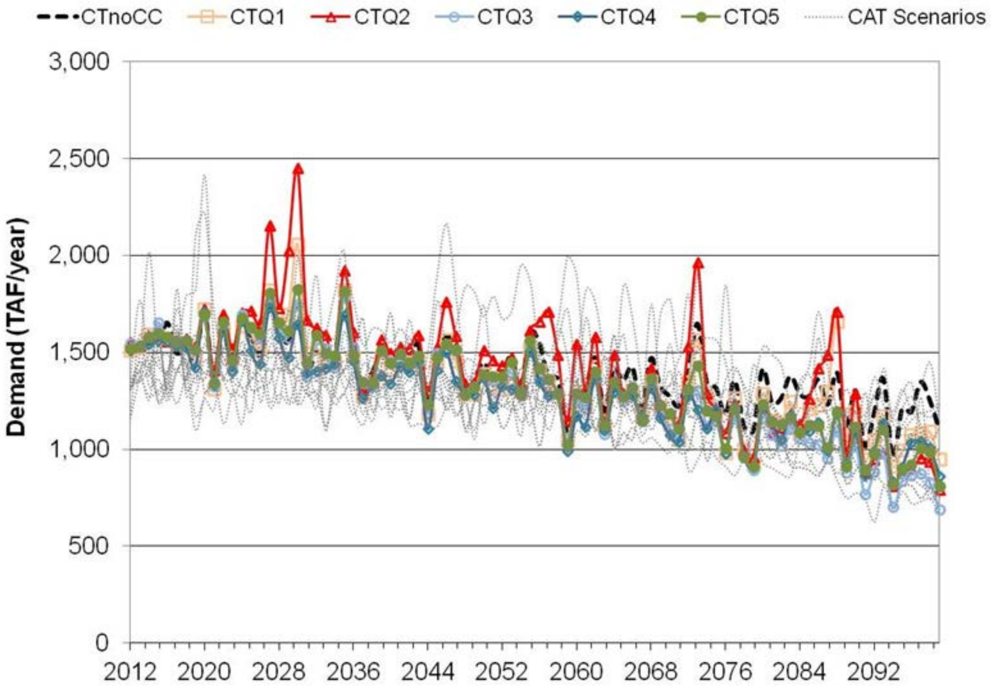


Figure 4-8. Annual Time Series of Agricultural Applied Water Demand in the East Side Streams and Delta in Each Scenario

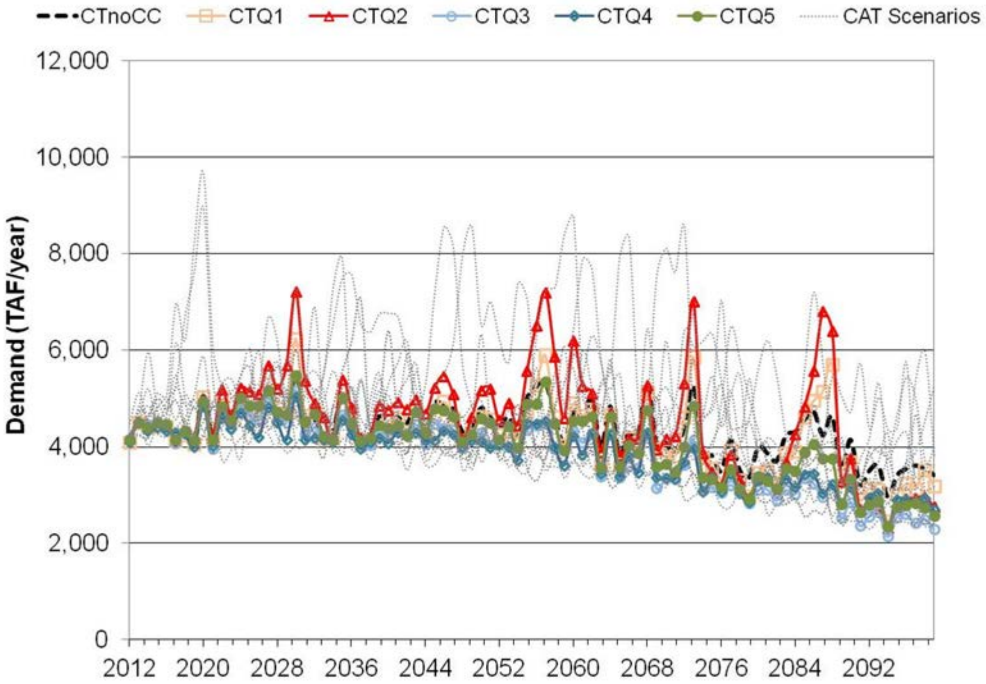


Figure 4-9. Annual Time Series of Agricultural Applied Water Demand in the San Joaquin River System in Each Scenario

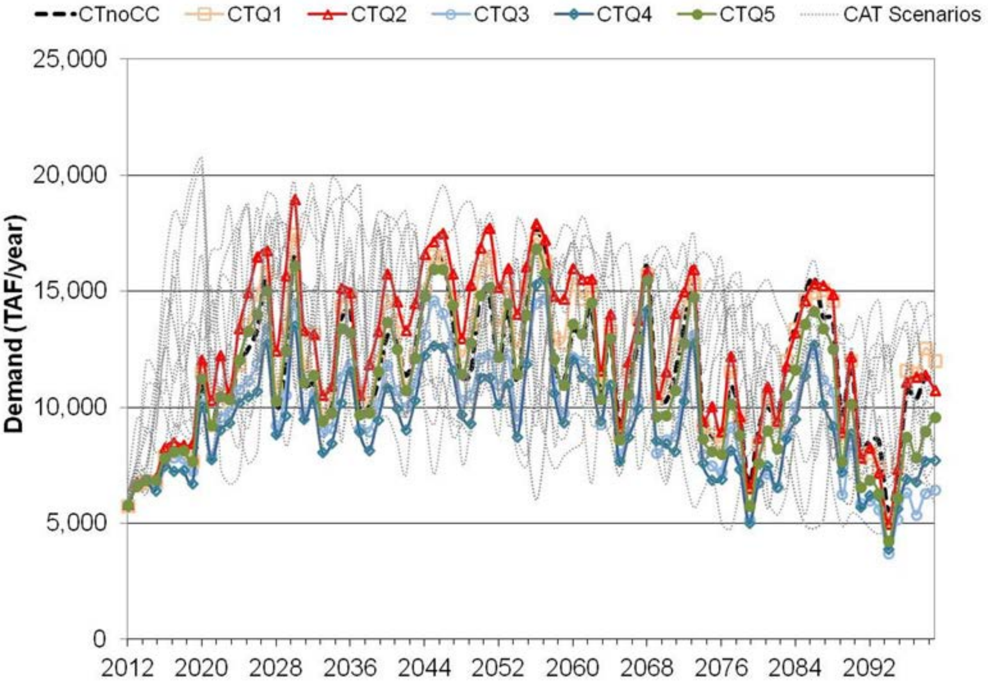


Figure 4-10. Annual Time Series of Agricultural Applied Water Demand in the Tulare Lake Region in Each Scenario

In contrast with agricultural demands, the urban demands do not show a large degree of year-to-year variability because much of the urban demand is for indoor uses which was assumed to be insensitive to precipitation variability. Because the urban demands are driven largely by population, they tend to change steadily over time with the growth in population and expansion in commercial activities.

Figures 4-11 through 4-15 present annual time series from 2012 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.

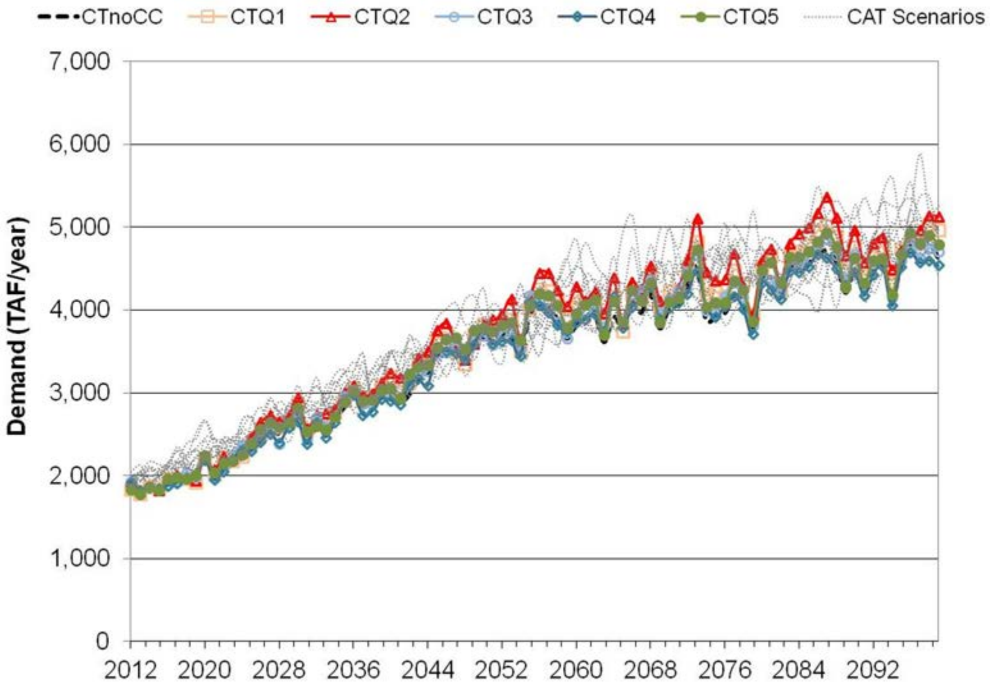


Figure 4-11. Annual Time Series of Total Urban Applied Water Demand in the Central Valley in Each Scenario

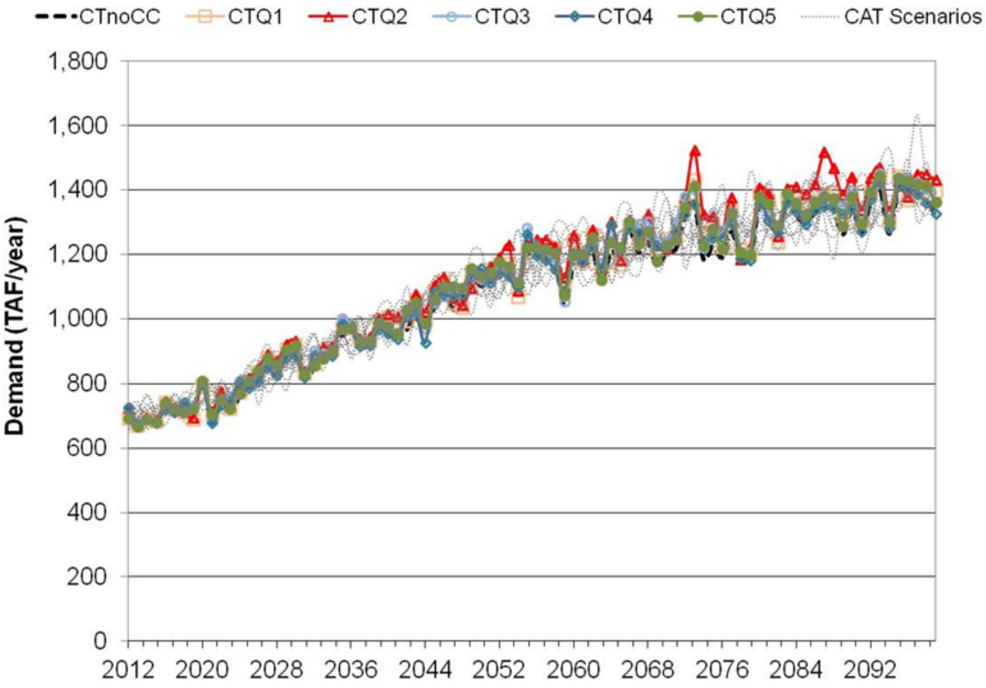


Figure 4-12. Annual Time Series of Urban Applied Water Demand in the Sacramento River System in Each Scenario

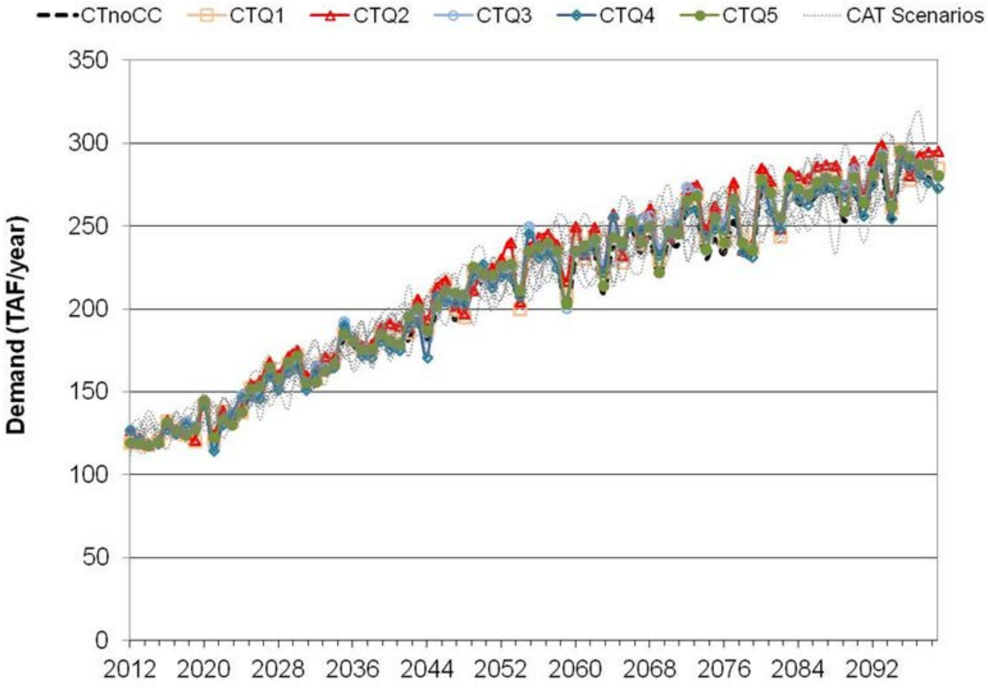


Figure 4-13. Annual Time Series of Urban Applied Water Demand in the East Side Streams and Delta in Each Scenario

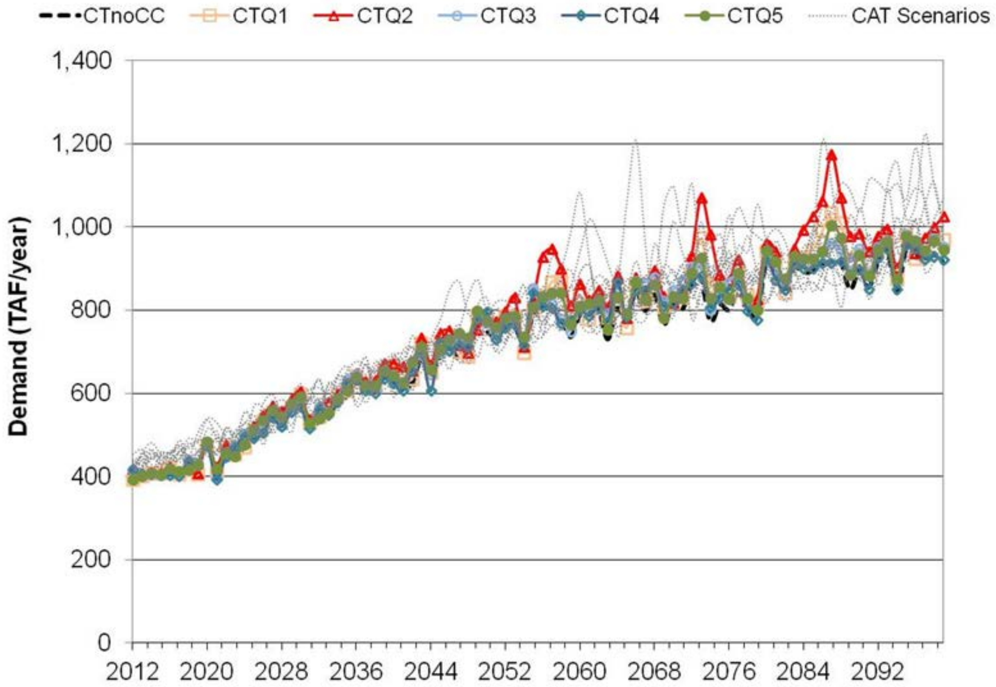


Figure 4-14. Annual Time Series of Urban Applied Water Demand in the San Joaquin River System in Each Scenario

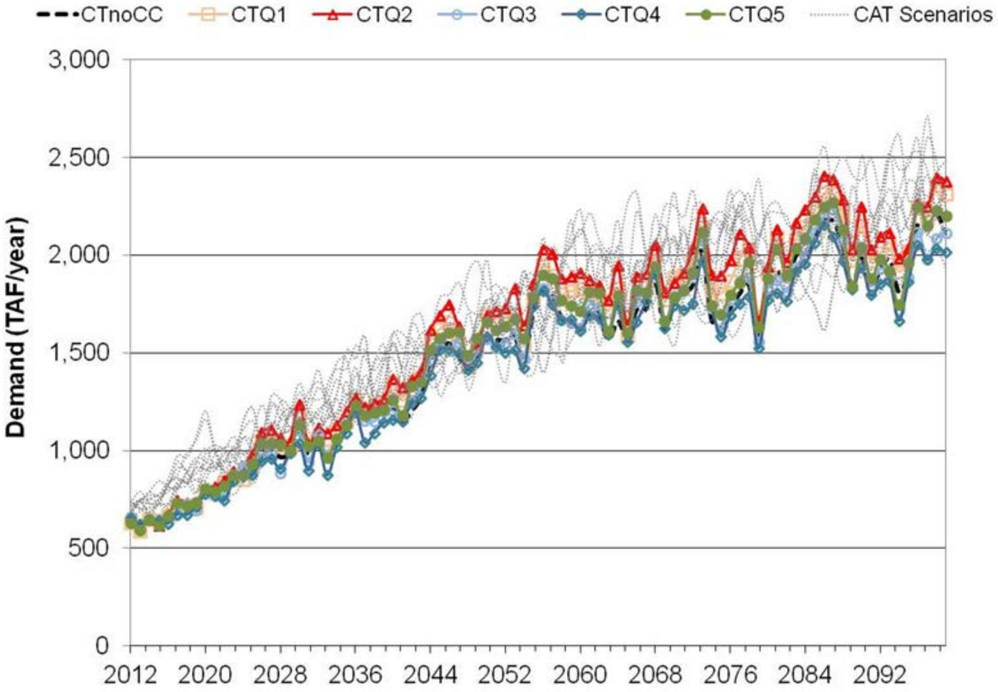


Figure 4-15. Annual Time Series of Urban Applied Water Demand in the Tulare Lake Region in Each Scenario

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# 5.0 System Risk and Reliability Assessment

## 5.1 System Risk and Reliability Metrics

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 six 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

### 5.1.1 Objective and Approach

To assess the risk and reliability for each of these resource categories, specific attributes of interest associated with each resource category were selected. Performance metrics indicating the ability of the water system to meet resource needs under changed socioeconomic-climate conditions were developed, and locations where metrics would offer relevant information about the system performance were identified.

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 was feasible, 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

For each of the six resource categories, Table 5-1 presents the attributes of interest with a brief description of the basis for using the metric. For each of the reliability metrics, key locations in the Central Valley were selected where metrics offer information relevant to the performance of the system.

Table 5-1. Resource Categories and Attributes of Interest

| Resource Category | Attribute of Interest | Basies for Use as Indicator Metric | Locations |
|---|---|---|---|
| Delivery Reliability | Unmet demands | Unmet demands provide an indication of the reliability of the system to meeting the demands in the regions. Supply and demand summaries provide the basis for understanding potential imbalances. | 18.6 Sacramento River, San Joaquin River, Delta, and Tulare Lake regions |
| | End-of-September system storage | End of September storage provides an indication of relative risk for future deliveries, particularly during drought years. | Shasta, Folsom, Oroville, New Melones, and San Luis reservoirs; Sacramento Valley surface storage total; San Joaquin Valley surface storage total; Tulare Lake Region surface storage total |
| | CVP and SWP Delta exports | Delta exports are a significant portion of the supply available to San Joaquin Valley, Tulare Lake, and out-of-basin users | Banks and Jones Pumping Plants |
| Water Quality | Delta Salinity (EC) | In-Delta EC conditions provide a measure of in-Delta water user risks and export user risks | State Water Resources Control Board (SWRCB) Decision 1641 (D1641) compliance locations (Emmaton, Rock Slough and Jersey Point) |
| | End-of- May project storage | Coldwater pool is generally managed from May through September. The initial May storage is correlated to the availability of coldwater pool to manage through the spring and summer. | Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs |
| Hydropower and GHG Emissions | Energy generation and use | Indicator of changing energy generation and use | CVP and SWP hydropower and pumping facilities |
| | GHG emissions | Indicator of environmental footprint or carbon intensity of operations | CVP and SWP hydropower and pumping facilities |
| Flood Control | Frequency of storage use for flood control | Indicator of changing flood management risks | Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs |
| | Frequency of releases above penstock capacities | Indicator of changing flood management risks | Keswick, Thermalito, and Natoma reservoirs |
| Recreational Resources | Available surface area in system reservoirs from May through September | Surface area is correlated to the recreational use potential for boating, shoreline use, and other uses | Shasta, Folsom, Oroville, New Bullards Bar, New Melones, New Don Pedro, McClure, Millerton, and Pine Flat |

| Resource Category | Attribute of Interest | Basies for Use as Indicator Metric | Locations |
|---|---|---|---|
| | | | reservoirs |
| Ecological Resources | Frequency of storage for water temperature for Sacramento River fisheries (End-of-April and End-of-September storage) | Storage above indicator levels is correlated with populations of listed salmonids and other fish species | Shasta Reservoir storage (>3,800 TAF in April or >2,200 TAF in September) |
| | Frequency of flood inundation flows (February-June) | Flows above indicator levels in certain reaches have been shown to benefit downstream riparian habitat | Sacramento River at Keswick (>15,000 cubic feet per second [cfs]), Feather River at Confluence (>10,000 cfs), and American River at Nimbus (>3,000 cfs) |
| | Frequency of high salinity for Pelagic Species Habitat (spring) | Pelagic species habitat extent is highly correlated to the extent of the low salinity zone in the Delta; 74 kilometers (km) is specified in the U.S. Fish and Wildlife Service (USFWS) Biological Opinion (BiOp) (2008).<br>Entrainment of extent of south delta habitat is correlated to the extent of reverse (negative) flows in the Old and Middle rivers (OMR). | X2 position >74 km<br>Note: X2 is defined as the location of the 2 ppt salinity concentration. It is measured in kilometers (km) from the Golden Gate Bridge<br>Frequency of flows on OMR (<-3,500 cfs)<br>Note: -3,500 cfs is approximately the median of the requirement in the USFWS BiOp. |
| | Frequency of high salinity for Pelagic Species Habitat (fall) | Pelagic species habitat extent is highly correlated to the extent of the low salinity zone in the Delta; 74 km is a goal specified in the USFWS BiOp. | X2 Position >74 km |
| | Frequency of flows for Adult San Joaquin salmonid migration | Entrainment of San Joaquin River fish is correlated to the extent of reverse (negative) flows in the OMR. | Frequency of flows OMR <5,000 cfs |
| | Frequency of flows affecting Food Web productivity | Food web productivity is correlated to the extent of reverse (negative) flows in the OMR. | Frequency of flows OMR <5,000 cfs |

## 5.2 System Risk and Reliability Assessment

The SWA mandates the analysis of impacts that changes in water supply may have on eight specific resource categories. The results presented in this report address only selected aspects of each resource category and by necessity 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, there exists considerable variability 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 for each of the eighteen socioeconomic-climate scenarios using the methods and models described in the previous sections. 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 without the implementation of any adaptation strategies.

The Impact Assessment used the same set of tools used for the CVP IRP 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. The following sections describe these analytical approaches in greater detail.

Table 5-2. Models Used for Resource Category Assessments

| Resource Category | Models | Metrics |
|---|---|---|
| Delivery Reliablity | CVP IRP CalLite | Unmet demands |
| | | CVP & SWP Delta exports |
| | | CVP & SWP reservoir storage |
| Water Qualiy | CVP IRP CalLite | Delta salinity |
| | | Reservoir storage |
| Hydropower & GHG emissions | LTGen &<br>SWP_Power | CVP & SWP net generation |
| Flood Control | CVP IRP CalLite | Reservoir storage & penstock releases |
| Recreation | CVP IRP CalLite | Surface area in CVP & SWP reservoirs |
| Ecological Resources | CVP IRP CalLite | Delta salinity |
| | | Delta outflow and instream river flows |

### 5.2.2 Delivery Reliability Results

#### *Unmet Demands*

Unmet demands provide an indication of the reliability of the system in meeting water supply needs in the study area. This performance metric is applicable to all three of the California’s Central Valley hydrologic basins.

Figures 5-1 through 5-6 present annual time series of groundwater, surface water, and unmet demand for the Central Valley in the no climate change and EI scenarios. All six 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. In the noCC scenario, unmet demands ranged from a low of about 495 TAF/year to a high of about 11,365 TAF/year over the course of the simulation period. The Current Trends – Central tendency (CTQ5) scenario showed only modest increases in demand and reductions in supply relative to the CTnoCC, with unmet demands ranging from 653 to 11,342 TAF/year. The warmer and drier (CTQ2) scenario had much greater increases in demand and reductions in supply as compared to the CTnoCC scenario, with unmet demands ranging from 863 to 16,573 TAF/year.

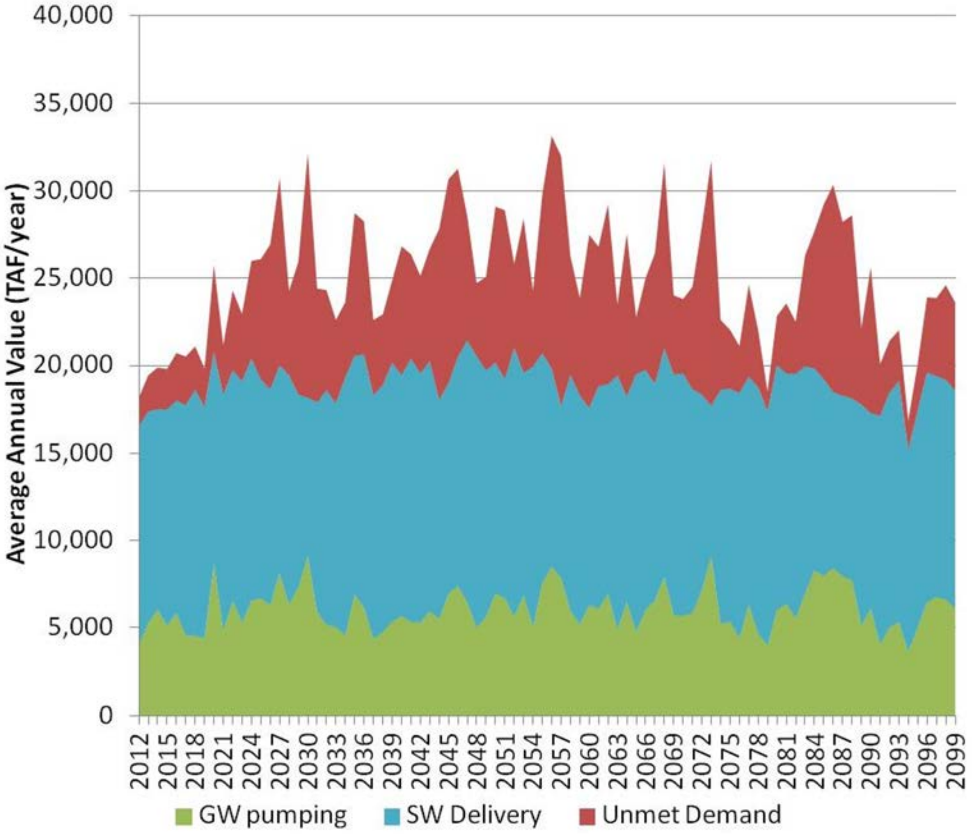

Figure 5-1. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTnoCC Scenario

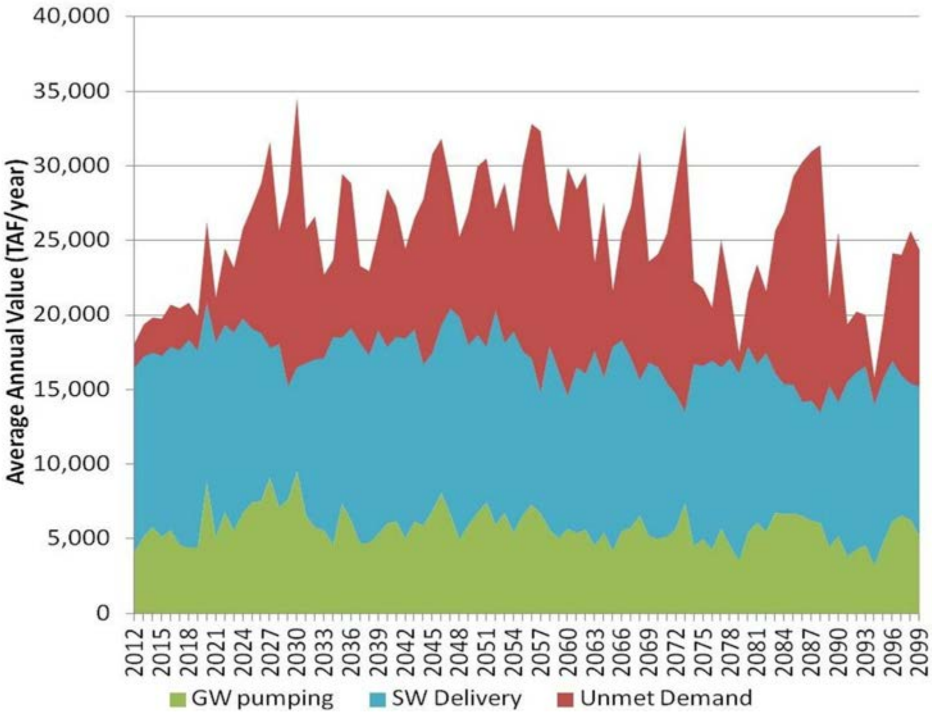

Figure 5-2. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTQ1 Scenario

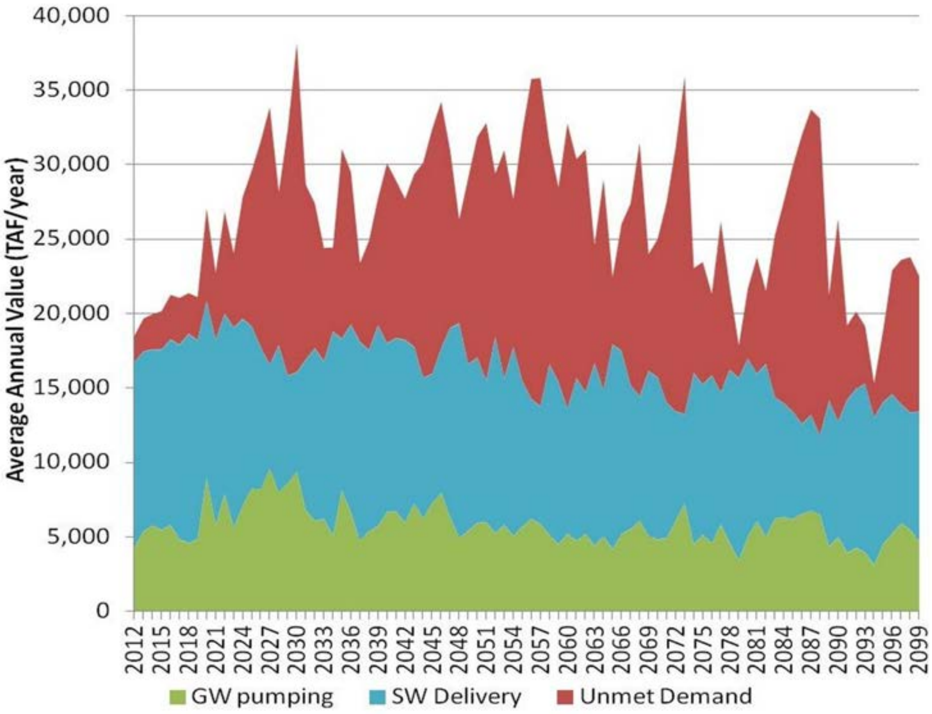

Figure 5-3. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTQ2 Scenario

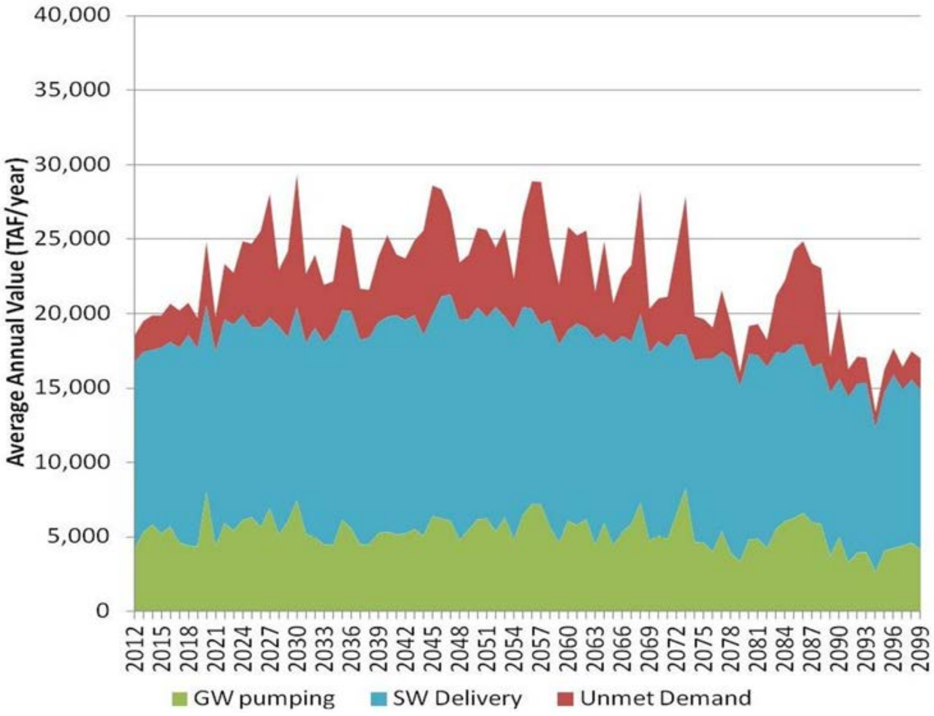

Figure 5-4. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTQ3 Scenario

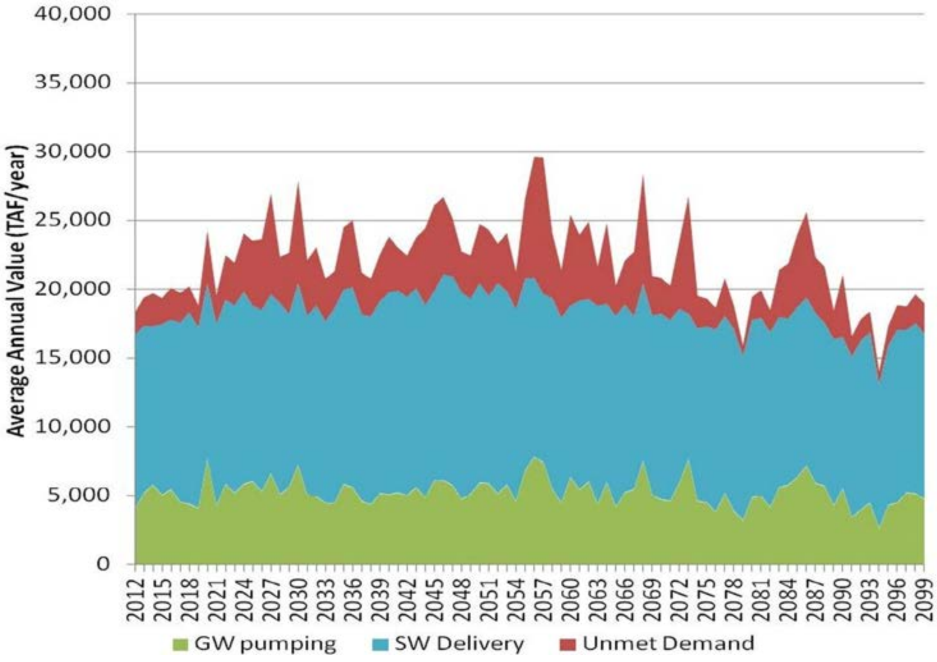

Figure 5-5. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTQ4 Scenario

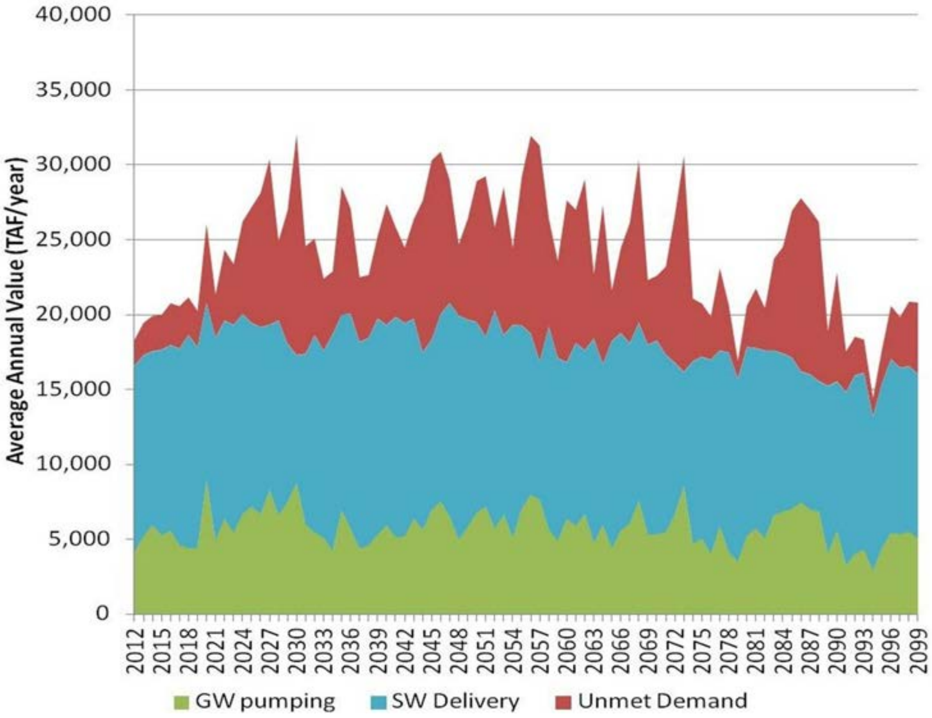

Figure 5-6. Annual Time Series of Supplies and Unmet Demand in the Central Valley in the CTQ5 Scenario

Conversely, the less warming and wetter (CTQ4) scenario had lower demands, higher supplies, and, consequently, lower unmet demands than the CTnoCC scenario, with unmet demands ranging from 280 to 8,031 TAF/year.

Figures 5-7 through 5-11 present 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 of the socioeconomic-climate scenarios over water years from 2012 to 2099. In all regions except for the San Joaquin River system, the 12 CAT scenario unmet demand results show a similar range across the scenarios as the EI scenarios. In the San Joaquin River system, some of the 12 CAT scenarios had higher demands and consistently higher unmet demands than those in the EI scenarios.

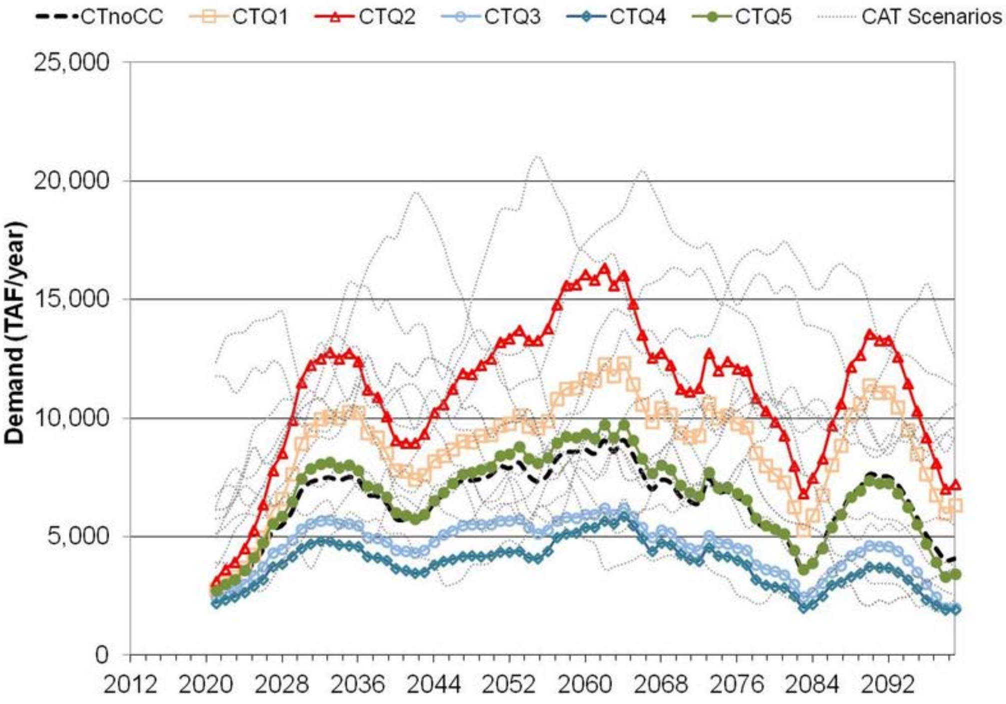

Figure 5-7. 10-Year Running Average of Unmet Demand in the Central Valley in Each Scenario

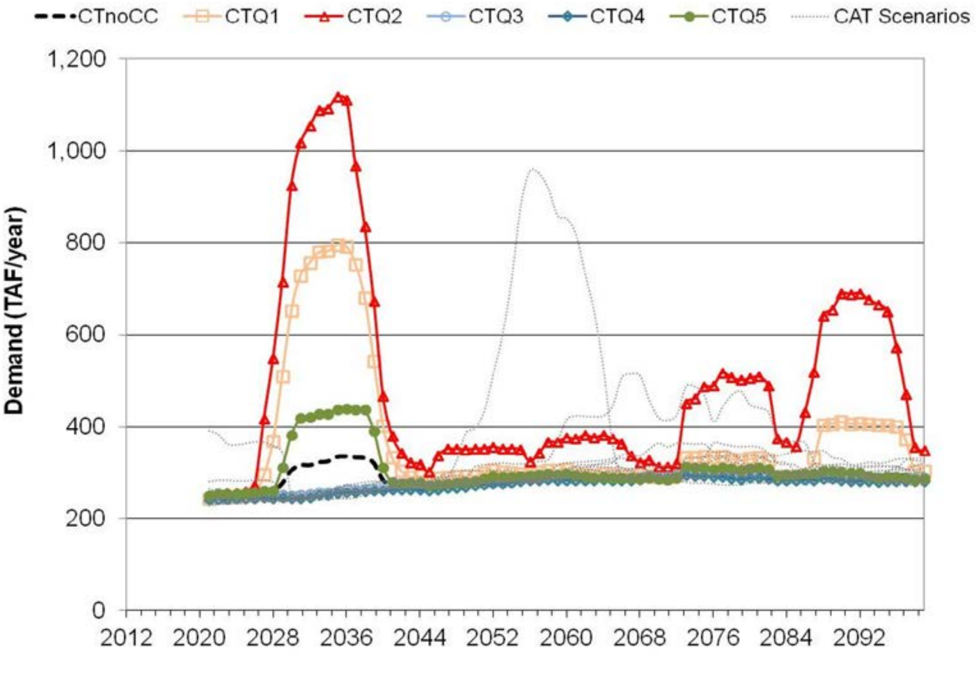

Figure 5-8. 10-Year Running Average of Unmet Demand in the Sacramento River System in Each Scenario

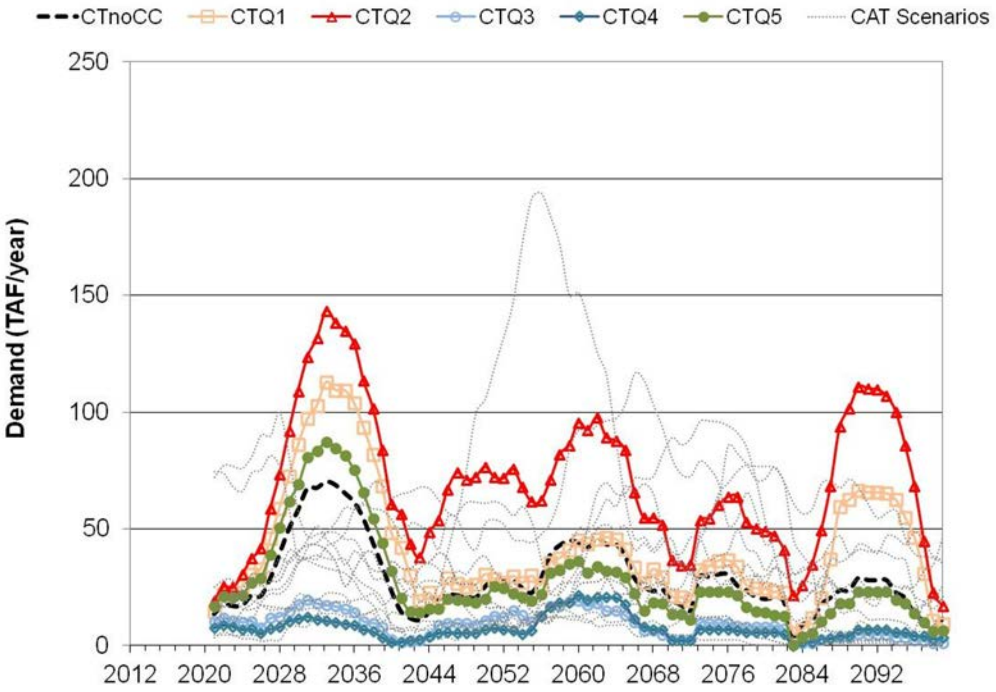

Figure 5-9. 10-Year Running Average of Unmet Demand in the Delta and Eastside Streams in Each Scenario

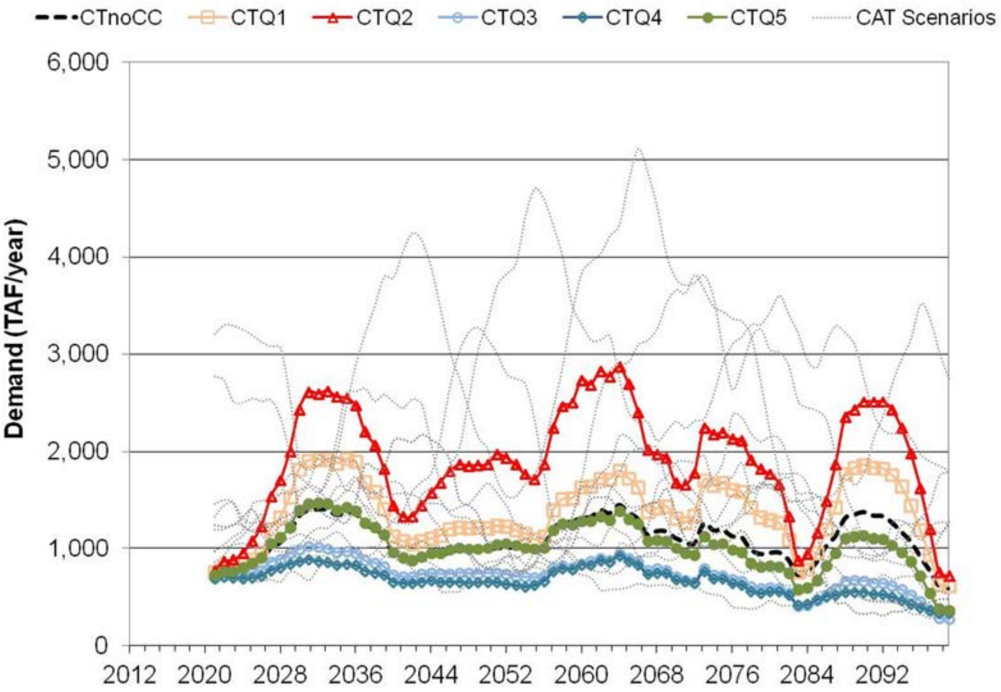

Figure 5-10. 10-Year Running Average of Unmet Demand in the San Joaquin River System in Each Scenario

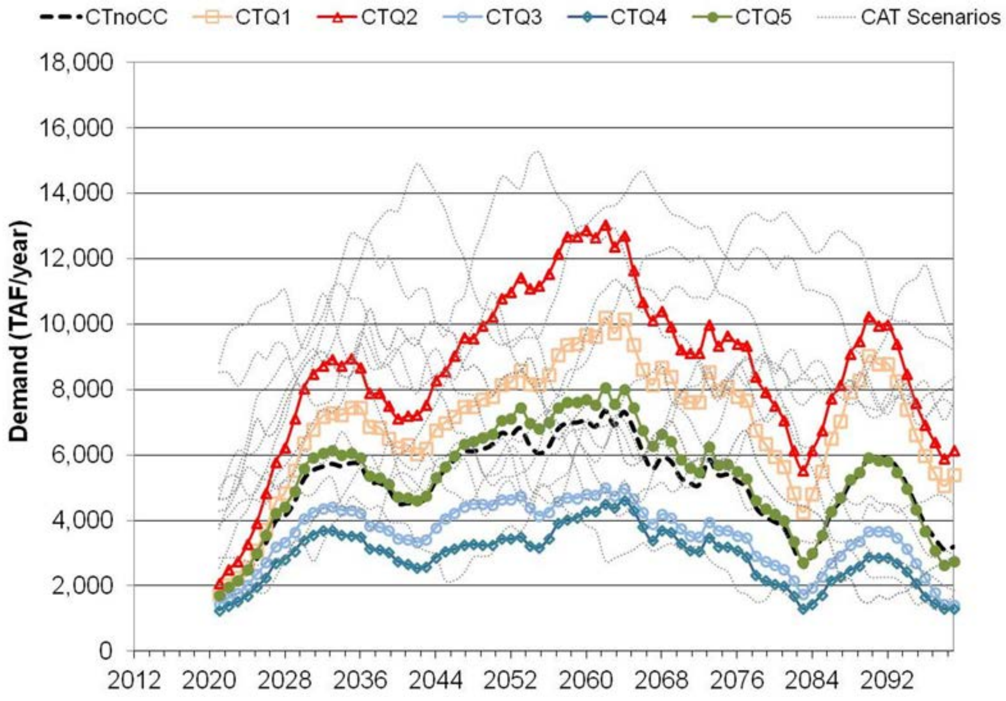

Figure 5-11. 10-Year Running Average of Unmet Demand in the Tulare Lake Region in Each Scenario

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 for each of the eighteen socioeconomic-climate scenarios for water years 2012 through 2099 and periods 2012-2040, 2041-2070, and 2071-2099.

In the no climate change (CTnoCC) scenario, Central Valley average annual unmet demand was 6,160 TAF/year from 2012 to 2099 and ranged from 5,198 TAF/year for 2012-2040; 7,673 TAF/year for 2041-2070; and 5,556 TAF/year for 2071-2099. Across the range of all climate scenarios, the average annual unmet demand in the Central Valley was 7,977 TAF/year, an increase of 29.8% compared to no climate change. It ranged from 3,511 to 12,017 TAF/year for 2012-2040; 4,627 to 16,108 TAF/year for 2041-2070; and 2,801 to 14,615 TAF/year for 2071-2099.

Table 5-3. Average Annual Unmet Demands in Each Scenario (in TAF/Year)

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 5,198 | 6,609 | 8,028 | 4,119 | 3,511 | 5,486 |
| | 2041–2070 | 7,673 | 10,125 | 13,283 | 5,407 | 4,627 | 8,155 |
| | 2071–2099 | 5,556 | 8,338 | 10,093 | 3,339 | 2,801 | 5,316 |
| | 2012–2099 | 6,160 | 8,377 | 10,500 | 4,301 | 3,657 | 6,340 |
| Sacramento River System | 2012–2040 | 282 | 439 | 557 | 254 | 250 | 3181 |
| | 2041–2070 | 286 | 297 | 347 | 284 | 281 | 289 |
| | 2071–2099 | 296 | 348 | 510 | 290 | 285 | 300 |
| | 2012–2099 | 288 | 361 | 470 | 276 | 272 | 302 |
| Delta and Eastside Streams | 2012–2040 | 33 | 51 | 64 | 11 | 7 | 40 |
| | 2041–2070 | 30 | 32 | 70 | 11 | 10 | 23 |
| | 2071–2099 | 19 | 33 | 58 | 4 | 5 | 13 |
| | 2012–2099 | 27 | 394 | 64 | 9 | 7 | 26 |
| San Joaquin River System | 2012–2040 | 1,023 | 1,253 | 1,575 | 820 | 746 | 1,044 |
| | 2041–2070 | 1,140 | 1,387 | 2,094 | 770 | 724 | 1,102 |
| | 2071–2099 | 970 | 1,267 | 1,667 | 519 | 482 | 777 |
| | 2012–2099 | 1,045 | 1,303 | 1,782 | 704 | 652 | 976 |
| Tulare Lake Region | 2012–2040 | 3,861 | 4,867 | 5,831 | 3,034 | 2,508 | 4,083 |
| | 2041–2070 | 6,218 | 8,408 | 10,772 | 4,342 | 3,612 | 6,742 |
| | 2071–2099 | 4,271 | 6,689 | 7,859 | 2,526 | 2,029 | 4,226 |
| | 2012–2099 | 4,800 | 6,675 | 8,184 | 3,313 | 2,727 | 5,037 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 5,198 | 5,052 | 9,239 | 11,788 | 9,654 | 9,654 | 6,209 |
| | 2041–2070 | 7,673 | 13,749 | 8,408 | 15,925 | 8,823 | 8,823 | 5,118 |
| | 2071–2099 | 5,556 | 7,110 | 11,223 | 11,579 | 4,003 | 4,003 | 2,765 |
| | 2012–2099 | 6,160 | 8,695 | 9,609 | 13,130 | 7,508 | 7,508 | 4,702 |
| Sacramento River System | 2012–2040 | 282 | 249 | 254 | 263 | 250 | 250 | 250 |
| | 2041–2070 | 286 | 320 | 289 | 383 | 292 | 292 | 279 |
| | 2071–2099 | 296 | 302 | 322 | 358 | 285 | 285 | 281 |
| | 2012–2099 | 288 | 291 | 288 | 335 | 276 | 276 | 270 |
| Delta and Eastside Streams | 2012–2040 | 33 | 12 | 29 | 42 | 32 | 32 | 14 |
| | 2041–2070 | 30 | 62 | 21 | 75 | 19 | 19 | 8 |
| | 2071–2099 | 19 | 22 | 36 | 27 | 2 | 2 | 0 |
| | 2012–2099 | 27 | 32 | 28 | 48 | 18 | 18 | 8 |
| San Joaquin River System | 2012–2040 | 1,023 | 1,034 | 1,435 | 2,266 | 1,595 | 1,595 | 1,036 |
| | 2041–2070 | 1,140 | 2,844 | 1,114 | 3,212 | 1,241 | 1,241 | 714 |
| | 2071–2099 | 970 | 1,187 | 2,037 | 1,854 | 551 | 551 | 457 |
| | 2012–2099 | 1,045 | 1,701 | 1,524 | 2,453 | 1,130 | 1,130 | 735 |
| Tulare Lake Region | 2012–2040 | 3,861 | 3,756 | 7,521 | 9,218 | 7,778 | 7,778 | 4,910 |
| | 2041–2070 | 6,218 | 10,523 | 6,983 | 12,256 | 7,271 | 7,271 | 4,116 |
| | 2071–2099 | 4,271 | 5,559 | 8,829 | 9,341 | 3,165 | 3,165 | 2,027 |
| | 2012–2099 | 4,800 | 6,670 | 7,769 | 10,294 | 6,085 | 6,085 | 3,689 |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Total Central Valley | 2012–2040 | 5,198 | 6,782 | 8,219 | 12,017 | 7,067 | 11,227 | 4,281 |
| | 2041–2070 | 7,673 | 7,986 | 9,504 | 16,108 | 7,514 | 8,337 | 6,461 |
| | 2071–2099 | 5,556 | 10,066 | 10,167 | 14,615 | 9,329 | 5,075 | 5,537 |
| | 2012–2099 | 6,160 | 8,275 | 9,299 | 14,268 | 7,965 | 8,215 | 5,438 |
| Sacramento River System | 2012–2040 | 282 | 253 | 266 | 304 | 249 | 271 | 248 |
| | 2041–2070 | 286 | 294 | 296 | 513 | 298 | 287 | 293 |
| | 2071–2099 | 296 | 310 | 295 | 319 | 300 | 307 | 309 |
| | 2012–2099 | 288 | 286 | 286 | 380 | 282 | 288 | 284 |
| Delta and Eastside Streams | 2012–2040 | 33 | 18 | 23 | 56 | 17 | 48 | 7 |
| | 2041–2070 | 30 | 19 | 28 | 99 | 31 | 20 | 18 |
| | 2071–2099 | 19 | 34 | 27 | 60 | 25 | 18 | 29 |
| | 2012–2099 | 27 | 24 | 26 | 72 | 25 | 28 | 18 |
| San Joaquin River System | 2012–2040 | 1,023 | 1,121 | 1,380 | 2,239 | 1,225 | 2,111 | 807 |
| | 2041–2070 | 1,140 | 1,189 | 1,319 | 2,984 | 1,211 | 1,135 | 1,082 |
| | 2071–2099 | 970 | 1,485 | 1,377 | 2,727 | 1,334 | 750 | 1,032 |
| | 2012–2099 | 1,045 | 1,264 | 1,358 | 2,654 | 1,256 | 1,330 | 975 |
| Tulare Lake Region | 2012–2040 | 3,861 | 5,391 | 6,550 | 9,418 | 5,576 | 8,798 | 3,219 |
| | 2041–2070 | 6,218 | 6,483 | 7,861 | 12,511 | 5,974 | 6,895 | 5,067 |
| | 2071–2099 | 4,271 | 8,237 | 8,469 | 11,509 | 7,670 | 4,000 | 4,166 |
| | 2012–2099 | 4,800 | 6,701 | 7,629 | 11,162 | 6,402 | 6,568 | 4,161 |

### *End-of-September System Storage*

End-of-September storage provides a measure of relative risk to making future deliveries, particularly during periods of extended drought. This “carryover” storage metric is applicable to major CVP, SWP and other reservoirs in all three of the Central Valley of California’s hydrologic basins.

Figures 5-12 through 5-20 are exceedance plots of storage at the end of September in Shasta, Folsom, Oroville, New Melones and San Luis reservoirs and for 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 socioeconomic-climate scenarios.

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 projections (CTQ1 and CTQ2), 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 Impact Assessment 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.

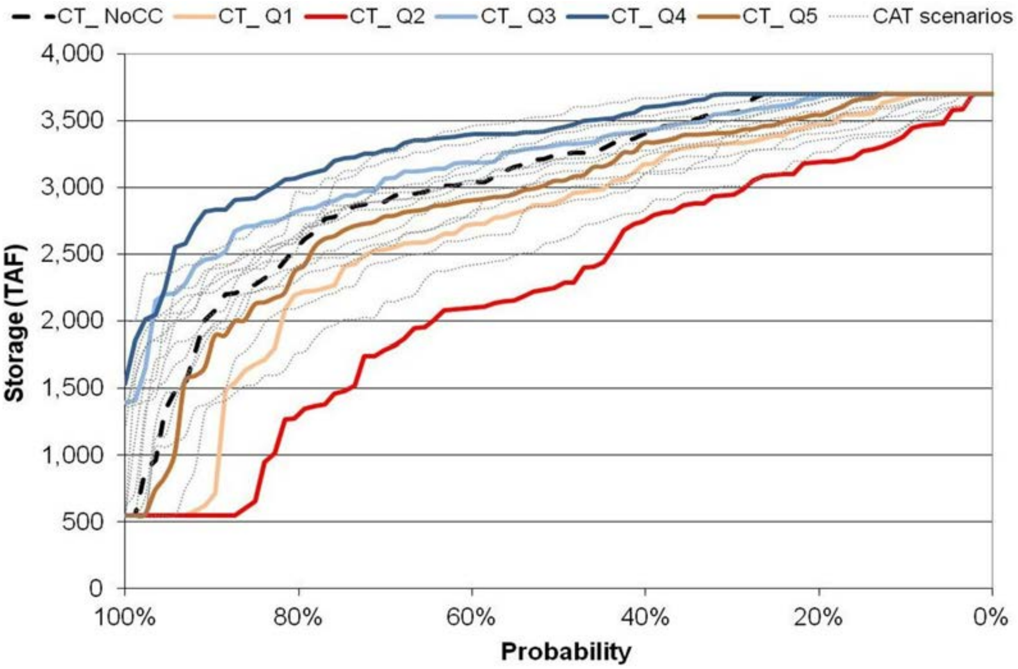

Figure 5-12. Exceedance Plot of Lake Shasta End-of-September Storage for Each Scenario

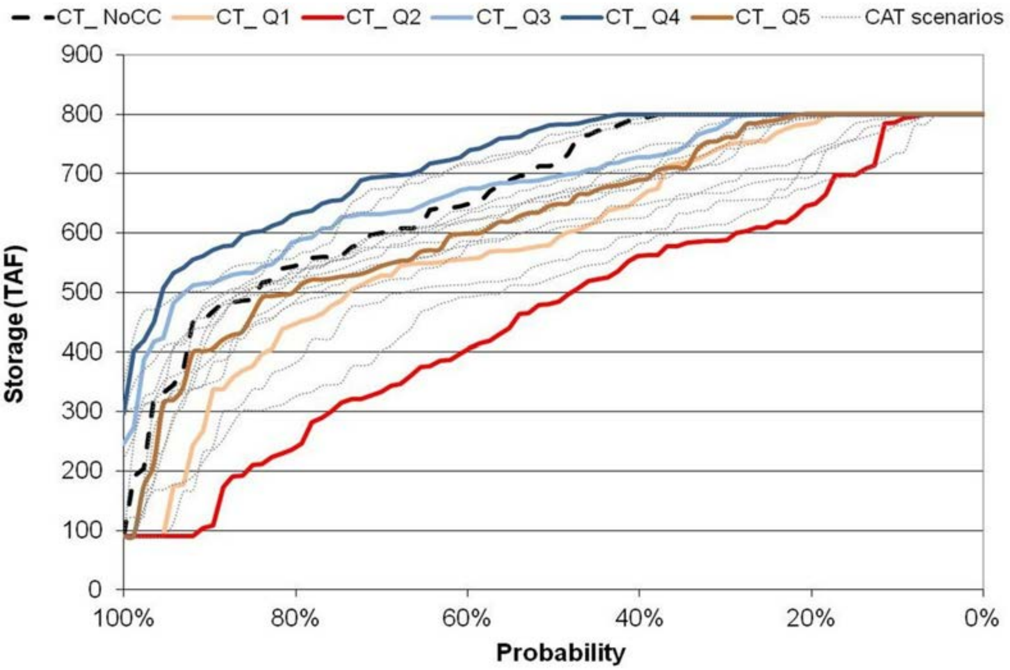

Figure 5-13. Exceedance Plot of Folsom Lake End-of-September Storage for Each Scenario

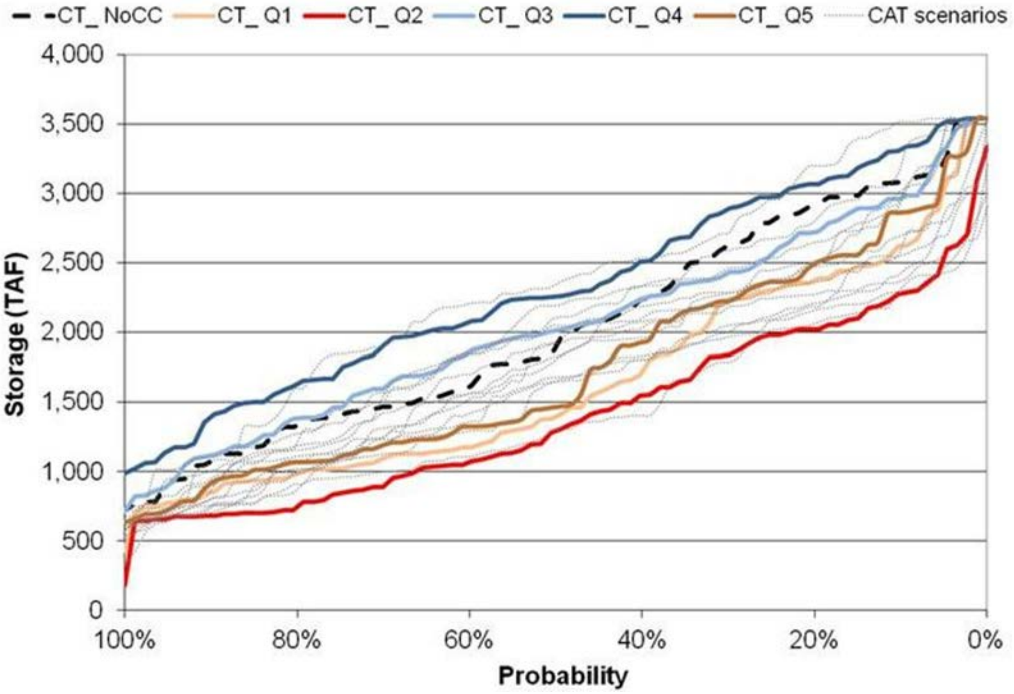

Figure 5-14. Exceedance Plot of Lake Oroville End-of-September Storage for Each Scenario

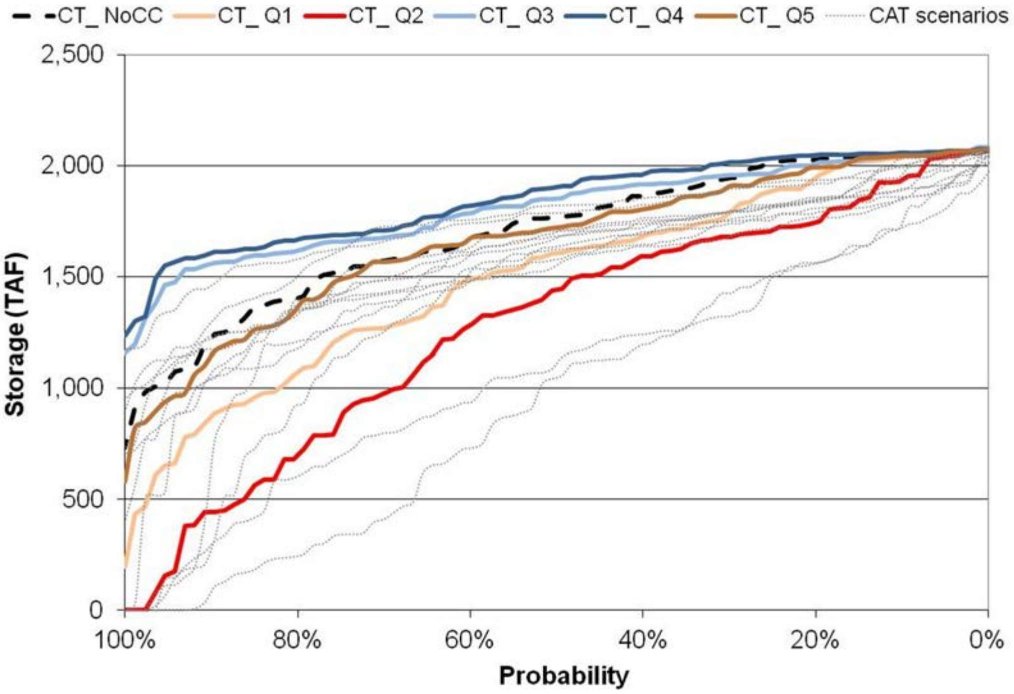

Figure 5-15. Exceedance Plot of New Melones Reservoir End-of-September Storage for Each Scenario

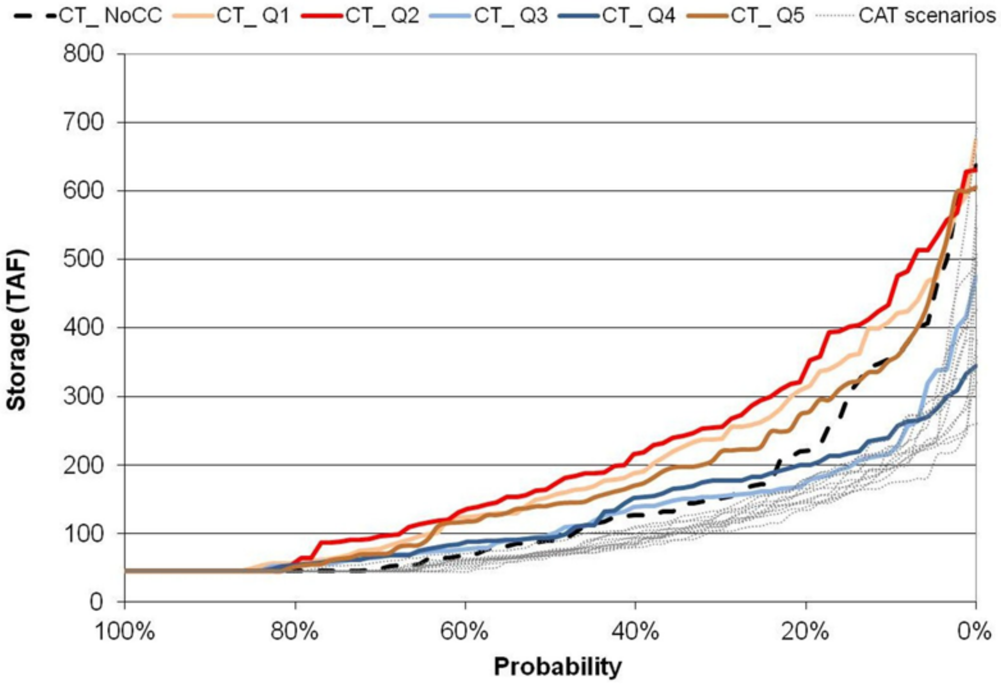

Figure 5-16. Exceedance Plot of CVP San Luis Reservoir End-of-September Storage for Each Scenario

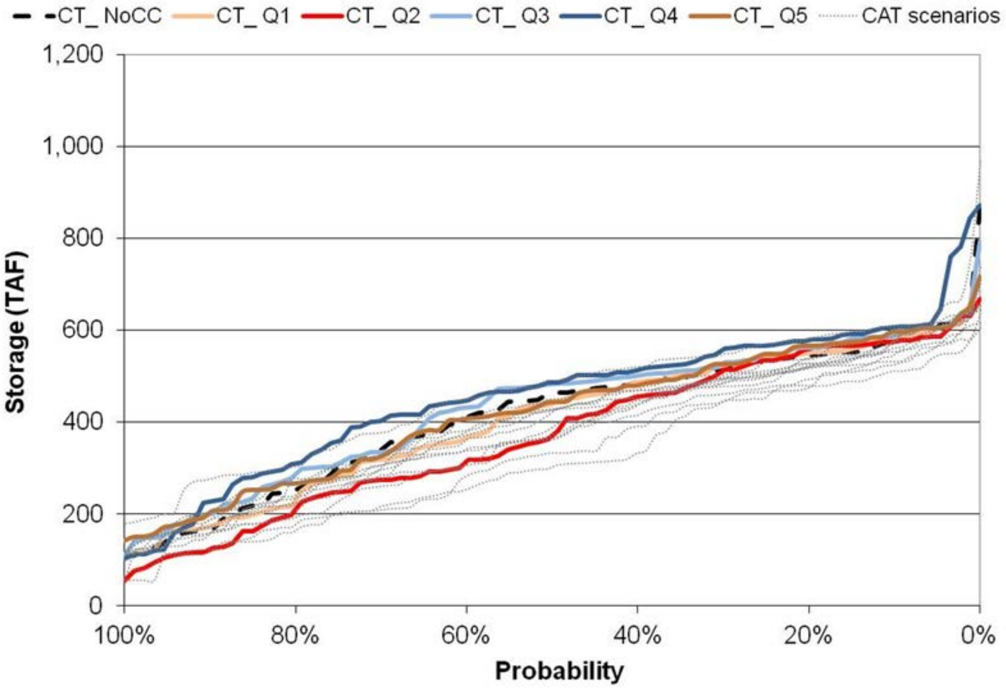

Figure 5-17. Exceedance Plot of SWP San Luis Reservoir End-of-September Storage for Each Scenario

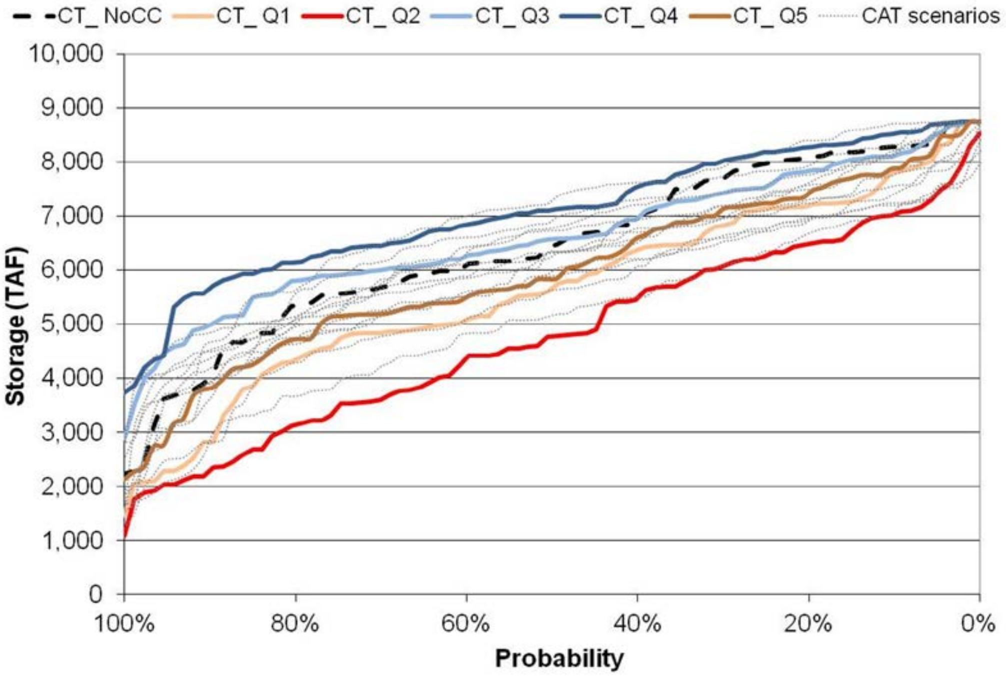

Figure 5-18. Exceedance Plot of Sacramento Valley End-of-September Storage for Each Scenario

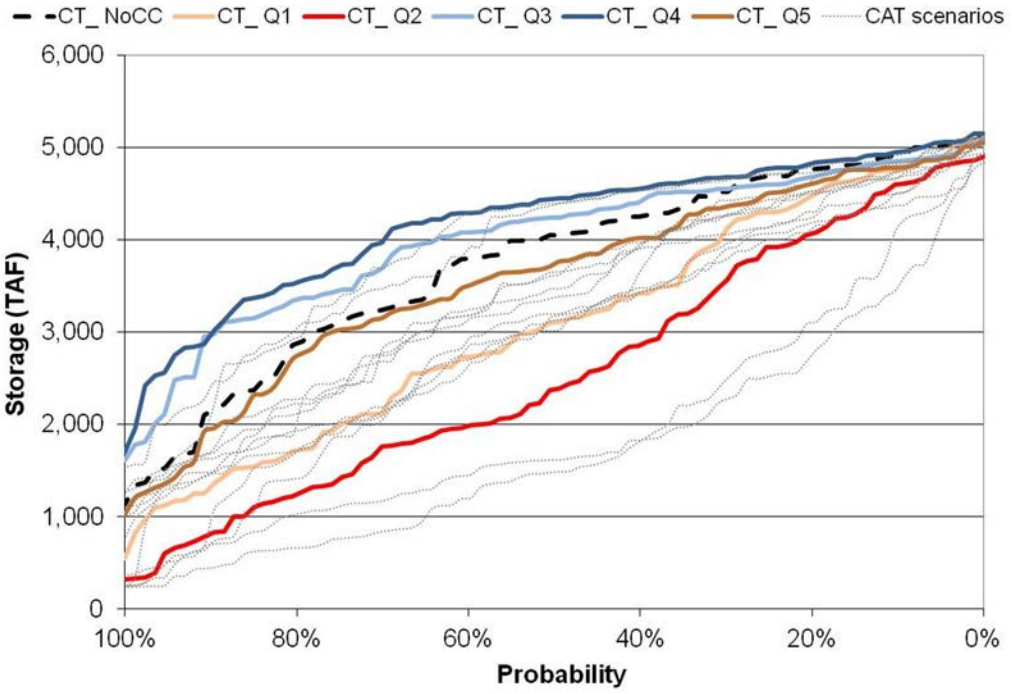

Figure 5-19. Exceedance Plot of San Joaquin Valley End-of-September Storage for Each Scenario

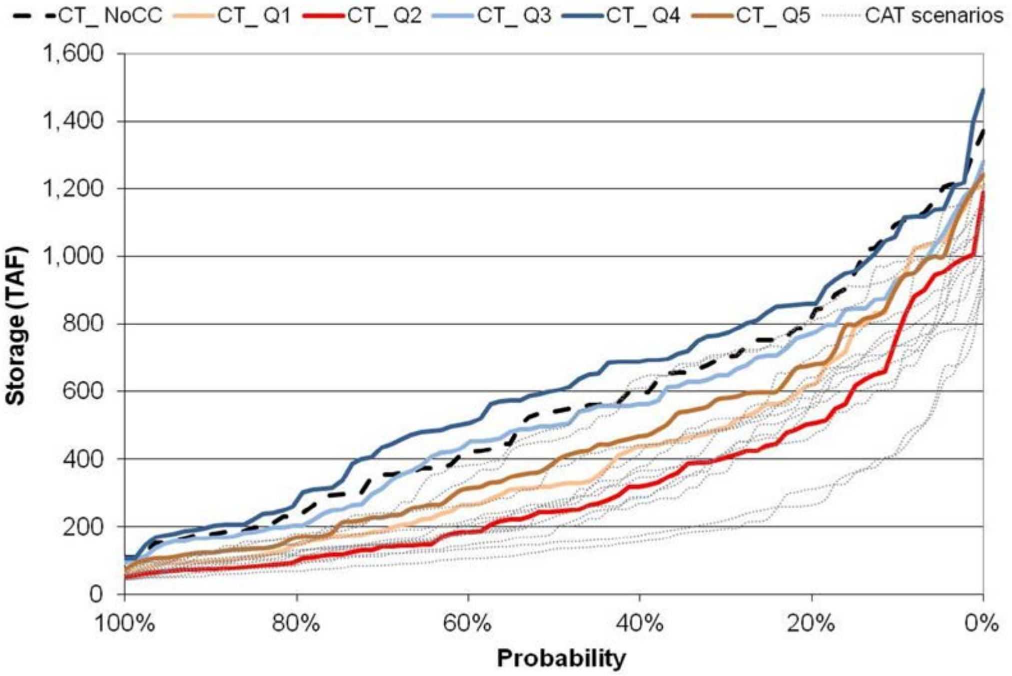

Figure 5-20. Exceedance Plot of Tulare Lake Region End-of-September Storage for Each Scenario

Figures 5-21 through 5-23 show the 10-year moving average of end-of-September storage in each scenario in the Sacramento Valley, San Joaquin Valley, and Tulare Lake region. Although the storage trends for the five ensemble-informed (EI) 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 CAT scenarios show significant variability across the twenty-first century in all three regions.

The median climate scenario (CTQ5) had storage levels very close to the CTnoCC scenario in Lake Oroville and a moderate amount lower than the CTnoCC scenario in Shasta, Folsom, and New Melones reservoirs. In all the reservoirs, the storage was higher under the wetter climate scenarios (CTQ3 and CTQ4) than under the CTnoCC scenario, with the highest storage levels in the wetter, less warming scenario (CTQ4). Conversely, the storage levels in September were lower under the drier climate scenarios (CTQ1 and CTQ2) than under the CTNoCC scenario, with the lowest storage levels in the drier, more warming scenario (CTQ2). Shasta, Oroville, Folsom, and New Melones reservoirs were all at dead storage in some proportion of years at the end of September under climate scenario CTQ2, with Lake Shasta the most likely to be at dead storage in about 15 percent of all years. In most of these reservoirs, dead storage conditions also occurred in the CTQ1 and CTQ5 scenarios, but less frequently than under the CTQ2 scenario.

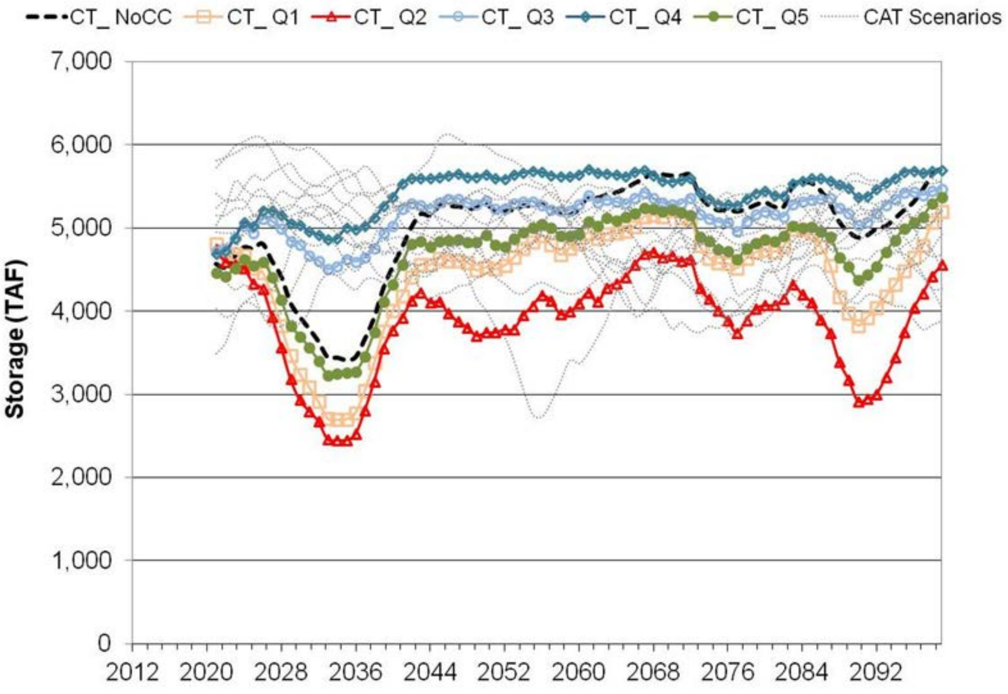

Figure 5-21. 10-Year Moving Average of Total Annual Storage in the Sacramento Valley in Each Scenario

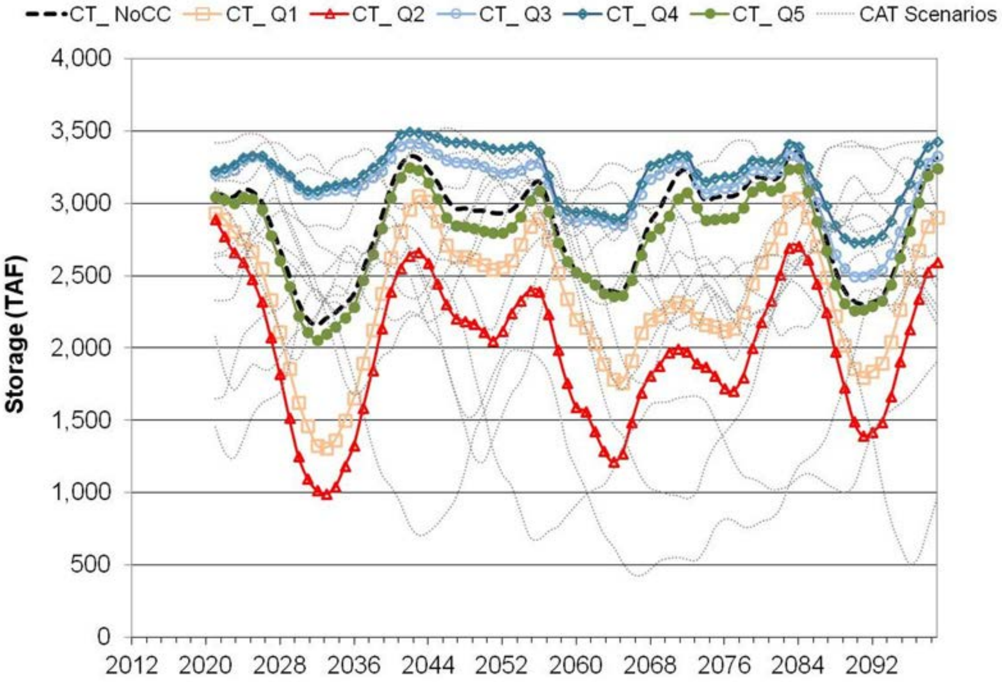

Figure 5-22. 10-Year Moving Average of Total Annual Storage in the San Joaquin Valley in Each Scenario

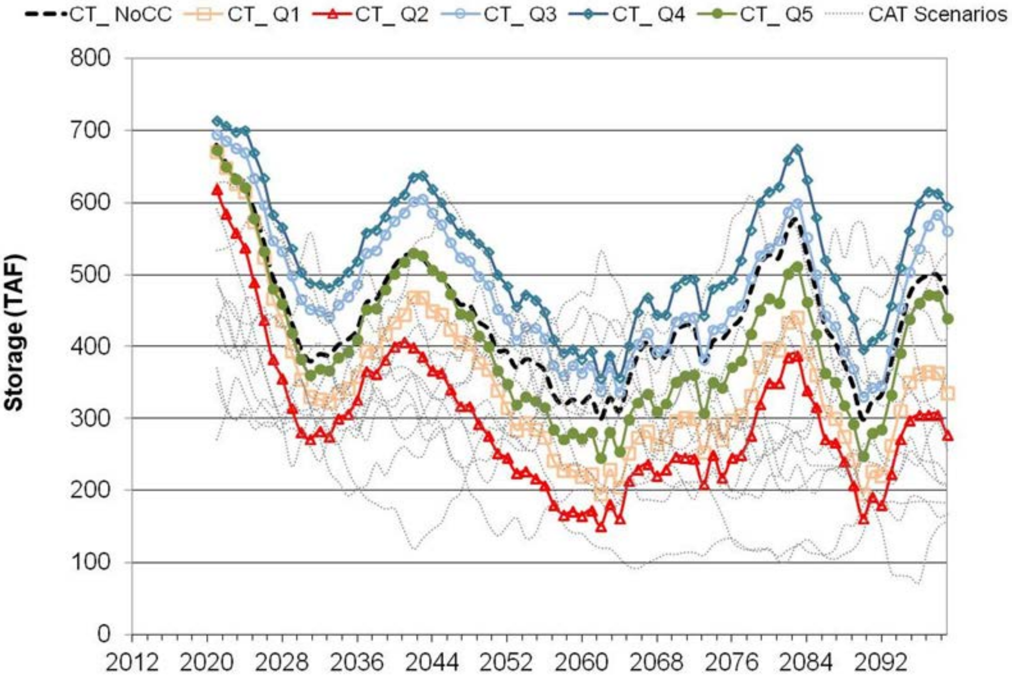

Figure 5-23. 10-Year Moving Average of Total Annual Storage in the Tulare Lake Region in Each Scenario

Table 5-4 presents the percentage of time that end-of-September storage is less than the 10th percentile storage value occurring in the CTnoCC scenario during the 21st century. 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 2012 through 2099 and for the periods from 2012-2040, 2041-2070, and 2071-2099.

In the no climate change (CTnoCC) scenario, overall end-of-September reservoir storages ranged from 3 to 24% less than the 2012-2099 performance metric for the 2012-2040 period; 0 to 20% less from 2041-2070; and 3 to 14% from 2071-2099 than the 10th percentile storage value in 2012-2099 period.

Across the range of all climate scenarios, the overall average Sacramento, San Joaquin and Tulare regions end-of-September storages were below their respective CTnoCC performance metrics for 12%, 26% and 33% of the years in the 21st century. During this period, the metric values ranged from minimum of 2% in the Sacramento Valley to a maximum of 83% in the San Jaoquin Valley more years with end-of-September storages below the 10th percentile of the CTnoCC scenario.

### *CVP and SWP Delta Exports*

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-the-study area water users. The CVP exports water at the C. W. “Bill” Jones Pumping Plant and SWP exports occur at the Harvey O. Banks Pumping Plant. Both pumping plants are located in the southern part of the Delta.

Figures 5-24 through 5-29 are annual exceedance and box plots of CVP and SWP exports at Harvey O. Banks Pumping Plant (Banks PP) and C. W. Jones Pumping Plant (Jones PP), and of total Delta exports. The box plots depict the mean, median, 25th and 75th percentiles, minimum, and maximum values for the annual flows at these same locations in each of the socioeconomic-climate scenarios.

The Delta export results differed significantly among the different climate scenarios. Banks PP and Jones PP pumping were all lower under climate scenarios CTQ5, CTQ1, and CTQ2 than under the CTnoCC scenario, with the lowest flows among the ensemble-informed scenarios occurring in the warmer-drier CTQ2 scenario. Conversely, the annual flows at both locations were greater under climate scenarios CT Q4 than under the CTnoCC scenario, with the highest flows among the ensemble-informed scenarios occurring in the less warm-wetter CTQ4 scenario. The drier climate scenarios (CTQ1 and CTQ2) showed a greater difference in Delta exports relative to the CTnoCC scenarios than did the wetter climate scenarios (CTQ3 and CTQ4) because exports in the wetter climate scenarios were frequently limited by CVP SWP conveyance

Table 5-4. Percentage of Years with End-of-September Storage Less than the 10th Percentile of Storage in the CTnoCC Scenario for Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 24% | 41% | 48% | 7% | 7% | 31% |
| | 2041–2070 | 0% | 0% | 27% | 0% | 0% | 0% |
| | 2071–2099 | 7% | 14% | 38% | 3% | 3% | 10% |
| | 2012–2099 | 10% | 8% | 38% | 3% | 3% | 14% |
| Folsom | 2012–2040 | 21% | 41% | 52% | 10% | 10% | 31% |
| | 2041–2070 | 0% | 0% | 43% | 3% | 0% | 0% |
| | 2071–2099 | 10% | 24% | 48% | 3% | 3% | 10% |
| | 2012–2099 | 10% | 22% | 48% | 6% | 5% | 14% |
| Oroville | 2012–2040 | 21% | 34% | 41% | 17% | 7% | 31% |
| | 2041–2070 | 7% | 27% | 37% | 7% | 3% | 13% |
| | 2071–2099 | 3% | 24% | 45% | 17% | 7% | 17% |
| | 2012–2099 | 10% | 28% | 41% | 14% | 6% | 20% |
| New Melones | 2012–2040 | 14% | 28% | 38% | 0% | 0% | 21% |
| | 2041–2070 | 7% | 27% | 37% | 3% | 0% | 10% |
| | 2071–2099 | 10% | 24% | 38% | 3% | 0% | 14% |
| | 2012–2099 | 10% | 26% | 38% | 2% | 0% | 15% |
| San Luis CVP | 2012–2040 | 14% | 10% | 14% | 7% | 17% | 7% |
| | 2041–2070 | 10% | 3% | 13% | 13% | 10% | 10% |
| | 2071–2099 | 7% | 7% | 24% | 3% | 10% | 10% |
| | 2012–2099 | 10% | 7% | 17% | 8% | 13% | 9% |
| San Luis SWP | 2012–2040 | 21% | 24% | 28% | 14% | 7% | 24% |
| | 2041–2070 | 3% | 17% | 37% | 7% | 0% | 10% |
| | 2071–2099 | 7% | 24% | 38% | 7% | 3% | 14% |
| | 2012–2099 | 10% | 22% | 34% | 9% | 3% | 16% |
| Sacramento Valley | 2012–2040 | 24% | 38% | 48% | 7% | 3% | 31% |
| | 2041–2070 | 0% | 0% | 30% | 0% | 0% | 0% |
| | 2071–2099 | 7% | 14% | 41% | 3% | 3% | 7% |
| | 2012–2099 | 10% | 17% | 40% | 3% | 2% | 13% |
| San Joaquin Valley | 2012–2040 | 10% | 28% | 41% | 0% | 0% | 10% |
| | 2041–2070 | 7% | 37% | 57% | 3% | 3% | 17% |
| | 2071–2099 | 14% | 28% | 41% | 14% | 3% | 17% |
| | 2012–2099 | 10% | 31% | 47% | 6% | 2% | 15% |
| Tulare Lake | 2012–2040 | 3% | 3% | 3% | 0% | 0$ | 3% |
| | 2041–2070 | 20% | 40% | 57% | 27% | 13% | 37% |
| | 2071–2099 | 7% | 41% | 59% | 24% | 7% | 31% |
| | 2012–2099 | 10% | 28% | 40% | 17% | 7% | 24% |

| Location | Period | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 0% | 7% | 17% | 3% | 28% | 3% |
| | 2041–2070 | 17% | 3% | 23% | 7% | 10% | 0% |
| | 2071–2099 | 7% | 31% | 21% | 3% | 3% | 3% |
| | 2012–2099 | 8% | 14% | 20% | 5% | 14% | 2% |
| Folsom | 2012–2040 | 0% | 14% | 17% | 10% | 24% | 3% |
| | 2041–2070 | 27% | 3% | 33% | 7% | 13% | 0% |
| | 2071–2099 | 7% | 31% | 31% | 7% | 7% | 0% |
| | 2012–2099 | 11% | 16% | 27% | 8% | 15% | 1% |
| Oroville | 2012–2040 | 7% | 17% | 21% | 17% | 34% | 10% |
| | 2041–2070 | 47% | 20% | 23% | 17% | 27% | 10% |
| | 2071–2099 | 14% | 31% | 24% | 14% | 10% | 3% |
| | 2012–2099 | 23% | 23% | 23% | 16% | 24% | 8% |
| New Melones | 2012–2040 | 7% | 10% | 48% | 17% | 31% | 7% |
| | 2041–2070 | 63% | 7% | 83% | 10% | 33% | 0% |
| | 2071–2099 | 10% | 48% | 55% | 3% | 0% | 3% |
| | 2012–2099 | 27% | 22% | 63% | 10% | 22% | 3% |
| San Luis CVP | 2012–2040 | 28% | 7% | 14% | 14% | 21% | 14% |
| | 2041–2070 | 20% | 17% | 13% | 7% | 13% | 13% |
| | 2071–2099 | 10% | 10% | 14% | 10% | 3% | 14% |
| | 2012–2099 | 19% | 11% | 14% | 10% | 13% | 14% |
| San Luis SWP | 2012–2040 | 7% | 17% | 10% | 3% | 28% | 10% |
| | 2041–2070 | 27% | 13% | 37% | 10% | 20% | 3% |
| | 2071–2099 | 14% | 31% | 21% | 14% | 10% | 3% |
| | 2012–2099 | 16% | 20% | 23% | 9% | 19% | 6% |
| Sacramento Valley | 2012–2040 | 0% | 7% | 14% | 7% | 24% | 3% |
| | 2041–2070 | 17% | 3% | 23% | 3% | 17% | 0% |
| | 2071–2099 | 7% | 21% | 17% | 3% | 3% | 3% |
| | 2012–2099 | 8% | 10% | 18% | 5% | 15% | 2% |
| San Joaquin Valley | 2012–2040 | 7% | 17% | 45% | 28% | 34% | 10% |
| | 2041–2070 | 70% | 17% | 87% | 23% | 37% | 0% |
| | 2071–2099 | 14% | 59% | 66% | 3% | 14% | 7% |
| | 2012–2099 | 31% | 31% | 66% | 18% | 28% | 6% |
| Tulare Lake | 2012–2040 | 7% | 34% | 48% | 34% | 31% | 17% |
| | 2041–2070 | 37% | 43% | 73% | 40% | 43% | 20% |
| | 2071–2099 | 28% | 76% | 79% | 28% | 48% | 28% |
| | 2012–2099 | 24% | 51% | 67% | 34% | 41% | 22% |

| Location | Period | CTB1_ cnrmcm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 10% | 7% | 21% | 0% | 24% | 3% |
| | 2041–2070 | 7% | 7% | 37% | 13% | 0% | 10% |
| | 2071–2099 | 17% | 3% | 24% | 7% | 14% | 14% |
| | 2012–2099 | 11% | 6% | 27% | 7% | 13% | 9% |
| Folsom | 2012–2040 | 10% | 10% | 24% | 0% | 24% | 3% |
| | 2041–2070 | 10% | 7% | 40% | 20% | 13% | 10% |
| | 2071–2099 | 21% | 10% | 41% | 7% | 14% | 14% |
| | 2012–2099 | 14% | 9% | 35% | 9% | 17% | 9% |
| Oroville | 2012–2040 | 10% | 21% | 24% | 7% | 31% | 7% |
| | 2041–2070 | 13% | 13% | 47% | 23% | 10% | 13% |
| | 2071–2099 | 24% | 17% | 31% | 10% | 14% | 10% |
| | 2012–2099 | 16% | 17% | 34% | 14% | 18% | 10% |
| New Melones | 2012–2040 | 10% | 14% | 41% | 17% | 41% | 0% |
| | 2041–2070 | 7% | 17% | 63% | 23% | 3% | 13% |
| | 2071–2099 | 10% | 10% | 62% | 3% | 3% | 14% |
| | 2012–2099 | 9% | 14% | 56% | 15% | 16% | 9% |
| San Luis CVP | 2012–2040 | 24% | 21% | 17% | 10% | 21% | 24% |
| | 2041–2070 | 10% | 17% | 27% | 23% | 10% | 17% |
| | 2071–2099 | 14% | 3% | 10% | 0% | 3% | 24% |
| | 2012–2099 | 16% | 14% | 18% | 11% | 11% | 22% |
| San Luis SWP | 2012–2040 | 10% | 21% | 21% | 7% | 34% | 0% |
| | 2041–2070 | 7% | 10% | 50% | 17% | 7% | 10% |
| | 2071–2099 | 14% | 7% | 24% | 10% | 10% | 10% |
| | 2012–2099 | 10% | 13% | 32% | 11% | 17% | 7% |
| Sacramento Valley | 2012–2040 | 10% | 10% | 24% | 0% | 28% | 0% |
| | 2041–2070 | 7% | 7% | 37% | 10% | 0% | 13% |
| | 2071–2099 | 17% | 3% | 21% | 3% | 14% | 14% |
| | 2012–2099 | 11% | 7% | 27% | 5% | 14% | 9% |
| San Joaquin Valley | 2012–2040 | 17% | 38% | 41% | 24% | 45% | 3% |
| | 2041–2070 | 13% | 20% | 80% | 17% | 10% | 17% |
| | 2071–2099 | 38% | 34% | 83% | 24% | 3% | 14% |
| | 2012–2099 | 23% | 31% | 68% | 22% | 19% | 11% |
| Tulare Lake | 2012–2040 | 14% | 28% | 38% | 21% | 34% | 14% |
| | 2041–2070 | 37% | 33% | 63% | 37% | 40% | 37% |
| | 2071–2099 | 55% | 62% | 83% | 69% | 17% | 24% |
| | 2012–2099 | 35% | 41% | 61% | 42% | 31% | 25% |

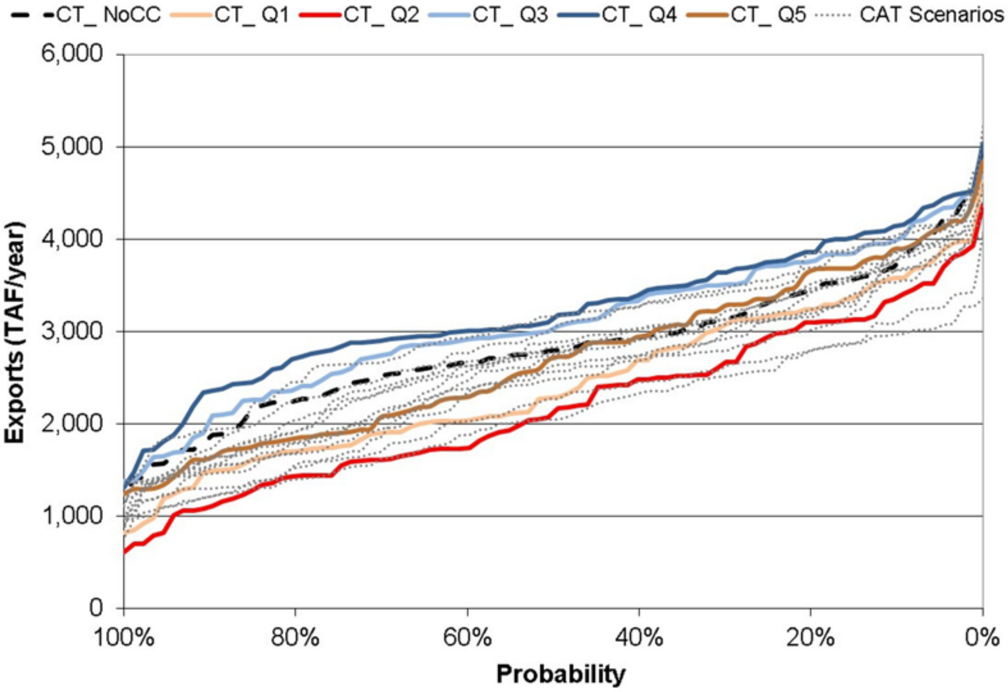

Figure 5-24. Annual Exceedance Plot of Banks Pumping for Each Scenario

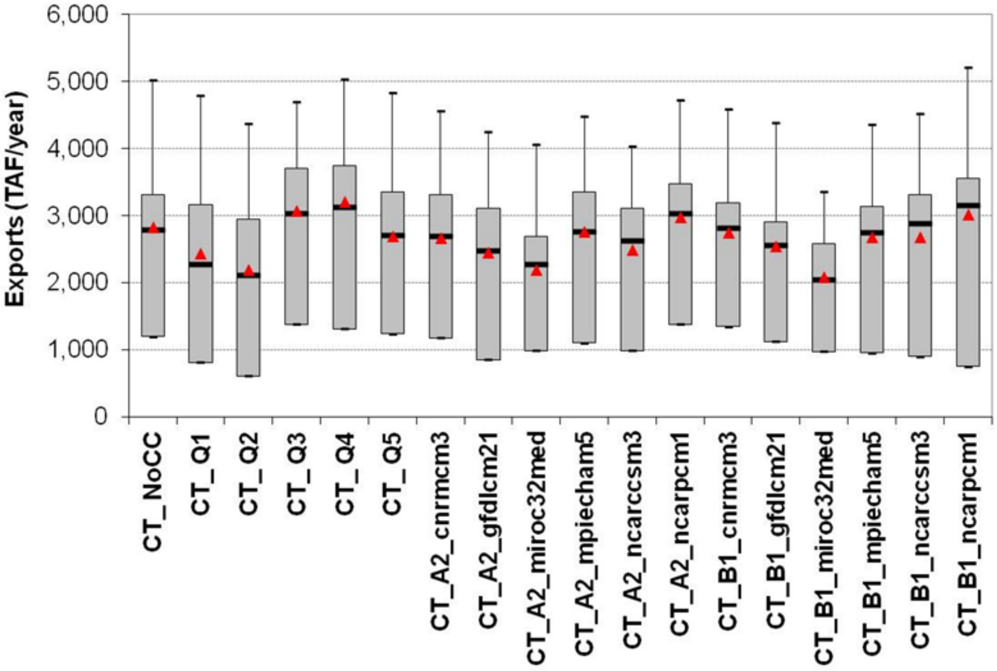

Figure 5-25. Box Plot of Banks Pumping for Each Scenario

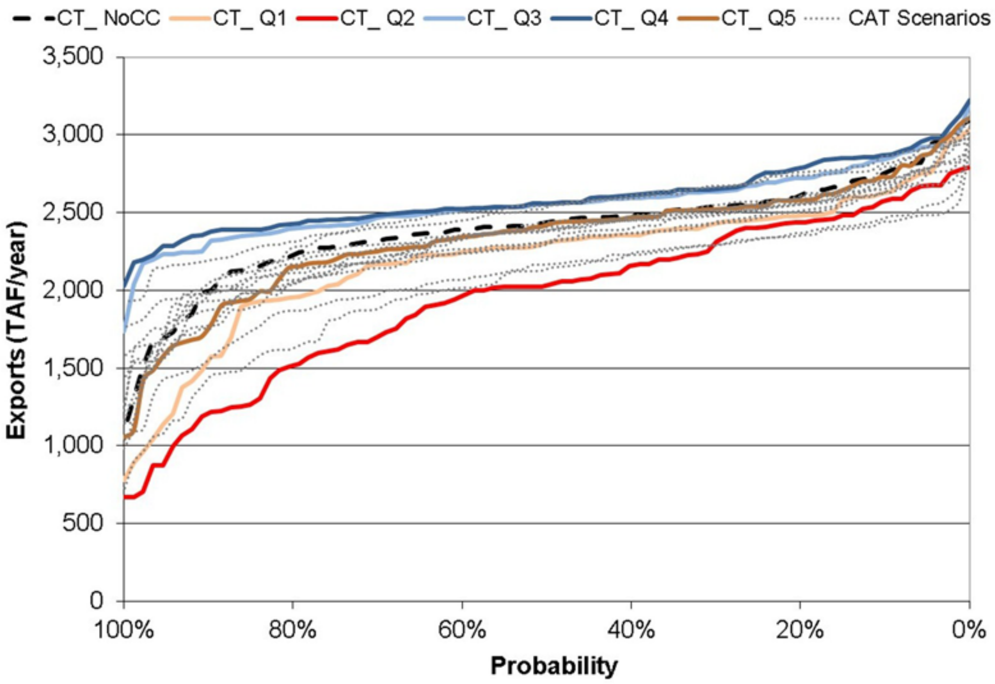

Figure 5-26. Annual Exceedance Plot of Jones PP Pumping for Each Scenario

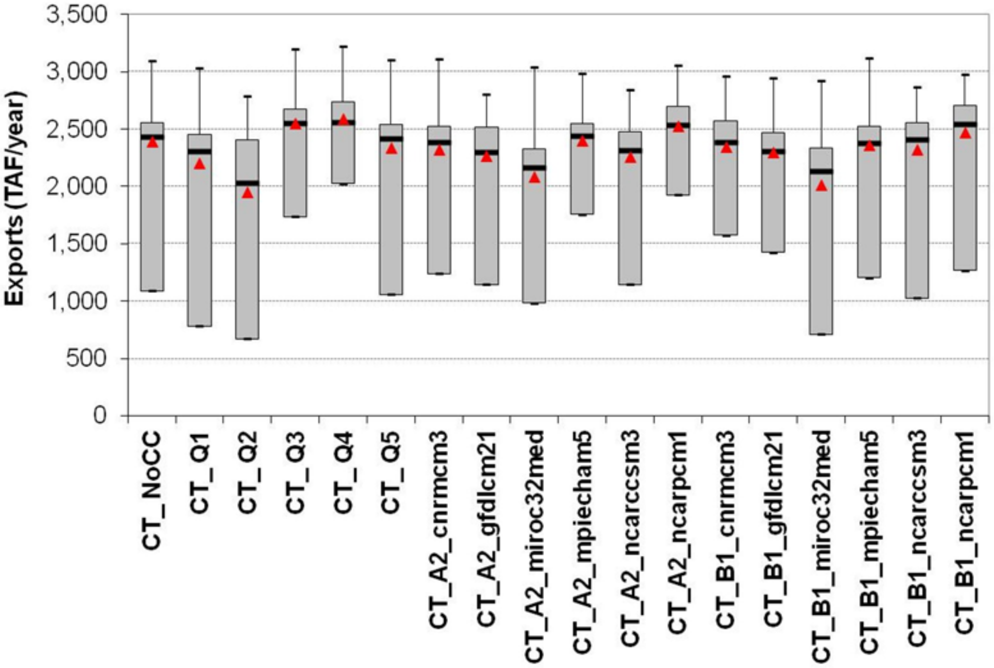

Figure 5-27. Box Plot of Jones PP Pumping for Each Scenario

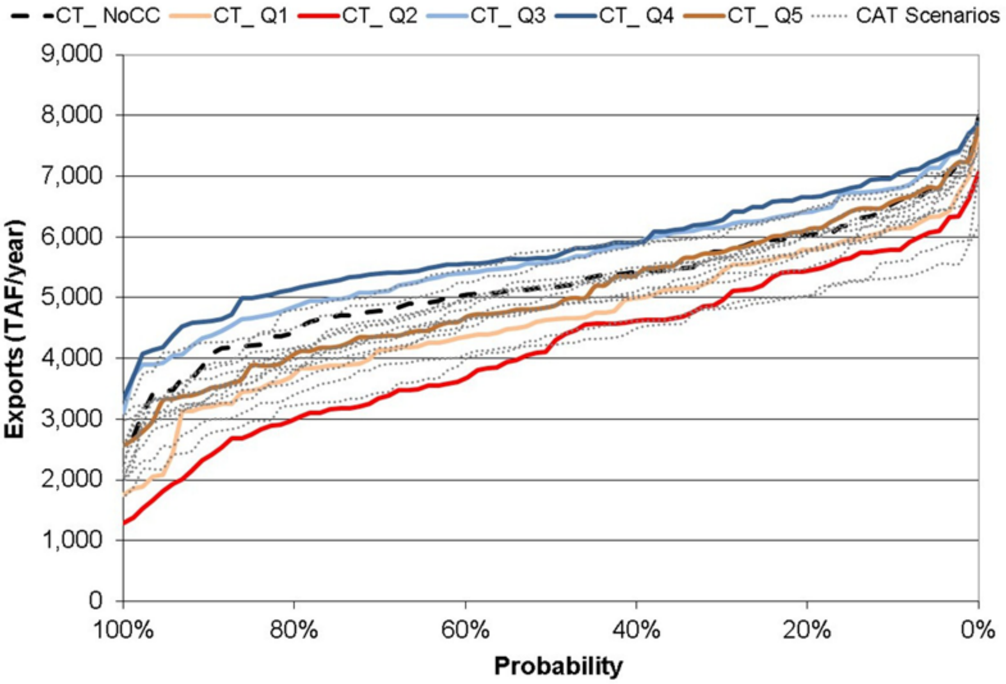

Figure 5-28. Annual Exceedance Plot of Total Delta Exports for Each Scenario

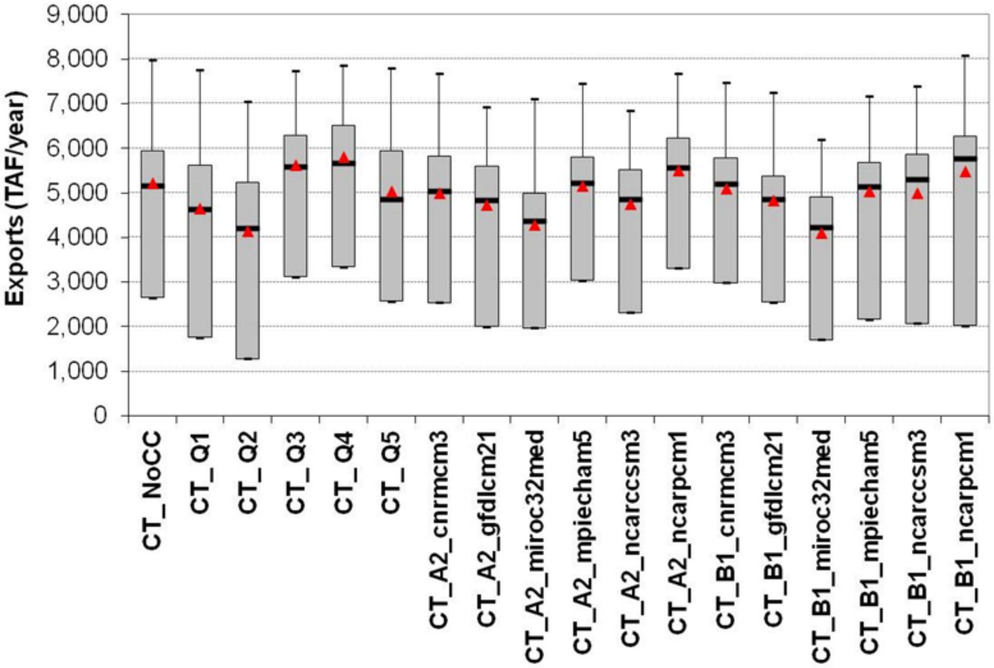

Figure 5-29. Box Plot of Total Delta Exports for Each Scenario

capacities and Delta regulatory requirements. The 12 CAT scenarios reflected a range of results similar to the ensemble-informed scenarios.

Figure 5-30 shows 10-year moving average time series of average annual Delta exports in each year in each socioeconomic-climate scenario. Although the trends for the five ensemble-informed 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 century.

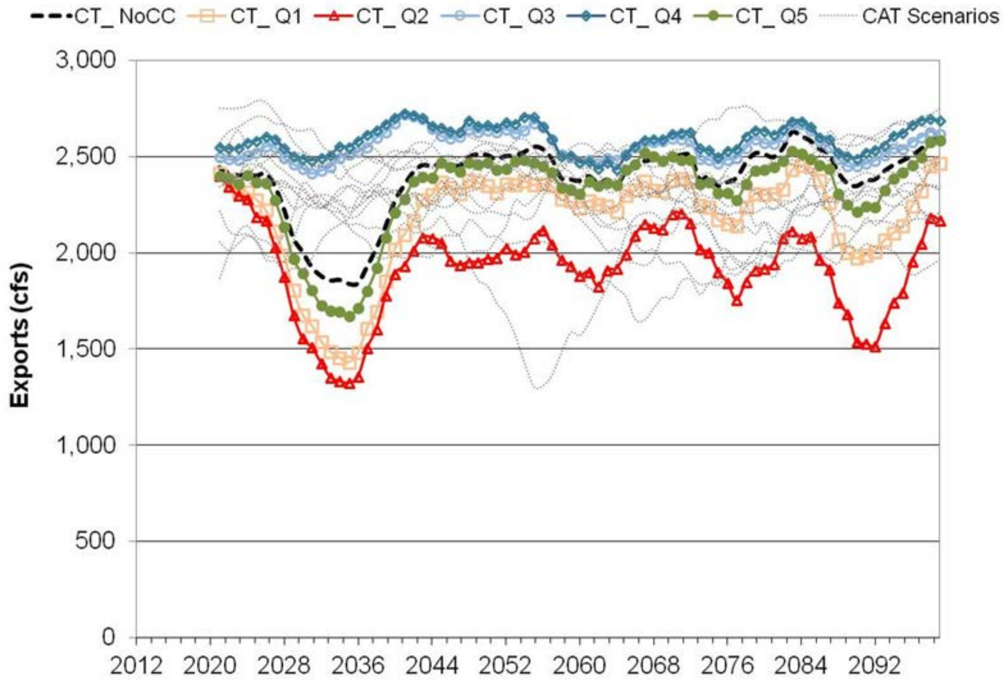

Figure 5-30. 10-Year Moving Average of Annual Total Delta Exports in the Baseline in Each Scenario

Table 5-5 shows the average annual exports from each pumping facility as well as total average annual exports from 2012 through 2099 and for the periods of 2012-2040, 2041-2070, and 2071-2099.

In the no climate change (noCC) scenario, total average annual export was 5,232 TAF/year from 2012 to 2099 and ranged from 4,900 TAF/year for 2012-2040; 5,319 TAF/year for 2041-2070; and 5,472 TAF/year for 2071-2099 periods. Across the range of all climate scenarios, the average annual total export was 4,977 TAF/year, a decrease of approximately 5% compared to no climate change. Export pumping ranged from 4,152 to 5967 TAF/year for 2012-2040; 3,784 to 5,808 TAF/year for 2041-2070; and 4,078 to 55,935 TAF/year for 2071-2099 period.

Table 5-5. Average Annual Exports at Banks PP, Jones PP and Total Exports for Each Scenario (in TAF/year)

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Banks | 2012–2040 | 2,663 | 2,378 | 2,201 | 2,993 | 3,109 | 2,653 |
| | 2041–2070 | 2,859 | 2,456 | 2,194 | 3,117 | 3,224 | 2,677 |
| | 2071–2099 | 2,982 | 2,497 | 2,178 | 3,121 | 3,323 | 2,780 |
| | 2012–2099 | 2,835 | 2,444 | 2,191 | 3,077 | 3,218 | 2,703 |
| Tracy | 2012–2040 | 2,237 | 2,039 | 1,951 | 2,547 | 2,592 | 2,161 |
| | 2041–2070 | 2,460 | 2,319 | 2,017 | 2,574 | 2,584 | 2,427 |
| | 2071–2099 | 2,490 | 2,252 | 1,900 | 2,558 | 2,612 | 2,424 |
| | 2012–2099 | 2,396 | 2,205 | 1,957 | 2,560 | 2,596 | 2,338 |
| Total | 2012–2040 | 4,900 | 4,417 | 4,152 | 5,540 | 5,701 | 4,813 |
| | 2041–2070 | 5,319 | 4,775 | 4,211 | 5,691 | 5,808 | 5,104 |
| | 2071–2099 | 5,472 | 4,749 | 4,078 | 5,679 | 5,935 | 5,204 |
| | 2012–2099 | 5,232 | 4,648 | 4,148 | 5,637 | 5,814 | 5,041 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Banks | 2012–2040 | 2,663 | 3,194 | 2,623 | 2,354 | 2,577 | 2,287 | 2,789 |
| | 2041–2070 | 2,859 | 2,142 | 2,689 | 2,046 | 2,690 | 2,424 | 2,968 |
| | 2071–2099 | 2,982 | 2,700 | 2,056 | 2,196 | 3,028 | 2,782 | 3,211 |
| | 2012–2099 | 2,835 | 2,672 | 2,458 | 2,197 | 2,764 | 2,497 | 2,989 |
| Tracy | 2012–2040 | 2,237 | 2,561 | 2,359 | 2,224 | 2,297 | 2,178 | 2,448 |
| | 2041–2070 | 2,460 | 2,139 | 2,407 | 1,913 | 2,391 | 2,244 | 2,517 |
| | 2071–2099 | 2,490 | 2,290 | 2,047 | 2,143 | 2,518 | 2,372 | 2,621 |
| | 2012–2099 | 2,396 | 2,328 | 2,272 | 2,091 | 2,402 | 2,265 | 2,528 |
| Total | 2012–2040 | 4,900 | 5,755 | 4,982 | 4,578 | 4,873 | 4,465 | 5,237 |
| | 2041–2070 | 5,319 | 4,281 | 5,095 | 3,959 | 5,081 | 4,669 | 5,484 |
| | 2071–2099 | 5,472 | 4,990 | 4,103 | 4,338 | 5,546 | 5,154 | 5,832 |
| | 2012–2099 | 5,232 | 5,000 | 4,731 | 4,288 | 5,166 | 4,761 | 5,517 |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncar pcm1 |
|---|---|---|---|---|---|---|---|---|
| Banks | 2012–2040 | 2,663 | 2,918 | 2,697 | 2,259 | 2,792 | 2,296 | 3,379 |
| | 2041–2070 | 2,859 | 2,884 | 2,609 | 1,915 | 2,784 | 2,769 | 2,835 |
| | 2071–2099 | 2,982 | 2,444 | 2,322 | 2,087 | 2,464 | 2,980 | 2,863 |
| | 2012–2099 | 2,835 | 2,750 | 2,543 | 2,085 | 2,681 | 2,683 | 3,023 |
| Tracy | 2012–2040 | 2,237 | 2,448 | 2,324 | 2,115 | 2,451 | 2,209 | 2,589 |
| | 2041–2070 | 2,460 | 2,399 | 2,292 | 1,869 | 2,323 | 2,416 | 2,417 |
| | 2071–2099 | 2,490 | 2,206 | 2,282 | 2,063 | 2,312 | 2,348 | 2,425 |
| | 2012–2099 | 2,396 | 2,352 | 2,299 | 2,014 | 2,362 | 2,325 | 2,476 |
| Total | 2012–2040 | 4,900 | 5,366 | 5,021 | 4,374 | 5,243 | 4,505 | 5,967 |
| | 2041–2070 | 5,319 | 5,283 | 4,900 | 3,784 | 5,107 | 5,185 | 5,251 |
| | 2071–2099 | 5,472 | 4,650 | 4,604 | 4,150 | 4,777 | 5,329 | 5,289 |
| | 2012–2099 | 5,232 | 5,102 | 4,842 | 4,099 | 5,043 | 5,008 | 5,500 |

### 5.2.3 Water Quality Results

Two attributes of interest were used to characterize the water quality resource category. These attributes include Delta salinity conditions and the volume of the cold water pool in Shasta Reservoir. The results for each of these performance metrics are discussed in the sections below.

#### *Delta Salinity*

Delta salinity conditions provide a measure of the risk to in-Delta and export water users that their water supplies will have higher salinity than what is required to be in compliance with standards for urban and agricultural beneficial uses set by the SWRCB in Decision 1641. The salinity standards are specified in units of electrical conductivity (EC) expressed as micro-Siemens per centimeter (µS/cm) 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 Rock Slough throughout the year (ranging from 631 to 965 µS/cm depending on the month and water year type).

Figures 5-31 and 5-32 show annual exceedance of EC at Emmaton and Jersey Point from April through August. Figure 5-33 shows the same information for EC at Rock Slough from October through September.

In the CTnoCC scenario, the EC at all three locations shows only small differences between the averages for the early, middle, and late portions of the twenty-first 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.,CT Q2) and lowest among the wetter scenarios (e.g., CTQ4).

Table 5-6 shows the average EC at each location in specific ranges of months for the periods 2012-2099 and for 2012-2040, 2041-2070, and 2071-2099 at the three locations.

In the no climate change (CTnoCC) scenario, average April-to-August EC at Emmatton was 1,940 µS/cm. Across the range of all climate scenarios, the average April-to-August EC at Emmatton was 3,152 µS/cm, an increase of 62% and ranged from a minimum of 2,305 to a maximum of 4,267 µS/cm during the 2012-2099 period.

In the no climate change (CTnoCC) scenario, average April-to-August EC at Jersey Point was 1,647 µS/cm. Across the range of all climate scenarios, the average April-to-August EC at Jersey Point was 2,359 µS/cm, an increase of 43% and ranged from a minimum of 1,895 to a maximum of 3,325 µS/cm during the 2012-2099 period.

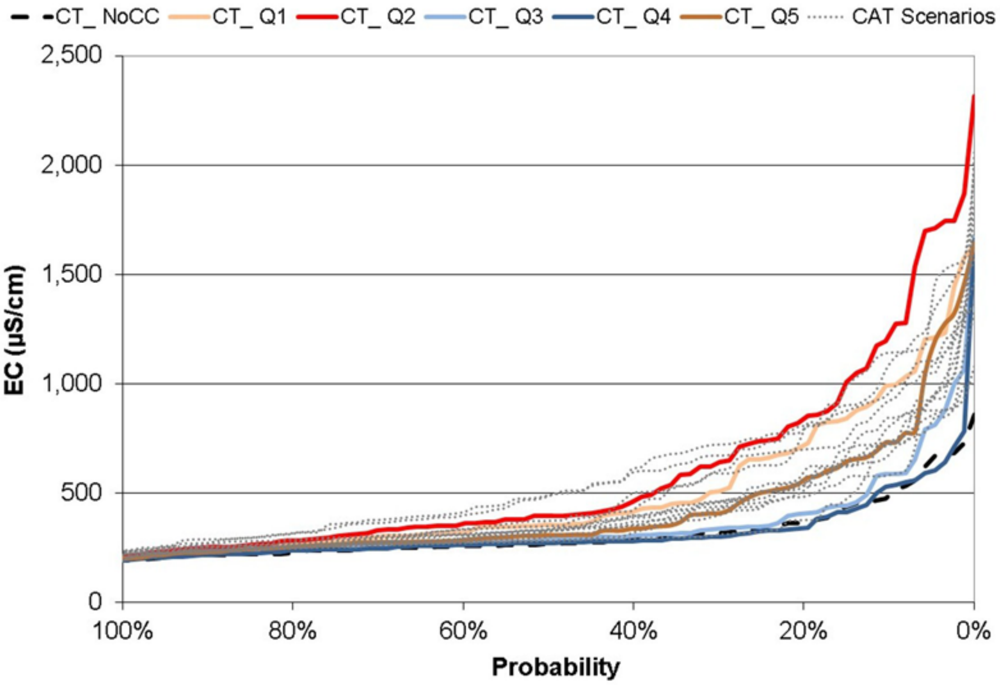

Figure 5-31. Exceedance Plot of Average April-to-August EC at Emmaton for Each Scenario

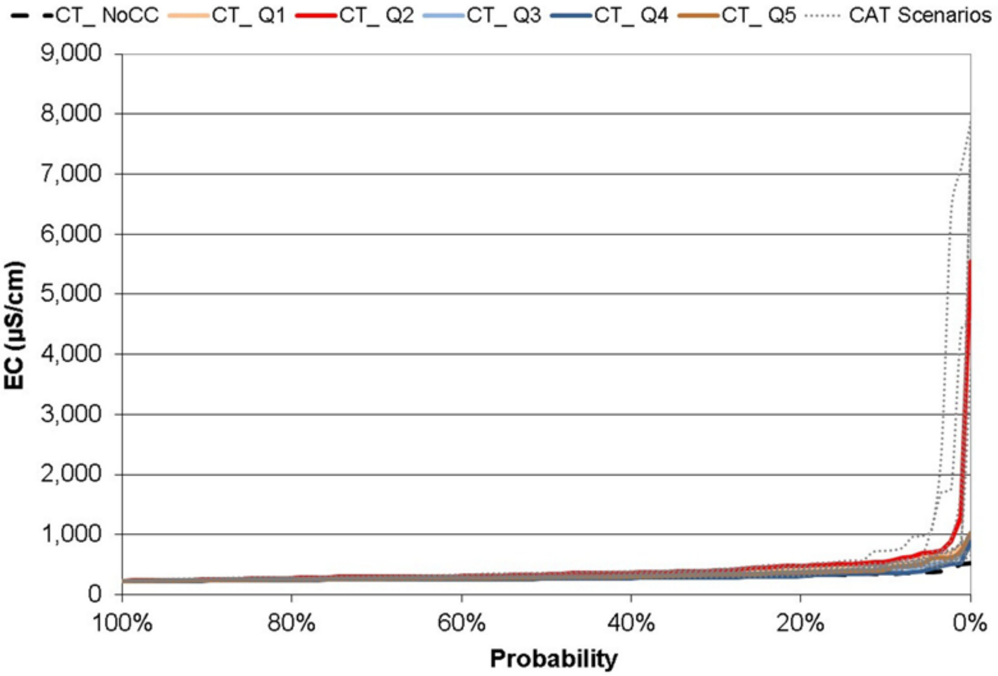

Figure 5-32. Exceedance Plot of Average April-to-August EC at Jersey Point for Each Scenario

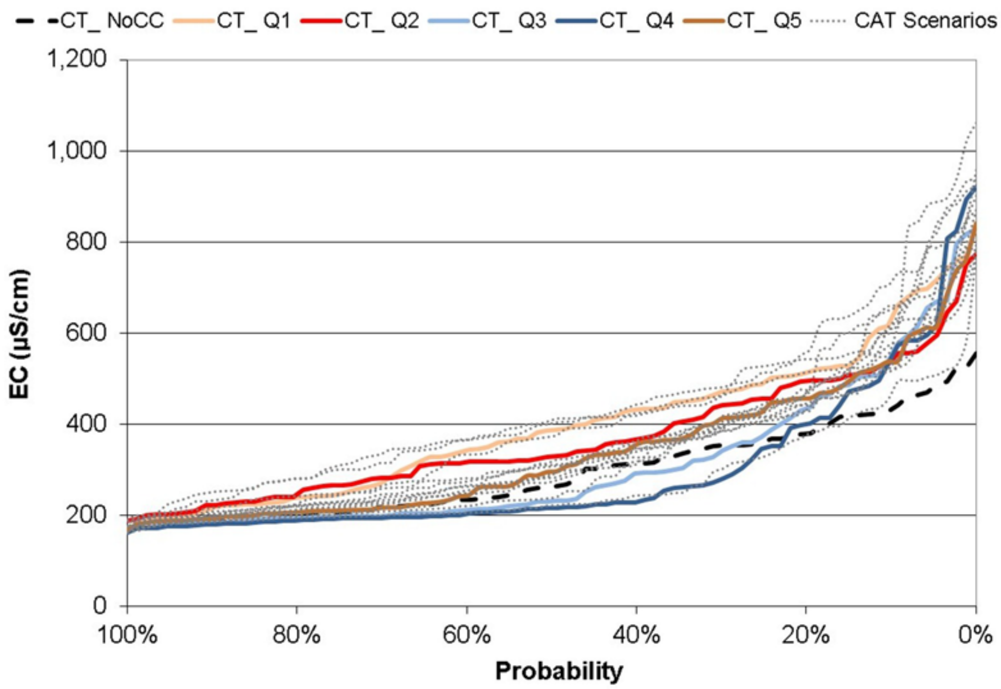

Figure 5-33. Exceedance Plot of Average Annual EC at Rock Slough for Each Scenario

Table 5-6. Average April-August EC (µS/cm) at Emmaton and Jersey Point and Average Annual EC at Rock Slough in Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Emmaton | 2012–2040 | 1,782 | 2,285 | 2,127 | 1,688 | 1,677 | 1,985 |
| | 2041–2070 | 1,768 | 2,770 | 3,029 | 1,986 | 1,864 | 2,268 |
| | 2071–2099 | 2,151 | 4,443 | 5,708 | 3,451 | 2,890 | 3,940 |
| | 2012–2099 | 1,940 | 3,472 | 4,141 | 2,612 | 2,305 | 2,988 |
| Jersey Point | 2012–2040 | 1,536 | 1,762 | 1,737 | 1,479 | 1,571 | 1,654 |
| | 2041–2070 | 1,600 | 2,133 | 1,990 | 1,724 | 1,622 | 1,885 |
| | 2071–2099 | 1,718 | 2,774 | 3,980 | 2,508 | 2,244 | 2,629 |
| | 2012–2099 | 1,647 | 2,385 | 2,855 | 2,051 | 1,895 | 2,195 |
| Rock Slough | 2012–2040 | 5,262 | 5,982 | 5,710 | 4,826 | 4,791 | 5,312 |
| | 2041–2070 | 4,703 | 6,551 | 5,888 | 4,317 | 3,746 | 4,973 |
| | 2071–2099 | 4,677 | 7,285 | 6,693 | 6,408 | 6,205 | 6,663 |
| | 2012–2099 | 4,879 | 6,605 | 6,095 | 5,173 | 4,901 | 5,641 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Emmaton | 2012–2040 | 1,782 | 1,851 | 2,495 | 3,355 | 2,783 | 2,066 | 2,145 |
| | 2041–2070 | 1,768 | 3,087 | 2,685 | 3,273 | 2,623 | 3,001 | 2,320 |
| | 2071–2099 | 2,151 | 3,832 | 5,572 | 5,485 | 3,361 | 4,201 | 3,732 |
| | 2012–2099 | 1,940 | 3,305 | 3,956 | 4,267 | 2,967 | 3,450 | 2,934 |
| Jersey Point | 2012–2040 | 1,536 | 1,804 | 1,898 | 1,906 | 1,984 | 1,953 | 1,954 |
| | 2041–2070 | 1,600 | 2,044 | 2,070 | 3,739 | 2,007 | 2,190 | 1,965 |
| | 2071–2099 | 1,718 | 2,943 | 3,721 | 3,191 | 2,630 | 3,212 | 2,584 |
| | 2012–2099 | 1,647 | 2,423 | 2,791 | 3,325 | 2,283 | 2,624 | 2,240 |
| Rock Slough | 2012–2040 | 5,262 | 4,048 | 4,823 | 5,998 | 5,068 | 5,596 | 4,652 |
| | 2041–2070 | 4,703 | 5,708 | 5,130 | 7,359 | 5,247 | 6,196 | 5,046 |
| | 2071–2099 | 4,677 | 6,703 | 8,748 | 8,353 | 6,784 | 7,907 | 7,817 |
| | 2012–2099 | 4,879 | 5,489 | 6,221 | 7,238 | 5,695 | 6,562 | 5,830 |
| **Location** | **Period** | **CTnoCC** | **CTB1_ cnrm cm3** | **CTB1_ gfdl cm21** | **CTB1_ miroc32 med** | **CTB1_ mpie cham5** | **CTB1_ ncarc csm3** | **CTB1_ ncarp cm1** |
| Emmaton | 2012–2040 | 1,782 | 1,636 | 2,218 | 2,293 | 1,876 | 1,995 | 1,667 |
| | 2041–2070 | 1,768 | 2,410 | 2,406 | 3,882 | 2,550 | 2,384 | 2,395 |
| | 2071–2099 | 2,151 | 3,740 | 3,689 | 4,613 | 3,899 | 3,140 | 3,167 |
| | 2012–2099 | 1,940 | 2,932 | 2,961 | 4,061 | 3,090 | 2,685 | 2,672 |
| Jersey Point | 2012–2040 | 1,536 | 1,576 | 1,852 | 1,698 | 1,770 | 1,715 | 1,568 |
| | 2041–2070 | 1,600 | 1,880 | 1,852 | 2,960 | 1,832 | 2,115 | 1,875 |
| | 2071–2099 | 1,718 | 2,609 | 2,860 | 2,602 | 3,085 | 2,368 | 2,235 |
| | 2012–2099 | 1,647 | 2,177 | 2,302 | 2,684 | 2,385 | 2,191 | 2,007 |
| Rock Slough | 2012–2040 | 5,262 | 4,133 | 4,509 | 5,403 | 4,747 | 5,201 | 4,009 |
| | 2041–2070 | 4,703 | 5,334 | 5,447 | 6,978 | 4,525 | 5,376 | 4,723 |
| | 2071–2099 | 4,677 | 6,944 | 7,524 | 8,415 | 8,348 | 6,798 | 5,023 |
| | 2012–2099 | 4,879 | 5,469 | 5,823 | 6,933 | 5,858 | 5,787 | 4,587 |

In the no climate change (CTnoCC) scenario, average annual EC at Rock Slough was 4,879 µS/cm. Across the range of all climate scenarios, the average annual EC at Rock Slough was 5,965 µS/cm, an increase of 22% and ranged from a minimum of 4,901 to a maximum of 7,238 µS/cm during the 2012-2099 period.

### *End-of-May Storage*

The end-of-May storage is the attribute of interest chosen to represent the water supply available for meeting in-stream water temperature needs during the summer and fall months. The end-of-May storage is an indicator of the magnitude of the "cold water pool" available to support salmon spawning reaches below major reservoirs. The performance metric chosen is the percentage of time that the end-of-May storage is less than the 10th percentile value in the CT_NoCC scenario. This low storage volume performance metric is applicable to major reservoirs in the CVP and SWP water management systems.

Figures 5-34 through 5-38 are exceedance plots of storage at the end of May in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs for each of the socioeconomic-climate scenarios. As shown on the figures, the reservoir storage results differed signifi¬cantly among the different climate scenarios. The median climate scenario (CTQ5) had storage levels a little lower than the CTnoCC scenarios in Lake Shasta and Lake Folsom and substantially lower than the CTnoCC scenario in Lake Oroville. New Melones storage was very similar in the CTnoCC and CTQ5 sceanrios. In all four reservoirs, the storage levels in May were higher under the wetter climate scenarios (CTQ3 and CTQ4) than under the CTnoCC scenarios, with the highest storage levels in the wetter, less warming scenario (CTQ4). Conversely, the storage levels were lower under the drier climate scenarios CT(Q1 and CTQ2) than under the CTnoCC scenarios, with the lowest storage levels in the drier, more warming scenario (CTQ2). The 12 CAT 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.

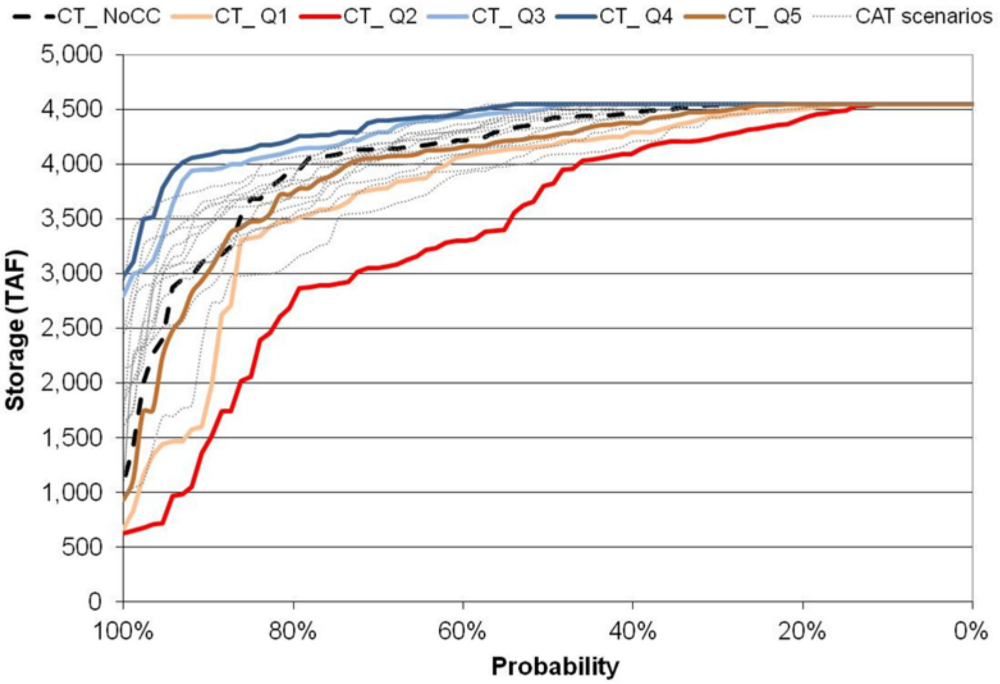

Figure 5-34. Exceedance Plot of Lake Shasta End-of-May Storage for Each Scenario

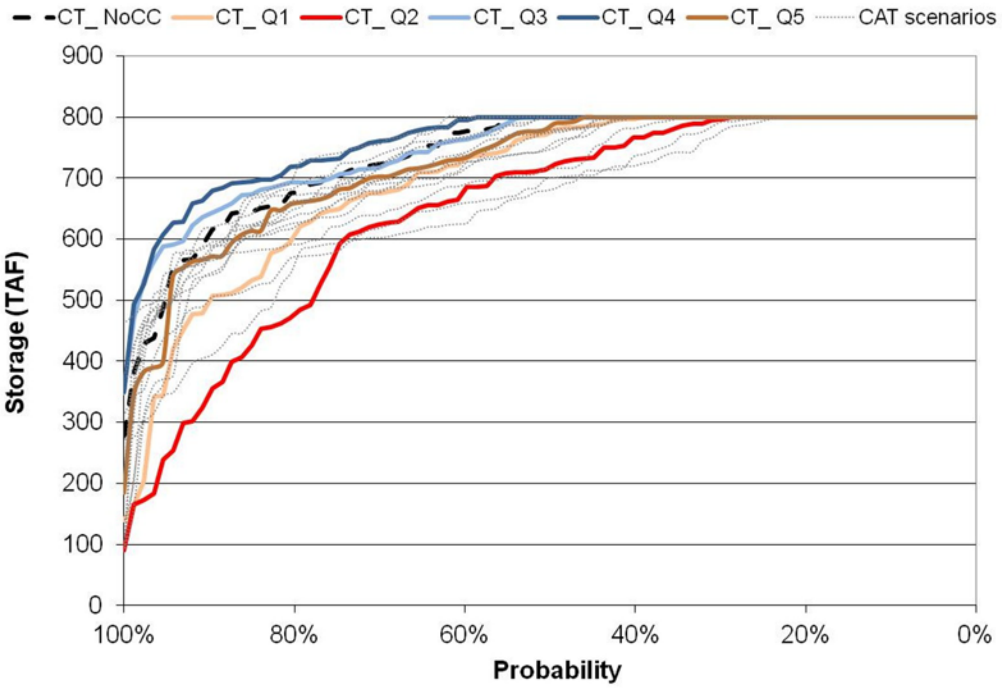

Figure 5-35. Exceedance Plot of Folsom Lake End-of-May Storage for Each Scenario

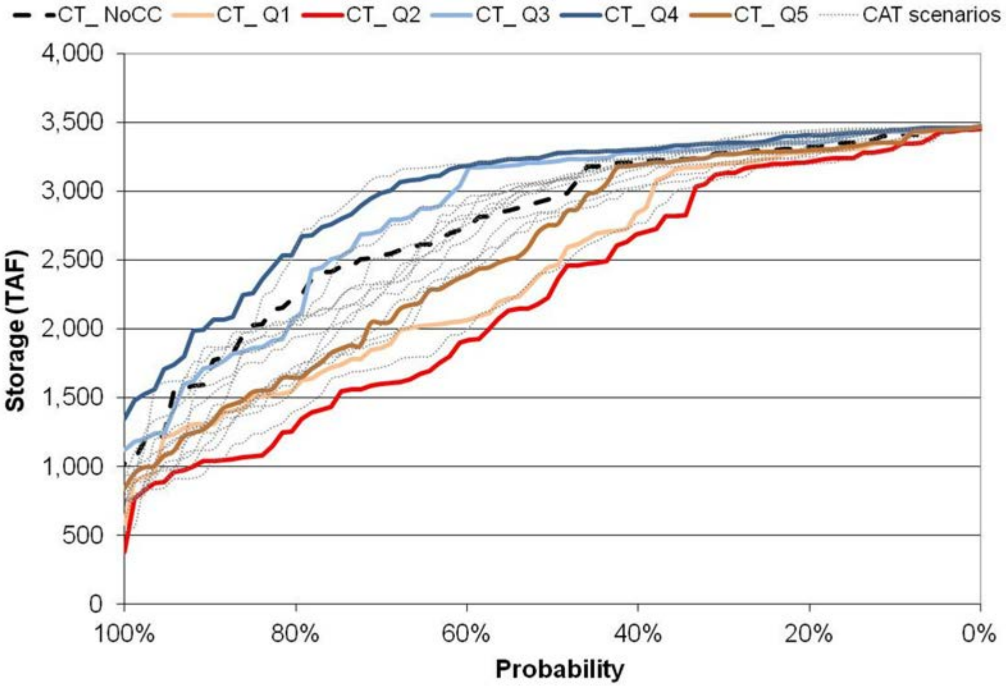

Figure 5-36. Exceedance Plot of Lake Oroville End-of-May Storage for Each Scenario

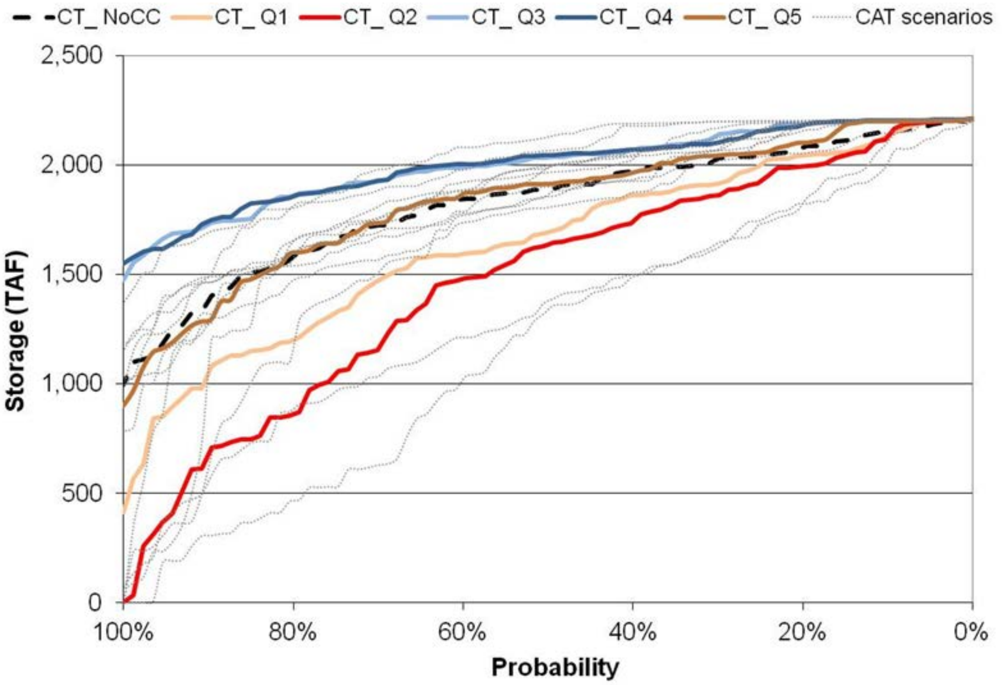

Figure 5-37. Exceedance Plot of New Melones End-of-May Storage for each Scenario

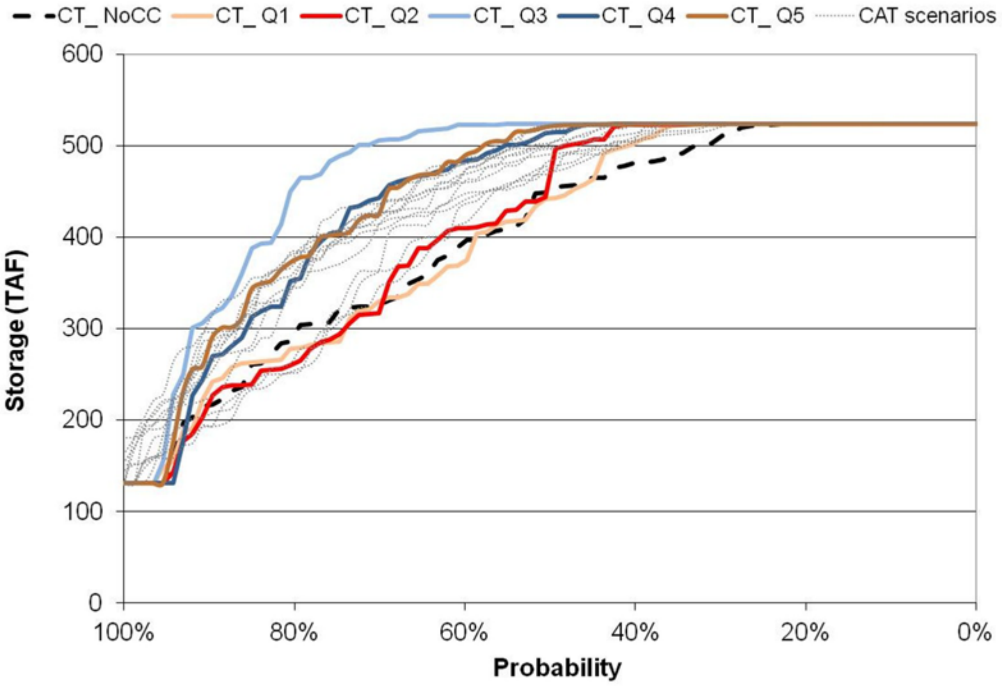

Figure 5-38. Exceedance Plot of Millerton End-of-May Storage for each Sceanario

Table 5-7 shows the percentage of time that the end-of-May storage is less than the 10th percentile value from the CTnoCC scenario in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs for each of the socioeconomic-climate scenarios in the periods of 2012-2099, 2012-2040, 2041-2070 and 2071-2099. Shasta and Millerton reservoirs were chosen for discussion in this section because they receive the largest average annual runoff in the Sacramento and San Joaquin river watersheds respectively.

Across the range of all climate scenarios, the end-of-May storage in Shasta Lake was less than the 10th percentile value from the CTnoCC scenario on average in 11% of the years between 2012-2099, an increase of 9%. During this period, it ranged from 1% to 40% of the end-of-May storages being less than the CTnoCC 10th percentile storage value.

Across the range of all climate scenarios, the end-of-May storage in Millerton Lake was less than the 10th percentile value in the CTnoCC scenario on average in 13% of the years between 2012-2099, an increase of 27%. During this period, it ranged from 6% to 24% of the end-of-May storages being less than the CTnoCC 10th percentile storage value.

Table 5-7. Percentage of End-of-May Storages Less than the 10th Percentile of Storage in the No-Climate Change Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012-2040 | 24% | 34% | 45% | 7% | 3% | 28% |
| | 2041-2070 | 0% | 0% | 30% | 0% | 0% | 0% |
| | 2071-2099 | 7% | 14% | 45% | 3% | 3% | 10% |
| | 2012-2099 | 10% | 16% | 40% | 3% | 2% | 13% |
| Folsom | 2012-2040 | 17% | 31% | 38% | 10% | 10% | 24% |
| | 2041-2070 | 3% | 10% | 40% | 13% | 0% | 10% |
| | 2071-2099 | 10% | 28% | 48% | 17% | 7% | 14% |
| | 2012-2099 | 10% | 23% | 42% | 14% | 6% | 16% |
| Oroville | 2012-2040 | 24% | 34% | 28% | 21% | 14% | 24% |
| | 2041-2070 | 3% | 23% | 37% | 10% | 0% | 17% |
| | 2071-2099 | 3% | 31% | 45% | 17% | 7% | 31% |
| | 2012-2099 | 10% | 30% | 36% | 16% | 7% | 24% |
| New Melones | 2012-2040 | 17% | 28% | 34% | 0% | 0% | 21% |
| | 2041-2070 | 7% | 23% | 37% | 0% | 0% | 7% |
| | 2071-2099 | 7% | 24% | 38% | 3% | 0% | 7% |
| | 2012-2099 | 10% | 25% | 36% | 1% | 0% | 11% |
| Millerton | 2012-2040 | 21% | 28% | 24% | 14% | 17% | 17% |
| | 2041-2070 | 3% | 10% | 17% | 0% | 0% | 0% |
| | 2071-2099 | 7% | 14% | 31% | 3% | 3% | 7% |
| | 2012-2099 | 10% | 17% | 24% | 6% | 7% | 8% |

| Location | Period | CTnoCC | CTA2_ cnrmcm3 | CTA2_ gfdlcm21 | CTA2_ miroc32med | CTA2_ mpiecham5 | CTA2_ ncarccsm3 | CTA2_ ncarpcm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012-2040 | 24% | 0% | 7% | 0% | 0% | 21% | 0% |
| | 2041-2070 | 0% | 10% | 7% | 23% | 3% | 10% | 0% |
| | 2071-2099 | 7% | 3% | 28% | 17% | 3% | 0% | 3% |
| | 2012-2099 | 10% | 5% | 14% | 14% | 2% | 10% | 1% |
| Folsom | 2012-2040 | 17% | 3% | 10% | 31% | 17% | 24% | 10% |
| | 2041-2070 | 3% | 10% | 13% | 43% | 23% | 27% | 17% |
| | 2071-2099 | 10% | 28% | 52% | 59% | 38% | 45% | 17% |
| | 2012-2099 | 10% | 14% | 25% | 44% | 26% | 32% | 15% |
| Oroville | 2012-2040 | 24% | 7% | 17% | 24% | 14% | 38% | 14% |
| | 2041-2070 | 3% | 47% | 20% | 30% | 23% | 27% | 10% |
| | 2071-2099 | 3% | 17% | 41% | 34% | 17% | 21% | 10% |
| | 2012-2099 | 10% | 24% | 26% | 30% | 18% | 28% | 11% |
| New Melones | 2012-2040 | 17% | 7% | 7% | 38% | 14% | 24% | 0% |
| | 2041-2070 | 7% | 60% | 0% | 80% | 10% | 33% | 0% |
| | 2071-2099 | 7% | 14% | 41% | 55% | 3% | 0% | 3% |
| | 2012-2099 | 10% | 27% | 16% | 58% | 9% | 19% | 1% |
| Millerton | 2012-2040 | 21% | 21% | 3% | 17% | 7% | 10% | 10% |
| | 2041-2070 | 3% | 30% | 10% | 27% | 10% | 7% | 3% |
| | 2071-2099 | 7% | 21% | 34% | 24% | 0% | 17% | 10% |
| | 2012-2099 | 10% | 24% | 16% | 23% | 6% | 11% | 8% |

| Location | Period | CTnoCC | CTB1_ cnrmcm3 | CTB1_ gfdlcm21 | CTB1_ miroc32med | CTB1_ mpiecham5 | CTB1_ ncarccsm3 | CTB1_ ncarpcm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012-2040 | 24% | 7% | 7% | 21% | 0% | 24% | 0% |
| | 2041-2070 | 0% | 3% | 7% | 30% | 10% | 0% | 7% |
| | 2071-2099 | 7% | 21% | 3% | 24% | 7% | 14% | 10% |
| | 2012-2099 | 10% | 10% | 6% | 25% | 6% | 13% | 6% |
| Folsom | 2012-2040 | 17% | 7% | 17% | 24% | 3% | 24% | 10% |
| | 2041-2070 | 3% | 10% | 13% | 50% | 17% | 30% | 13% |
| | 2071-2099 | 10% | 21% | 28% | 45% | 34% | 24% | 24% |
| | 2012-2099 | 10% | 13% | 19% | 40% | 18% | 26% | 16% |
| Oroville | 2012-2040 | 24% | 14% | 21% | 31% | 3% | 41% | 3% |
| | 2041-2070 | 3% | 7% | 13% | 50% | 20% | 13% | 17% |
| | 2071-2099 | 3% | 28% | 24% | 31% | 21% | 14% | 17% |
| | 2012-2099 | 10% | 16% | 19% | 38% | 15% | 23% | 13% |
| New Melones | 2012-2040 | 17% | 7% | 7% | 31% | 14% | 38% | 0% |
| | 2041-2070 | 7% | 7% | 13% | 67% | 20% | 3% | 10% |
| | 2071-2099 | 7% | 14% | 7% | 69% | 3% | 3% | 14% |
| | 2012-2099 | 10% | 9% | 9% | 56% | 13% | 15% | 8% |
| Millerton | 2012-2040 | 21% | 0% | 7% | 21% | 7% | 21% | 10% |
| | 2041-2070 | 3% | 10% | 10% | 17% | 10% | 0% | 10% |
| | 2071-2099 | 7% | 24% | 14% | 21% | 7% | 10% | 10% |
| | 2012-2099 | 10% | 11% | 10% | 19% | 8% | 10% | 10% |

### 5.2.4 Hydropower and GHG Emissions Results

***Energy Generation and Use***

Net hydropower generation is the attribute chosen as an indicator of the energy balance for the operations of CVP and SWP systems. 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).

Figures 5-39 through 5-41 show the 10-year moving average of annual average SWP, CVP, and total SWP + CVP net hydropower generation in each scenario. In all the socioeconomic-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. 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. In the SWP system, the scenarios with the greatest amount of Banks pumping 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 Banks pumping had the least SWP net energy use.

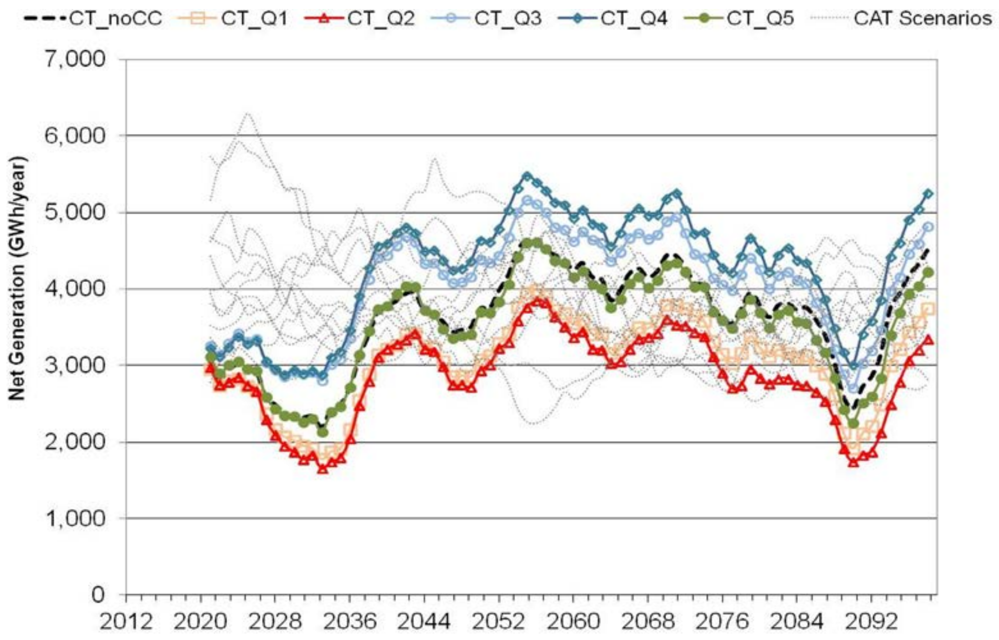

Figure 5-39. 10-Year Moving Average of Annual Net Energy Generation for the CVP System for each Scenario

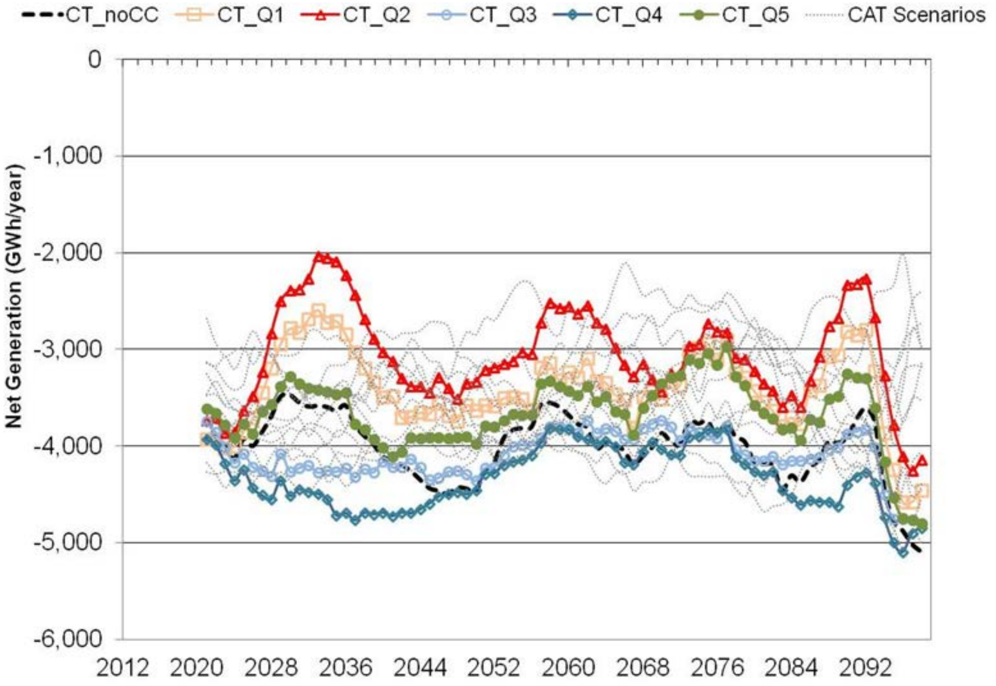

Figure 5-40. 10-Year Moving Average of Annual Net Energy Generation for the SWP System for Each Scenario

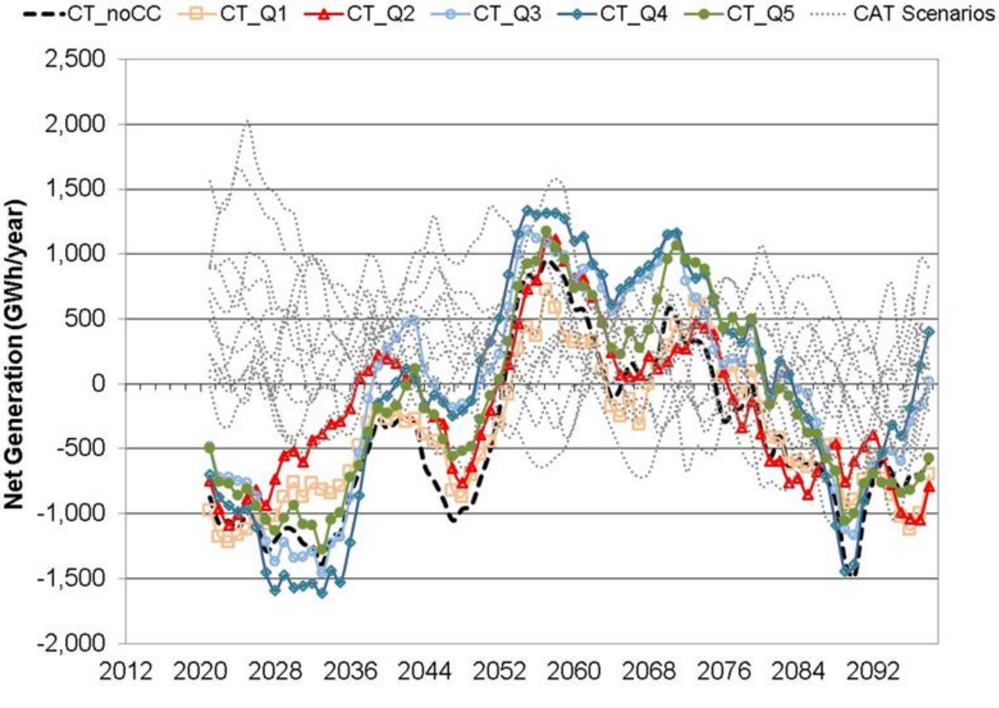

Figure 5-41. 10-Year Moving Average of Annual Net Energy Generation for the Combined CVP and SWP Systems for each Scenario

Table 5-8 shows the average annual net energy use for the CVP and SWP systems under each socioeconomic-climate scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the no climate change (CTnoCC) scenario, annual net energy generation for the CVP system was 3,626 GWh/year. Across the range of all climate scenarios, the annual net energy generation for the CVP was 3,718 GWh/year, an increase of slightly more than 2% and ranged from a minimum of 2,912 to a maximum of 4,478 GWh/year during the 2012-2099 period.

In the no climate change (CTnoCC) scenario, annual net energy generation for the SWP system was -4,071 GWh/year. Across the range of all climate scenarios, the annual net energy generation for the CVP was -3,635 GWh/year, an increase of 12% and ranged from a minimum of -4,334 to a maximum of -2,973 GWh/year during the 2012-2099 period.

Table 5-8. Average Annual Net Energy Generation (GWh/year) for the CVP and SWP Systems in Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | -3,841 | -3,403 | -3,052 | -4,045 | -4,358 | -3,645 |
| | 2041–2070 | -4,002 | -3,458 | -3,108 | -3,971 | -4,105 | -3,586 |
| | 2071–2099 | -4,382 | -3,598 | -3,287 | -4,324 | -4,555 | -3,928 |
| | 2012–2099 | -4,071 | -3,485 | -3,147 | -4,109 | -4,334 | -3,715 |
| CVP | 2012–2040 | 3,062 | 2,739 | 2,696 | 3,562 | 3,602 | 3,100 |
| | 2041–2070 | 4,145 | 3,476 | 3,307 | 4,633 | 4,914 | 4,060 |
| | 2071–2099 | 3,654 | 3,063 | 2,712 | 3,974 | 4,295 | 3,459 |
| | 2012–2099 | 3,626 | 3,098 | 2,912 | 4,064 | 4,277 | 3,547 |
| Total | 2012–2040 | -779 | -664 | -356 | -483 | -756 | -544 |
| | 2041–2070 | 143 | 18 | 199 | 661 | 809 | 475 |
| | 2071–2099 | -728 | -535 | -575 | -349 | -260 | -469 |
| | 2012–2099 | -445 | -387 | -235 | -45 | -57 | -169 |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | -3,841 | -4,050 | -3,534 | -3,336 | -3,568 | -3,274 | -3,810 |
| | 2041–2070 | -4,002 | -3,013 | -3,598 | -2,876 | -3,636 | -3,482 | -3,936 |
| | 2071–2099 | -4,382 | -3,707 | -3,020 | -2,844 | -3,693 | -3,601 | -4,064 |
| | 2012–2099 | -4,071 | -3,582 | -3,391 | -3,019 | -3,632 | -3,451 | -3,936 |
| CVP | 2012–2040 | 3,062 | 5,029 | 3,777 | 3,425 | 3,859 | 3,341 | 3,952 |
| | 2041–2070 | 4,145 | 3,458 | 3,697 | 3,117 | 4,003 | 3,421 | 4,019 |
| | 2071–2099 | 3,654 | 3,943 | 2,990 | 3,158 | 3,801 | 3,522 | 3,929 |
| | 2012–2099 | 3,626 | 4,138 | 3,496 | 3,233 | 3,890 | 3,427 | 3,968 |
| Total | 2012–2040 | -779 | 980 | 243 | 89 | 290 | 67 | 142 |
| | 2041–2070 | 143 | 445 | 99 | 240 | 367 | -61 | 83 |
| | 2071–2099 | -728 | 236 | -30 | 314 | 108 | -79 | -135 |
| | 2012–2099 | -445 | 556 | 106 | 213 | 258 | -24 | 32 |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | -3,841 | -3,709 | -3,497 | -3,121 | -3,913 | -3,235 | -4,273 |
| | 2041–2070 | -4,002 | -3,850 | -3,520 | -2,789 | -3,680 | -3,836 | -3,748 |
| | 2071–2099 | -4,382 | -3,278 | -3,621 | -3,017 | -3,388 | -4,308 | -3,912 |
| | 2012–2099 | -4,071 | -3,619 | -3,545 | -2,973 | -3,663 | -3,788 | -3,976 |
| CVP | 2012–2040 | 3,062 | 4,287 | 4,333 | 3,463 | 4,203 | 3,415 | 5,068 |
| | 2041–2070 | 4,145 | 4,208 | 4,067 | 2,882 | 4,167 | 3,809 | 4,216 |
| | 2071–2099 | 3,654 | 3,682 | 3,515 | 3,163 | 3,267 | 3,795 | 4,147 |
| | 2012–2099 | 3,626 | 4,065 | 3,978 | 3,166 | 3,889 | 3,673 | 4,478 |
| Total | 2012–2040 | -779 | 577 | 836 | 342 | 290 | 179 | 795 |
| | 2041–2070 | 143 | 358 | 546 | 93 | 488 | -27 | 468 |
| | 2071–2099 | -728 | 404 | -106 | 146 | -121 | -513 | 236 |
| | 2012–2099 | -445 | 446 | 433 | 193 | 226 | -115 | 502 |

### *Greenhouse Gas Emissions*

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 GHG emissions. 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 (mTCO2e) per year of power generation. In the simulations, the CVP system was assumed to provide excess power to an electrical grid system which produces 300 mTCO2e GHG emissions per GWh generated. 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. Therefore, SWP emissions drop sharply over the first half of the century due to this assumption.

Figures 5-42 through 5-44 show 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 scenario. Because the CVP system is assumed to provide excess power to the energy grid (with emissions of 300 metric tons of CO2 equivalents per gigawatt hour (mTCO2e/GWh) throughout the twenty-first century, the year-to-year changes in GHG emission results for the CVP system are consistent with changes in net generation as described above. For the SWP system, the sources of power used by the project are projected to gradually transition from sources with higher GHG emissions to those with lower GHG emissions over the course of the twenty-first century. Therefore, the GHG

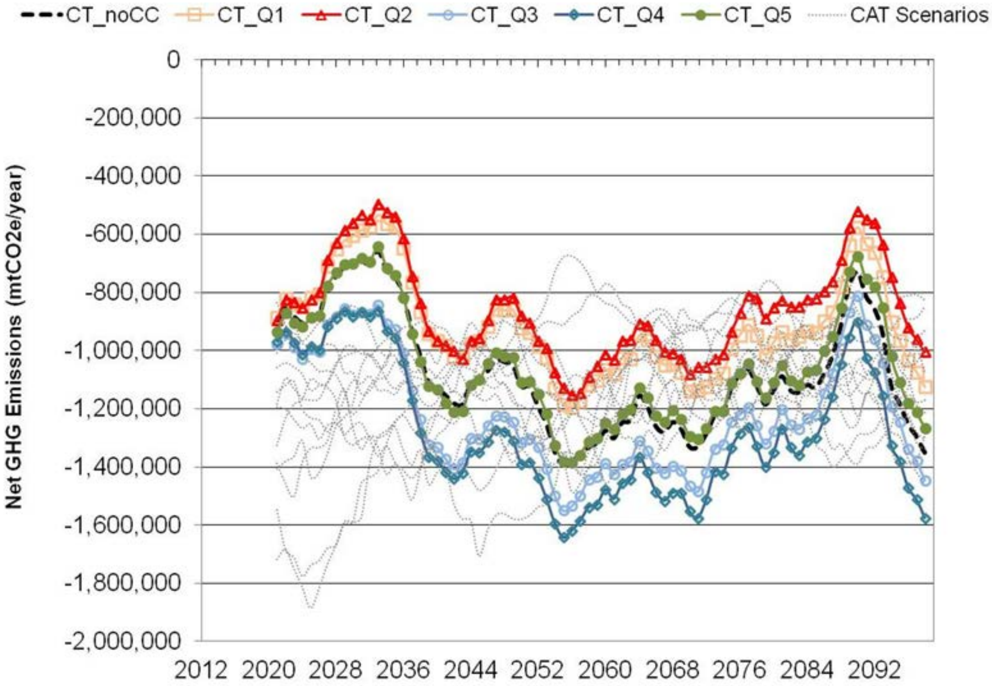

Figure 5-42. 10-Year Moving Average of Annual GHG Emissions or Potential Offsets for the CVP System for each Scenario

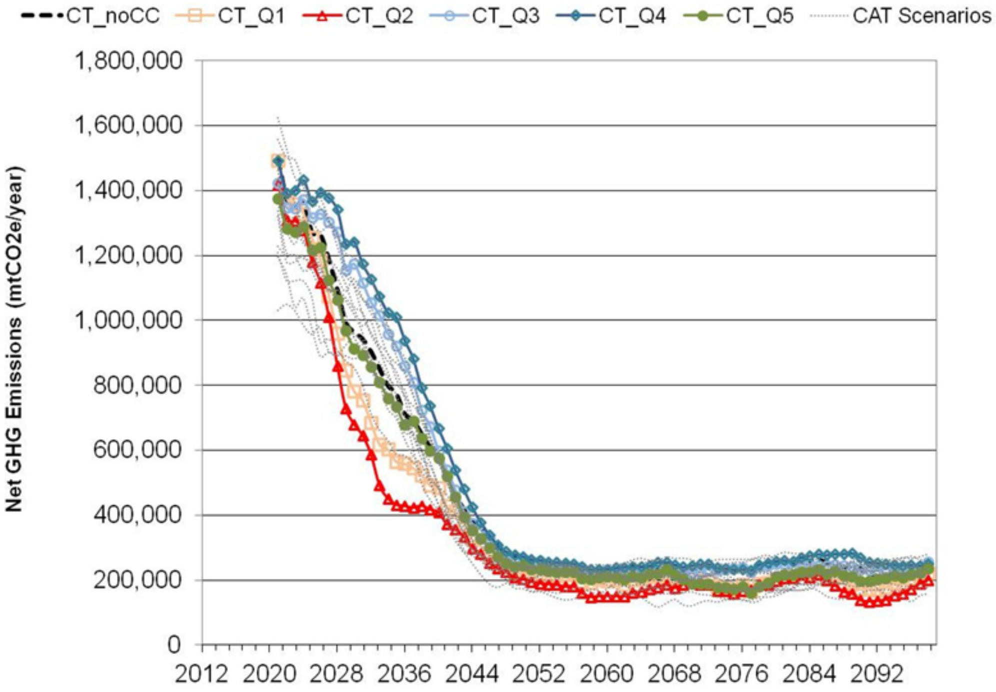

Figure 5-43. 10-Year Moving Average of Annual GHG Emissions or Potential Offsets for the SWP System for each Scenario

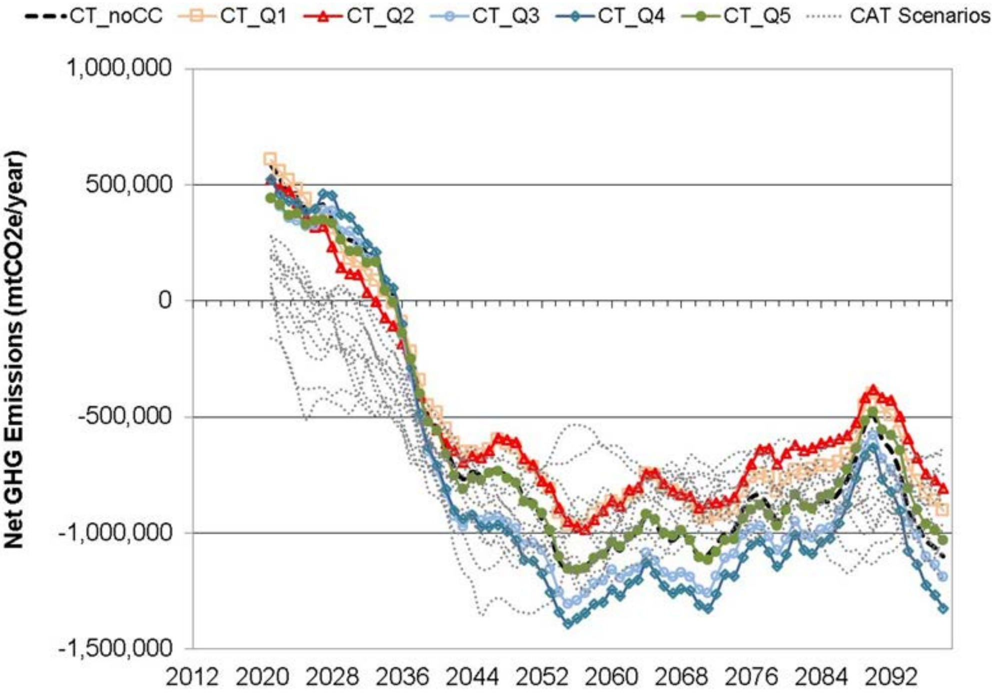

Figure 5-44. 10-Year Moving Average of Annual GHG Emissions or Potential Offsets for the Combined CVP and SWP Systems for each Scenario

emissions drop sharply over the first half of the twenty-first century, resulting in less GHG emissions per unit of energy consumed.

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.

Table 5-9 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 from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the no climate change (CTnoCC) scenario, average annual GHG offset in the CVP system was 1,087,462 mTCO2e/year. Across the range of all climate scenarios, the average annual GHG offset for the CVP was 1,115,014 mTCO2e/year, an increase of slightly more than 2% and ranged from a minimum of 873,196 to a maximum of 1,342,866 mTCO2e/year during the 2012-2099 period.

In the no climate change (noCC) scenario, average annual GHG emissions in the SWP system was 499,876 mTCO2e/year. Across the range of all climate scenarios, the average annual GHG emission for the SWP was 463,917 mTCO2e/year, a decrease of 7% and ranged from a minimum 382,489 up to a maximum 543,832 of mTCO2e/year during the 2012-2099 period.

Table 5-9. Average Annual GHG Emissions or Potential GHG Offsets (mTCO2e/year) for the CVP and SWP Systems in Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | 1,011,801 | 914,570 | 831,617 | 1,052,265 | 1,119,069 | 951,925 |
|  | 2041–2070 | 242,291 | 209,498 | 182,049 | 239,459 | 250,815 | 214,559 |
|  | 2071–2099 | 245,651 | 199,521 | 180,282 | 247,824 | 261,997 | 216,487 |
|  | 2012–2099 | 499,876 | 441,311 | 398,003 | 513,086 | 543,832 | 460,968 |
| CVP | 2012–2040 | -918,354 | -821,480 | -808,480 | -1,068,253 | -1,080,172 | -929,793 |
|  | 2041–2070 | -1,243,074 | -1,042,493 | -991,624 | -1,389,349 | -1,473,614 | -1,217,695 |
|  | 2071–2099 | -1,095,884 | -918,722 | -813,336 | -1,191,865 | -1,288,104 | -1,037,302 |
|  | 2012–2099 | -1,087,462 | -928,988 | -873,196 | -1,218,759 | -1,282,762 | -1,063,670 |
| Total | 2012–2040 | 93,447 | 93,090 | 23,137 | -15,988 | 38,897 | 22,132 |
|  | 2041–2070 | -1,000,783 | -832,995 | -809,575 | -1,149,890 | -1,222,798 | -1,003,136 |
|  | 2071–2099 | -850,232 | -719,201 | -633,054 | -944,041 | -1,026,107 | -820,815 |
|  | 2012–2099 | -587,587 | -487,677 | -475,193 | -705,672 | -738,930 | -602,702 |

| Location | Period | CTnoCC | CTA2_ cnrmcm3 | CTA2_ gfdlcm21 | CTA2_ miroc32med | CTA2_ mpiecham5 | CTA2_ ncarccsm3 | CTA2_ ncarpcm1 |
|---|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | 1,011,801 | 1,058,521 | 951,963 | 915,724 | 930,001 | 857,269 | 993,967 |
|  | 2041–2070 | 242,291 | 173,938 | 216,945 | 164,929 | 221,316 | 212,369 | 237,669 |
|  | 2071–2099 | 245,651 | 199,625 | 172,112 | 178,568 | 245,085 | 239,880 | 259,746 |
|  | 2012–2099 | 499,876 | 477,066 | 447,522 | 419,584 | 465,194 | 436,190 | 496,874 |
| CVP | 2012–2040 | -918,354 | -1,508,221 | -1,132,742 | -1,027,159 | -1,157,190 | -1,001,929 | -1,185,158 |
|  | 2041–2070 | -1,243,074 | -1,037,076 | -1,108,763 | -934,717 | -1,200,526 | -1,026,066 | -1,205,299 |
|  | 2071–2099 | -1,095,884 | -1,182,446 | -896,583 | -946,971 | -1,139,954 | -1,056,167 | -1,178,340 |
|  | 2012–2099 | -1,087,462 | -1,240,910 | -1,048,469 | -969,475 | -1,166,586 | -1,027,708 | -1,189,909 |
| Total | 2012–2040 | 93,447 | -449,700 | -180,779 | -111,435 | -227,189 | -144,661 | -191,191 |
|  | 2041–2070 | -1,000,783 | -863,138 | -891,818 | -769,788 | -979,211 | -813,697 | -967,630 |
|  | 2071–2099 | -850,232 | -982,822 | -724,472 | -768,403 | -894,869 | -816,287 | -918,594 |
|  | 2012–2099 | -587,587 | -763,844 | -600,947 | -549,891 | -701,392 | -591,519 | -693,035 |

| Location | Period | CTnoCC | CTB1_ cnrmcm3 | CTB1_ gfdlcm21 | CTB1_ miroc32 med | CTB1_ mpiec ham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| SWP | 2012–2040 | 1,011,801 | 982,265 | 926,091 | 807,923 | 1,009,856 | 837,419 | 1,129,120 |
|  | 2041–2070 | 242,291 | 235,353 | 212,711 | 167,269 | 221,839 | 233,011 | 225,572 |
|  | 2071–2099 | 245,651 | 201,821 | 200,512 | 172,452 | 221,610 | 248,448 | 218,633 |
|  | 2012–2099 | 499,876 | 473,532 | 446,578 | 382,489 | 484,438 | 439,449 | 524,521 |
| CVP | 2012–2040 | -918,354 | -1,285,594 | -1,299,466 | -1,038,440 | -1,260,483 | -1,024,061 | -1,519,852 |
|  | 2041–2070 | -1,243,074 | -1,262,111 | -1,219,604 | -864,207 | -1,249,799 | -1,142,352 | -1,264,235 |
|  | 2071–2099 | -1,095,884 | -1,104,126 | -1,054,117 | -948,620 | -979,726 | -1,138,044 | -1,243,806 |
|  | 2012–2099 | -1,087,462 | -1,219,093 | -1,192,964 | -949,452 | -1,166,440 | -1,101,535 | -1,342,866 |
| Total | 2012–2040 | 93,447 | -303,329 | -373,375 | -230,517 | -250,627 | -186,642 | -390,732 |
|  | 2041–2070 | -1,000,783 | -1,026,758 | -1,006,894 | -696,938 | -1,027,960 | -909,341 | -1,038,664 |
|  | 2071–2099 | -850,232 | -902,305 | -853,604 | -776,168 | -758,117 | -889,595 | -1,025,173 |
|  | 2012–2099 | -587,587 | -745,561 | -746,386 | -566,964 | -682,003 | -662,086 | -818,345 |

### 5.2.5 Flood Control Results

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.

#### *Frequency of Storage Use for Flood Control Storage*

Table 5-10 shows the percentage of months from October through June that the reservoir storage in Shasta, Folsom, Oroville, New Melones, and Millerton reservoirs is within 10 TAF of the flood conservation pool under each socioeconomic-climate scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099.

In the CTnoCC scenario from 2012-2099, the flood conservation pool is reached in 27 percent of all months in Lake Shasta, in 22 percent of all months in Folsom Lake, in 46 percent of all months in Lake Oroville, in 14 percent of all months in New Melones Lake, and in 18 percent of all months in Lake Millerton. Across the range of climate scenarios, this performance metric ranges from 10 percent to 46 percent in Lake Shasta, from 25 percent to 51 percent in Folsom Lake, from 11 percent to 35 percent in Lake Oroville, from 2 percent to 23 percent in New Melones Lake, and from 14 percent to 26 percent in Millerton Lake, with the wetter scenarios hitting the flood conservation pool more often than the CTnoCC scenario and the drier scenarios hitting the flood conservation pool less often.

#### *Frequency Releases Above Hydropower Penstock Capacities*

Table 5-11 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 each socioeconomic-climate scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099.

In the CTnoCC scenario during the 2012-2099 period, releases are made above penstock capacities in 9 percent of all months at Keswick, in 3 percent of all months at Thermalito, and in 21 percent of all months at Natoma.

Across the range of all climate scenarios, releases exceeding penstock capacities range from 6 percent to 17 percent at Keswick, from 2 percent to 8 percent at Thermalito, and from 15 percent to 26 percent at Natoma. 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.

Table 5-10. Percentage of Months from October through June that Storage Is Within 10 TAF of the Flood Conservation Pool in Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 10% | 11% | 8% | 18% | 23% | 8% |
| | 2041–2070 | 35% | 19% | 10% | 37% | 49% | 26% |
| | 2071–2099 | 36% | 19% | 11% | 43% | 54% | 25% |
| | 2012–2099 | 27% | 16% | 10% | 33% | 42% | 20% |
| Folsom | 2012–2040 | 39% | 31% | 28% | 46% | 48% | 40% |
| | 2041–2070 | 54% | 36% | 27% | 51% | 57% | 44% |
| | 2071–2099 | 44% | 27% | 20% | 43% | 47% | 33% |
| | 2012–2099 | 46% | 32% | 25% | 46% | 51% | 39% |
| Oroville | 2012–2040 | 12% | 11% | 11% | 19% | 19% | 11% |
| | 2041–2070 | 24% | 15% | 11% | 27% | 33% | 18% |
| | 2071–2099 | 31% | 22% | 13% | 29% | 33% | 24% |
| | 2012–2099 | 22% | 16% | 11% | 25% | 28% | 18% |
| New Melones | 2012–2040 | 8% | 6% | 5% | 13% | 13% | 8% |
| | 2041–2070 | 15% | 8% | 3% | 28% | 29% | 13% |
| | 2071–2099 | 19% | 12% | 8% | 24% | 27% | 17% |
| | 2012–2099 | 14% | 9% | 6% | 22% | 23% | 13% |
| Millerton | 2012–2040 | 15% | 15% | 15% | 23% | 21% | 18% |
| | 2041–2070 | 17% | 16% | 14% | 27% | 26% | 20% |
| | 2071–2099 | 21% | 19% | 15% | 28% | 28% | 25% |
| | 2012–2099 | 18% | 17% | 15% | 26% | 25% | 21% |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 10% | 56% | 33% | 27% | 39% | 23% | 35% |
| | 2041–2070 | 35% | 24% | 22% | 21% | 32% | 19% | 36% |
| | 2071–2099 | 36% | 31% | 16% | 20% | 42% | 34% | 39% |
| | 2012–2099 | 27% | 37% | 24% | 23% | 38% | 25% | 37% |
| Folsom | 2012–2040 | 39% | 57% | 45% | 33% | 43% | 38% | 46% |
| | 2041–2070 | 54% | 37% | 42% | 32% | 43% | 39% | 47% |
| | 2071–2099 | 44% | 36% | 23% | 28% | 39% | 34% | 42% |
| | 2012–2099 | 46% | 43% | 37% | 31% | 42% | 37% | 45% |
| Oroville | 2012–2040 | 12% | 37% | 19% | 14% | 21% | 10% | 23% |
| | 2041–2070 | 24% | 12% | 18% | 13% | 24% | 12% | 23% |
| | 2071–2099 | 31% | 21% | 8% | 15% | 28% | 18% | 31% |
| | 2012–2099 | 22% | 23% | 15% | 14% | 24% | 13% | 25% |
| New Melones | 2012–2040 | 8% | 20% | 11% | 8% | 7% | 3% | 16% |
| | 2041–2070 | 15% | 2% | 11% | 0% | 11% | 7% | 20% |
| | 2071–2099 | 19% | 11% | 5% | 3% | 22% | 13% | 24% |
| | 2012–2099 | 14% | 11% | 9% | 4% | 14% | 7% | 20% |
| Millerton | 2012–2040 | 15% | 25% | 21% | 16% | 15% | 16% | 22% |
| | 2041–2070 | 17% | 12% | 21% | 14% | 23% | 22% | 27% |
| | 2071–2099 | 21% | 23% | 15% | 15% | 29% | 23% | 26% |
| | 2012–2099 | 18% | 20% | 19% | 15% | 23% | 20% | 25% |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 10% | 36% | 33% | 23% | 43% | 16% | 58% |
| | 2041–2070 | 35% | 39% | 33% | 14% | 34% | 30% | 40% |
| | 2071–2099 | 36% | 25% | 27% | 16% | 27% | 34% | 39% |
| | 2012–2099 | 27% | 33% | 31% | 18% | 35% | 27% | 46% |
| Folsom | 2012–2040 | 39% | 47% | 41% | 35% | 47% | 34% | 61% |
| | 2041–2070 | 54% | 49% | 44% | 31% | 48% | 41% | 49% |
| | 2071–2099 | 44% | 34% | 33% | 31% | 31% | 40% | 38% |
| | 2012–2099 | 46% | 43% | 40% | 32% | 42% | 38% | 49% |
| Oroville | 2012–2040 | 12% | 25% | 23% | 14% | 27% | 10% | 50% |
| | 2041–2070 | 24% | 23% | 17% | 7% | 29% | 22% | 31% |
| | 2071–2099 | 31% | 16% | 16% | 11% | 12% | 26% | 26% |
| | 2012–2099 | 22% | 21% | 19% | 11% | 22% | 19% | 35% |
| New Melones | 2012–2040 | 8% | 16% | 12% | 2% | 13% | 6% | 25% |
| | 2041–2070 | 15% | 16% | 9% | 2% | 16% | 11% | 14% |
| | 2071–2099 | 19% | 5% | 7% | 0% | 11% | 20% | 26% |
| | 2012–2099 | 14% | 13% | 9% | 2% | 13% | 12% | 21% |
| Millerton | 2012–2040 | 15% | 30% | 24% | 16% | 18% | 18% | 28% |
| | 2041–2070 | 17% | 24% | 21% | 14% | 23% | 25% | 17% |
| | 2071–2099 | 21% | 16% | 18% | 13% | 20% | 31% | 31% |
| | 2012–2099 | 18% | 23% | 21% | 14% | 20% | 24% | 25% |

Table 5-11. Percentage of Months from October through June that Releases Exceed Penstock Capacities in Each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Keswick | 2012–2040 | 7% | 5% | 5% | 10% | 8% | 7% |
| | 2041–2070 | 10% | 9% | 8% | 17% | 18% | 11% |
| | 2071–2099 | 10% | 8% | 5% | 14% | 14% | 10% |
| | 2012–2099 | 9% | 7% | 6% | 14% | 14% | 10% |
| Thermalito | 2012–2040 | 2% | 1% | 1% | 6% | 5% | 3% |
| | 2041–2070 | 3% | 1% | 2% | 6% | 6% | 4% |
| | 2071–2099 | 4% | 3% | 3% | 9% | 10% | 7% |
| | 2012–2099 | 3% | 2% | 2% | 7% | 7% | 5% |
| Natoma | 2012–2040 | 21% | 15% | 16% | 27% | 26% | 23% |
| | 2041–2070 | 21% | 14% | 13% | 24% | 26% | 19% |
| | 2071–2099 | 22% | 18% | 15% | 23% | 27% | 19% |
| | 2012–2099 | 21% | 16% | 15% | 25% | 26% | 20% |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Keswick | 2012–2040 | 7% | 13% | 16% | 7% | 12% | 9% | 23% |
|  | 2041–2070 | 10% | 14% | 12% | 3% | 13% | 10% | 13% |
|  | 2071–2099 | 10% | 11% | 9% | 8% | 7% | 8% | 16% |
|  | 2012–2099 | 9% | 13% | 12% | 6% | 11% | 9% | 17% |
| Thermalito | 2012–2040 | 2% | 5% | 6% | 0% | 3% | 2% | 11% |
|  | 2041–2070 | 3% | 3% | 4% | 0% | 4% | 2% | 6% |
|  | 2071–2099 | 4% | 4% | 2% | 1% | 2% | 5% | 7% |
|  | 2012–2099 | 3% | 4% | 4% | 1% | 3% | 3% | 8% |
| Natoma | 2012–2040 | 21% | 28% | 23% | 15% | 21% | 15% | 32% |
|  | 2041–2070 | 21% | 21% | 21% | 11% | 23% | 20% | 23% |
|  | 2071–2099 | 22% | 18% | 13% | 13% | 12% | 23% | 21% |
|  | 2012–2099 | 21% | 22% | 19% | 13% | 19% | 19% | 25% |

| Location | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Keswick | 2012–2040 | 7% | 24% | 8% | 9% | 10% | 7% | 10% |
|  | 2041–2070 | 10% | 10% | 10% | 7% | 13% | 8% | 11% |
|  | 2071–2099 | 10% | 16% | 6% | 7% | 11% | 10% | 13% |
|  | 2012–2099 | 9% | 17% | 8% | 8% | 11% | 9% | 11% |
| Thermalito | 2012–2040 | 2% | 10% | 4% | 2% | 2% | 2% | 5% |
|  | 2041–2070 | 3% | 2% | 3% | 0% | 4% | 3% | 6% |
|  | 2071–2099 | 4% | 7% | 2% | 2% | 7% | 3% | 8% |
|  | 2012–2099 | 3% | 6% | 3% | 2% | 5% | 3% | 6% |
| Natoma | 2012–2040 | 21% | 34% | 18% | 12% | 20% | 13% | 23% |
|  | 2041–2070 | 21% | 14% | 18% | 13% | 24% | 17% | 20% |
|  | 2071–2099 | 22% | 20% | 14% | 13% | 21% | 19% | 23% |
|  | 2012–2099 | 21% | 22% | 17% | 13% | 22% | 17% | 22% |

### 5.2.6 Recreation Results

The attribute of interest selected as an indicator of recreational use is the percentage of months from May through September that reservoir surface area is less than the reservoir's median surface area in the CTnoCC scenario. This metric is applicable at all major CVP, SWP and non-project reservoirs in the Central Valley hydrologic basins.

Table 5-12 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 for each scenario from 2012 through 2099 and the 2012-2040, 2041-2070, and 2071-2099 periods.

Table 5-12. Percentage of Months in Each Scenario from May through September that Reservoir Surface Area Is Less than the Monthly Median in the CTnoCC Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 76% | 75% | 84% | 63% | 57% | 80% |
| | 2041–2070 | 37% | 67% | 94% | 47% | 21% | 61% |
| | 2071–2099 | 37% | 61% | 77% | 38% | 23% | 54% |
| | 2012–2099 | 50% | 68% | 85% | 50% | 33% | 65% |
| Folsom | 2012–2040 | 64% | 66% | 81% | 63% | 50% | 72% |
| | 2041–2070 | 43% | 67% | 91% | 65% | 45% | 70% |
| | 2071–2099 | 43% | 71% | 88% | 68% | 49% | 70% |
| | 2012–2099 | 50% | 68% | 87% | 65% | 48% | 71% |
| Oroville | 2012–2040 | 63% | 74% | 71% | 51% | 43% | 68% |
| | 2041–2070 | 43% | 61% | 75% | 36% | 15% | 54% |
| | 2071–2099 | 44% | 56% | 72% | 41% | 37% | 52% |
| | 2012–2099 | 50% | 64% | 73% | 43% | 32% | 58% |
| New Bullards Bar | 2012–2040 | 79% | 90% | 92% | 81% | 74% | 87% |
| | 2041–2070 | 72% | 90% | 96% | 81% | 71% | 85% |
| | 2071–2099 | 79% | 86% | 96% | 88% | 80% | 85% |
| | 2012–2099 | 77% | 89% | 95% | 83% | 75% | 86% |
| New Melones | 2012–2040 | 63% | 75% | 79% | 41% | 43% | 61% |
| | 2041–2070 | 47% | 70% | 83% | 35% | 30% | 51% |
| | 2071–2099 | 40% | 63% | 77% | 34% | 32% | 53% |
| | 2012–2099 | 50% | 70% | 80% | 37% | 35% | 55% |
| New Don Pedro | 2012–2040 | 46% | 68% | 69% | 26% | 17% | 52% |
| | 2041–2070 | 59% | 74% | 86% | 46% | 35% | 65% |
| | 2071–2099 | 44% | 61% | 64% | 35% | 29% | 39% |
| | 2012–2099 | 50% | 68% | 73% | 36% | 27% | 52% |
| McClure | 2012–2040 | 52% | 69% | 75% | 46% | 30% | 61% |
| | 2041–2070 | 49% | 75% | 88% | 52% | 37% | 69% |
| | 2071–2099 | 49% | 66% | 82% | 63% | 52% | 61% |
| | 2012–2099 | 50% | 70% | 82% | 54% | 40% | 64% |
| Millerton | 2012–2040 | 46% | 62% | 63% | 60% | 48% | 58% |
| | 2041–2070 | 54% | 64% | 84% | 63% | 47% | 63% |
| | 2071–2099 | 50% | 73% | 86% | 76% | 60% | 72% |
| | 2012–2099 | 50% | 66% | 78% | 66% | 52% | 64% |
| Pine Flat | 2012–2040 | 43% | 55% | 64% | 42% | 34% | 50% |
| | 2041–2070 | 60% | 83% | 94% | 69% | 51% | 81% |
| | 2071–2099 | 47% | 64% | 70% | 39% | 30% | 57% |
| | 2012–2099 | 50% | 68% | 76% | 50% | 39% | 63% |

| Location | Period | CTnoCC | CTA2_ cnrmcm3 | CTA2_ gfdlcm21 | CTA2_ miroc32med | CTA2_ mpiecham5 | CTA2_ ncarccsm3 | CTA2_ ncarpcm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 76% | 25% | 64% | 64% | 53% | 72% | 41% |
| | 2041–2070 | 37% | 72% | 71% | 71% | 54% | 76% | 45% |
| | 2071–2099 | 37% | 62% | 84% | 77% | 37% | 58% | 39% |
| | 2012–2099 | 50% | 53% | 73% | 71% | 48% | 69% | 42% |
| Folsom | 2012–2040 | 64% | 46% | 69% | 78% | 64% | 72% | 48% |
| | 2041–2070 | 43% | 85% | 83% | 92% | 72% | 84% | 65% |
| | 2071–2099 | 43% | 88% | 97% | 93% | 68% | 90% | 59% |
| | 2012–2099 | 50% | 73% | 83% | 88% | 68% | 82% | 57% |
| Oroville | 2012–2040 | 63% | 31% | 54% | 59% | 48% | 66% | 49% |
| | 2041–2070 | 43% | 79% | 62% | 65% | 43% | 68% | 49% |
| | 2071–2099 | 44% | 60% | 78% | 75% | 44% | 66% | 39% |
| | 2012–2099 | 50% | 57% | 65% | 67% | 45% | 67% | 45% |
| New Bullards Bar | 2012–2040 | 79% | 73% | 88% | 94% | 80% | 94% | 79% |
| | 2041–2070 | 72% | 93% | 93% | 95% | 82% | 90% | 85% |
| | 2071–2099 | 79% | 96% | 97% | 95% | 86% | 94% | 83% |
| | 2012–2099 | 77% | 88% | 93% | 95% | 83% | 93% | 82% |
| New Melones | 2012–2040 | 63% | 48% | 62% | 79% | 74% | 88% | 54% |
| | 2041–2070 | 47% | 90% | 68% | 97% | 58% | 74% | 45% |
| | 2071–2099 | 40% | 68% | 88% | 90% | 48% | 77% | 39% |
| | 2012–2099 | 50% | 69% | 73% | 89% | 60% | 80% | 46% |
| New Don Pedro | 2012–2040 | 46% | 34% | 57% | 83% | 67% | 76% | 41% |
| | 2041–2070 | 59% | 91% | 57% | 97% | 51% | 74% | 28% |
| | 2071–2099 | 44% | 67% | 79% | 90% | 47% | 59% | 39% |
| | 2012–2099 | 50% | 64% | 64% | 90% | 55% | 70% | 36% |
| McClure | 2012–2040 | 52% | 44% | 62% | 73% | 70% | 72% | 53% |
| | 2041–2070 | 49% | 91% | 79% | 95% | 73% | 79% | 43% |
| | 2071–2099 | 49% | 87% | 94% | 96% | 59% | 85% | 45% |
| | 2012–2099 | 50% | 74% | 78% | 88% | 67% | 79% | 47% |
| Millerton | 2012–2040 | 46% | 52% | 67% | 70% | 61% | 66% | 51% |
| | 2041–2070 | 54% | 87% | 79% | 89% | 63% | 72% | 54% |
| | 2071–2099 | 50% | 88% | 86% | 92% | 72% | 83% | 59% |
| | 2012–2099 | 50% | 76% | 77% | 84% | 65% | 74% | 55% |
| Pine Flat | 2012–2040 | 43% | 43% | 64% | 72% | 67% | 59% | 41% |
| | 2041–2070 | 60% | 90% | 73% | 95% | 69% | 77% | 45% |
| | 2071–2099 | 47% | 73% | 83% | 93% | 54% | 77% | 39% |
| | 2012–2099 | 50% | 69% | 73% | 87% | 63% | 71% | 41% |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdlcm 21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Shasta | 2012–2040 | 76% | 57% | 57% | 69% | 35% | 81% | 22% |
| | 2041–2070 | 37% | 47% | 63% | 89% | 48% | 65% | 36% |
| | 2071–2099 | 37% | 72% | 68% | 79% | 60% | 57% | 48% |
| | 2012–2099 | 50% | 59% | 63% | 79% | 48% | 68% | 35% |
| Folsom | 2012–2040 | 64% | 63% | 70% | 73% | 56% | 77% | 35% |
| | 2041–2070 | 43% | 69% | 68% | 92% | 65% | 80% | 59% |
| | 2071–2099 | 43% | 88% | 85% | 90% | 86% | 70% | 67% |
| | 2012–2099 | 50% | 73% | 74% | 85% | 69% | 76% | 54% |
| Oroville | 2012–2040 | 63% | 43% | 47% | 59% | 34% | 72% | 17% |
| | 2041–2070 | 43% | 47% | 52% | 87% | 37% | 53% | 41% |
| | 2071–2099 | 44% | 59% | 57% | 68% | 62% | 35% | 37% |
| | 2012–2099 | 50% | 50% | 52% | 72% | 44% | 53% | 32% |
| New Bullards Bar | 2012–2040 | 79% | 81% | 86% | 88% | 72% | 92% | 68% |
| | 2041–2070 | 72% | 83% | 85% | 95% | 81% | 87% | 75% |
| | 2071–2099 | 79% | 94% | 92% | 93% | 88% | 85% | 83% |
| | 2012–2099 | 77% | 86% | 88% | 92% | 80% | 88% | 75% |
| New Melones | 2012–2040 | 63% | 53% | 77% | 83% | 61% | 72% | 32% |
| | 2041–2070 | 47% | 59% | 64% | 92% | 52% | 64% | 47% |
| | 2071–2099 | 40% | 70% | 72% | 100% | 73% | 49% | 38% |
| | 2012–2099 | 50% | 60% | 71% | 92% | 62% | 62% | 39% |
| New Don Pedro | 2012–2040 | 46% | 36% | 68% | 80% | 50% | 65% | 23% |
| | 2041–2070 | 59% | 63% | 72% | 99% | 49% | 60% | 41% |
| | 2071–2099 | 44% | 82% | 88% | 97% | 74% | 38% | 32% |
| | 2012–2099 | 50% | 60% | 76% | 92% | 58% | 54% | 32% |
| McClure | 2012–2040 | 52% | 46% | 66% | 73% | 52% | 70% | 33% |
| | 2041–2070 | 49% | 61% | 73% | 97% | 53% | 75% | 46% |
| | 2071–2099 | 49% | 79% | 83% | 99% | 85% | 60% | 52% |
| | 2012–2099 | 50% | 62% | 74% | 90% | 63% | 68% | 44% |
| Millerton | 2012–2040 | 46% | 57% | 66% | 66% | 54% | 75% | 46% |
| | 2041–2070 | 54% | 64% | 67% | 84% | 59% | 73% | 52% |
| | 2071–2099 | 50% | 84% | 81% | 87% | 85% | 64% | 51% |
| | 2012–2099 | 50% | 68% | 71% | 79% | 66% | 71% | 50% |
| Pine Flat | 2012–2040 | 43% | 51% | 61% | 66% | 50% | 67% | 37% |
| | 2041–2070 | 60% | 61% | 73% | 94% | 49% | 69% | 50% |
| | 2071–2099 | 47% | 80% | 81% | 97% | 87% | 56% | 51% |
| | 2012–2099 | 50% | 64% | 72% | 85% | 62% | 64% | 46% |

In the NoCC scenario for the 2012-2099 period, all reservoirs, by definition of the metric, have surface areas that are the performance metric’s median surface area. Under most of the climate scenarios, all reservoirs show a greater frequency of falling below the median value.

In the following discussion, 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.

Across the range of all climate scenarios, the percentage of months that Shasta Reservoir was below the surface area metric was 59% of the months from May to September during the period from 2012-2099, an increase of 18% and ranged from a minimum of 33% to a maximum of 85% during the 2012-2099 period.

Across the range of all climate scenarios, the percentage of months that Millerton Reservoir was below the surface area metric was 67% of the months from May to September during the period from 2012-2099, an increase of 35% and ranged from a minimum of 50% to a maximum of 84% during the 2012-2099 period.

Across the range of all climate scenarios, the percentage of months that Pine Flat Reservoir was below the surface area metric was 67% of the months from May to September during the period from 2012-2099, an increase of 35% and ranged from a minimum of 39% to a maximum of 97% during the 2012-2099 period.

### 5.2.7 Ecological Resources Results

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.

#### *Coldwater Pool Management*

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. 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.

Table 5-13 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 from 2012 through 2099 and the 2012-2040, 2041 2070, and 2071-2099 periods.

In the no climate change scenario (CTnoCC), Lake Shasta storage was below the April and September metrics by 22% and 18% respectively of the years during 2012-2099 period.

Across the range of all climate scenarios, Lake Shasta storage was below the April and September metrics by 22% and 18% respectively of the years during 2012-2099 period corresponding to an increase of 22% in April and a decrease of 2% in September and ranged from a minimum of 6% to a maximum of 50% for April and ranged from a minimum of 2% to a maximum of 52% for September.

Table 5-13. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in each Scenario

| Month | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| September | 2012–2040 | 45% | 45% | 59% | 21% | 17% | 52% |
| | 2041–2070 | 0% | 7% | 47% | 3% | 0% | 3% |
| | 2071–2099 | 10% | 21% | 52% | 3% | 3% | 10% |
| | 2012–2099 | 18% | 24% | 52% | 9% | 7% | 22% |
| April | 2012–2040 | 41% | 52% | 52% | 14% | 14% | 48% |
| | 2041–2070 | 0% | 10% | 43% | 0% | 0% | 7% |
| | 2071–2099 | 14% | 34% | 55% | 7% | 3% | 14% |
| | 2012–2099 | 18% | 32% | 50% | 7% | 6% | 23% |

| Month | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| September | 2012–2040 | 45% | 0% | 10% | 17% | 7% | 28% | 3% |
| | 2041–2070 | 0% | 27% | 17% | 33% | 13% | 13% | 0% |
| | 2071–2099 | 10% | 7% | 34% | 31% | 7% | 3% | 3% |
| | 2012–2099 | 18% | 11% | 20% | 27% | 9% | 15% | 2% |
| April | 2012–2040 | 41% | 7% | 14% | 14% | 17% | 24% | 7% |
| | 2041–2070 | 0% | 30% | 20% | 33% | 13% | 23% | 13% |
| | 2071–2099 | 14% | 28% | 38% | 41% | 24% | 24% | 14% |
| | 2012–2099 | 18% | 22% | 24% | 30% | 18% | 24% | 11% |

| Month | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| September | 2012–2040 | 45% | 10% | 14% | 21% | 3% | 31% | 3% |
| | 2041–2070 | 0% | 10% | 7% | 43% | 20% | 10% | 13% |
| | 2071–2099 | 10% | 28% | 3% | 41% | 17% | 17% | 14% |
| | 2012–2099 | 18% | 16% | 8% | 35% | 14% | 19% | 10% |
| April | 2012–2040 | 41% | 14% | 14% | 21% | 0% | 34% | 0% |
| | 2041–2070 | 0% | 13% | 17% | 50% | 20% | 13% | 20% |
| | 2071–2099 | 14% | 31% | 17% | 41% | 31% | 31% | 24% |
| | 2012–2099 | 18% | 19% | 16% | 38% | 17% | 26% | 15% |

### *Floodplain Processes*

During the months of February through June, flows in excess of 15,000 cfs at Keswick Dam below Shasta Reservoir, 10,000 cfs at the mouth of Feather River and 3,000 cfs in American River flows at Natoma are a useful indicators of floodplain processes capable of sustaining favorable riparian habitat conditions in the Sacramento River watershed.

Table 5-14 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 metric values for each scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the CTnoCC scenario, the flow metric is not met in 96% of all months at Keswick, in 69% of all months in the Feather River, and in 57% of all months at Natoma. Thus, the floodplain process flows are more frequent in the Feather and American River systems than in the Sacramento River.

Across the range of all climate scenarios, the percentage of months that Keswick flows were below the flow metric was 93% of the months from February through June during the period from 2012-2099, an decrease of 3% and ranged from a minimum of 88% to a maximum of 96% during the 2012-2099 period.

Across the range of all climate scenarios, the percentage of months that Feather River flows at the mouth were below the flow metric was 75% of the months from February through June during the period from 2012-2099, an increase of 9% and ranged from a minimum of 61% to a maximum of 86% during the 2012-2099 period.

Across the range of all climate scenarios, the percentage of months that American River flows at Natoma were below the flow metric was 70% of the months from February through June during the period from 2012-2099, an increase of 23% and ranged from a minimum of 59% to a maximum of 79% during the 2012-2099 period.

Table 5-14. Percentage of Months that Lake Shasta Storage Is Less than 2,200 TAF in September and 3,800 TAF in April in each Scenario

| Location | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| Sacramento River at Keswick (15,000 cfs) | 2012–2040 | 96% | 96% | 95% | 91% | 94% | 94% |
| | 2041–2070 | 97% | 95% | 92% | 93% | 94% | 95% |
| | 2071–2099 | 94% | 97% | 97% | 91% | 92% | 95% |
| | 2012–2099 | 96% | 96% | 95% | 92% | 94% | 95% |
| Feather River at the Mouth (10,000 cfs) | 2012–2040 | 73% | 81% | 83% | 72% | 66% | 76% |
| | 2041–2070 | 64% | 81% | 89% | 63% | 59% | 67% |
| | 2071–2099 | 70% | 78% | 86% | 79% | 72% | 79% |
| | 2012–2099 | 69% | 80% | 86% | 71% | 66% | 74% |
| American River at Natoma (3,000 cfs) | 2012–2040 | 58% | 60% | 64% | 53% | 52% | 55% |
| | 2041–2070 | 50% | 69% | 72% | 63% | 57% | 67% |
| | 2071–2099 | 63% | 80% | 84% | 81% | 68% | 79% |
| | 2012–2099 | 57% | 70% | 73% | 65% | 59% | 67% |

| Location | Period | CTno CC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Sacramento River at Keswick (15,000 cfs) | 2012–2040 | 96% | 85% | 95% | 90% | 91% | 92% | 92% |
| | 2041–2070 | 97% | 94% | 93% | 95% | 89% | 95% | 93% |
| | 2071–2099 | 94% | 94% | 94% | 94% | 94% | 94% | 93% |
| | 2012–2099 | 96% | 91% | 94% | 93% | 91% | 93% | 93% |
| Feather River at the Mouth (10,000 cfs) | 2012–2040 | 73% | 57% | 77% | 82% | 68% | 83% | 70% |
| | 2041–2070 | 64% | 83% | 75% | 87% | 69% | 81% | 72% |
| | 2071–2099 | 70% | 82% | 88% | 88% | 74% | 87% | 77% |
| | 2012–2099 | 69% | 74% | 80% | 85% | 70% | 84% | 73% |
| American River at Natoma (3,000 cfs) | 2012–2040 | 58% | 53% | 69% | 72% | 66% | 68% | 64% |
| | 2041–2070 | 50% | 78% | 75% | 78% | 72% | 81% | 65% |
| | 2071–2099 | 63% | 87% | 90% | 88% | 81% | 87% | 73% |
| | 2012–2099 | 57% | 73% | 78% | 79% | 73% | 79% | 67% |

| Location | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| Sacramento River at Keswick (15,000 cfs) | 2012–2040 | 96% | 90% | 87% | 92% | 87% | 92% | 82% |
| | 2041–2070 | 97% | 90% | 92% | 96% | 89% | 91% | 90% |
| | 2071–2099 | 94% | 94% | 94% | 92% | 96% | 98% | 91% |
| | 2012–2099 | 96% | 91% | 91% | 94% | 91% | 93% | 88% |
| Feather River at the Mouth (10,000 cfs) | 2012–2040 | 73% | 66% | 76% | 79% | 66% | 75% | 51% |
| | 2041–2070 | 64% | 61% | 74% | 89% | 65% | 75% | 61% |
| | 2071–2099 | 70% | 77% | 86% | 89% | 88% | 72% | 70% |
| | 2012–2099 | 69% | 68% | 79% | 86% | 73% | 74% | 61% |
| American River at Natoma (3,000 cfs) | 2012–2040 | 58% | 58% | 64% | 67% | 56% | 69% | 50% |
| | 2041–2070 | 50% | 71% | 69% | 78% | 65% | 75% | 57% |
| | 2071–2099 | 63% | 76% | 79% | 86% | 90% | 79% | 72% |
| | 2012–2099 | 57% | 68% | 71% | 77% | 70% | 75% | 60% |

### *Pelagic Species Habitat (Spring)*

The attributes of interest selected to assess changes in habitat suitable for endangered pelagic species such as the Delta smelt are the spring X2 performance metric and the frequency of reverse direction (negative) flows in the Old and Middle River (OMR) channels of the San Joaquin River .

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. Greater X2 positions indicate that salinity has moved farther eastward into the Delta. Maintaining X2 positions of less than 74 km in spring months is one of the goals specified in the U.S. Fish and Wildlife Service's Biological Opinion and the SWRCB's Water Rights Decision D-1641.

The entrainment of Delta smelt in the south Delta channels leading to the Banks and Jones pumping plants is correlated with the frequency of reverse OMR flows referred to as more negative than -3,500 cfs.

Figures 5-45 and 5-46 show exceedance and box plots of the X2 position from February through June for each of the scenarios. The X2 position results under the wetter climate scenarios (CTQ3 and CTQ4) were similar to those of the CTnoCC scenario because the increased flows into the Delta in those wetter scenarios compensated for the increased sea level rise. However, the X2 position was greater under the central tendency CTQ5 and the drier climate scenarios (CTQ1 and CTQ2), where sea level rise combined with reduced Delta inflows relative to the CTnoCC scenario resulted in greater X2 positions.

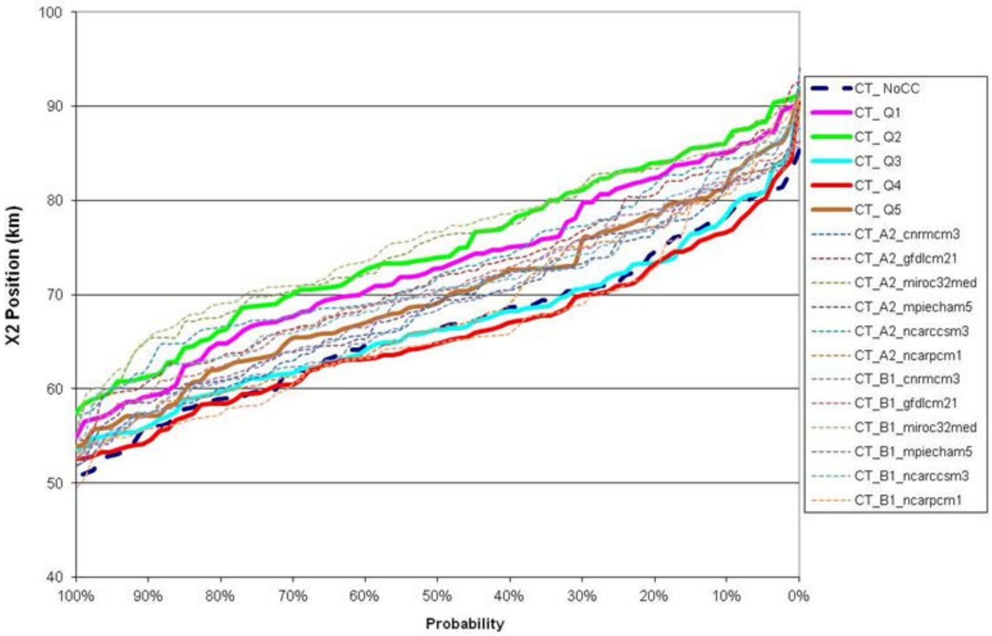

Figure 5-45. Exceedance of Average February-to-June X2 Position in the Baseline in Each Scenario

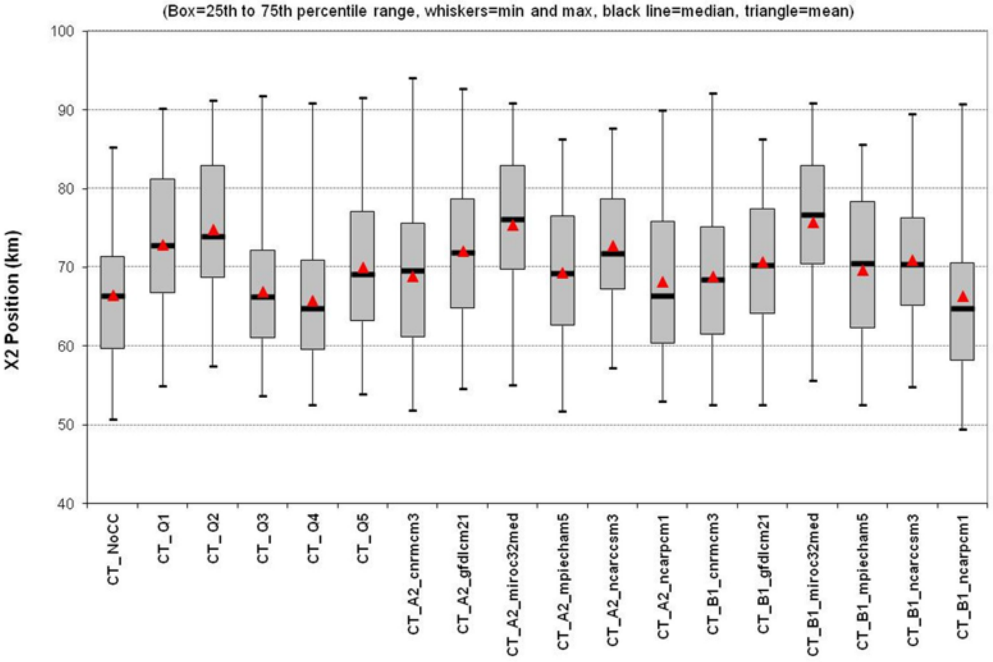

Figure 5-46. Box Plot of Average February-to-June X2 Position in the Baseline in Each Scenario

Table 5-15 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 for each scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods. Maintaining X2 positions of less than 74 km is a goal that is specified in the USFWS BiOp. The period from February through June is when CVP and SWP reservoirs were operated to maintain SWRCB D1641 regulatory requirements concerning the location of X2 within the Delta.

In the CTnoCC scenario, X2 is greater than the 74 km performance metric in 27% of the months from February through June for the 2012-2099 period.

Across the range of all scenarios, the X2 location is greater than the performance metric on average in 41% of the months from February through June for the 2012-2099 period, an increase of 53% and ranges from a minimum of 25% to a maximum of 59% during this period.

Table 5-15. Percentage of Months that the February-to-June X2 Position Is Greater than Metric Values in Each Scenario

| Position | Period | CtnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 26% | 42% | 48% | 20% | 18% | 34% |
| | 2041–2070 | 21% | 47% | 56% | 26% | 21% | 33% |
| | 2071–2099 | 34% | 59% | 66% | 39% | 34% | 50% |
| | 2012–2099 | 27% | 49% | 57% | 28% | 25% | 39% |

| Position | Period | CTnoCC | CTA2_ cnrmcm3 | CTA2_ gfdlcm21 | CTA2_ miroc32med | CTA2_ mpiecham5 | CTA2_ ncarccsm3 | CTA2_ ncarpcm1 |
|---|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 26% | 17% | 34% | 50% | 33% | 41% | 33% |
| | 2041–2070 | 21% | 47% | 37% | 58% | 39% | 50% | 35% |
| | 2071–2099 | 34% | 48% | 63% | 68% | 44% | 52% | 43% |
| | 2012–2099 | 27% | 37% | 45% | 58% | 39% | 48% | 37% |

| Position | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 26% | 30% | 32% | 41% | 27% | 48% | 14% |
| | 2041–2070 | 21% | 32% | 37% | 68% | 37% | 38% | 33% |
| | 2071–2099 | 34% | 50% | 60% | 68% | 59% | 44% | 42% |
| | 2012–2099 | 27% | 37% | 43% | 59% | 41% | 43% | 30% |

Table 5-16 shows the percentage of months from March through June that OMR flow is less (more negative) than -3,500 cfs for scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the NoCC scenario, OMR flows were less than -3,500 cfs in 36 percent of all months. In the climate change scenarios, the percentage of months that exceed the threshold ranged from 30 percent to 43 percent. 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. The differences between climate scenarios are similar across the periods 2012-2040, 2041-2070, and 2071-2099.

Table 5-16. Percentage of Months in Each Scenario that March-through-June OMR Flow Is Less (more negative) than 3,500 cfs

| **Period** | **CTnoCC** | **CTQ1** | **CTQ2** | **CTQ3** | **CTQ4** | **CTQ5** |
|---|---|---|---|---|---|---|
| 2012–2040 | 32% | 28% | 28% | 42% | 40% | 31% |
| 2041–2070 | 41% | 38% | 33% | 48% | 49% | 42% |
| 2071–2099 | 34% | 33% | 28% | 41% | 40% | 36% |
| 2012–2099 | 36% | 33% | 30% | 43% | 43% | 36% |
| **Period** | **CTnoCC** | **CTA2_ cnrm cm3** | **CTA2_ gfdl cm21** | **CTA2_ miroc32 med** | **CTA2_ mpie cham5** | **CTA2_ ncarc csm3** | 
| 2012–2040 | 32% | 45% | 38% | 34% | 40% | 39% |
| 2041–2070 | 41% | 31% | 41% | 29% | 40% | 36% |
| 2071–2099 | 34% | 41% | 30% | 32% | 42% | 36% |
| 2012–2099 | 36% | 39% | 36% | 32% | 41% | 37% |

<table>
<tr><th>Period</th><th>CTnoCC</th><th>CTA2_ cnrm cm3</th><th>CTA2_ gfdl cm21</th><th>CTA2_ miroc32 med</th><th>CTA2_ mpie cham5</th><th>CTA2_ ncarc csm3</th><th>CTA2_ ncarp cm1</th></tr>
<tr><td>2012–2040</td><td>32%</td><td>45%</td><td>38%</td><td>34%</td><td>40%</td><td>39%</td><td>40%</td></tr>
<tr><td>2041–2070</td><td>41%</td><td>31%</td><td>41%</td><td>29%</td><td>40%</td><td>36%</td><td>41%</td></tr>
<tr><td>2071–2099</td><td>34%</td><td>41%</td><td>30%</td><td>32%</td><td>42%</td><td>36%</td><td>41%</td></tr>
<tr><td>2012–2099</td><td>36%</td><td>39%</td><td>36%</td><td>32%</td><td>41%</td><td>37%</td><td>40%</td></tr>
<tr><th>Period</th><th>CTnoCC</th><th>CTB1_ cnrm cm3</th><th>CTB1_ gfdl cm21</th><th>CTB1_ miroc32 med</th><th>CTB1_ mpie cham5</th><th>CTB1_ ncarc csm3</th><th>CTB1_ ncarp cm1</th></tr>
<tr><td>2012–2040</td><td>32%</td><td>44%</td><td>41%</td><td>37%</td><td>42%</td><td>37%</td><td>44%</td></tr>
<tr><td>2041–2070</td><td>41%</td><td>43%</td><td>41%</td><td>27%</td><td>41%</td><td>39%</td><td>42%</td></tr>
<tr><td>2071–2099</td><td>34%</td><td>41%</td><td>36%</td><td>33%</td><td>34%</td><td>40%</td><td>42%</td></tr>
<tr><td>2012–2099</td><td>36%</td><td>42%</td><td>39%</td><td>32%</td><td>39%</td><td>39%</td><td>43%</td></tr>
</table>

### *Pelagic Species Habitat (Fall)*

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 is a goal that is specified in the USFWS BiOp.

Table 5-17 shows the percentage of months from September through November that the average X2 position is greater than 74 km for each scenario from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the CTnoCC scenario, X2 is greater than the 74 km performance metric in 85% of the months from September through November for the 2012-2099 period.

Across the range of all scenarios, the X2 location is greater than the performance metric on average in 95% of the months from September through November for the 2012-2099 period, an increase of 12% and ranges from a minimum of 91% to a maximum of 98% during this period.

Table 5-17. Percentage of Months that September-through-November X2 Position Is Greater than Metric Value in Each Scenario

| Position | Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 88% | 100% | 100% | 98% | 96% | 100% |
| | 2041–2070 | 88% | 98% | 99% | 96% | 92% | 98% |
| | 2071–2099 | 83% | 98% | 99% | 93% | 89% | 94% |
| | 2012–2099 | 85% | 97% | 98% | 94% | 91% | 96% |

| Position | Period | CTnoCC | CTA2_ cnrm cm3 | CTA2_ gfdl cm21 | CTA2_ miroc32 med | CTA2_ mpie cham5 | CTA2_ ncarc csm3 | CTA2_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 88% | 89% | 95% | 98% | 98% | 100% | 93% |
| | 2041–2070 | 88% | 99% | 98% | 98% | 100% | 99% | 94% |
| | 2071–2099 | 83% | 98% | 100% | 98% | 99% | 97% | 100% |
| | 2012–2099 | 85% | 94% | 97% | 97% | 98% | 97% | 95% |

| Position | Period | CTnoCC | CTB1_ cnrm cm3 | CTB1_ gfdl cm21 | CTB1_ miroc32 med | CTB1_ mpie cham5 | CTB1_ ncarc csm3 | CTB1_ ncarp cm1 |
|---|---|---|---|---|---|---|---|---|
| X2 (74 km) | 2012–2040 | 88% | 93% | 94% | 96% | 95% | 96% | 83% |
| | 2041–2070 | 88% | 96% | 91% | 97% | 99% | 98% | 97% |
| | 2071–2099 | 83% | 100% | 99% | 100% | 100% | 97% | 99% |
| | 2012–2099 | 85% | 95% | 94% | 97% | 97% | 96% | 92% |

### *Adult San Joaquin Salmonid Migration*

The attribute of interest selected for assessing the migration of endangered salmonids through the Delta is the frequency of negative (upstream) flows in the OMR channels of the San Joaquin River in the Delta. 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 -5000 cfs in these channels during the months of October through December.

Table 5-18 shows the percentage of months from October through December that OMR flow is less (more negative) than -5,000 cfs from 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the CTnoCC scenario, OMR flows are more negative than the -5000 cfs performance metric in 59% of the months from October through December for the 2012-2099 period.

Across the range of all scenarios, the OMR flow is greater than the performance metric on average in 60% of the months from September through

November for the 2012-2099 period, an increase of 1% and ranges from a minimum of 53% to a maximum of 64% during this period.

Table 5-18. Percentage of Months that October-through-December OMR Flow Is Less (more negative) than -5,000 cfs in each Scenario

| Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|
| 2012–2040 | 62% | 51% | 48% | 64% | 66% | 59% |
| 2041–2070 | 60% | 61% | 58% | 62% | 58% | 61% |
| 2071–2099 | 56% | 56% | 54% | 56% | 63% | 59% |
| 2012–2099 | 59% | 56% | 53% | 61% | 62% | 59% |
| **Period** | **CTnoCC** | **CTA2_ cnrm cm3** | **CTA2_ gfdl cm21** | **CTA2_ miroc32 med** | **CTA2_ mpie cham5** | **CTA2_ ncarc csm3** | **CTA2_ ncarp cm1** |
| 2012–2040 | 62% | 60% | 64% | 55% | 60% | 61% | 63% |
| 2041–2070 | 60% | 62% | 62% | 50% | 63% | 57% | 64% |
| 2071–2099 | 56% | 60% | 52% | 62% | 66% | 63% | 63% |
| 2012–2099 | 59% | 61% | 59% | 56% | 63% | 60% | 64% |
| **Period** | **CTnoCC** | **CTB1_ cnrm cm3** | **CTB1_ gfdl cm21** | **CTB1_ miroc32 med** | **CTB1_ mpie cham5** | **CTB1_ ncarc csm3** | **CTB1_ ncarp cm1** |
| 2012–2040 | 62% | 60% | 57% | 56% | 62% | 54% | 63% |
| 2041–2070 | 60% | 60% | 62% | 57% | 62% | 62% | 62% |
| 2071–2099 | 56% | 62% | 56% | 52% | 60% | 64% | 63% |
| 2012–2099 | 59% | 61% | 59% | 55% | 61% | 60% | 63% |

### *Food Web Productivity*

The attribute of interest selected for assessing the food web productivity in the Delta is the frequency of negative (upstream) flows in the OMR channels of the San Joaquin River in the Delta. Food web productivity is highly correlated with the frequency of flows more negative than -5000 cfs in these channels during the months of July through September.

Table 5-19 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 2012 through 2099 and for 2012-2040, 2041-2070, and 2071-2099 periods.

In the CTnoCC scenario, OMR flows are more negative than the -5000 cfs performance metric in 87% of the months from July through September for the 2012-2099 period.

Across the range of all scenarios, the OMR flows are greater than the performance metric on average in 81% of the months from July through September for the 2012-2099 period, an decrease of 7% and ranges from a minimum of 58% to a maximum of 93% during this period.

Table 5-19. Percentage of Months that July-through-September OMR Flow Is Less (more negative) than -5,000 cfs in Each Scenario

| Period | CTnoCC | CTQ1 | CTQ2 | CTQ3 | CTQ4 | CTQ5 |
|---|---|---|---|---|---|---|
| 2012–2040 | 76% | 69% | 57% | 86% | 90% | 70% |
| 2041–2070 | 92% | 84% | 61% | 92% | 92% | 82% |
| 2071–2099 | 92% | 74% | 54% | 93% | 97% | 84% |
| 2012–2099 | 87% | 76% | 58% | 91% | 93% | 79% |
| **Period** | **CTnoCC** | **CTA2_ cnrm cm3** | **CTA2_ gfdl cm21** | **CTA2_ miroc 32med** | **CTA2_ mpie cham5** | **CTA2_ ncarc csm3** | **CTA2_ ncarp cm1** |
| 2012–2040 | 76% | 92% | 84% | 75% | 80% | 69% | 84% |
| 2041–2070 | 92% | 68% | 84% | 60% | 89% | 78% | 91% |
| 2071–2099 | 92% | 84% | 70% | 75% | 93% | 90% | 94% |
| 2012–2099 | 87% | 81% | 80% | 70% | 88% | 79% | 90% |
| **Period** | **CTnoCC** | **CTB1_ cnrm cm3** | **CTB1_ gfdl cm21** | **CTB1_ miroc 32med** | **CTB1_ mpie cham5** | **CTB1_ ncarc csm3** | **CTB1_ ncarp cm1** |
| 2012–2040 | 76% | 90% | 76% | 67% | 91% | 66% | 97% |
| 2041–2070 | 92% | 90% | 88% | 53% | 81% | 86% | 87% |
| 2071–2099 | 92% | 78% | 85% | 69% | 83% | 87% | 84% |
| 2012–2099 | 87% | 86% | 83% | 63% | 85% | 80% | 89% |

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Table 6-1. Reference Information for Citations on Figure 4-7

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# Technical Supplement: Baseline Assumptions for the Impact Assessment CVP IRP CalLite Model

| **Sacramento and San Joaquin Basins Climate Impact Assessment**<br>**TECHNICAL SUPPLEMENT** | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| **General** | |
| Planning horizon | Transient simulation from 2012-2099 |
| Demarcation date[a] | February 2009 (but with June 2009 NMFS BO included) |
| Period of simulation | 88 years (Water Years 2012-2099) |
| **Hydrology** | |
| Inflows/supplies | Future climate-based hydrology determined by WEAP |
| Level of development | Transient assumptions from 2012-2099 |
| **Demands, Water Rights, CVP-SWP Contracts** | |
| **Sacramento River Region (excluding American River)** | |
| CVP[b] | WEAP-based, limited by contract amounts |
| SWP (FRSA)[c] | WEAP-based, limited by contract amounts |
| Non-project | WEAP-based, limited by water rights and SWRCB decisions for existing facilities |
| Antioch | Pre-1914 water right |
| Federal refuges[d] | Firm Level 2 water needs |
| **Sacramento River Region - American River**[e] | |
| Water rights | Year 2025, full water rights |
| CVP | Year 2025, full water rights, including Freeport Regional Water Project |
| **San Joaquin River Region**[f] | |
| Friant Unit | Limited by contract amounts, based on current allocation policy |
| Lower Basin | WEAP-based, based on district-level operations and constraints |
| Stanislaus River[g] | WEAP-based, Revised Operations Plan[m] and NFMS BO (June 2009) Actions III.1.2 and III.1.3[o] |
| **San Francisco Bay, Central Coast, Tulare Lake, and South Coast Regions** (CVP-SWP project facilities) | |
| CVP[b] | Demand based on contracts amounts |
| CCWD[n] | 195 TAF/yr CVP contract supply and water rights |
| SWP[c,l] | Demand based on full Table A amounts |
| Article 56 | Based on 2001-2008 contractor requests |
| Article 21 | MWD demand up to 200 TAF/month from December to March subject to conveyance capacity, KCWA demand up to 180 TAF/month, and other contractor demands up to 34 TAF/month in all months, subject to conveyance capacity |
| NBA | 77 TAF/yr demand under SWP contracts, up to 43.7 cfs of excess flow under Fairfield, Vacaville, and Benicia Settlement |

| **Sacramento and San Joaquin Basins Climate Impact Assessment<br>TECHNICAL SUPPLEMENT** | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| | Agreement |
| Federal refuges[d] | Firm Level 2 water needs |
| **Facilities** | |
| **Systemwide** | |
| Systemwide | Existing facilities |
| Isolated facility | None |
| **Sacramento River Region** | |
| Shasta Lake | Existing, 4,552 TAF capacity |
| Red Bluff Diversion Dam | Diversion dam operated with gates out all year, NMFS BO (June 2009) Action I.3.1v; assume permanent facilities in place |
| Colusa Basin | Existing conveyance and storage facilities |
| Upper American River[e,j] | PCWA American River Pump Station |
| Lower Sacramento River | Freeport Regional Water Project |
| Freemont Weir/Yolo Bypass | Existing weir |
| **San Joaquin River Region** | |
| Millerton Lake (Friant Dam) | Existing, 520-TAF capacity |
| Lower San Joaquin River | City of Stockton Delta Water Supply Project, 30-mgd capacity |
| **Delta Region** | |
| SWP Banks Pumping Plant (South Delta) | Physical capacity is 10,300 cfs but 6,680-cfs permitted capacity in all months up to 8,500 cfs during Dec 15 – March 15 depending on Vernalis flow conditions[k] |
| CVP C.W. Bill Jones Pumping Plant (Tracy PP) | Permit capacity is 4,600 cfs in all months (allowed for by the Delta-Mendota Canal–California Aqueduct Intertie) |
| Upper Delta-Mendota Canal capacity | Not simulated in CalLite |
| CCWD intakes | Los Vaqueros existing storage capacity, 100 TAF, existing pump locations, AIP included[l] |
| **San Francisco Bay Region** | |
| SBA | Not simulated in CalLite |
| **South Coast Region** | |
| California Aqueduct East Branch | Not simulated in CalLite |
| **Regulatory Standards** | |
| **North Coast Region** | |
| *Trinity River* | |
| Minimum flow below Lewiston Dam | Trinity EIS Preferred Alternative (369-815 TAF/yr) |
| Trinity Reservoir end-of-September minimum storage | Not simulated in CalLite |
| **Sacramento River Region** | |
| *Clear Creek* | |
| Minimum flow below Whiskeytown Dam | Downstream water rights, 1963 Reclamation Proposal to USFWS and NPS, predetermined CVPIA 3406(b)(2) flows, |

| **Sacramento and San Joaquin Basins Climate Impact Assessment TECHNICAL SUPPLEMENT** | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| | and NMFS BO (June 2009) Action I.1.1v |
| *Upper Sacramento River* | |
| Shasta Lake end-of-September minimum storage | Not simulated in CalLite |
| Minimum flow below Keswick Dam | SWRCB WR 90-5 temperature control, predetermined CVPIA 3406(b)(2) flows, and NMFS BO (June 2009) Action I.2.2v |
| *Feather River* | |
| Minimum flow below Thermalito Diversion Dam | Not simulated in CalLite |
| Minimum flow below Thermalito Afterbay outlet | 1983 DWR, CDFW Agreement (750-1,700 cfs) |
| *Yuba River* | |
| Minimum flow below Daguerre Point Dam | Minimum flows from Yuba River Model |
| *American River* | |
| Minimum flow below Nimbus Dam | American River Flow Management as required by NMFS BO (June 2009) Action II.1[o] |
| Minimum flow at H Street Bridge | SWRCB D-893 |
| *Lower Sacramento River* | |
| Minimum flow at Freeport | None |
| North Delta Diversion Bypass flow | None |
| | None |
| | None |
| Minimum flow near Rio Vista | SWRCB D-1641 |
| **San Joaquin River Region** | |
| *Mokelumne River* | |
| Minimum flow below Camanche Dam | Not simulated in CalLite |
| Minimum flow below Woodbridge Diversion Dam | Not simulated in CalLite |
| *Stanislaus River* | |
| Minimum flow below Goodwin Dam | 1987 Reclamation, CDFW agreement, and flows required for NMFS BO (June 2009) Action III.1.2 and III.1.3[o] |
| Minimum dissolved oxygen | SWRCB D-1422 |
| *Merced River* | |
| Minimum flow below Crocker-Huffman Diversion Dam | Davis-Grunsky (180-220 cfs, Nov-Mar), and Cowell Agreement |
| Minimum flow at Shaffer Bridge | FERC 2179 (25-100 cfs) |
| *Tuolumne River* | |
| Minimum flow at Lagrange Bridge | FERC 2299-024, 1995 (Settlement Agreement) (94-301 TAF/yr) |
| *San Joaquin River* | |
| San Joaquin River below Friant Dam/ Mendota Pool | Water Year 2010 Interim Flows Project[n] |

| **Sacramento and San Joaquin Basins Climate Impact Assessment TECHNICAL SUPPLEMENT** | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| Maximum salinity near Vernalis | SWRCB D-1641 |
| Minimum flow near Vernalis | SWRCB D-1641 and NMFS BO (June 2009) Action IV.2.1[o] |
| **Sacramento River–San Joaquin Delta Region** | |
| Delta Outflow Index (Flow, NDOI) | SWRCB D-1641 |
| Delta Outflow Index (Salinity, X2) - Spring | SWRCB D-1641 |
| Delta Outflow (Salinity, X2) - Fall | USFWS BO (Dec 2008) Action 4 (Reservoir release cap for November is not implemented) |
| Delta Cross Channel gate operation | SRWCB D-1641 with additional days closed from Oct 1 – Jan 31 based on NMFS BO (June 2009) Action IV.1.2[o] (closed during flushing flows from Oct 1 – Dec 14 unless adverse water quality conditions); NMFS BO requirement is modeled by a month by WYType table□ |
| South Delta exports (Jones PP and Banks PP) | SWRCB D-1641, Vernalis flow-based export limits April 1 – May 31 as required by NMFS BO (June 2009) Action IV.2.1[o] |
| Combined flow in OMR | USFWS BO (Dec 2008) Actions 1 through 3 and NMFS BO (June 2009) Action IV.2.3o; USFWS BO requirement is modeled by a month by WYType table |
| Delta water quality | SWRCB D-1641 |
| **Operations Criteria** | |
| **Sacramento River Region** | |
| Upper Sacramento River: Flow objective for navigation (Wilkins Slough) | NMFS BO (June 2009) Action I.4o; 3,500 – 5,000 cfs based on CVP water supply condition |
| American River: Folsom Dam flood control | Variable 400/670 flood control diagram (without outlet modifications) |
| Feather River: Flow at mouth of Feather River (above Verona) | Maintain CDFW/DWR flow target of 2,800 cfs for April – Sept dependent on Oroville inflow and FRSA allocation |
| **San Joaquin River Region** | |
| Stanislaus River: Flow below Goodwin Dam[i] | Revised Operations Planm and NMFS BO (June 2009) Action III.1.2 and III.1.3[o] |
| San Joaquin River: Salinity at Vernalis | Grasslands Bypass Project (full implementation) |
| **Operations Criteria: Systemwide** | |
| **North & South Delta Intakes Operation Criteria** | |
| Water quality and residence time | None |
| **CVP Water Allocation** | |
| Settlement / Exchange | 100% (75% in Shasta critical years) |
| Refuges | 100% (75% in Shasta critical years) |
| Agriculture Service | 100%-0% based on supply, South-of-Delta allocations are additionally limited due to SWRCB D-1641, USFWS BO (Dec 2008), and NMFS BO (June 2009) export restrictions[o] |

| **Sacramento and San Joaquin Basins Climate Impact Assessment<br>TECHNICAL SUPPLEMENT** | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| Municipal & Industrial Service | 100%-50% based on supply, South-of-Delta allocations are additionally limited due to SWRCB D-1641, USFWS BO (Dec 2008), and NMFS BO (June 2009) export restrictions[o] |
| **SWP Water Allocation** | |
| North of Delta (FRSA) | Contract-specific |
| South of Delta (including North Bay Aqueduct) | Based on supply; equal prioritization between Ag and M&I based on Monterey Agreement; allocations are additionally limited due to SWRCB D-1641, USFWS BO (Dec 2008), and NMFS BO (June 2009) export restrictions[o] |
| **CVP-SWP Coordinated Operations** | |
| Sharing of responsibility for in-basin use | 1986 Coordinated Operations Agreement (FRWP EBMUD and two-thirds of the North Bay Aqueduct diversions considered as Delta Export; one-third of the North Bay Aqueduct diversion considered as in-basin-use) |
| Sharing of surplus flows | 1986 Coordinated Operations Agreement |
| Sharing of total allowable export capacity for project-specific priority pumping | Equal sharing of export capacity under SWRCB D-1641, USFWS BO (Dec 2008), and NMFS BO (June 2009) export restrictions[o] |
| Water transfers | Not simulated in CalLite |
| Sharing of export capacity for lesser priority and wheeling-related pumping | CALFED ROD defined Joint Point of Diversion (JPOD); Cross Valley Canal wheeling is not simulated in CalLite |
| San Luis Reservoir | San Luis Reservoir is allowed to operate to a minimum storage of 100 TAF |
| **CVPIA 3406(b)(2)** | |
| Policy Decision | Not simulated in CalLite |
| Allocation | Not simulated in CalLite |
| Actions | Not simulated in CalLite |
| Accounting | Not simulated in CalLite |
| **Water Management Actions** | |
| **Water Transfer Supplies (long-term programs)** | |
| Lower Yuba River Accord | Not simulated in CalLite |
| Phase 8 | Not simulated in CalLite |
| **Water Transfers (short-term or temporary programs)** | |
| Sacramento Valley acquisitions conveyed through Banks PP | Not simulated in CalLite |
| **CALSIM Notes** | |
| [a] These assumptions have been developed under the direction of the DWR and Reclamation management team for the BDCP HCP and EIR/EIS. | |
| [b] CVP contract amounts have been updated according to existing and amended contracts as appropriate. | |
| [c] SWP contract amounts have been updated as appropriate based on recent Table A transfers/agreements. | |
| [d] Water needs for federal refuges have been reviewed and updated as appropriate. Refuge Level 4 ( and incremental Level 4) water is not analyzed. | |

| Sacramento and San Joaquin Basins Climate Impact Assessment TECHNICAL SUPPLEMENT | |
|---|---|
| **CALSIM II and CalLite Modeling Assumptions** | |
| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
| [e] The Sacramento Area Water Forum Agreement, its dry-year diversion reductions, Middle Fork Project operations, and “mitigation” water are not included. | |
| [f] The CalLite representation of the San Joaquin River reflects the CALSIM II implementation of the 2030 level of development representation of the San Joaquin River Basin. | |
| [g] The CalLite model representation for the Stanislaus River does not necessarily represent Reclamation’s current or future operational policies. A suitable plan for supporting flows has not been developed for NMFS BO (June 2009) Action 3.1.3. | |
| [h] The actual amount diverted is operated in conjunction with supplies from the Los Vaqueros project. The existing Los Vaqueros storage capacity is 100 TAF. Associated water rights for Delta excess flows are included. | |
| [i] It is assumed that SWP Contractors can take delivery of all Table A allocations and Article 21 supplies. Article 56 provisions are assumed and allow for SWP Contractors to manage storage and delivery conditions such that full Table A allocations can be delivered. Article 21 deliveries are limited in wet years under the assumption that demand is decreased in these conditions. Article 21 deliveries for the NBA are dependent on excess conditions only, all other Article 21 deliveries also require that San Luis Reservoir be at capacity and that Banks PP and the California Aqueduct have available capacity to divert from the Delta for direct delivery. | |
| [j] PCWA American River pumping facility upstream of Folsom Lake is included. The diversion is assumed to be 35.5 TAF/yr. | |
| [k] Current ACOE permit for Banks PP allows for an average diversion rate of 6,680 cfs in all months. Diversion rate can increase up to one-third of the rate of San Joaquin River flow at Vernalis during Dec 15 – March 15 up to a maximum diversion of 8,500 cfs, if Vernalis flow exceeds 1,000 cfs. | |
| [l] The CCWD AIP, an intake at Victoria Canal, which operates as an alternate Delta diversion for Los Vaqueros Reservoir. This assumption is consistent with the future no-project condition defined by the Los Vaqueros Enlargement study team. | |
| [m] The model operates the Stanislaus River using a 1997 Interim Plan of Operation-like structure, i.e., allocating water for SEWD and CSJWCD, Vernalis water quality dilution and Vernalis D-1641 flow requirements based on the New Melones Index. OID and SSJID allocations are based on their 1988 agreement and Ripon DO requirements are represented by a static set of minimum instream flow requirements during June thru Sept. Instream flow requirements for fish below Goodwin are based on NMFS BO Action III.1.2. NMFS BO Action IV.2.1's flow component is not assumed to be in effect. | |
| [n] SJR Restoration Water Year 2010 Interim Flows Project are assumed, but are not input into the models; operation not regularly defined at this time. | |
| [o] In cooperation with Reclamation, National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Wildlife, the California Department of Water Resources has developed assumptions for implementation of the USFWS BO (Dec 15, 2008) and NMFS BO (June 4, 2009) in CALSIM II. | |
| **Definitions** | |
| ACOE = Army Corps of Engineers | |
| Ag = agriculture | |
| AIP = Alternative Intake Project | |
| BDCP = Bay Delta Conservation Plan | |
| BO = biological opinion | |
| CCWD = Contra Costa Water District | |
| CDFW = California Department of Fish and Wildlife | |
| cfs = cubic foot (feet) per second | |

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**CALSIM II and CalLite Modeling Assumptions**

| **Parameter Category/ Study CVP IRP** | **CalLite Baseline Assumption** |
|---|---|
| CSJWCD = Central San Joaquin Water Conservation District<br>CVP = Central Valley Project | |
| CVPIA = Central Valley Project Improvement Act | |
| DO = dissolved oxygen | |
| DWR = California Department of Water Resources | |
| EBMUD = East Bay Municipal Utility District | |
| EIR = environmental impact report | |
| EIS = environmental impact statement | |
| FERC = Federal Energy Regulatory Commission | |
| FRSA = Feather River Service Area | |
| HCP = Habitat Conservation Plan | |
| IRP = Installation Restoration Program | |
| KCWA = Kern County Water Agency | |
| M&I = municipal and industrial | |
| mgd = million gallons per day | |
| MWD = Metropolitan Water District of Southern California | |
| NBA = North Bay Aqueduct | |
| NDOI = Net Delta Outflow Index | |
| NMFS = National Marine Fisheries Service | |
| NPS= National Park Service | |
| OID = Oakdale Irrigation District | |
| OMR = Old and Middle River | |
| PCWA = Placer County Water Agency | |
| PP= Pumping Plant | |
| Reclamation = Bureau of Reclamation | |
| SBA = South Bay Aqueduct | |
| SEWD = Stockton East Water District | |
| SJR = San Joaquin River | |
| SSJID = South San Joaquin Irrigation District | |
| SWP= State Water Project | |
| SWRCB = State Water Resources Control Board | |
| TAF = thousand acre-feet | |
| USFWS = U.S. Fish and Wildlife Service | |
| WEAP = Water Evaluation and Planning (model) | |
| yr = year | |
| **References** | |
| United States Fish and Wildlife Service (USFWS). 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). December 2008. | |
| National Marine Fisheries Service (NMFS). 2009. Biological and conference opinion on the long-term operations of the Central Valley Project and State Water Project. June 2009. | |