Draft

Climate Change Modeling Attachment

Upper San Joaquin River Basin Storage Investigation

Prepared by:

United States Department of the Interior
Bureau of Reclamation
Mid-Pacific Region

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Bureau of Reclamation

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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.

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Abbreviations and Acronyms

°C	degrees Celsius
°F	degrees Fahrenheit
ANN	artificial neural network
B	site-specific parameter
Bay-Delta	San Francisco Bay/Sacramento-San Joaquin Delta
BDCP	Bay Delta Conservation Plan
CALFED	CALFED Bay-Delta Program
CalLite	California Lite Simulation
CAT	Climate Action Team
CCWD	Contra Costa Water District
CDF	cumulative distribution function
CIMIS	California Irrigation Management Information System
cm	centimeter
CO_2	carbon dioxide
CT	Current Trend
CT_NoCC	central tendency-no climate change
CVP IRP	Central Valley Project Integrated Resources Plan
CVP	Central Valley Project
CWP	California Water Plan
Delta	Sacramento-San Joaquin Delta
DMC	Delta-Mendota Canal
DOF	California Department of Finance
DWR	California Department of Water Resources
D-xxxx	State Water Resources Control Board Water Right Decision No. xxxx
EG	Expansive Growth
ENSO	El Nino Southern Oscillation
ET	evapotranspiration
FACE	Free Air Carbon Exchange
FKC	Friant-Kern Canal
GCM	Global Circulation Model
GHG	greenhouse gas
GIS	geographical information system
HR	Hydrologic Region
in/year	inches per year

IPCC	Intergovernmental Panel on Climate Change
km	kilometer
Ko	dew point depression
LAWS	Land Atmosphere Water Simulator
LCPSIM	Least Cost Planning Simulation Model
LOD	level of development
LTGen	LongTermGen
M&I	municipal and industrial
MAF	million acre-feet
mm	millimeter
msl	mean sea level
$mTCO_2e$	metric tons of carbon dioxide equivalents
NEPA	National Environmental Policy Act
NoCC	no climate change
NRC	National Research Council
OMWEM	Other Municipal Water Economics Model
ppm	parts per million
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RH	relative humidity
RM	River Mile
Ro	clear radiation
Rs	solar radiation
Sac	Sacramento
SBWQM	South Bay Water Quality Model
SG	Slow Growth
SJ	San Joaquin
SJRRP	San Joaquin River Restoration Program
SJRWQM	San Joaquin River Water Quality Model
SLIS	selective level intake structure
SOD	South-of-Delta
SRWQM	Sacramento River Water Quality Model
SWAP	Statewide Agricultural Production Model
SWE	Snow Water Equivalent
SWP_Power	State Water Project Power
SWP	State Water Project
TAF	thousand acre feet
Tdew	dew point temperature

TL	Tulare Lake
Tmax	daily maximum temperature
Tmin	daily minimum temperature
USJRBSI	Upper San Joaquin River Basin Storage Investigation
VPD	vapor pressure deficit
WEAP	Water Evaluation and Planning
WEAP-CV	WEAP model of the Central Valley watershed

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Chapter 1 Introduction

This Modeling Appendix provides a description of assumptions, methods and modeling of the effects of future uncertainties in socioeconomic and climate conditions on the Upper San Joaquin River Basin Storage Investigation (USJRBSI).

In keeping with the U.S. Department of the Interior, Bureau of Reclamation's (Reclamation) policy to use the best available science to inform decision making, quantitative methods and modeling tools were used whenever possible. For the climate change impact assessment, Reclamation's existing suite of climate, hydrology, operations and performance assessment models were modified specifically to simulate the sensitivity of the USJRBSI to uncertainties in future socioeconomic-climate conditions. As extensive as the capabilities of these tools are, they do not include the capacity to quantitatively evaluate all the resources categories associated with potential climate impacts on the Investigation. Furthermore because of the practical limitations imposed by computational requirements, climate impact assessment models are not designed to simulate highly detailed water management operations. Consequently, a single suite of models was not used for the all the analyses. Rather models deemed to be the most appropriate to providing the best information for the intended purpose were used. These limitations also mean that some of the details of the various Investigation alternatives could not be represented in the quantitative modeling of climate impact assessments. Nevertheless, the results presented in this chapter provide as comprehensive a level of detail as currently possible to inform decision makers on the potential impacts of future uncertainties change on the project.

This appendix is organized as follows:

- Chapter 2 of this appendix presents information on a summary of global climate projections and relevant research on climate change implications for California water resources, particularly those for the Central Valley of California.

- Chapter 3 of this appendix presents the results of the projected transient climate change analysis of the potential sensitivity of USJRBSI to a range of climate change effects.

- Chapter 4 contains the technical references list.

Chapter 2
Summary of Previous Studies of Climate Change in the Study Area

This chapter provides a summary of global climate projections and relevant research on climate change implications for California water resources, including a summary of key findings on the sensitivity of California water resources to climate changes, particularly those for the Central Valley of California.

Study Area Setting

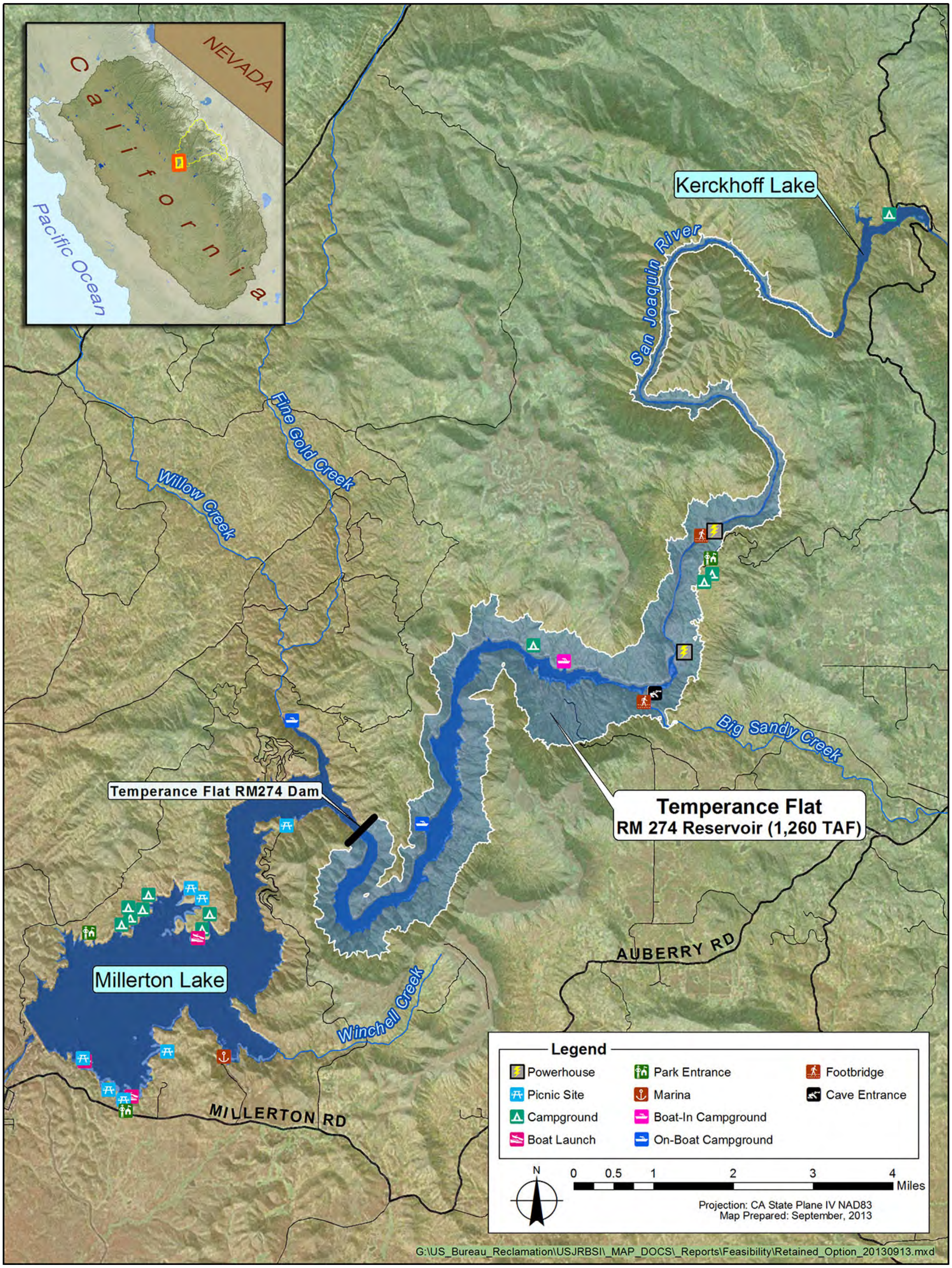
The upper San Joaquin River Basin comprises the San Joaquin River and tributary lands upstream from its confluence with the Merced River to its source high in the Sierra Nevada. Friant Dam, located on the San Joaquin River about 20 miles northeast of Fresno, diverts much of the water from the San Joaquin River to the eastern portions of the San Joaquin and Tulare Lake hydrologic regions, from Chowchilla in the north to Bakersfield in the south.

The study area comprises features and areas that would be affected by changes in water management to support Investigation objectives and opportunities. The study area has been refined as the Investigation has progressed. Through previous study phases, geographic areas were added and deleted from consideration as the potential effects of alternatives were better understood, and management measures were added and deleted.

At this stage in the Investigation, the primary study area encompasses the San Joaquin River watershed upstream from Friant Dam to Kerckhoff Dam, including Millerton Lake, and areas that would be directly affected by construction-related activities, including the footprint of Temperance Flat River Mile (RM) 274 Reservoir and related facilities upstream from Friant Dam (Figure 1-1).

The extended study area presented in this document encompasses locations of potential project features and areas potentially affected by alternative implementation and/or operation (Figure 1-2). These locations and areas include the following:

- San Joaquin River watershed upstream from Friant Dam
- San Joaquin River downstream from Friant Dam, including the Sacramento-San Joaquin Delta (Delta)
- Lands with San Joaquin River water rights
- Friant Division of the Central Valley Project (CVP), including underlying groundwater basins in the eastern San Joaquin Valley
- South-of-Delta (SOD) water service areas of the CVP and State Water Project (SWP)



Key: RM = River Mile

Figure 1-1. Primary Study Area and Temperance Flat RM 274 Reservoir

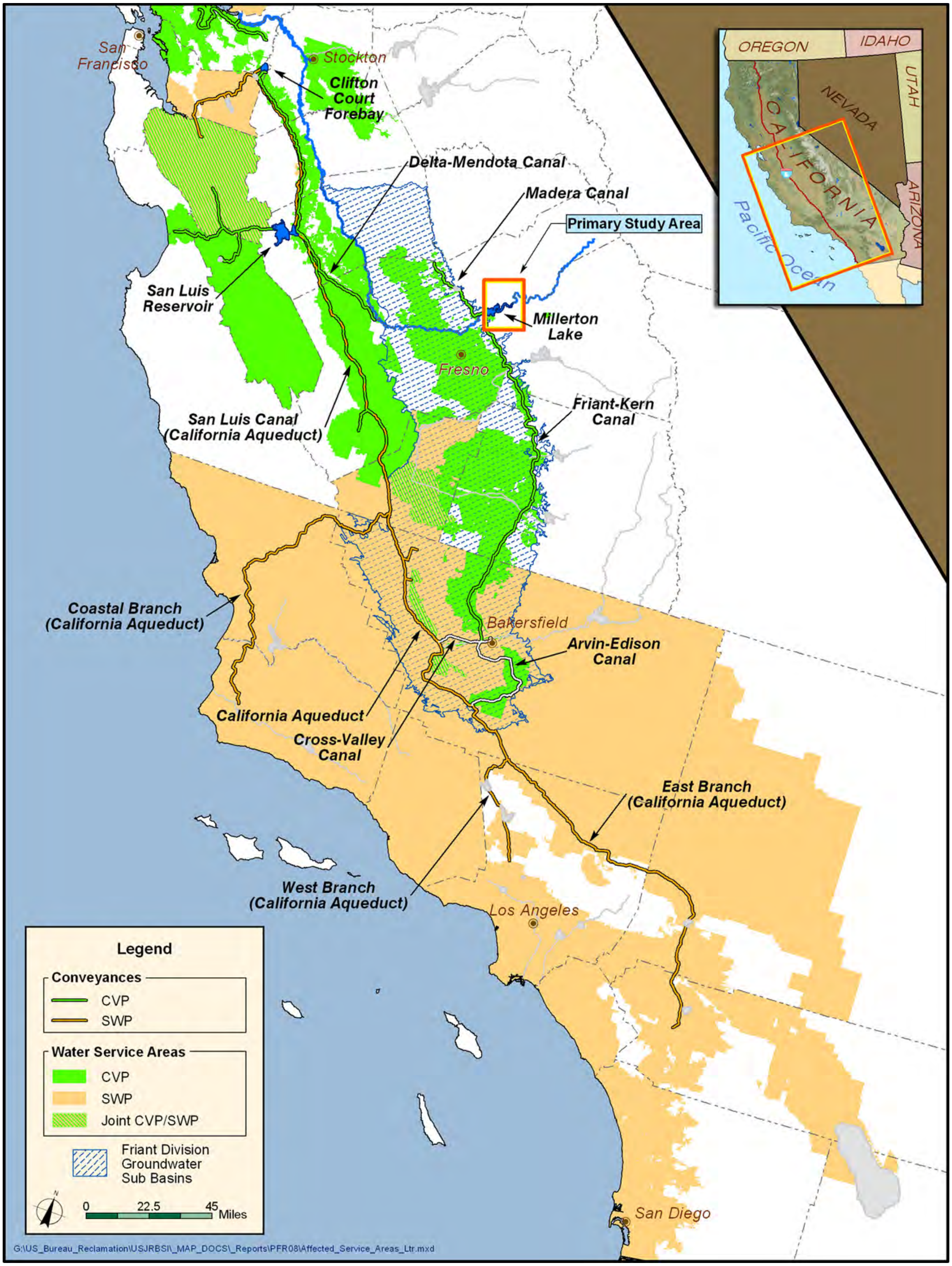


Figure 1-2. Extended Study Area

This chapter also includes a discussion of the potential influence of climate changes over the larger Central Valley area represented by the Sacramento, San Joaquin, Tulare Lake watersheds and the Delta system to provide a comprehensive assessment of potential impacts and opportunities.

The Sacramento River drains the northern portion and the San Joaquin River drains the central and southern portions of the Central Valley, a large north to south trending alluvial basin extending over 450 miles from the southern Cascade Mountains near the City of Redding to the Tehachapi Mountains south of the City of Bakersfield. The basin is about 40 to 60 miles wide and is bounded by the Coast Range to the west and the Sierra Nevada Mountains on the east. Hydrologically, the Central Valley is divided into three hydrographic regions including the Sacramento, San Joaquin and Tulare Lake Basins. Both the Sacramento and San Joaquin rivers flow into the Delta. This region is the largest estuary on the west coast of the United States. Typically, the Tulare Lake Basin is internally drained. However, in some wetter than normal years, flow from the Tulare Lake region reaches the San Joaquin River. Together, the Sacramento and San Joaquin rivers drain and area of approximately 59,000 square miles.

The Sacramento River is the largest river in California with an historic mean annual flow of 22 million acre-feet. It drains an area of about 27,000 square miles. The Sacramento River arises in the volcanic plateaus of northern California where it is joined by the Pit River above Shasta Dam, a Reclamation facility. Below Shasta Dam, transmountain diversions from the Trinity River (tributary to the Klamath River) along with many small- and moderate-sized tributaries join the river as it flows south through the Sacramento Valley. Major tributaries also join the river from the east including the Feather, Yuba, and American Rivers. Major facilities on these rivers include Oroville Dam operated by the California State Water Project on the Feather River and Folsom Dam operated by Reclamation on the American River. After a journey of over 400 miles, the river reaches Suisun Bay in the Sacramento-San Joaquin Delta before discharging into San Francisco Bay and the Pacific Ocean.

The San Joaquin River is the second largest river in California with an historic mean annual flow of 7.5 million acre-feet. It drains an area of 32,000 square miles. The San Joaquin originates in the high Sierra Nevada Mountains in east-central California. The river initially flows westward reaching Friant

Dam, a Reclamation facility, before entering the San Joaquin Valley. At Friant Dam, diversions are made to the Friant Division of the Central Valley Project, which is primarily located in the Tulare Lake Basin. Before implementation of the San Joaquin Restoration Program, flows below the dam were minimal except during flood conditions. Releases from the dam flow initially westward until reaching the Chowchilla Bypass (a constructed flood control facility) or the Mendota Pool (a managed irrigation water control facility). From there, the river turns northward and begins receiving returns flows from agricultural and wildlife refuge areas upstream from its confluence with the Merced River, a major tributary. As the river continues northward, it receives inflows from several eastside tributaries including the Toulumne, Stanislaus, Calaveras, and Mokelumne Rivers, each of which have major dams that store water and regulate flows. After a distance of 330 miles, the San Joaquin joins the Sacramento River near Suisun Bay in the Sacramento-San Joaquin Delta.

Reclamation’s major role in the Central Valley began in 1933 with the construction of the CVP. Today the CVP consists of 20 dams, 11 power plants and more than 500 miles of canals that serve many purposes including providing, on average, 5 million acre-feet of water per year to irrigate approximately 3 million acres of land in the Sacramento, San Joaquin, and Tulare Lake basins, 600,000 acre-feet per year of water for urban users, and 800,000 acre-feet of annual supplies for environmental purposes.

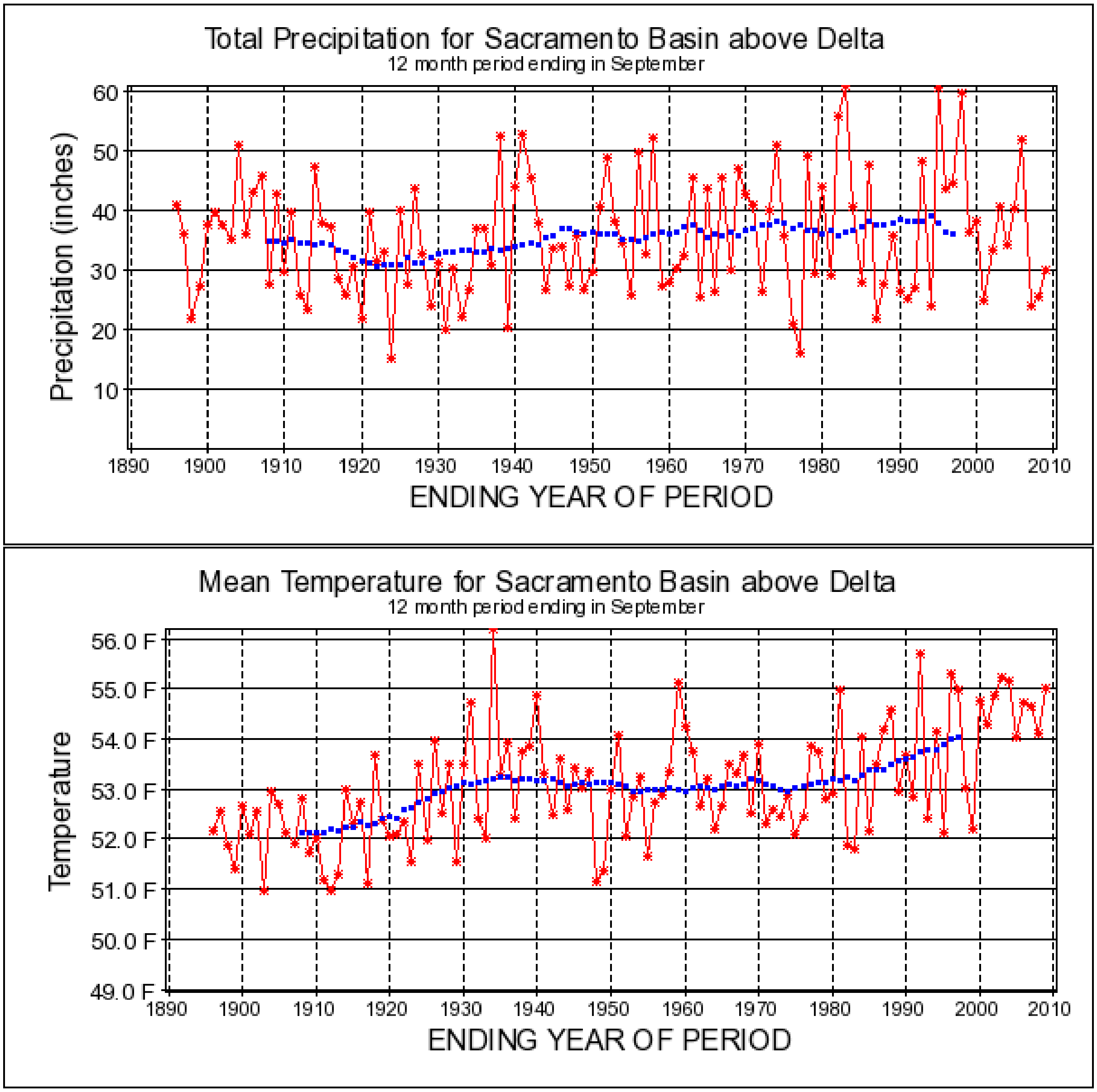
Historical Climate

The historical climate of the Central Valley is characterized by hot and dry summers and cool and damp winters. Summer daytime temperatures can reach 90 degrees Fahrenheit (°F) with occasional heat waves bringing temperatures exceeding 115°F. The majority of precipitation occurs from mid-autumn to mid-spring. The Sacramento Valley receives greater precipitation than the San Joaquin and Tulare Lake basins. In winter, temperatures below freezing may occur, but snow in the valley lowlands is rare. The Central Valley typically has a frost-free growing season ranging from 225 to 300 days. During the growing season, relative humidity is characteristically low; in the winter, humidity is usually moderate to high, and ground fog may form. The Central Valley is located within the zone of prevailing westerly winds, but local terrain exerts a significant influence on wind directions. Warmer-than-normal temperatures often are associated with more northerly winds flowing out of the Great

Basin to the east. During summer, strong westerly winds driven by the large temperature difference between the San Francisco Bay and interior Great Valley often occur in the Sacramento-San Joaquin Delta.

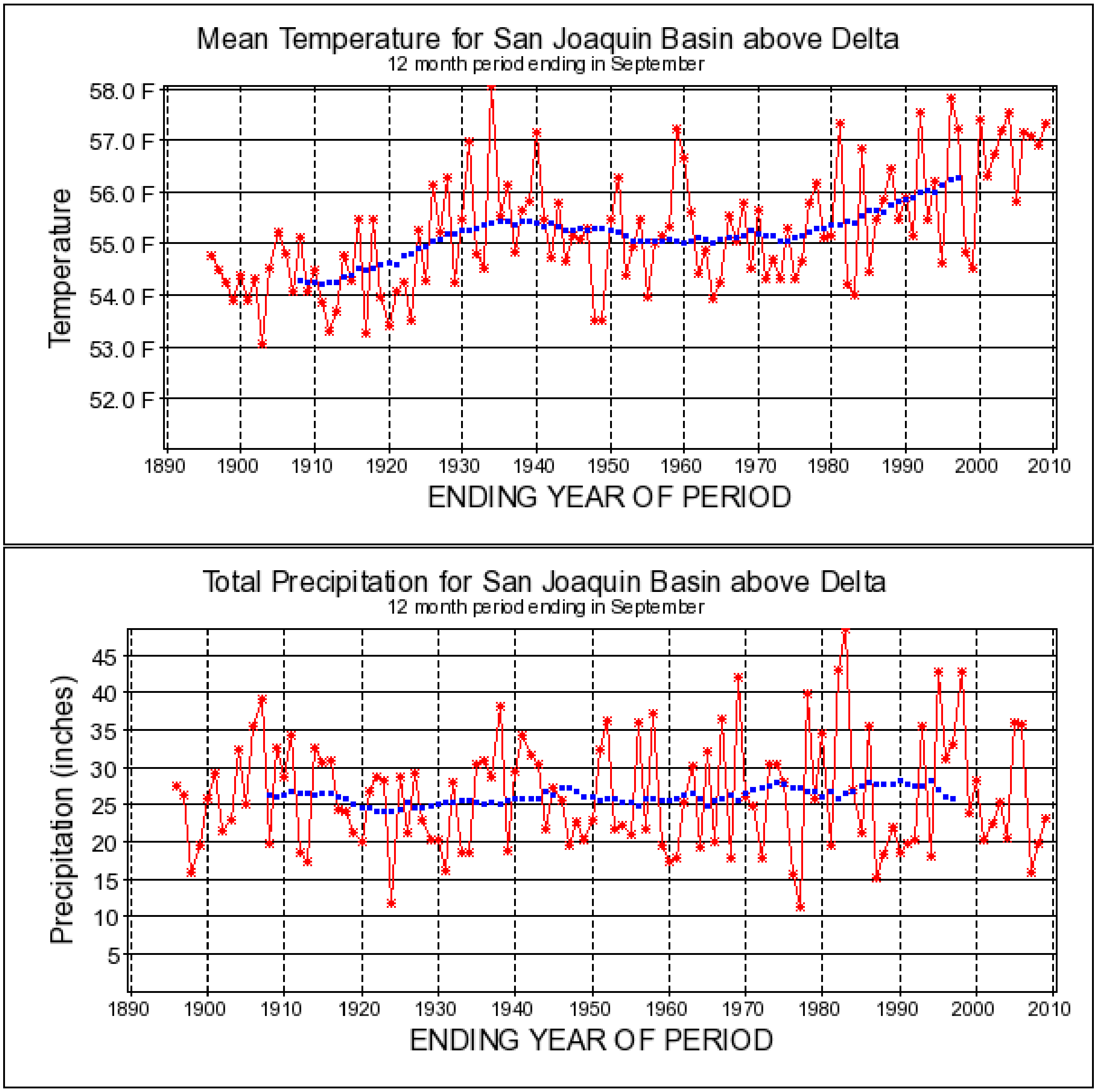
The inter-annual variability of the Central Valley climate is strongly influenced by conditions occurring in the Pacific Ocean including the El Nino Southern Oscillation (ENSO) and the existence of a semi-permanent high-pressure area in the northern Pacific Ocean. During the summer season, the northerly position of the Pacific high blocks storm tracks well to the north and results in little summertime precipitation. During the winter months, the Pacific high typically moves southward allowing storms into the Central Valley. Such storms often bring widespread, moderate rainfall to the Central Valley lowlands and the accumulation of snow in the surrounding mountainous regions. When strong ENSO global circulation patterns occur, storm centers can approach the California coast from a southwesterly direction, transporting large amounts of tropical moisture with resulting heavy rains that can produce high runoff and the potential for widespread flooding in the Central Valley.

Over the course of the 20th century, warming has been prevalent over the Sacramento and San Joaquin River basins. Basin average mean-annual temperature has increased by approximately 2°F during the course of the 20th century for just the Sacramento River basin above the Delta (Figure 2-1) or the San Joaquin River basin above the Delta (Figure 2-2). Warming has not occurred steadily throughout the 20th century. Increases in air temperatures occurred primarily during the early part of the 20th century between 1910 and 1935. Subsequently, renewed warming began again in the mid-1970s and appears to be continuing at present, as shown for the Sacramento River basin in Figure 2-1. Similar results are apparent for the San Joaquin River basin (Figure 2-2) and have been reported in other studies. Cayan et al. (2001) reported that Western United States spring temperatures have increased 1 to 3 degrees Celsius (°C) (1.8 to 5.4°F) since the 1970s; whereas, increased winter temperature trends in central California were observed to average about 0.5°C (0.9°F) per decade (Dettinger and Cayan 1995). In both the Sacramento and San Joaquin basins, the overall 20th century warming has been about 3°F.



Source: Western Climate Mapping Initiative (WestMap) available at: http://www.cefa.dri.edu/ Westmap/. Red line indicates annual time series for the given geographic region. Blue line indicates 25-year moving annual mean values, where each value is plotted on the center year of its respective 25-year period. WestMap data are derived from the PRISM climate mapping system (Daly et al. 1994; Gibson et al. 2002).

Figure 2-1. Observed Annual (red) and Moving-Mean Annual (blue) Temperature and Precipitation, Averaged over the Sacramento River Basin



Source: Western Climate Mapping Initiative (WestMap) available at: http://www.cefa.dri.edu/ Westmap/. Red line indicates annual time series for the given geographic region. Blue line indicates 25-year moving annual mean values, where each value is plotted on the center year of its respective 25-year period. WestMap data are derived from the PRISM climate mapping system (Daly et al. 1994; Gibson et al. 2002).

Figure 2-2. Observed Annual (red) and Moving-Mean Annual (blue) Temperature and Precipitation, Averaged Over the San Joaquin River Basin

In the Sacramento basin, the warming trend also has been accompanied by a gradual trend starting in the 1930s toward increasing precipitation (Figure 2-1, bottom panel). However, a similar precipitation trend is not evident in the San Joaquin basin (Figure 2-2). Other studies have shown similar results. Regonda et al. (2005) reported increased winter precipitation trends from 1950 to 1999 at many Western United States locations, including several in California's Sierra Nevada; but a consistent region-wide trend was not apparent. The variability of annual precipitation appears to have increased in the latter part of the 20th century, as can be seen by comparing the range of differences in high and low values of the solid red line in Figure 2-1 and Figure 2-2. These extremes in wet and dry years have been especially frequent since the mid-1970s in both the Sacramento and San Joaquin basins.

Historical Hydrology

Streamflow in the Sacramento River and San Joaquin River basins has historically varied considerably from year to year. Runoff also varies geographically; during any particular year, some portions of the basin may experience relatively greater runoff conditions while others areas experience relatively less runoff (e.g., more abundance runoff in the northern Sacramento Valley versus relatively drier conditions in southern San Joaquin Valley). On a monthly to seasonal basis, runoff is generally greater during the winter to early summer months, with winter runoff generally originating from rainfall-runoff events and spring to early summer runoff generally supported by snowmelt from the Cascade Mountains and Sierra Nevada.

The historical changes in climate have resulted in several important effects on Sacramento and San Joaquin basin hydrology. Although annual precipitation may have slightly increased or remained relatively unchanged, corresponding increases in mean annual runoff in the Sacramento and San Joaquin rivers did not occur (Dettinger and Cayan 1995). However, a shift in the seasonal timing of runoff has been observed. In the Sacramento River Basin, a decrease of about 10 percent in the fraction of total runoff occurring between April through July has been observed over the course of the 20th century (Roos 1991). Similar results were obtained from analyses of the combined basin runoffs for both the Sacramento and San Joaquin basins by Dettinger and Cayan (1995).

Increases in winter runoff have been observed. Analysis of data for 18 Sierra Nevada river basins found earlier runoff trends (Peterson et al. 2008). Of the potential climatic factors that could produce such changes, analyses indicated that increasing spring temperatures rather than increased winter precipitation was the primary cause of the observed trends (Cayan 2001). Studies by these researchers and others showed that the magnitude of the decreases in April through July runoff was correlated with the altitude of the basin watershed. High altitude basins like the San Joaquin exhibited less decrease in spring runoff than lower elevation watersheds such as the Sacramento. However, it is noted that the appearance of runoff trends in the basins depends on location and period of record being assessed. For example, runoff trends were evaluated for this report during the last half of the 20th century; and although similar trend directions were founds, they were found to be statistically weak.[1]

Other studies of the magnitude of spring snowpack changes during the 20th century found that snowpack as measured by April 1st Snow Water Equivalent (SWE) showed a decreasing trend in the latter half of the 20th century (Mote 2005). Coincident with these trends, reduced snowpack and snowfall ratios were indicated by analyses SWE measurements made from 1948 through 2001 at 173 Western United States stations (Knowles et al. 2007). Regonda et al. (2005) reported decreasing spring SWE trends in 50 percent of Western United States locations evaluated.

The changes discussed in the previous paragraphs over regional drainages such as the Sacramento and San Joaquin River basins are sensitive to the uncertainties of station measurements as well as the periods of analyses and analyzed locations. For the entire Western United States, observed trends of temperature, precipitation, snowpack, and streamflow might be partially explained by anthropogenic influences on climate (e.g., Barnett et al. 2008; Pierce et al. 2008; Bonfils et al. 2008; Hidalgo et al. 2009; and Das et al. 2009). However, it remains difficult to attribute observed changes in hydroclimate to historical human influences or anthropogenic forcings. This is particularly the case for trends in precipitation (Hoerling et al. 2010) and for trends in basin-scale conditions rather than at the larger Western United States scale (Hidalgo et al. 2009).

Sea level change is also an important factor in assessing the effect of climate on California's water resources because of its effect on water quality in the Sacramento-San Joaquin Delta. Higher mean sea levels (msl) are associated with increasing salinity in the Delta, which influences the suitability of its

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[1] Trend significance was assessed using statistical testing during the period from 1951 through 1999 applied to historical simulated runoff results under observed historical weather conditions (Reclamation 2011a). Trends were computed and assessed for four Missouri basin locations, focusing on annual and April–July runoff. In all cases, computed trends were judged to not be statistically significant with 95 percent confidence.

water for agricultural, urban, and environmental uses. The global rate of msl change was estimated by IPCC (2007) to be 1.8 +/- 0.5 millimeters (mm)/year (0.07 +/- 0.02 inches per year (in/year)) from 1961–2003 and 3.1 +/- 0.7 mm/year (0.12 +/0.03 in/year) during 1993–2003. During the 20th century, msl at Golden Gate Bridge in San Francisco Bay has risen by an average of 2 mm/year (0.08 in/year) (Anderson et al. 2008). These rates of sea level rise appear to be accelerating based on tidal gauges and remote sensing measurements (Church and White 2006; Beckley et al. 2007).

Future Changes in Climate and Hydrology

This section summarizes results from studies focused on future climate and hydrologic conditions within the Sacramento and San Joaquin River basins. The first subsection summarizes literature relevant to the study area. The subsequent section focuses on results from Reclamation (2011d), which were produced within the context of a western United States-wide hydrologic analysis to identify risks to water supplies in a consistent manner throughout the Colorado, Columbia, Klamath, Missouri, Rio Grande, Sacramento, San Joaquin, and Truckee river basins consistent with Public Law 111-11, Subtitle F (the SECURE Water Act).

Summary of Future Climate and Hydrology Studies

Potential future changes in Central Valley climate and hydrology have been the subject of numerous studies. For the Central Valley watersheds, Moser et al (2009) reports specifically on future climate possibilities over California and suggest that warmer temperatures are expected during the 21st century, with an end-of-century increase of 3°F to 10.5°F. For mean annual precipitation in northern California, the study indicates a generally decreasing trend of between 10 percent and 15 percent by the end of the century.

The effects of projected changes in future climate were assessed by Maurer (2007) for four river basins in the western Sierra Nevada contributing to runoff in the Central Valley. These results indicate a tendency toward increased winter precipitation; this was quite variable among the models, while temperature increases and associated SWE projections were more consistent. The effect of increased temperature was shown by Kapnick and Hall (2008) to result in a shift in the date of peak of snowpack accumulation from 4 and 14 days earlier in the winter season by the end of the century. Null et al. (2010) reported on climate change impacts for 15 western-slope watersheds in the Sierra Nevada under warming scenarios of 2°C, 4°C, and 6°C increase in mean-annual air temperature relative to historical conditions. Under these scenarios, total runoff decreased; earlier runoff was projected in all watersheds relative to increasing temperature scenarios; and decreased runoff was most severe in the northern part of the Central Valley. This study also indicated that the high elevation southern-central region was more susceptible to earlier runoff, and the central region was more vulnerable to longer low flow periods.

Sea level changes also have been projected to occur during the 21st century due to increasing air temperatures causing thermal expansion of the oceans and additional melting of the land-based Greenland and Antarctic ice sheets (IPCC 2007). The CALFED Bay-Delta Program (CALFED) Independent Science Board estimated a range of sea level rise at Golden Gate of 1.6 feet to 4.6 feet by the end of the century (CALFED ISB 2007). The California Department of Water Resources (DWR) used the 12 future climate projections to estimate future sea levels. Their estimates indicate sea level rise by mid-century ranges from 0.8 feet to 1.0 feet with an uncertainty range spanning 0.5 feet to 1.3 feet. By the end of the century, sea level was projected to rise between 1.8 feet and 3.1 feet, with an uncertainty range spanning from 1.0 feet to 3.9 feet. There is also the potential for increased extremely high sea level events to occur when high tides coincide with winter storms (Moser et al. 2009).

Projections of Future Climate

This section summarizes climate projections developed by Reclamation (2011d) consistent with the SECURE Water Act. The methods and assumptions used to develop the projections discussed below are described in detail in a report titled *West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections* (Reclamation 2011a).

First, basin-wide averages of projected climate conditions are presented and, secondly, the projected distribution throughout the basin is presented. A summary of snow-related effects under future climate conditions as they may be distributed throughout the basin is then presented; and, finally, climate and snowpack changes translated into effects on annual and seasonal runoff as well as acute runoff events relevant to flood control and ecosystems management are discussed. Runoff-

Reporting locations described in this section are shown in Figure 2-3.

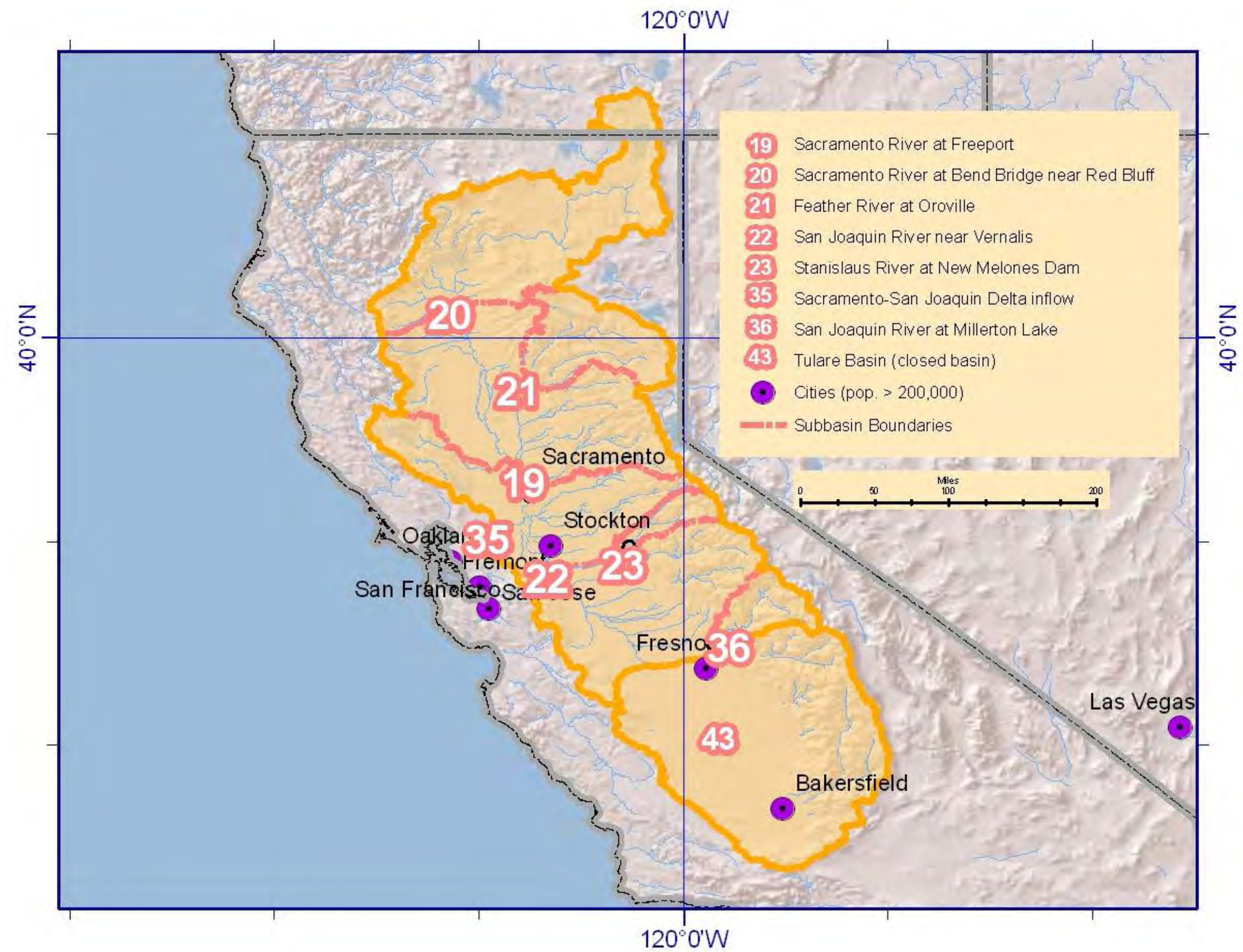


Figure 2-3. Runoff-Reporting Locations in the Sacramento River, San Joaquin River, and Tulare River Basins Described in this Section

Before summarizing climate projection and climate change information, it is noted that the projected changes have geographic variation, they vary through time, and the progression of change through time varies among climate projection ensemble members. Starting with a regional view of the time series climate projections and drawing attention to the projections' median condition through time, results suggest that temperatures throughout the Sacramento and San Joaquin basins may increase steadily during the 21st century. Focusing on the Sacramento River subbasin at Freeport, San Joaquin River subbasin at Vernalis, and on the combined basins' inflow to the Delta (Figure 2-4), the basin-average mean-annual temperature is projected to increase by roughly 5°F to 6°F during the 21st century. For each subbasin view, the range of annual possibility appears to widen through time.

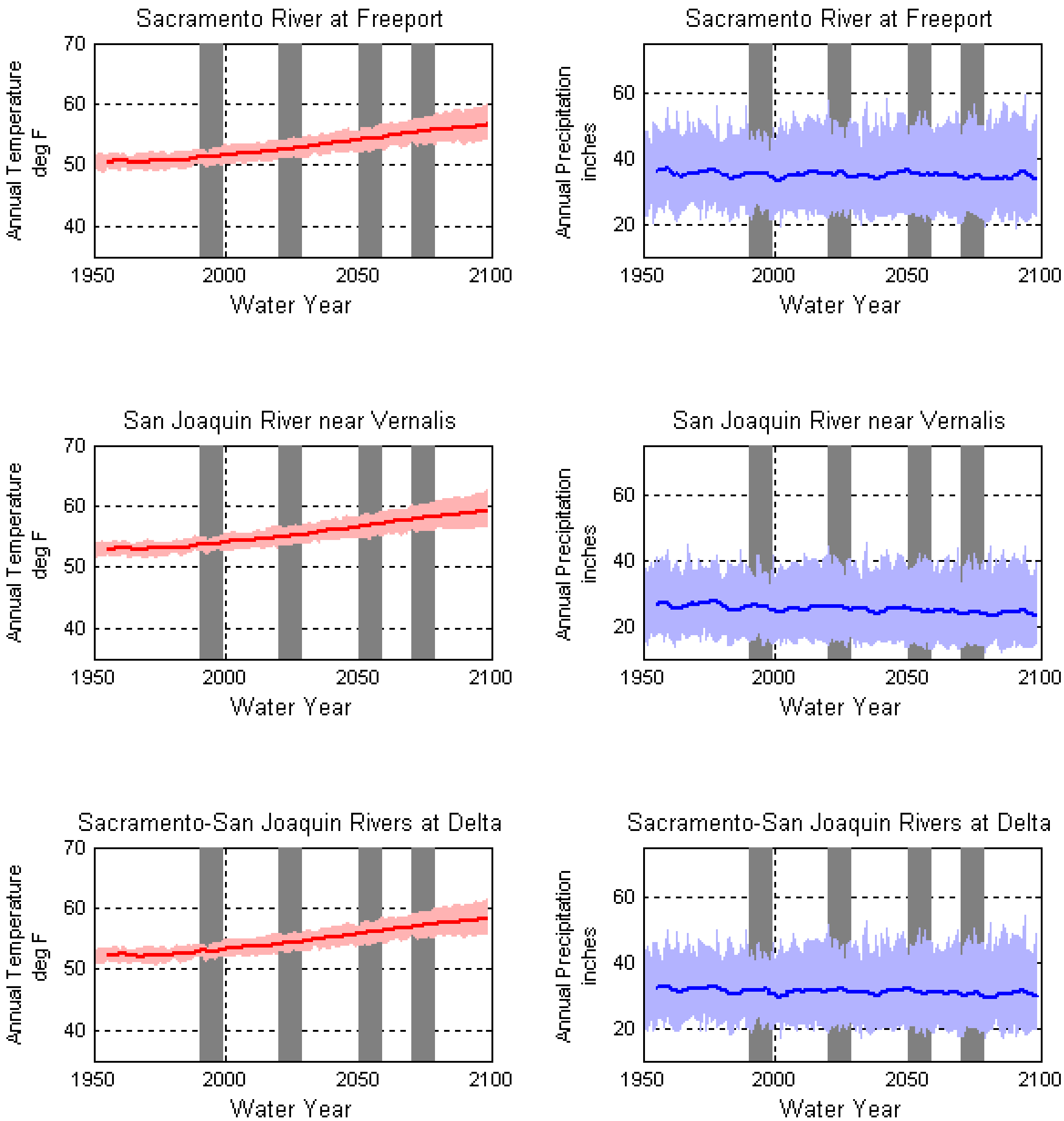


Figure 2-4. Simulated Annual Climate Averaged over Sacramento and San Joaquin River Subbasins

The ensemble mean of projections indicates that mean-annual precipitation, averaged over either subbasin (Figure 2-4), appears to stay generally steady during the 21st century, with little change in the northern portion of the Central Valley (Sacramento River subbasin at Freeport) and a slight decrease within the southern portion (San Joaquin River near Vernalis). This is evident by following the ensemble median of the annual precipitation through time for both basins. The projections also suggest that annual precipitation in the Sacramento and San Joaquin basins should remain quite variable over the next century. Despite the statements about the mean of the ensemble, there is significant disagreement among the climate projections regarding change in annual precipitation over the region.

Projection of climate change is geographically complex over the Sacramento and San Joaquin River basins, particularly for precipitation. For example, consider the four decades highlighted on Figure 2-4 (vertical gray bars): the 1990s, 2020s, 2050s, and 2070s. The 1990s are the baseline climate from which climate changes are assessed for the three future decades (2020s, 2050s, and 2070s). The baseline climate indicates that local climate varies considerably within the basin. For example, in the Sacramento River at Freeport (Figure 2-4, top left panel), annual average temperatures are generally cooler in the high-elevation upper reaches in the north and along the mountainous rim to the east. Warmer temperatures occur to the south and in the lower lying valley area. This is similarly the case for the San Joaquin River near Vernalis (Figure 2-4, top right panel). For precipitation, amounts are generally greater along the mountainous spine extending from the Cascades in the north-central part of the basin throughout the Sierra Nevada to the southeast (Figure 2-4, top left panel) and lesser in the interior plateau northeast of these mountain ranges and in the lower lying valley areas to the south and west. In the San Joaquin River Basin, precipitation amounts are also greater in the Sierra Nevada (Figure 2-4, top left panel).

Regarding climate change, temperature changes are generally uniform over both the Sacramento River (Figure 2-4) and San Joaquin River basins (Figure 2-4) and steadily increase through time. Changes are projected to be perhaps slightly greater in the eastern portions of the basins (Figure 2-5). For precipitation, similar geographic consistency is found, although there is a little less uniformity in the direction of change between the two basins and through the progression of 21st century decades. It is important to note that, while the mean-annual amount of precipitation may only change slightly under increasing temperature projections, the character of precipitation within the Sacramento and San Joaquin River basins also is expected to change under warming conditions, resulting in more frequent rainfall events, less frequent snowfall events.

Figure 2-4 displays the ensemble of temperature and precipitation projections from Bias Corrected and Spatially Downscaled WCRP CMIP3 Climate Projections. Annual conditions represent spatially averaged results over the basin. Darker colored lines indicate the median-annual condition through time, sampled from the ensemble of 112 climate simulations, and then smoothed using a 5-year running average. Lighter-colored areas represent the time-series range of 10th to 90th percentile annual values within the ensemble from simulated 1950 through simulated 2099.

Figure 2-5 presents basin-distributed views of change in mean annual temperature over the Sacramento River Basin upstream from Freeport. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations. Temperature units are °F for baseline and change. Precipitation and SWE units are inches for baseline and percentage for change. For SWE, areas that are white on the plots have less 1990s decade-mean conditions of less than 0.0004 inch and are not considered in the change assessment.

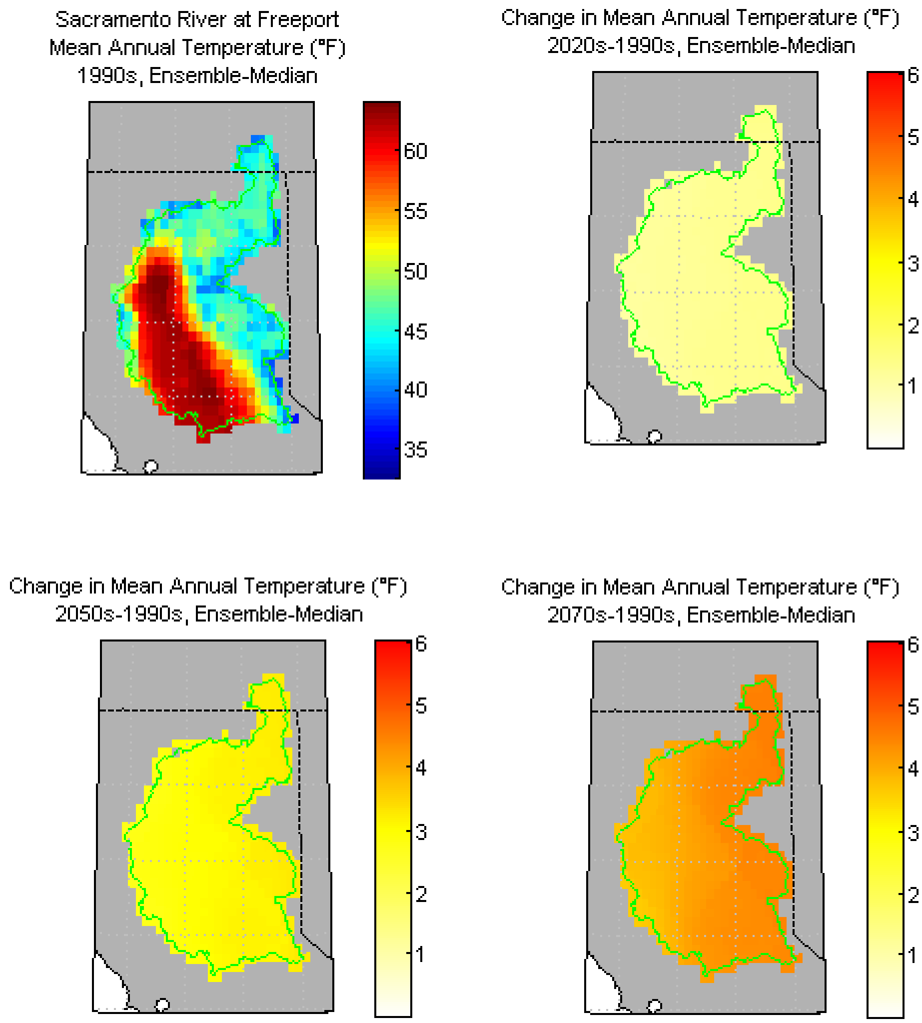


Figure 2-5. Simulated Decade-Mean Temperature over the Sacramento River Basin Above Freeport, California

Figure 2-6 presents basin-distributed views of change in mean annual temperature over the San Joaquin River Basin upstream from Vernalis. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations.

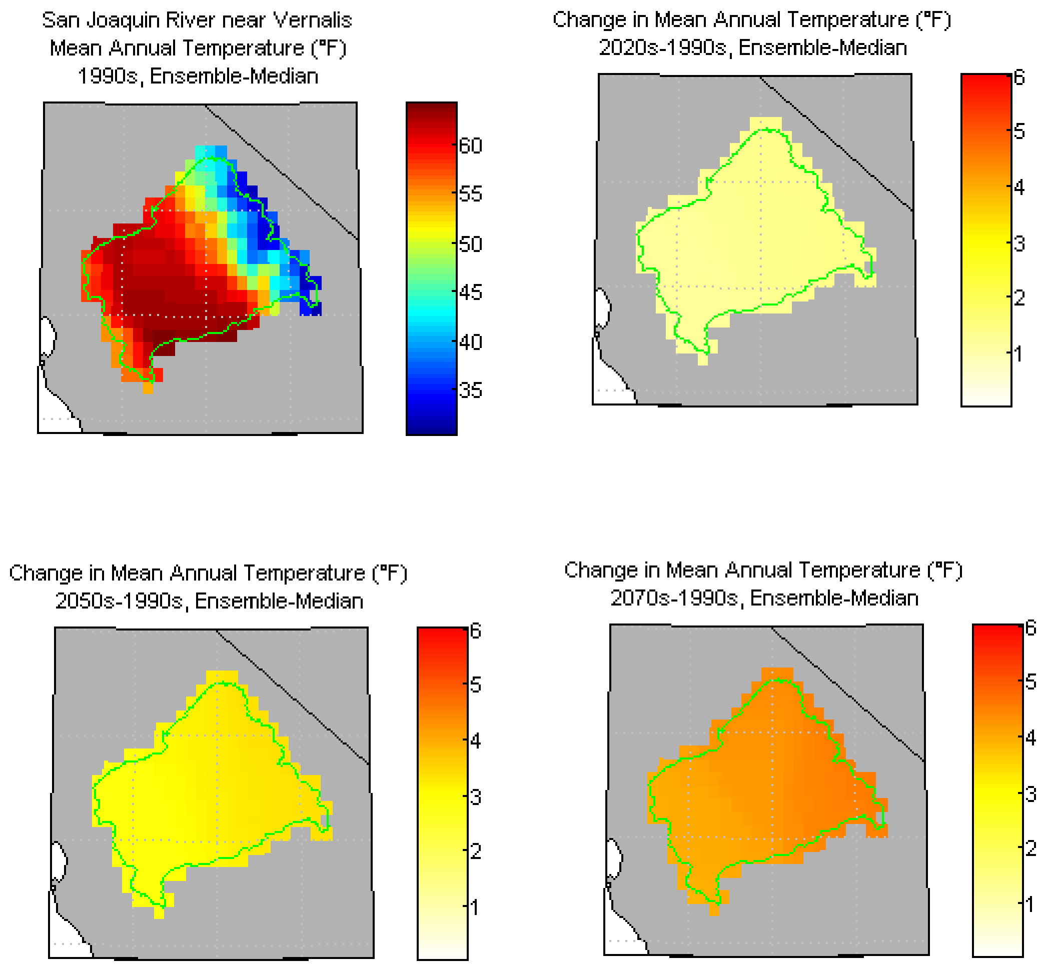


Figure 2-6. Simulated Decade-Mean Temperature over the San Joaquin River Basin Above Vernalis, California

Figure 2-7 presents basin-distributed views of change in mean annual precipitation over the Sacramento River Basin upstream from Freeport. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations. For SWE, areas that are white on the plots have less 1990s decade-mean conditions of less than 0.0004 inch and are not considered in the change assessment.

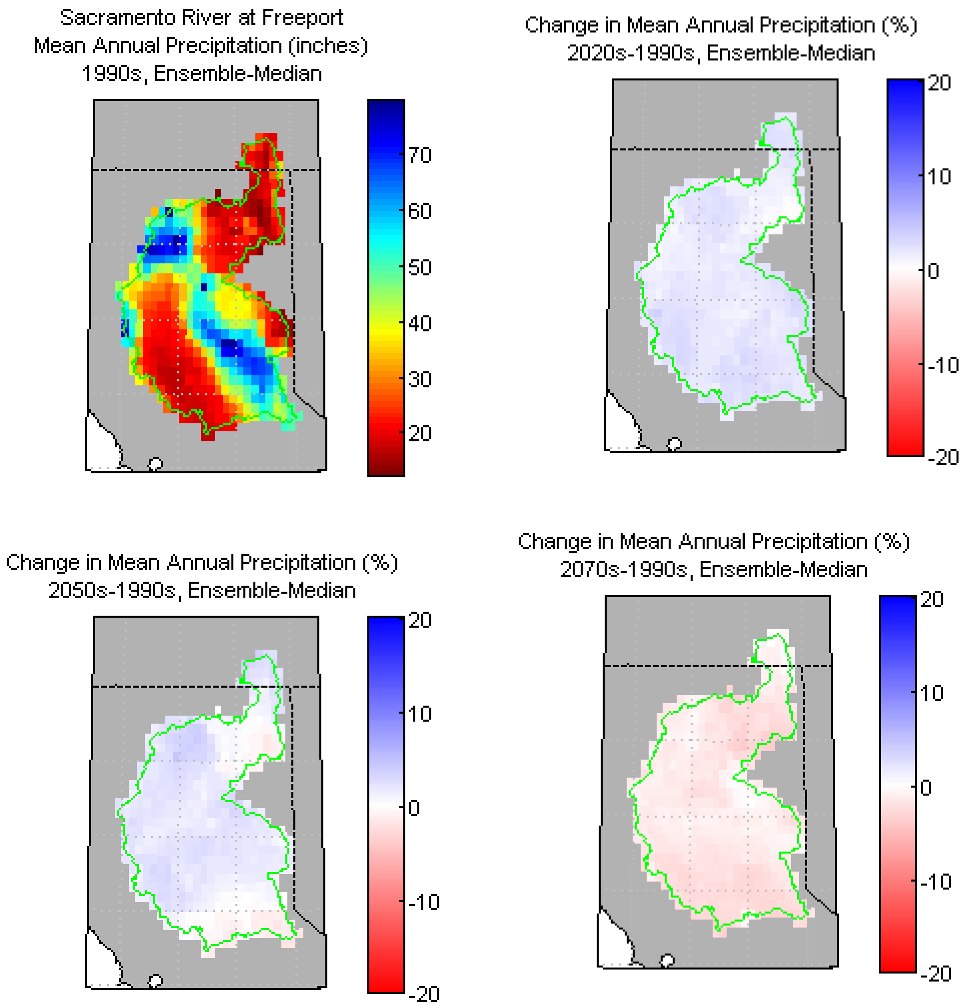


Figure 2-7. Simulated Decade-Mean Precipitation over the Sacramento River Basin Above Freeport, California

Figure 2-8 presents basin-distributed views of change mean annual precipitation over the San Joaquin River Basin upstream from Vernalis. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations. For SWE, areas that are white on the plots have less 1990s decade-mean conditions of less than 0.0004 inch and are not considered in the change assessment.

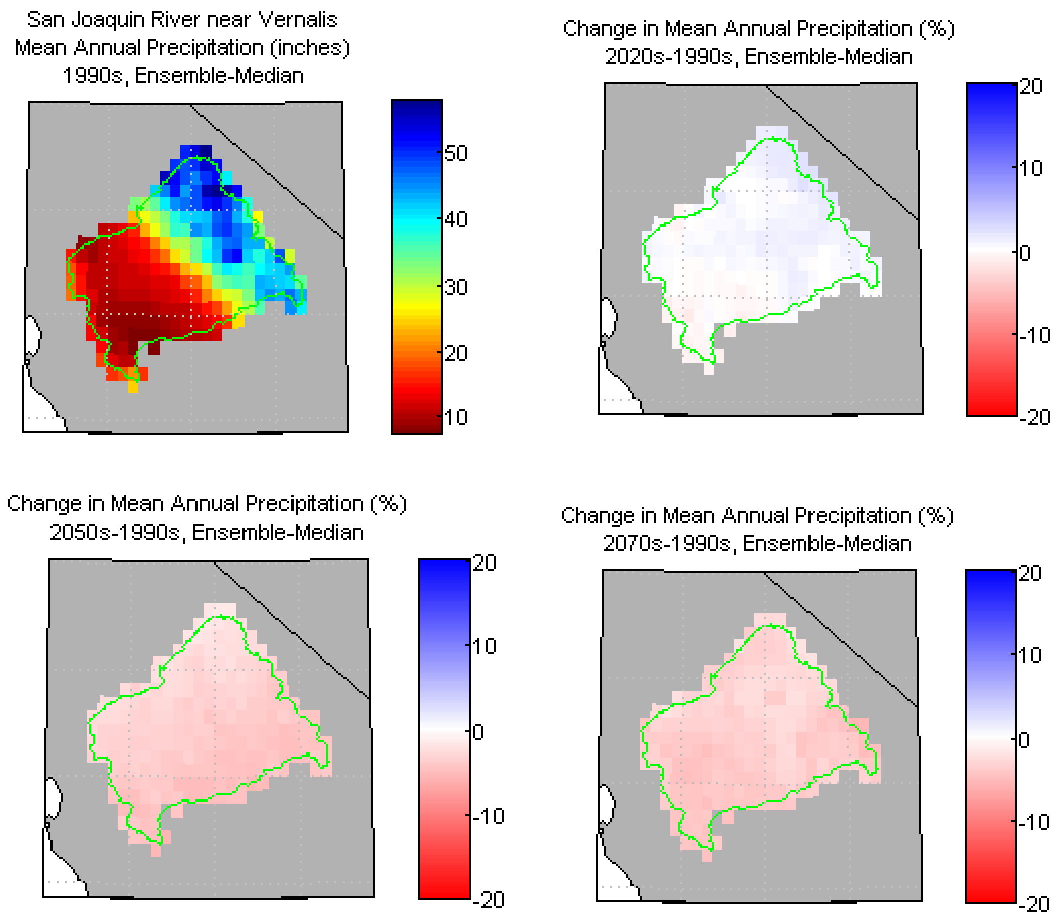


Figure 2-8. Simulated Decade-Mean Precipitation over the San Joaquin River Basin Above Vernalis, California

Temperature and precipitation changes are expected to affect hydrology in various ways including snowpack development. As noted previously, increased warming is expected to diminish the accumulation of snow during the cool season (i.e., late autumn through early spring) and the availability of snowmelt to sustain runoff during the warm season (i.e., late spring through early autumn). Although increases or decreases in cool season precipitation could somewhat offset or amplify changes in snowpack, it is apparent that the projected warming in the Sacramento River and San Joaquin River basins tends to dominate projected effects (e.g., changes in April 1st snowpack distributed over the basin, shown on Figure 2-9 and Figure 2-10 for the two basins, respectively). Snowpack decrease is projected to be more substantial over the portions of the basin where baseline cool season temperatures are generally closer to freezing thresholds and more sensitive to projected warming. Such areas include much of the northern Sierra Nevada and Cascade Mountains of the Sacramento River basin as well as lower to middle elevations in the southern Sierra Nevada of the San Joaquin River basin. However, even in the highest elevations of the southern Sierra Nevada, losses are projected to be significant by the late 21st century.

Figure 2-9 presents basin-distributed views of change SWE over the Sacramento River Basin upstream from Freeport. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations.

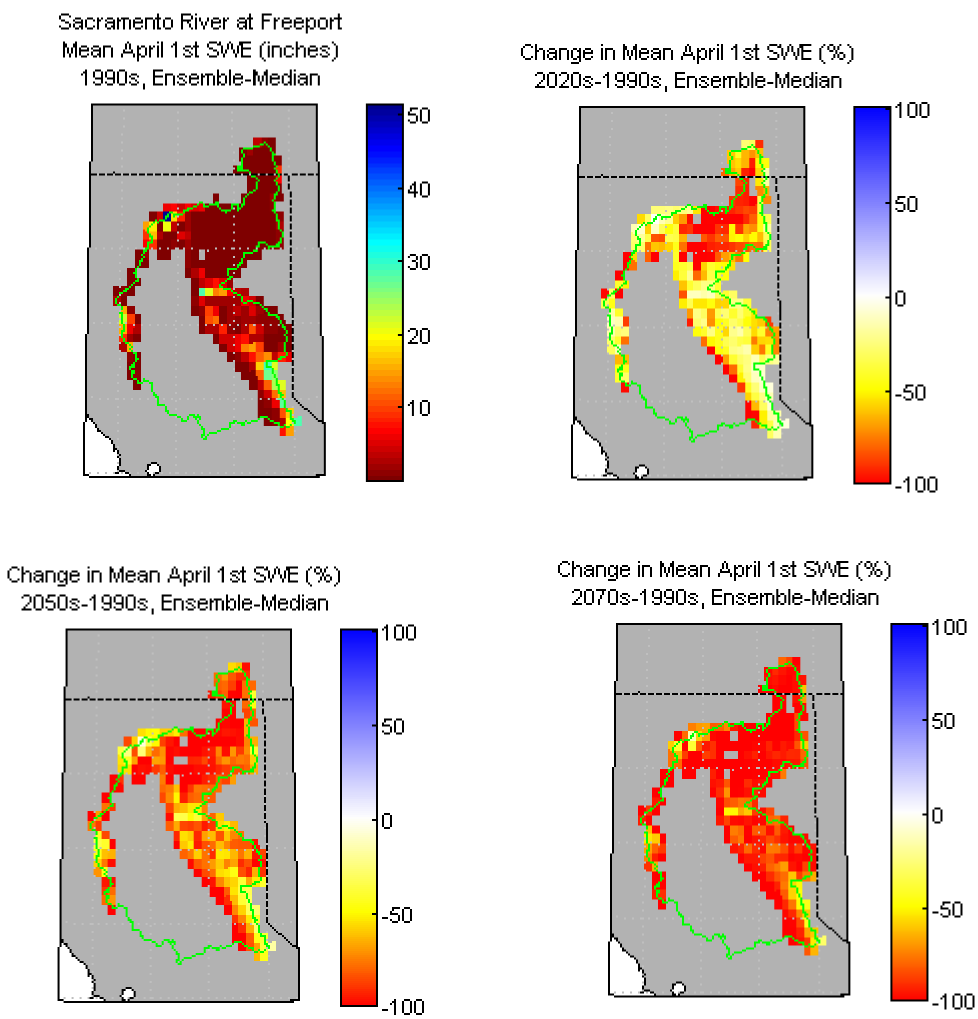


Figure 2-9. Simulated Decade-Mean April 1st Snow Water Equivalent Over the Sacramento River Basin Above Freeport, California

Figure 2-10 presents basin-distributed views of change in SWE over the San Joaquin River Basin upstream from Vernalis. Figure data are simulated conditions as described in Reclamation (2011a). The upper left panel shows the baseline mean-annual condition (1990s), and next three panels show changes from baseline conditions for three future decades (2020s, 2050s, and 2070s). Both historical and future conditions are from climate simulations. Mapped values for baseline conditions (1990s) are median-values from the collection of climate simulations. Mapped changes (next three panels) are median changes from the collection of climate simulations. For SWE, areas that are white on the plots have less 1990s decade-mean conditions of less than 0.0004 inch and are not considered in the change assessment.

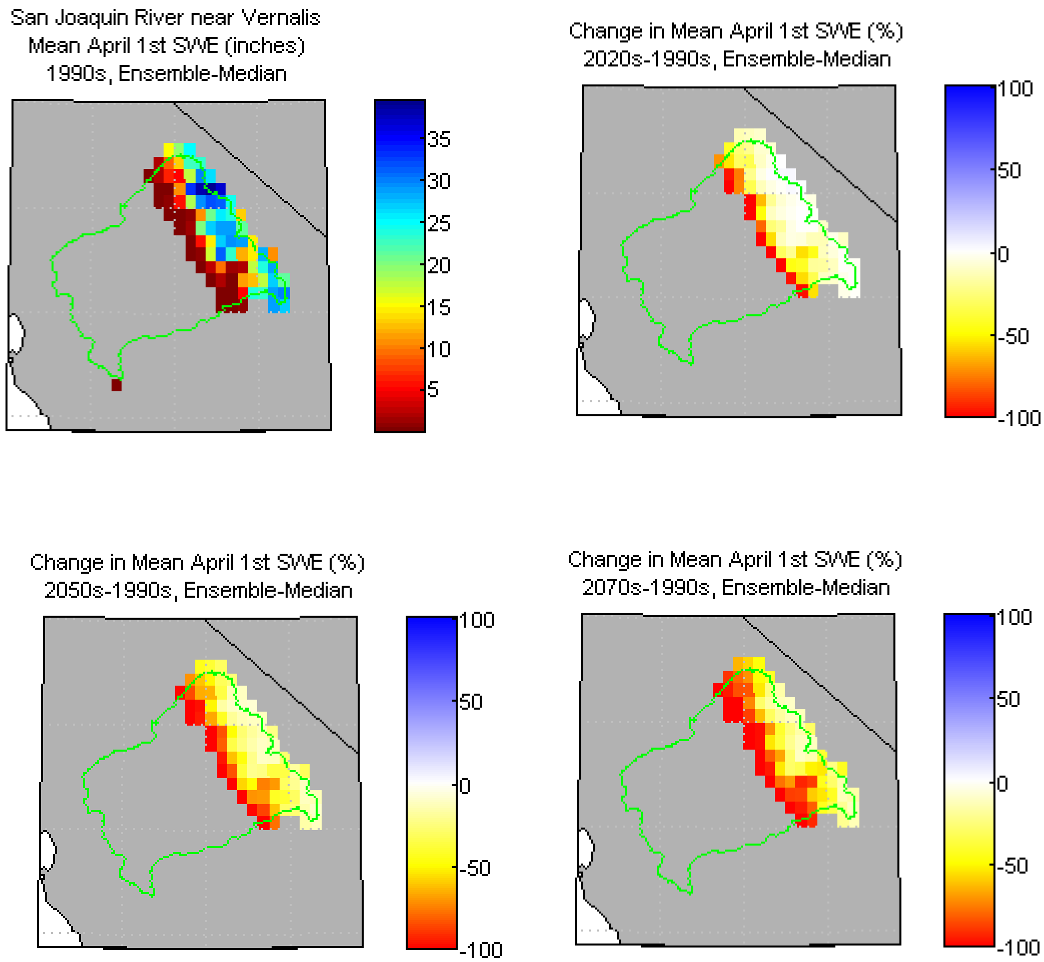


Figure 2-10. Simulated Decade-Mean April 1st Snow Water Equivalent over the San Joaquin River Basin Above Vernalis, California

Changes in climate and snowpack within the Sacramento and San Joaquin River basins will change the availability of natural water supplies. These effects may be experienced in terms of changes to annual runoff and changes in runoff seasonality. For example, warming without precipitation change may lead to increased evapotranspiration from the watershed and decreased annual runoff. Precipitation increases or decreases (either as rainfall or snowfall) offset or amplify the effect.

Figure 2-11 presents annual, December through March, and April through July runoff impacts for subbasins shown. Each panel shows percentage changes in mean runoff (annual or either season) for three future decades (2020s, 2050s, and 2070s) relative to baseline conditions (1990s). Development of runoff information is described in Reclamation (2011a) based on climate simulations previously discussed. Results from Reclamation (2011a) suggest that annual runoff effects are generally consistent but do slightly vary by location within the basins, as shown in Figure 2-11, depending on baseline climate and the projected temperature and precipitation changes. For example, in the Sacramento River and its major tributaries, the Feather River and the American River, annual runoff increases very slightly during the early and middle part of the 21st century. However, in all of these watersheds, a slight decline is projected to occur in the latter half of the century. In the San Joaquin River basin and its major tributaries, similar results are found but with mean-annual runoff declines projected to occur by the mid-21st century.

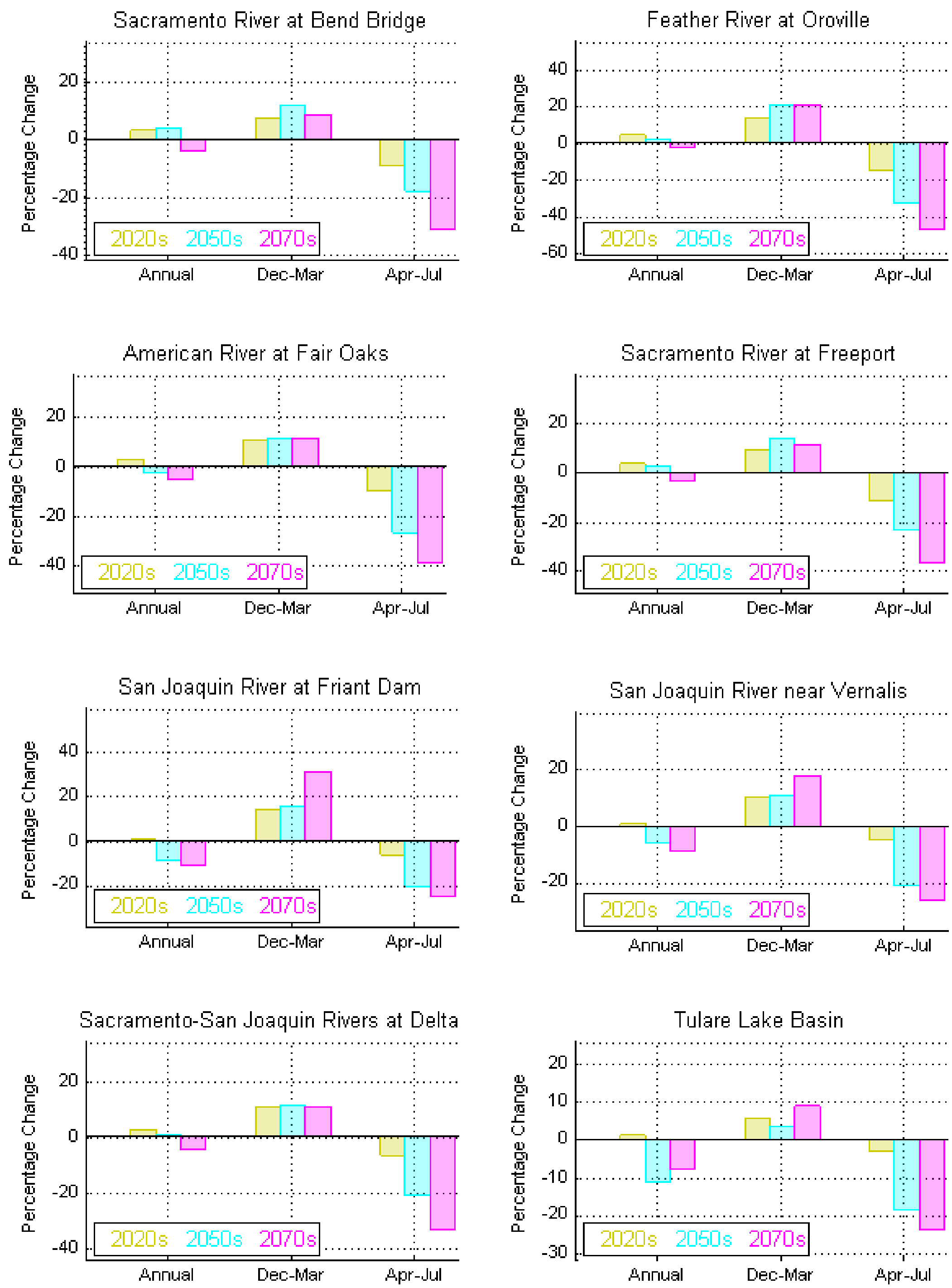


Figure 2-11. Simulated Changes in Decade-Mean Runoff for Several Subbasins in the Sacramento and San Joaquin River Basins

The seasonality of runoff is also projected to change. Warming may lead to more rainfall-runoff during the cool season rather than snowpack accumulation. This conceptually leads to increases in December through March runoff and decreases in April through July runoff. Results over the two basins suggest that this concept generally holds throughout the two basins, but the degree of seasonal change does vary by basin location (Figure 2-11).

This combination of increased winter and decreased spring runoff points to the important role of temperature in determining 21st century seasonal water supplies for both basins. In the lower left-hand corner of Figure 2-11, the combined runoff change is depicted based on runoff changes in the Sacramento River, San Joaquin River, and other Delta tributaries. Overall, the changes are more similar to those found in the Sacramento River basin and are reflective of the larger contribution of the Sacramento River (see Sacramento River at Freeport) relative to the San Joaquin River (see San Joaquin near Vernalis) to Delta flows. It may be noticed that percentage reductions in April through July runoff may appear to be small compared to some percentage reductions in lower elevation April 1st snowpack from the preceding discussion. The fact that percentage April through July runoff reductions are smaller speaks to how higher elevation snowpack contributes proportionally more to April through July runoff than lower elevation snowpack, and how percentage snow losses at higher elevations are relatively smaller than those at lower elevation.

Climate change in relation to acute runoff events are also of interest as they relate to flood control and ecosystem management in both basins. There is less certainty in the analysis of these types of acute events relative to effects in annual or seasonal runoff. Generally speaking, streamflow variability over the basin is expected to continue under changing climate conditions. For this discussion, annual maximum- and minimum-week runoff are used as metrics of acute runoff events.

Figure 2-12 displays the ensemble of annual “maximum 7-day” and “minimum 7-day” runoff projections for the subbasins shown development of runoff information is described in Reclamation (2011a) based on climate simulations previously discussed. It should be noted that these results are derived from simulations that have been computed at a daily time step, but have been calibrated to monthly natural flows. As such, there is considerable uncertainty that is reflected in the lightly shaded regions around the heavier dark line. These values are presented for qualitative, rather than quantitative analysis. The maximum weekly runoff typically occurs sometime between late fall and early summer, whereas the minimum weekly runoffs are most likely to occur between late summer and early fall. Because the selected locations are upstream from major aquifers in the Central Valley, the runoff extremes are only minimally affected by groundwater and bank storage processes.

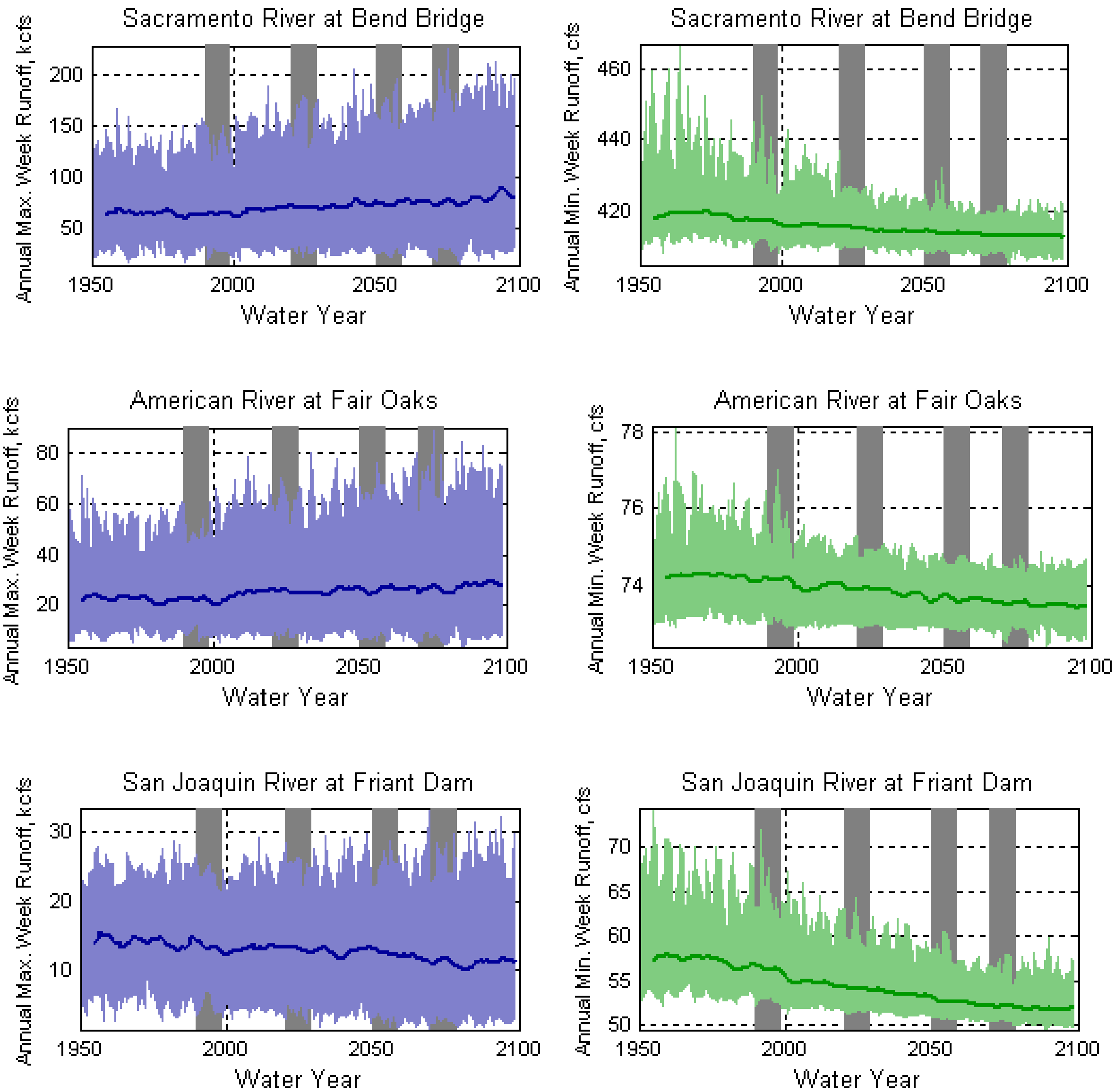


Figure 2-12. Simulated Annual Maximum and Minimum Week Runoff for Several Subbasins in the Sacramento and San Joaquin River Basins

For annual maximum-week runoff, results for the Sacramento River and San Joaquin River basins appear to differ. For the two subbasins shown in the Sacramento River basin, it appears that expected annual maximum-week runoff may gradually increase during the 21st century. The range of possibility also appears to increase during the century. These findings raise questions about whether increases in maximum weekly runoff may be indicative of potentially greater flood risks during the 21st century. However, for the San Joaquin River Basin upstream from Friant Dam, results suggest a slight decline in annual maximum-week runoff.

For annual minimum-week runoff, results suggest a gradual decrease in the expected annual value as the 21st century progresses. The range of projected possibility also reduces with time. These declines are likely the result of decreased snowpack accumulation and increased soil evaporation and plant transpiration in the upper watershed. Decreasing minimum runoff may lead to adverse effects on aquatic habitats by reducing both wetted stream perimeters and availability of aquatic habitat and through increased water temperatures detrimental to temperature-sensitive aquatic organisms.

A summary of climate and hydrologic changes is provided in Table 2-1 for four subbasins of the Sacramento River and San Joaquin River basins: Sacramento River at Bend Bridge, Sacramento River at Freeport, San Joaquin River at Friant Dam, and San Joaquin River at Vernalis. The tabulated changes reflect a subbasin-average view and are measured relative to 1990s baseline conditions, as shown on the preceding figures.

Table 2-1. Summary of Simulated Changes in Decade-Mean Hydroclimate for Several Subbasins in the Sacramento and San Joaquin River Basins

Hydroclimate Metric (change from 1990s)	2020s	2050s	2070s
Sacramento River at Bend Bridge			
Mean Annual Temperature (°F)	1.3	3.0	4.2
Mean Annual Precipitation (%)	1.0	1.8	-0.9
Mean April 1st Snow Water Equivalent (%)	-58.7	-79.0	-90.8
Mean Annual Runoff (%)	3.3	4.1	-3.8
Mean December–March Runoff (%)	7.0	11.6	8.6
Mean April–July Runoff (%)	-8.8	-17.7	-30.9
Mean Annual Maximum Week Runoff (%)	10.8	16.2	17.0
Mean Annual Minimum Week Runoff (%)	-0.4	-0.7	-1.0
Sacramento River at Freeport			
Mean Annual Temperature (°F)	1.3	3.0	4.2
Mean Annual Precipitation (%)	-0.3	0.6	-2.7
Mean April 1st Snow Water Equivalent (%)	-53.4	-75.9	-88.6
Mean Annual Runoff (%)	3.5	2.5	-3.6
Mean December–March Runoff (%)	9.0	13.6	11.0
Mean April–July Runoff (%)	-11.1	-23.0	-36.1
Mean Annual Maximum Week Runoff (%)	12.9	18.4	18.3
Mean Annual Minimum Week Runoff (%)	-0.3	-0.5	-0.6
San Joaquin River at Friant Dam			
Mean Annual Temperature (°F)	1.4	3.3	4.5
Mean Annual Precipitation (%)	-1.3	-5.3	-8.6
Mean April 1st Snow Water Equivalent (%)	-23.1	-39.6	-48.7
Mean Annual Runoff (%)	0.7	-8.7	-10.7
Mean December–March Runoff (%)	13.9	15.8	31.0
Mean April–July Runoff (%)	-6.1	-20.2	-25.0
Mean Annual Maximum Week Runoff (%)	-2.3	-6.6	-16.0
Mean Annual Minimum Week Runoff (%)	-4.0	-6.4	-7.6
San Joaquin River at Vernalis			
Mean Annual Temperature (°F)	1.3	3.1	4.3
Mean Annual Precipitation (%)	-1.0	-4.2	-7.7
Mean April 1st Snow Water Equivalent (%)	-27.2	-45.9	-56.3
Mean Annual Runoff (%)	0.8	-5.9	-8.4
Mean December–March Runoff (%)	10.1	10.7	17.2
Mean April–July Runoff (%)	-4.8	-20.6	-25.8
Mean Annual Maximum Week Runoff (%)	1.6	-1.8	-4.9
Mean Annual Minimum Week Runoff (%)	-1.2	-1.9	-2.3

Key:
ºF = degree Fahrenheit

Chapter 3
Assessment of the Effects of Future Socioeconomic-Climate Uncertainties

Introduction

This chapter presents an assessment of the potential effects of future 21st century socioeconomic and climate uncertainties on the USJRBSI. It is important to recognize that the complexity of the global climate system and its local scale expression precludes an accurate prediction of what actual future climate changes will occur. The Department of Interior's policy indicates that when developing plans for making major investments the use of well-defined and established approaches for addressing uncertainty may include vulnerability assessments, scenario planning, adaptive management and other risk management or structured decision-making approaches. Although there is currently no detailed guidance for addressing climate change impacts in National Environmental Policy Act (NEPA) documents, the draft guidance provided by the Council on Environmental Quality in February of 2010 indicates that when climate change modeling is applied to a NEPA analysis the uncertainties associated with the climate projections should be considered.

For the Investigation, the analysis of uncertainty was performed by employing a scenario-based approach in which a wide range of potential 21st century socioeconomic-climate conditions were modeled using tools and methods developed by Reclamation for the Central Valley Project Integrated Resource Plan (CVP IRP).

In this section, the following topics are discussed:

1. Description of the Modeling Tools and Socioeconomic-Climate Scenarios

2. Assessment of Potential Socioeconomic-Climate Uncertainties with No Action (Baseline) conditions

3. Assessment of Potential Socioeconomic-Climate Uncertainties with USJRBSI Representative Alternative

Description of the Modeling Tools and Socioeconomic-Climate Scenarios

A description of the CVP IRP modeling tools and methods is presented in this section. A more detailed description is presented in the Reclamation's CVP IRP technical modeling appendices (Reclamation 2013). The CVP IRP analytical framework was developed to evaluate the combined effects of climate change and socioeconomic uncertainties on water supplies, demands and other important CVP/SWP water management conditions in the Sacramento, San Joaquin, and Tulare Lake basins.

In the CVP IRP analytical framework, the effects of climatic uncertainties on supply and demand are consistently evaluated. Climate impacts on supply are simulated through the use of hydrologic models. To provide consistent evaluation of agricultural and outdoor urban water requirements, the Land Atmosphere Water Simulator (LAWS) model was used to assess how climate change affects the water requirements and yields of major crops. This information was used as input to the Water Evaluation and Planning (WEAP) model. The calibrated WEAP model of the Central Valley watershed (WEAP-CV) was used to generate surface water and groundwater flows and local area demands, which are used as inputs for the CVP IRP California Lite Simulation (CalLite) model. The CVP IRP CalLite model was then used to simulate CVP and SWP facilities, operations, and allocation decisions. The results of the hydrology and systems analysis were subsequently used to provide inputs for additional performance-assessment tools to evaluate how potential water management actions affect economics, water quality and temperature, hydropower generation and use, and greenhouse gases (GHG) emissions.

To account for a range of uncertainty in future conditions, a suite of scenarios was developed to reflect the following conditions:

- Three future socioeconomic conditions
- Six future climate conditions, including one reflecting historical conditions without climate changes and five reflecting potential future climate change conditions

These three socioeconomic futures and six climate futures were combined to form the suite of eighteen future scenarios. Each scenario was analyzed for the period from 2011 through 2099 using a transient approach in which the climate and socioeconomic factors gradually change as the simulation moves through time. The following sections describe how the socioeconomic and climate futures are developed.

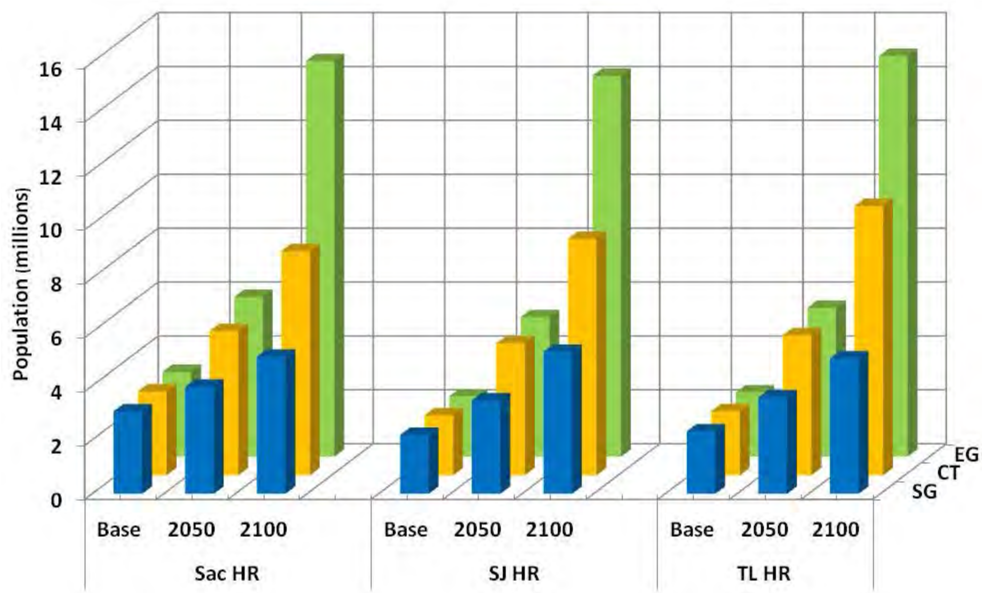
Socioeconomic Futures

The analysis uses the three socioeconomic future scenarios developed by California Department of Water Resources DWR in the California Water Plan (CWP) Update 2009 (DWR 2009):

- 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

Figure 3-1 shows the population projections for the Sacramento, San Joaquin and Tulare Lake hydrologic regions in the years 2005 (Base), 2050 and 2100. The projections were based on data developed by the California Department of Finance (DOF) (DOF 2007). The DOF data included a single population projection for each county through 2050. These projections were extended from 2050 to 2100 using data from a study by the Public Policy Institute of California (Johnson 2008) with some additional adjustments to make the projections more consistent with the DOF projections from 2010 to 2050. 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).

Figure 3-1 shows the population of each Central Valley Hydrologic Region (HR) including the Sacramento (Sac), San Joaquin (SJ), and Tulare Lake (TL) basins for the Slow Growth (SG), Current Trends (CT) and Expansive Growth (EG) scenarios in 2005 (Base), 2050, and 2100.

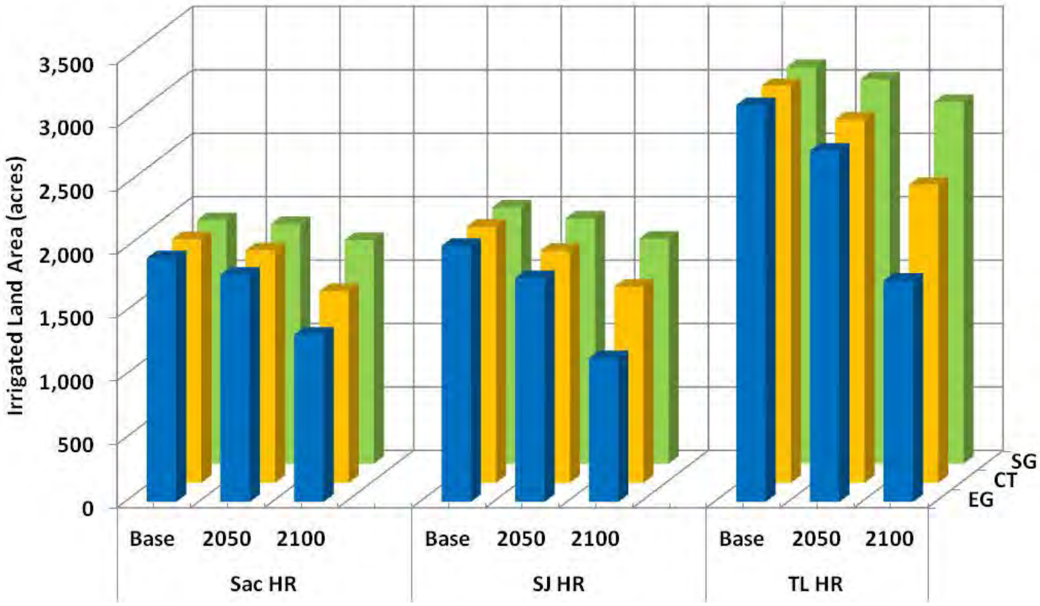


Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-1. Central Valley Population Projections by Hydrologic Regions for Base, 2050 and 2100 for Each Scenario

Irrigated Land Area Projections

After the population projections were developed, the socioeconomic scenarios were used to project irrigated land areas in each county. For each scenario in the CWP, DWR developed assumptions about the relationships between population growth and urban and agricultural land use. This approach has been used to extend projected irrigated land areas beyond 2050 for use in the USJRBSI analysis. Figure 3-2 shows the total irrigated land area in each Central Valley HR including the Sac, SJ, and TL basins for each scenario in 2005 (Base), 2050, and 2100.

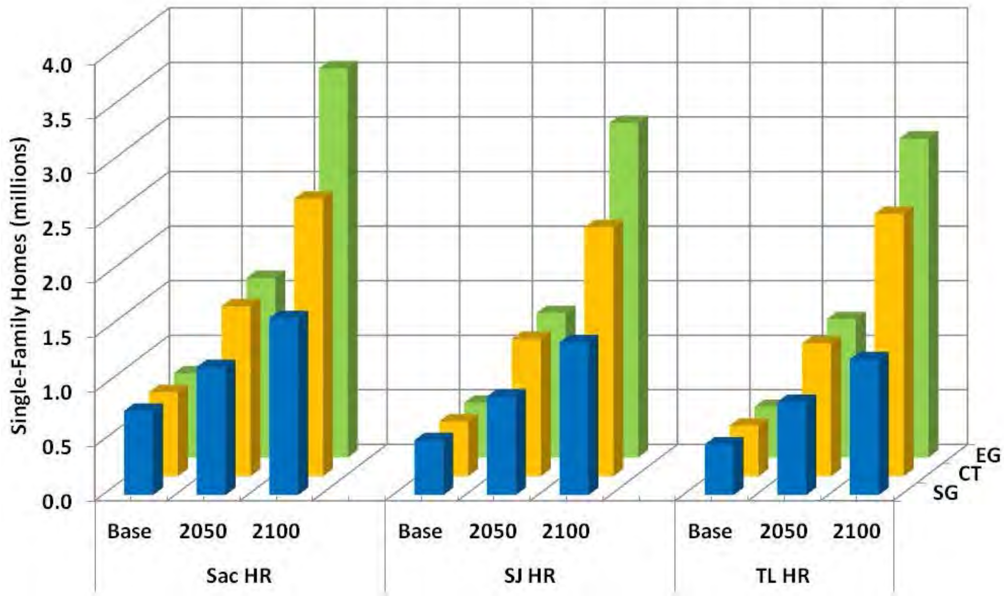


Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-2. Central Valley Irrigated Land Area Projections by Hydrologic Regions for Base, 2050 and 2100 for Each Scenario

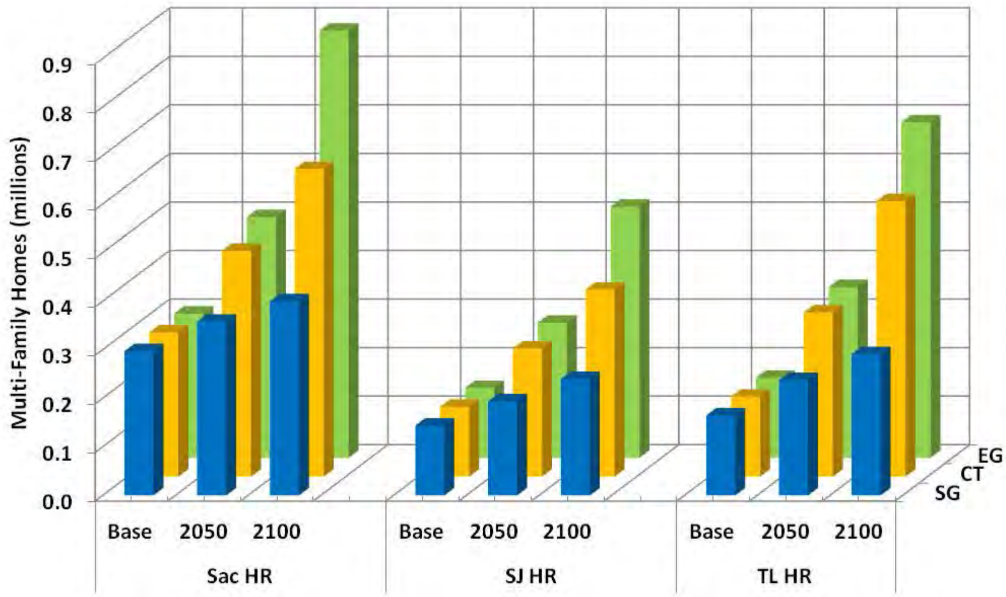
WEAP Urban Input Projection

The population projections are also used to develop residential, commercial and industrial inputs for each of the DWR Planning Areas used in the WEAP-CV model of the Central Valley. Figure 3-3 through Figure 3-6 show the projected numbers of single-family homes, multi-family homes, commercial employment, and industrial employment in each Central Valley Hydrologic Region for each scenario in 2005 (Base), 2050 and 2100.



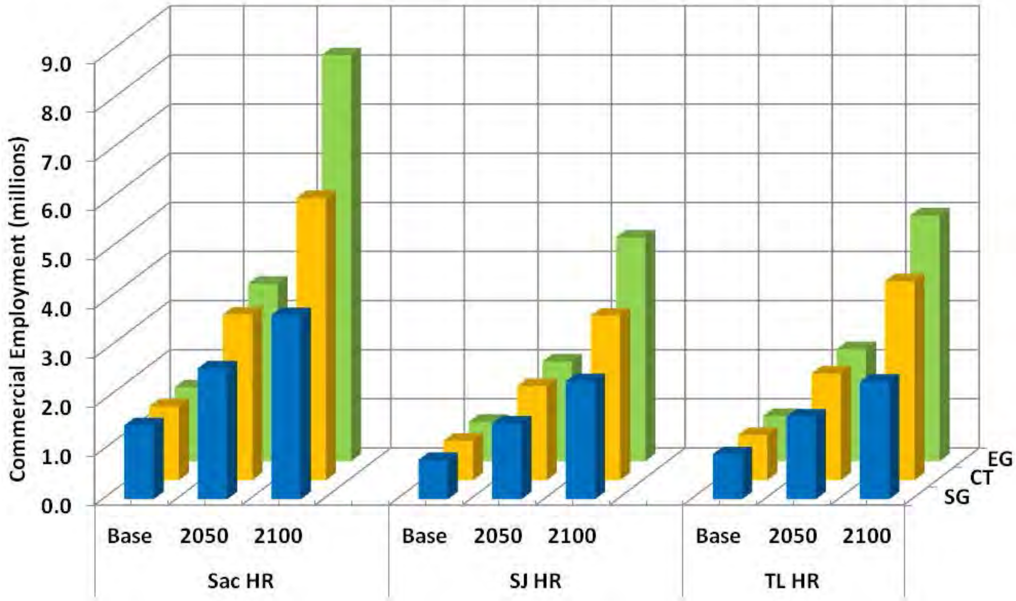
Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-3. Central Valley Single-Family Home Projections by Hydrologic Regions for Base, 2050 and 2100 for Each Scenario



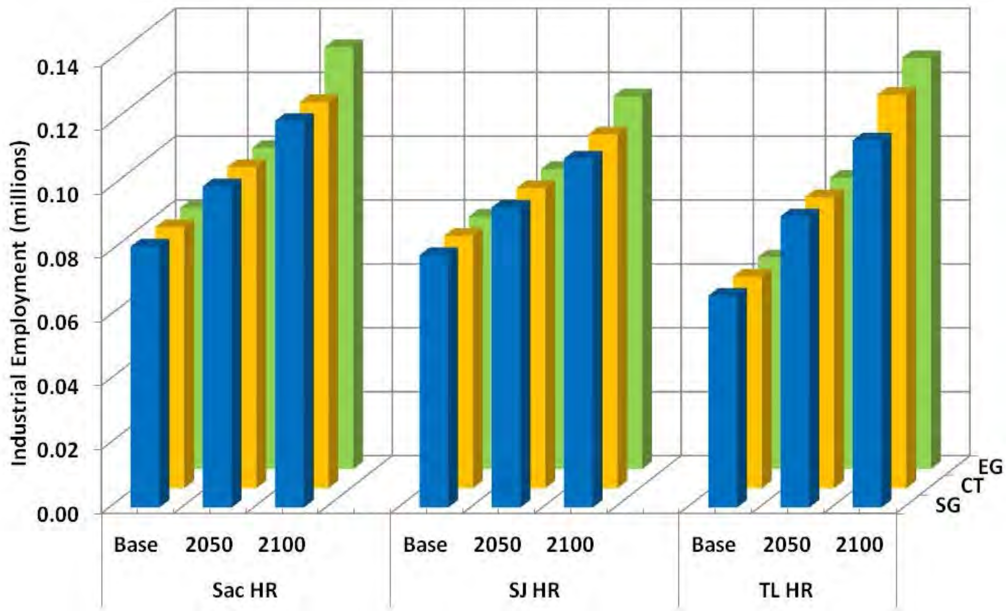
Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-4. Central Valley Multi-Family Home Projections Under Each Scenario



Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-5. Central Valley Commercial Employment Projections Under Each Scenario



Key:
CT = Current Trends
EG = Expansive Growth
HR = Hydrologic Region
Sac = Sacramento
SG = Slow Growth
SJ = San Joaquin
TL = Tulare Lake

Figure 3-6. Central Valley Industrial Employment Projections Under Each Scenario

Climate Futures

The USJRBSI analysis uses six transient climate future projections: one reflecting the historical hydrology without climate change, and five statistically representative climate change projections that employ the same approach used for the CVP IRP study (Reclamation 2013) and other studies such as the Bay Delta Conservation Plan (BDCP). Each climate change future is characterized by changes in hydrology and sea level rise. The following sections describe how ensemble-informed climate hydrology and sea level rise inputs were developed for each climate future.

Ensemble-informed Climate Scenarios

Five climate sequences were developed using statistical techniques that consider the full range of the 112 (see Figure 3-7) bias-corrected, spatially downscaled climate change projections (Maurer et al 2007), as described in Reclamation (2013), developed by Reclamation and others. These projections were used to develop statistically relevant climate scenarios employed in USJRBSI analysis. The five representative climate sequences were developed using a multi-model hybrid delta ensemble approach in which the ensemble of future climate change projections is broken into regions representing future climate uncertainties ranging from (Q1) drier, less warming, (Q2) drier, more warming, (Q3) wetter, more warming, and (Q4) wetter, less warming scenarios than the captured by the ensemble median projection (Q5). These quadrants are labeled Q1 through Q4 in Figure 3-7. The fifth region (Q5) samples from inner-quartiles (25th to 75th percentile) of the ensemble and represents the central tendency of 112 projected climate changes. In each of the five regions, the subset of climate change projections, consisting of those contained within the region's boundary is identified. For the Q1 through Q4 regions, this subset consists of the 10 nearest neighbors to the 10-90 percentile points (see Figure 3-7: 10-90 percentiles occur at intersections of red lines).

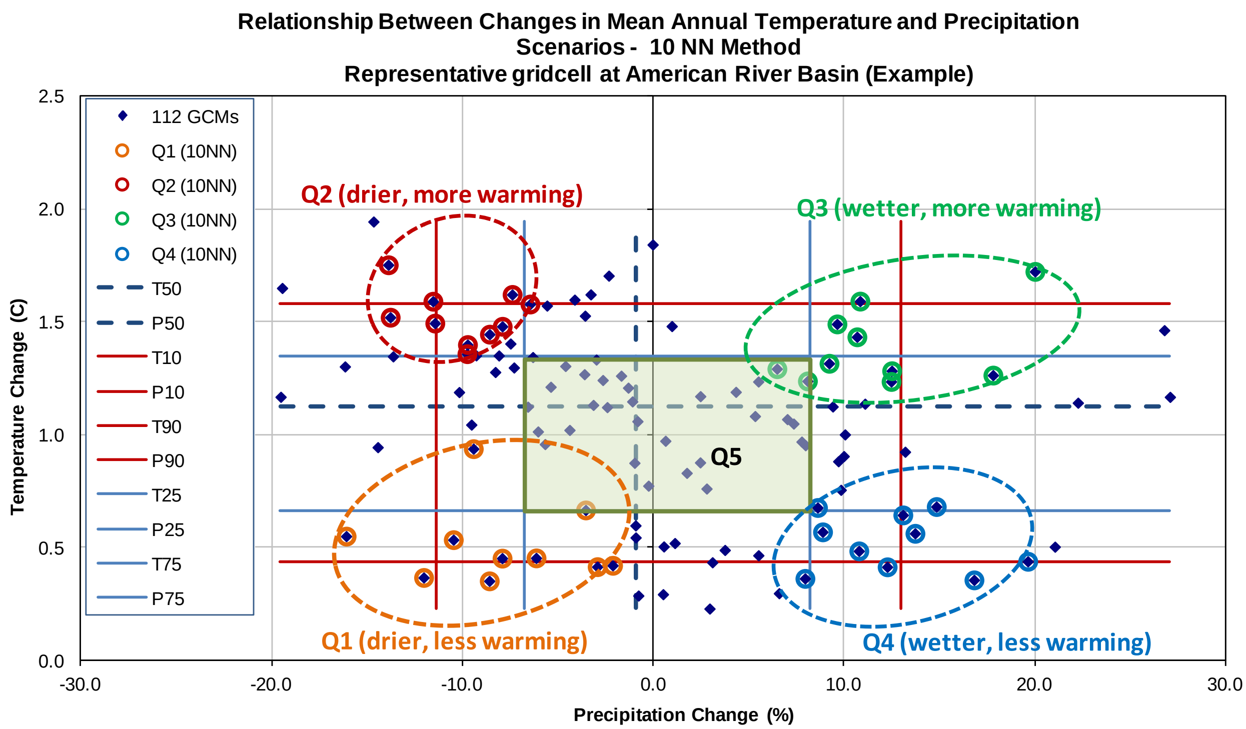
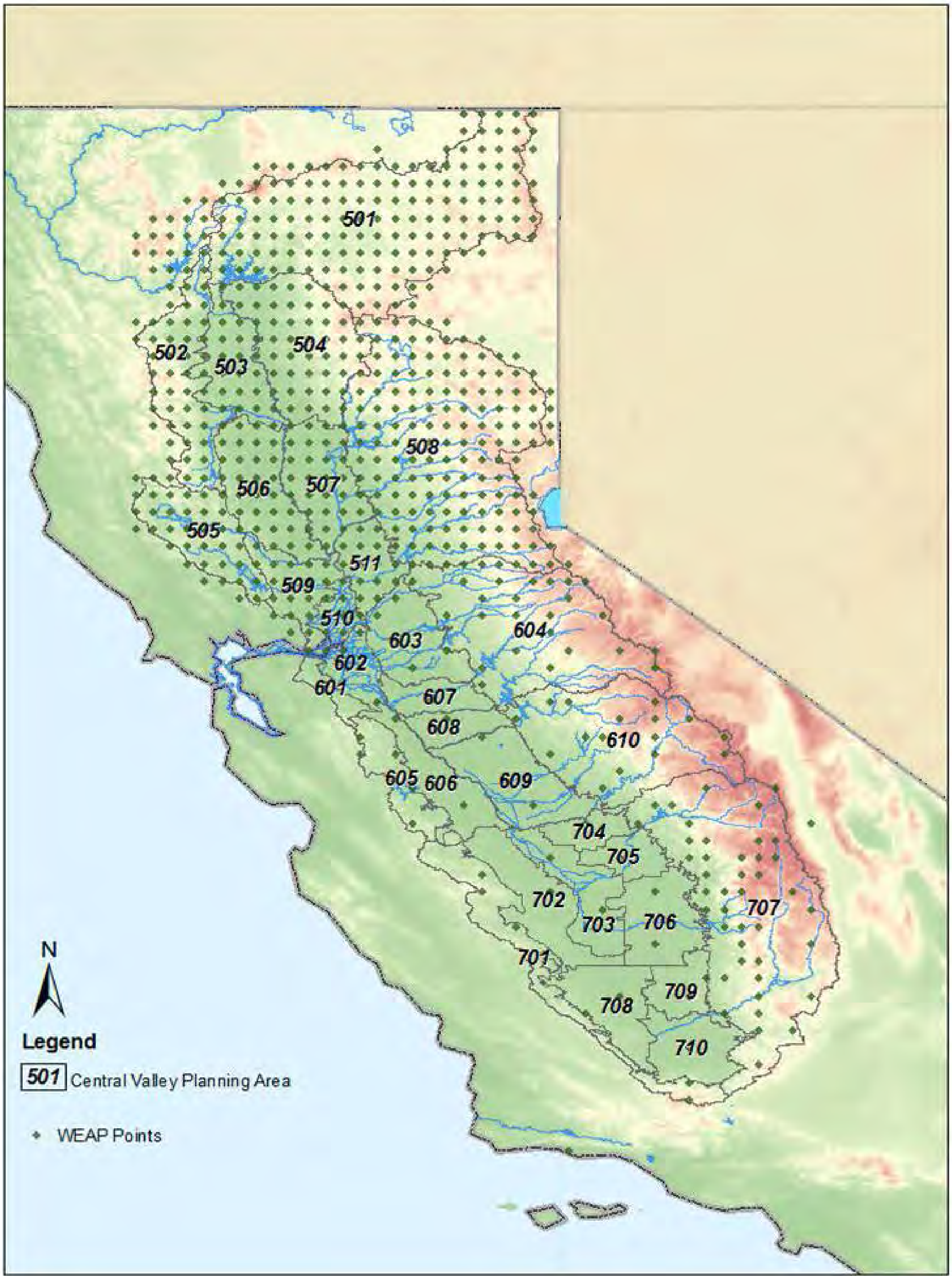


Figure 3-7. Downscaled Climate Projections and Sub-Ensembles Used for Deriving Climate Scenarios (Q1-Q5) at a Location in the American River Basin at 2025

To develop the transient climate change scenarios for each of the five regions, a historical cumulative distribution function (CDF) was developed using a 30-year period centered around 1985 (1971 through 2000). In addition, three future CDFs were developed using 30-year periods centered around 2025 (2011 through 2040), 2055 (2041 through 2070) and 2084 (2070 through 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 through 2003) and the projected climate change. The method applies the change for any particular year by interpolating from the two CDFs that bracket the simulation year. This process adjusts the historic observed climate records by the climate shifts projected to occur in the future.

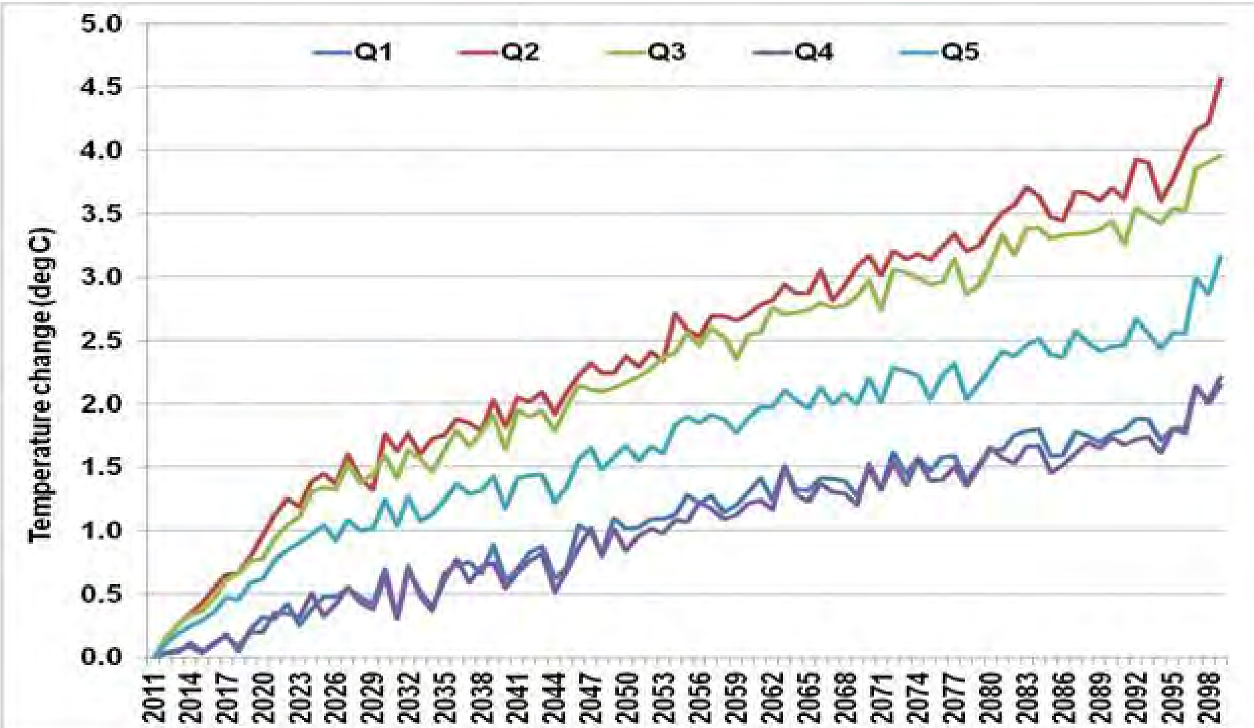
This method was used to develop transient climate projections for each of the Central Valley locations shown on Figure 3-8.



Key:
WEAP-CV = WEAP model of the Central Valley watershed

Figure 3-8. Map Showing the Climate Projection Locations and Planning Areas Used in the WEAP-CV Hydrologic Modeling

Figure 3-9 shows the change in average annual temperature for the transient climate scenarios Q1 through Q5 for a representative grid cell in the American River basin for the period from 2011 to 2099.



Source: Hamlet and Lettenmaier, 2005
Key: C = Celsius

Figure 3-9. Transient Ensemble-Informed Changes in Average Annual Temperature for a Representative Grid Cell in the American River Basin from 2011 to 2099

Figure 3-10 shows the projected changes in average annual precipitation under each of the transient climate scenarios. Trends in precipitation projections are less steady because of naturally occurring decadal and multi-decadal precipitation variations. By construction, the transient climate scenarios method preserves the inter-annual variability as observed in the historical time series. However, the variability expands as directed by the climate projections.

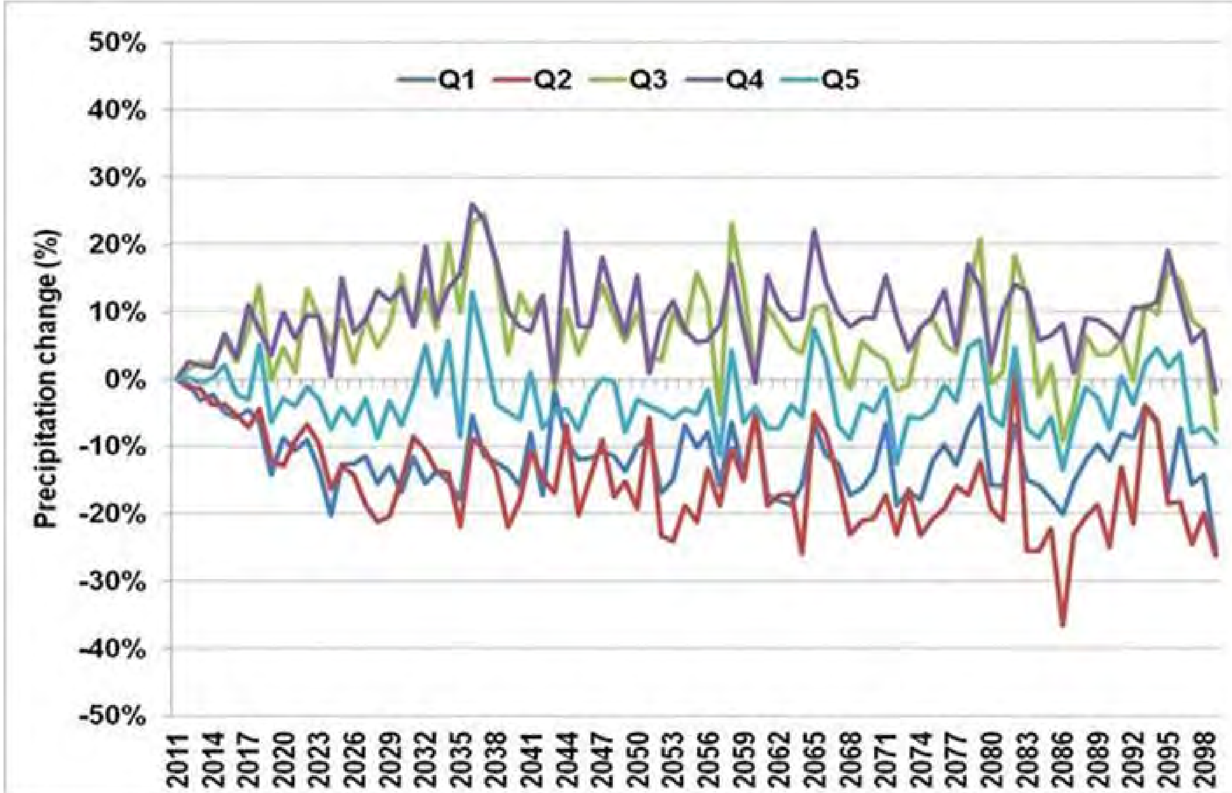


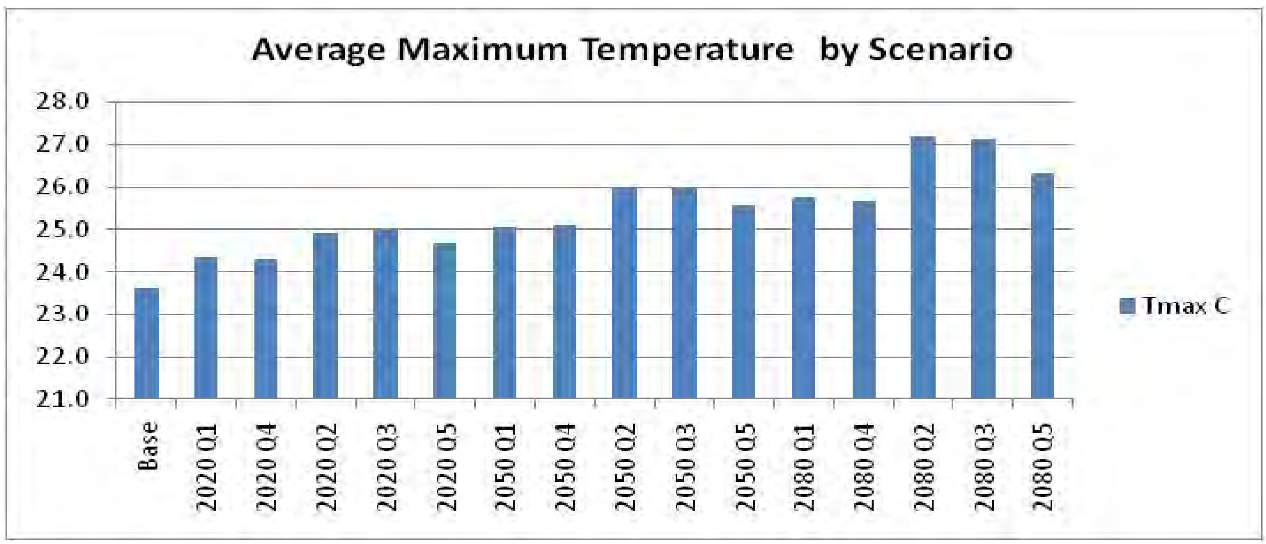
Figure 3-10. Transient Ensemble-Informed Changes in Average Annual Precipitation for a Representative Grid Cell in the American River Basin from 2011 to 2099

An analysis of the effects of potential future climate changes on agricultural water demands and productivity requires more than just projections of future temperature and precipitation conditions. Crop growth, yield and evapotranspiration (ET) are also sensitive to other meteorological conditions including solar radiation, atmospheric humidity, wind speed and carbon dioxide. However, the climate projections described above did not include projections for these meteorological conditions. Consequently, several estimation methods as described below using the Q1 through Q5 temperature and precipitation projections were employed to obtain values for these meteorological conditions corresponding to the future climate projections.

To represent the spatial variability in these meteorological conditions in the Central Valley, four locations were selected to provide representative conditions in the Central Valley. They include existing California Irrigation Management Information System (CIMIS) stations located at Gerber, Davis, Firebaugh, and Shafter. These stations were chosen because at these locations long term observations of daily maximum and minimum temperature (Tmax, Tmin), solar radiation (Rs), dew point temperature (Tdew), relative humidity (RH), and wind speed were available. All historical data from the stations were carefully checked for erroneous values before preparing the subsequent projections.

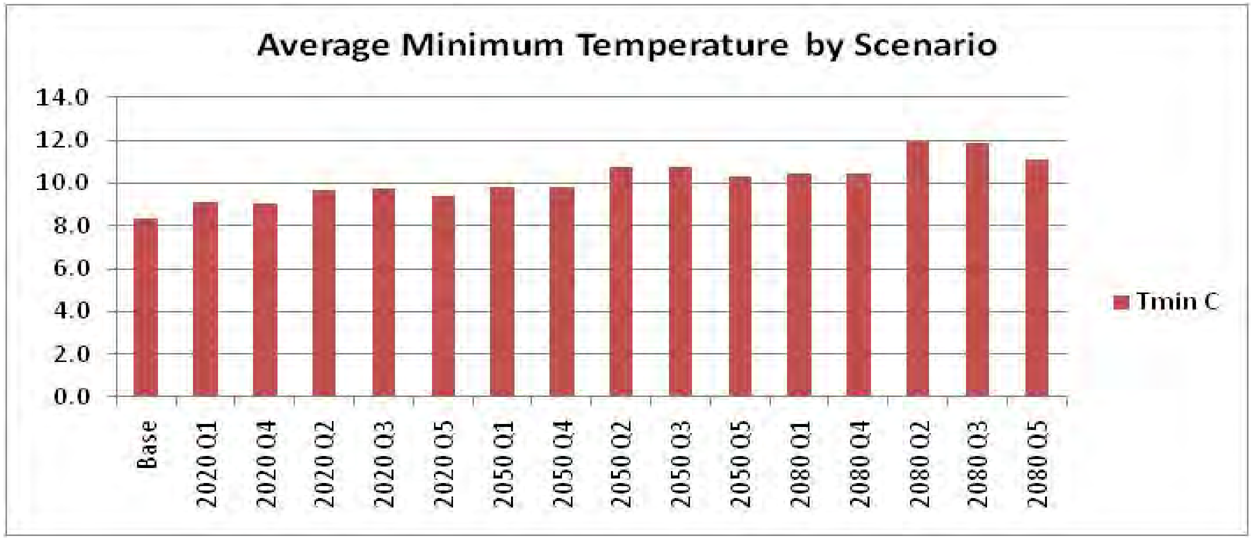
Solar radiation is one of the primary factors effecting crop ET. It can be estimated from the Tmax and Tmin using the clear radiation (Ro) which only depends on latitude and the day of the year and a site-specific parameter (B). The CIMIS station historical records where used to calibrate B and the climate projections of daily Tmax and Tmin were then used to compute Rs based on the method of Thornton and Running (Thornton and Running 1999) for each of the climate projections (Q1 through Q5).

The average daily Tmax, Tmin and Rs results the Base historical period and each of the 5 climate projections during the early (2020), mid (2050) and late (2080) 21st century are presented in Figure 3-11 through Figure 3-13.



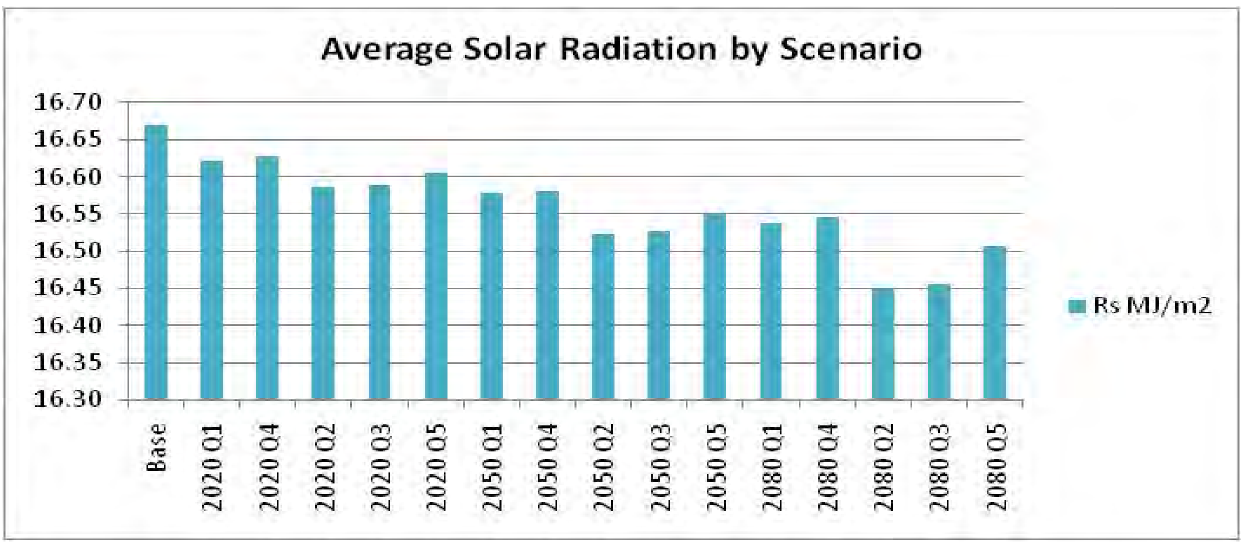
Key:
C = Celsius
Tmax = daily maximum temperature

Figure 3-11. Projected Average Daily Maximum Temperatures in Degrees Celsius for Each Climate Scenario



Key:
C = Celsius
Tmin = daily minimum temperature

Figure 3-12. Projected Average Daily Minimum Temperatures in Degrees Celsius for Each Climate Scenario During the Early (2020), mid (2050) and late (2080) 21st Century



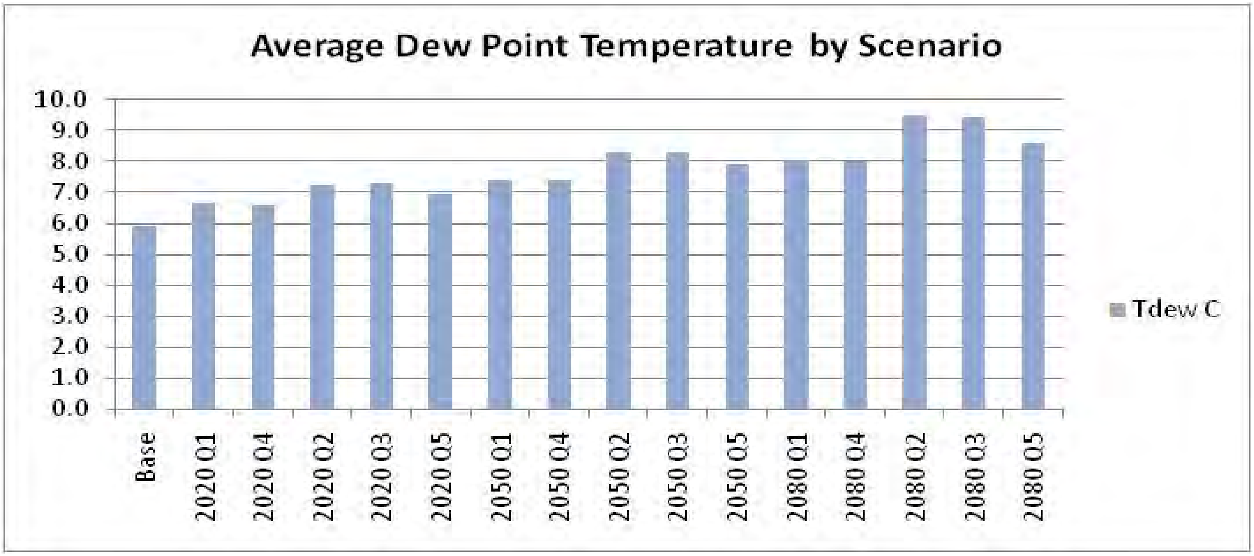
Key:
MJ/m2 = megajoules per square meter
Rs = solar radiation

Figure 3-13. Projected Average Solar Radiation in Mega-Joules per Square Meter for Each Climate Scenario During the Early (2020), mid (2050) and late (2080) 21st Century

Atmospheric humidity is also a major driver of crop ET. As the air becomes drier, ET generally increases. The dew point temperature (Tdew) is a measure of the moisture content of the air. As the atmospheric humidity increases, Tdew also increases. The Tmin is a good surrogate for Tdew because cloudiness and high humidity reduce the amount of heat loss from the surface to the upper atmosphere which is reflected in higher Tmin values. To estimate projected changes in atmospheric humidity, an analysis of the CIMIS station records was made to determine the monthly average difference between the observed Tmin and Tdew values. This difference is referred to as the dew point depression (Ko). To estimate projected changes in Tdew, these monthly average observed Ko values were subtracted from the projected Tmin values. The results are presented in Figure 3-14.

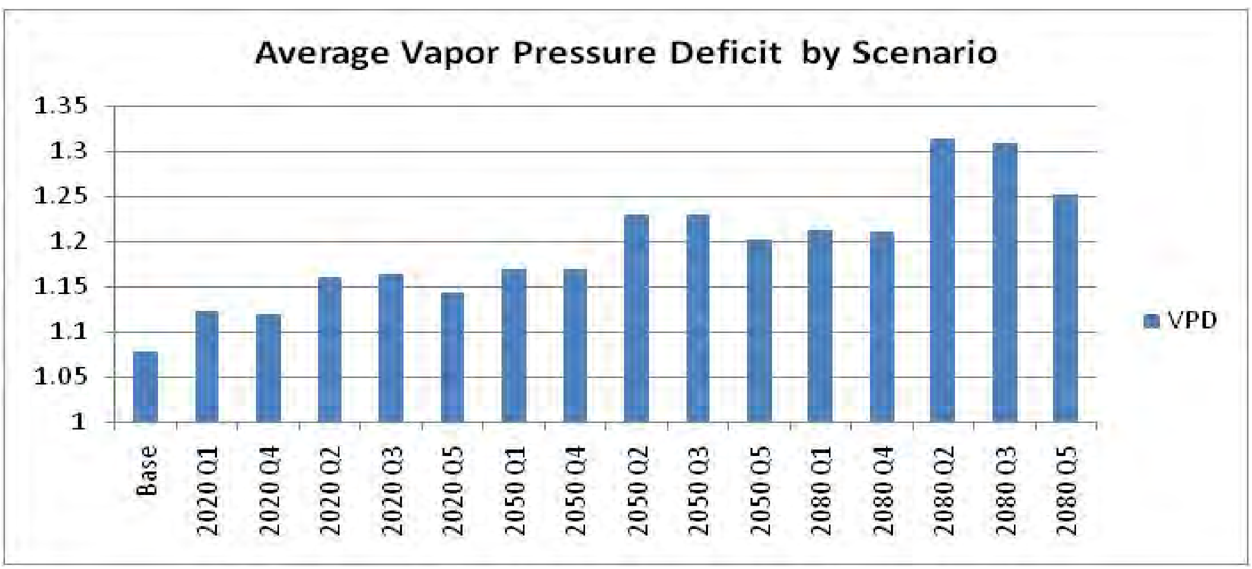
The effects of atmospheric humidity are reflected in ET as the difference between the saturated vapor pressure in the moist plant leaves and the typically drier surrounding atmosphere. This difference is referred to as the vapor pressure deficit (VPD). As the VPD increases, crop ET generally increases. Because the saturation vapor pressure is a function of temperature, projections of VPD can be computed from the projections of daily Tmax, Tmin and Tdew using the results described above. Figure 3-15 shows the projected VPD results associated with each climate scenario.

Carbon dioxide (CO_2) has been observed to exert a strong effect on crop ET. As CO_2 concentrations increase, many crops have been demonstrated to have reduced ET. Consequently, an analysis of the Q1 through Q5 climate projections was made to determine the frequency of the different GHG emission scenarios present in each of these ensembles. Because the CO_2 concentrations associated with each ensemble member are known, a weighted average CO_2 concentration could be computed for five projections on a decadal basis throughout the 21st century. These results are presented in Figure 3-16.



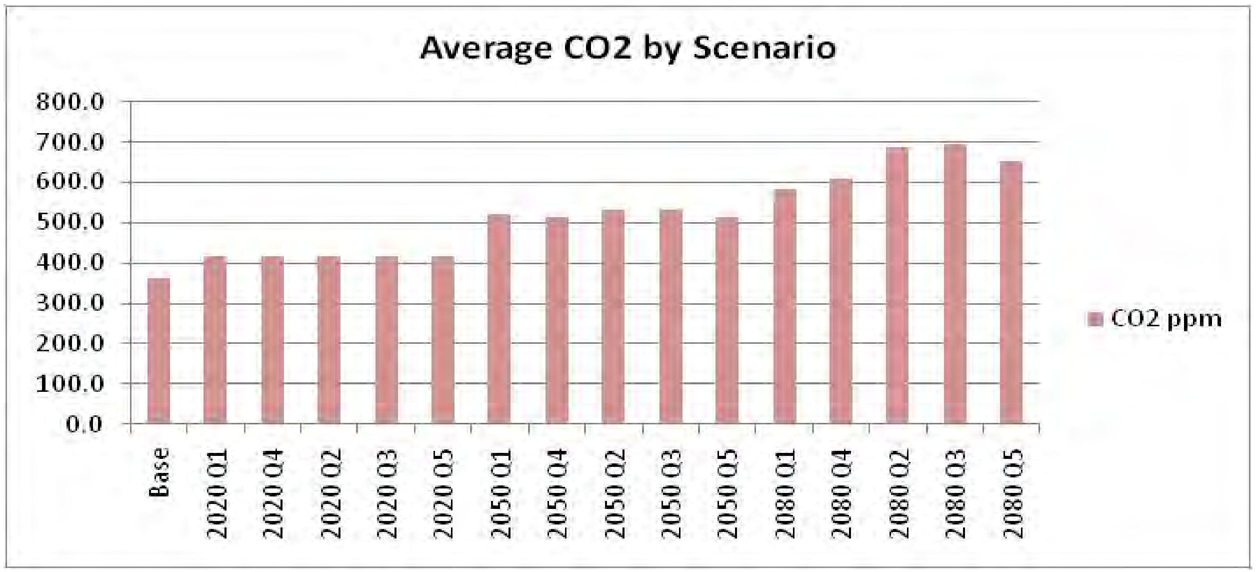
Key:
C = Celsius
Tdew = dew point temperature

Figure 3-14. Projected Average Daily Dew Point Temperatures in Degrees Celsius for Each Climate Scenario During the Early (2020), mid (2050) and late (2080) 21st Century



Key:
VPD = vapor pressure deficit

Figure 3-15. Projected Average Daily Vapor Pressure Deficits in Kilo Pascals for Each Climate Scenario During the Early (2020), mid (2050) and late (2080) 21st Century



Key:
CO_2 = carbon dioxide
ppm = parts per million

Figure 3-16. Projected Average Daily Average Carbon Dioxide Concentrations (parts per Million (ppm) of CO_2 by Volume of air) for each Climate Scenario During the Early (2020), mid (2050) and late (2080) 21st Century

Sea Level Changes

The CALFED Science Program, State of California, National Academy of Science and others have made assessments of the range of potential future sea level rise throughout 2100. These studies indicate that as sea level rise progresses during the 21st century, the hydrodynamics of the Delta will change causing the salinity of water in the Delta to increase. This increasing salinity will most likely have significant impacts on water management throughout the Central Valley and other regions of the State.

Figure 3-17 below shows various projected ranges of potential sea level change in the San Francisco Bay/Sacramento-San Joaquin Delta (Bay-Delta) through the year 2100. Some State and Federal planning processes in the Central Valley have considered sea level rise through mid-century. In these studies, sea level rises from 60 to 90 centimeters (cm) (2 to 3 feet) have been simulated using existing hydrodynamic models. Under current conditions, sea level rise much greater than these levels would most likely inundate many of the Delta islands and would likely cause large-scale levee failures that cannot be simulated without making broad policy assumptions related to levee hardening and land use throughout the Bay-Delta.

As part of the USJRBSI transient climate change analysis approach, sea level rise was assumed to gradually increase. Several transient sea level rise projections were developed based on the National Research Council (NRC) report (NRC 2012) projections. The report suggested mean sea level rise projections as well as upper and lower bounds at three future times relative to 2000 in the San Francisco Bay would be approximately 6, 12, 36 inches by 2030, 2050, and 2100 respectively. Figure 3-18 shows the mean sea level rise and bounding projections. In the CalLite simulations, an artificial neural network (ANN) model reflecting a no sea level rise condition was used to determine salinity requirements and conditions in the Delta. This ANN was adjusted to reflect changes in Delta conditions due to sea level rise. For USJRBSI, the mean sea level rise projection was used in the simulations. To adjust the inputs and outputs of the no sea level rise ANN, relationships between flow and salinity were developed and incorporated into the CVP IRP CalLite model to simulate the effects of the projected sea level rise on the Bay-Delta system. These relationships were developed using results derived from the UNTRIM model simulations (MacWilliams et al. 2008) and through calibration with CalSim-II simulations that incorporate sea level rise.

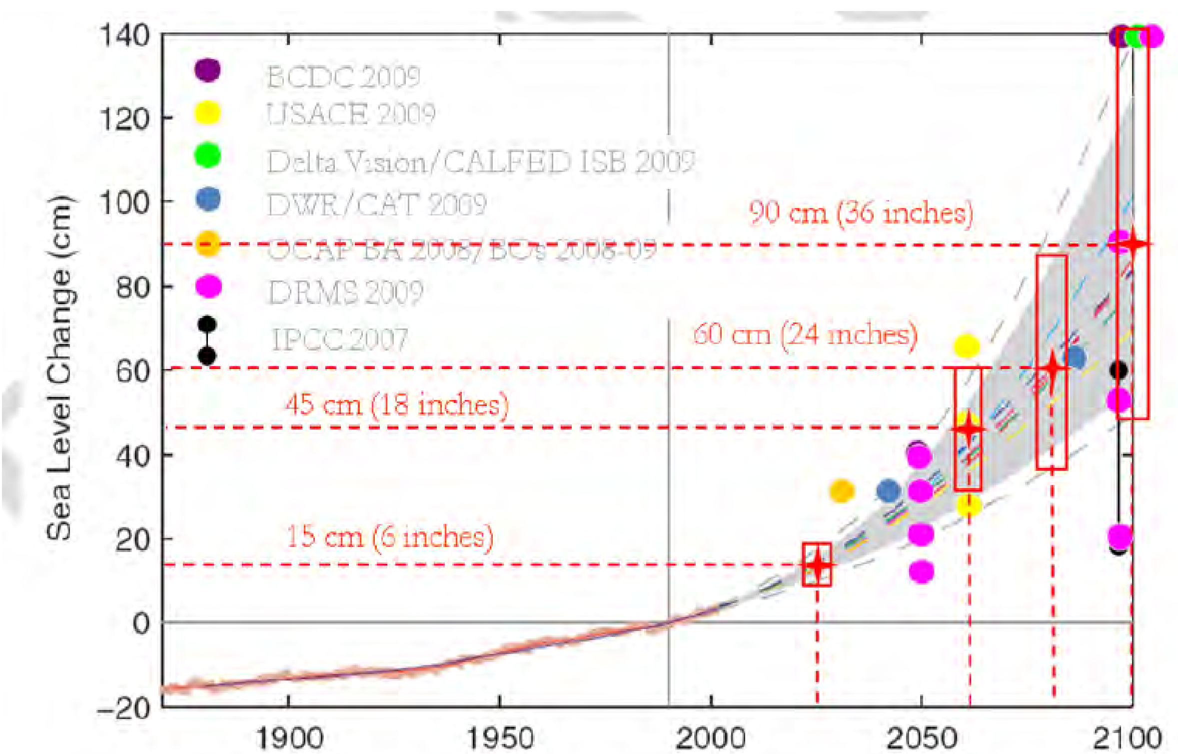


Figure 3-17. Range of Future Mean Sea Level Based on Global Mean Temperature Projections and Sea Level Rise Values (centimeters)

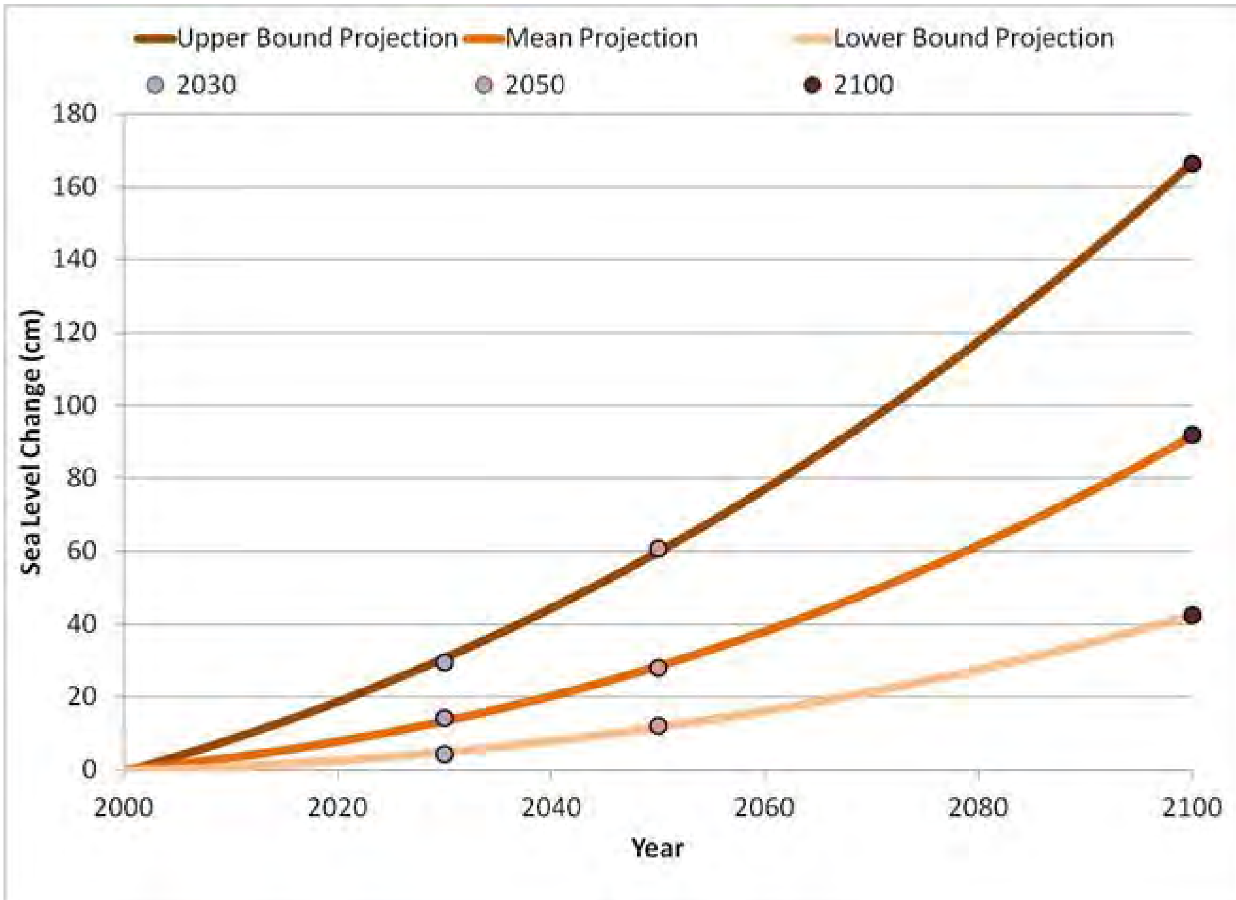


Figure 3-18. Mean and Bounding Projected Sea Level Rise Values (centimeters) used in the Simulations

Agricultural Water Demand and Productivity

In the previous sections, the approaches used to develop the projections climate change on water supply and demand were described. The projections were developed to provide a consistent assessment of how climate change affects both water supply and agricultural demands. The LAWS model (Tansey et al. 2011) was used to compute crop water requirements, growth, and yield based on climate scenarios Q1 through Q5. To accomplish this objective, the LAWS model was modified to include the biophysical processes that are needed to simulate the major effects of climate on crop ET, growth and yield. Crop growth and yield modeling are considered important because climate effects on crop yields have important implications for agricultural productivity and economics.

Before employing the projected climate changes in the LAWS model, it was calibrated using the historically observed climate data from the Gerber, Davis, Firebaugh and Shafter CIMIS stations for 20 major crops grown in the Central Valley. The "California Crop and Soil Evapotranspiration" (Irrigation Training and Research Center 2003) study was used to provide historic period data on crop ET at the four CIMIS calibration locations. Historic crop yield data was obtained from the State Wide Agricultural Production (SWAP) model (Howitt et al. 2012). Initial estimates of crop parameters used in the modeling were obtained from the literature sources and adjusted to match the reported ET and yield data. The calibrated LAWS model was used to provide initial crop modeling parameters for WEAP-CV modeling. The WEAP-CV parameters were further adjusted based on Planning Area water budgets developed for the California Water Plan Update 2013. Reclamation (2013) provides additional information on the calibration method.

By including the effects of projected climate changes on both water supply and demands, an improved representation of climate effects on the CVP/SWP system operations and performance was achieved. These improvements in supply and demand consistency also benefit the agricultural economic evaluations performed for the USJRBSI alternative using the SWAP model. The SWAP model has been calibrated based on 15 years of observed farmers' decisions about cropping patterns, and it uses water supply and demands over time along with consideration of the costs and revenues associated with these production systems to determine optimal land and water resource allocation to maximize economic benefits. Using both the LAWS ET and major crop yield datasets in the SWAP model also provides an improved consistency between the projected economic changes for each of the Q1 through Q5 climate projections.

Hydrology and Systems Analysis

Geographic Representation of the CVP Service Area

Although CVP IRP technical analysis was designed to report modeling results for each CVP Division, the tools actually simulate the entire CVP, SWP and non-project water management system. The supply and demand information is derived primarily from WEAP-CV model results, which are computed at the CWP's Planning Area scale. Therefore, the hydrology and systems analysis models are designed to translate the Planning Area–scale data to produce results for each CVP Division.

CVP IRP Divisions

The CVP includes the following nine Divisions:

- Trinity River Division
- Shasta Division
- Sacramento River Division
- American River Division
- Delta Division
- West San Joaquin Division
- Friant Division
- East Side Division
- San Felipe Division

The geographic extent of each Division is defined by the boundaries of the CVP districts that divert water from the facilities and rivers within that Division (Figure 3-19). Similarly, the demand for each Division is equal to the sum of the demands of all of the CVP districts within the Division.

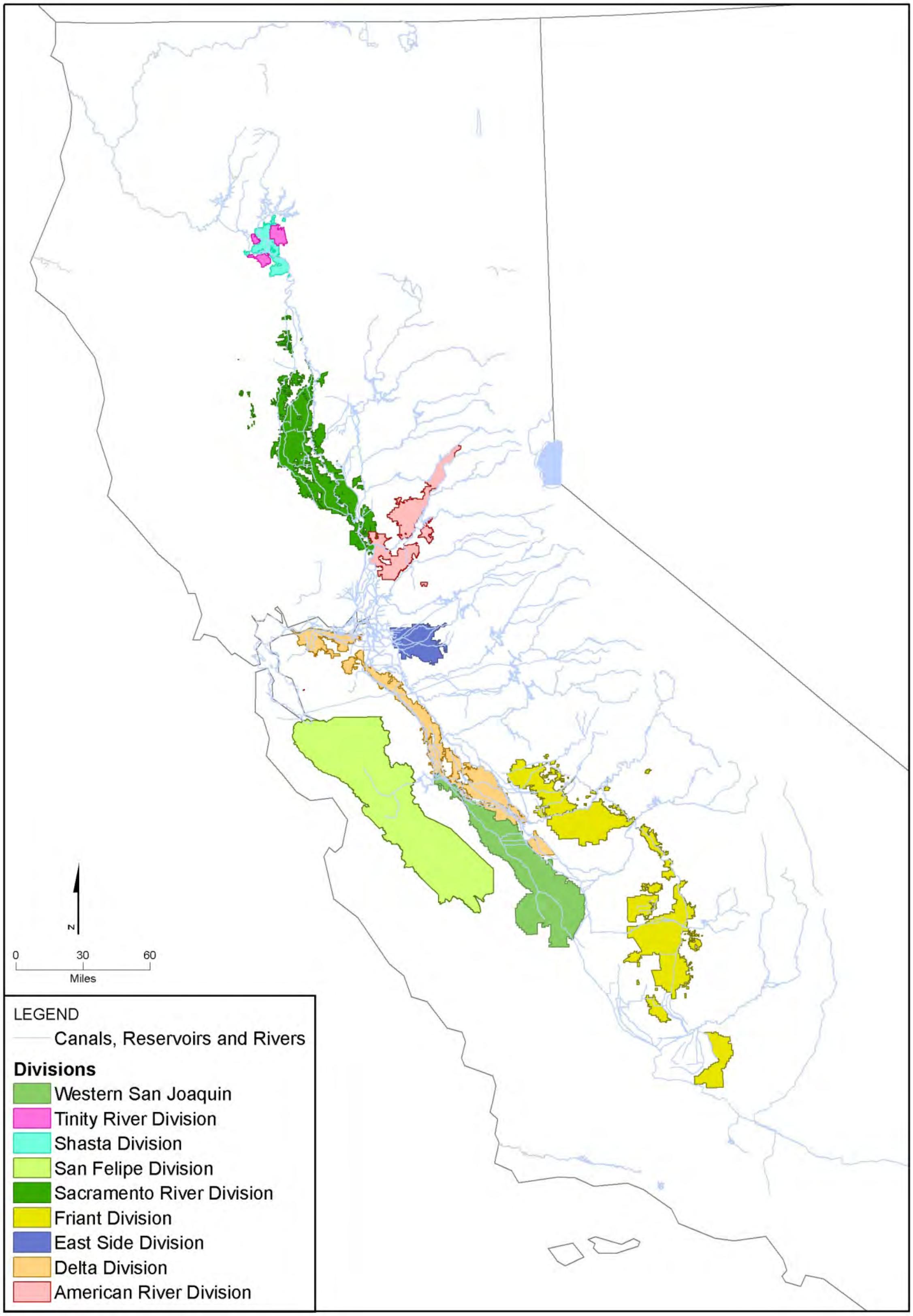
California Water Plan Geographic Regions

The CWP develops and uses data at the spatial scales of Hydrologic Regions and Planning Areas. California is divided into 10 Hydrologic Regions, each of which is divided into a number of Planning Areas. The CWP has used the WEAP model to develop estimates of hydrology and demand at the Planning Area–scale in the Sacramento River, San Joaquin River, and Delta Hydrologic Regions. In some cases, the Planning Areas have been subdivided into even smaller geographic units for the purpose of improved model simulations.

The Planning Area regions modeled for these Hydrologic Regions are shown in Figure 3-20. These Hydrologic Regions provide coverage for the entire CVP Service Area with the exception of the San Felipe Division. Therefore, hydrology and demand data for the San Felipe Division has been developed outside of the WEAP-CV model as described in the following discussion.

Simulation of the CVP-SWP Integrated Water System

This section describes how simulations are performed using the CVP IRP models for the baseline socioeconomic and climate conditions and to simulate the USJRBSI project. Each scenario is analyzed for the period from 2011 through 2099 using a transient approach in which the climate and socioeconomic factors gradually change as the simulation progresses through time.



Key: CVP = Central Valley Project

Figure 3-19. Map of the CVP Divisions

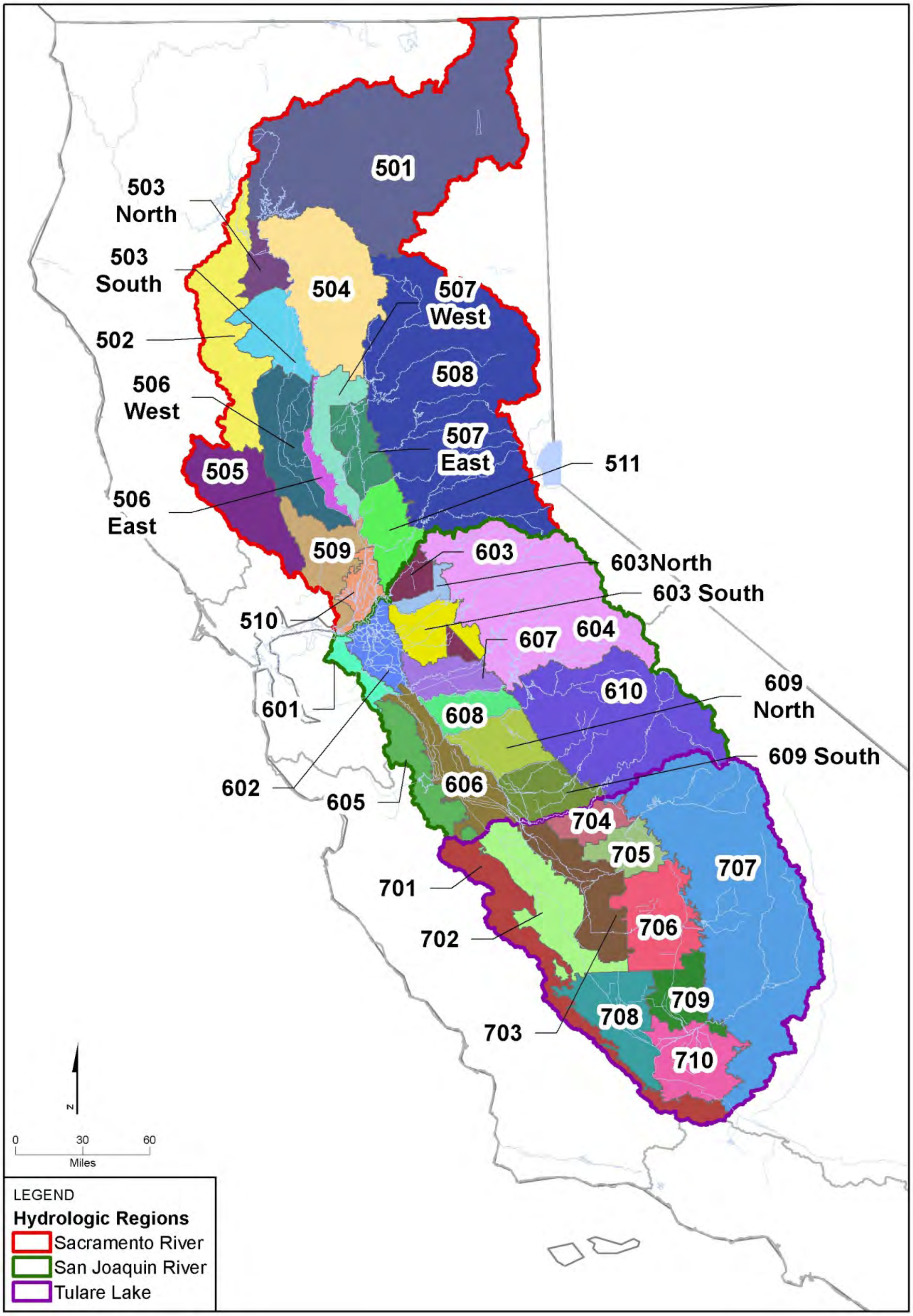


Figure 3-20. Planning Areas in the Sacramento River, San Joaquin River, and Tulare Lake Hydrologic Regions

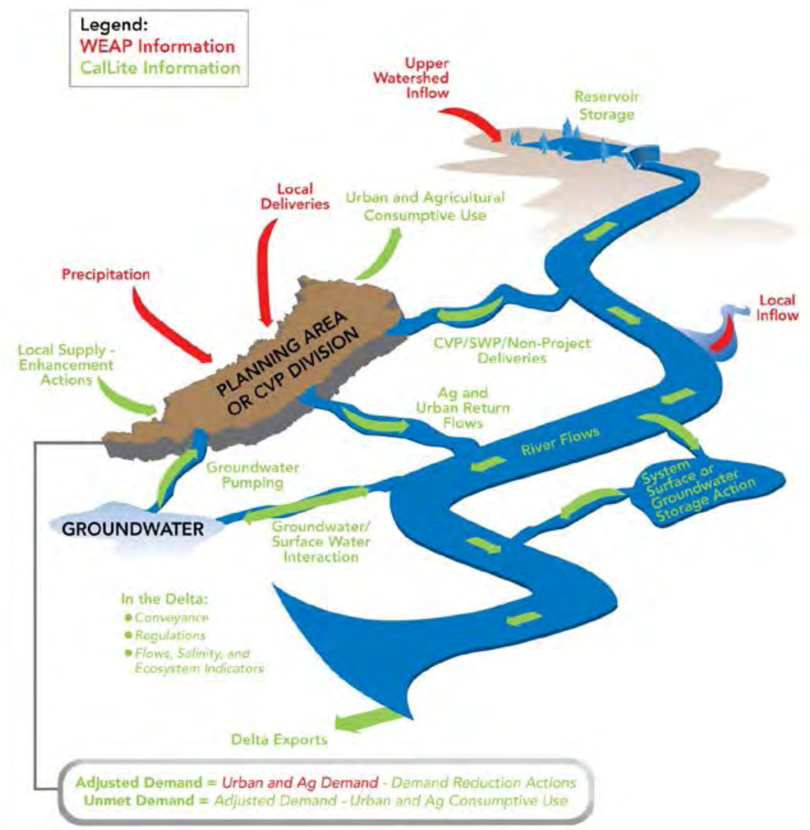
Approach

The simulation of the USJRBSI socioeconomic-climate scenarios described above was performed using the CVP IRP CalLite and WEAP-CV models in an integrated manner. The WEAP-CV model was used to develop climate-based watershed runoff for the main watersheds of the Central Valley and climate-based demand estimates for the Delta, Sacramento, San Joaquin, and Tulare Lake Hydrologic Regions. The model includes rainfall-runoff modules of the source watersheds and water demand modules for each Planning Area in the Central Valley water system. Figure 3-21 depicts a generic representation of a reservoir and river system simulated by the WEAP-CalLite integrated models. The figure depicts hydrology, demand, and operational components included in the simulation and indicates which model provides the data for each component of the analysis. Table 3-1 lists the components simulated by each model. The WEAP-CV model produces the hydrology and demand components, and the CVP IRP CalLite model produces outputs relating to system operations and local and system-wide management actions and infrastructure.

Table 3-1. CVP IRP Simulation Components Produced by Each Model

WEAP	CalLite
Upper watershed inflow	SWP/CVP/non-project deliveries
Local inflow	River flows
Precipitation	Reservoir storage
Urban and agricultural water demand	Agricultural and urban return flows
Local deliveries	Groundwater pumping
	Local supply-enhancement actions
	Local demand-reduction actions
	Systemwide management actions
	Adjusted demand
	Unmet demand
	Delta conveyance, regulations, and exports
	Delta flow, salinity, and ecosystem indicators
	Groundwater-surface water interaction

Key:
CVP = Central Valley Project
IRP = Integrated Resource Plan
SWP = State Water Project
WEAP = Water Evaluation and Planning



Key:
CalLite = California Lite Simulation
CVP IRP = Central Valley Project Integrated Resources Plan
WEAP-CV = WEAP model of the Central Valley watershed

Figure 3-21. WEAP-CV and CVP IRP CalLite Integration of the Supply and Demand Hydrology Components

Because the Planning Area–scale WEAP-CV model does not cover the San Felipe Division, the WEAP-CV components shown in Table 3-1 were developed separately for the San Felipe Division and included as inputs into the CVP IRP CalLite simulation. Local inflow and precipitation, agricultural and urban water use, demand, return flows, local deliveries, and groundwater pumping for the San Felipe Division are estimated using county scale information for San Benito and Santa Clara Counties developed by DWR's Water Plan Update (DWR 2009b).

The CVP IRP CalLite model simulates SWP, CVP, and non-project deliveries to the San Felipe Division along with local supply-enhancement and demand-reduction actions. Therefore, local water management actions in the San Felipe Division are evaluated despite the absence of a Planning Area–scale WEAP model of the region.

The WEAP-CV model was used to simulate each of the 18 socioeconomic-climate scenarios for the period from 2011 through 2099 to evaluate the range of future uncertainties associated hydrology of the system. 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. The climate-based supply and demand factors produced by WEAP were subsequently used as inputs to the CVP IRP CalLite model to perform simulations under the different socioeconomic and climatic conditions.

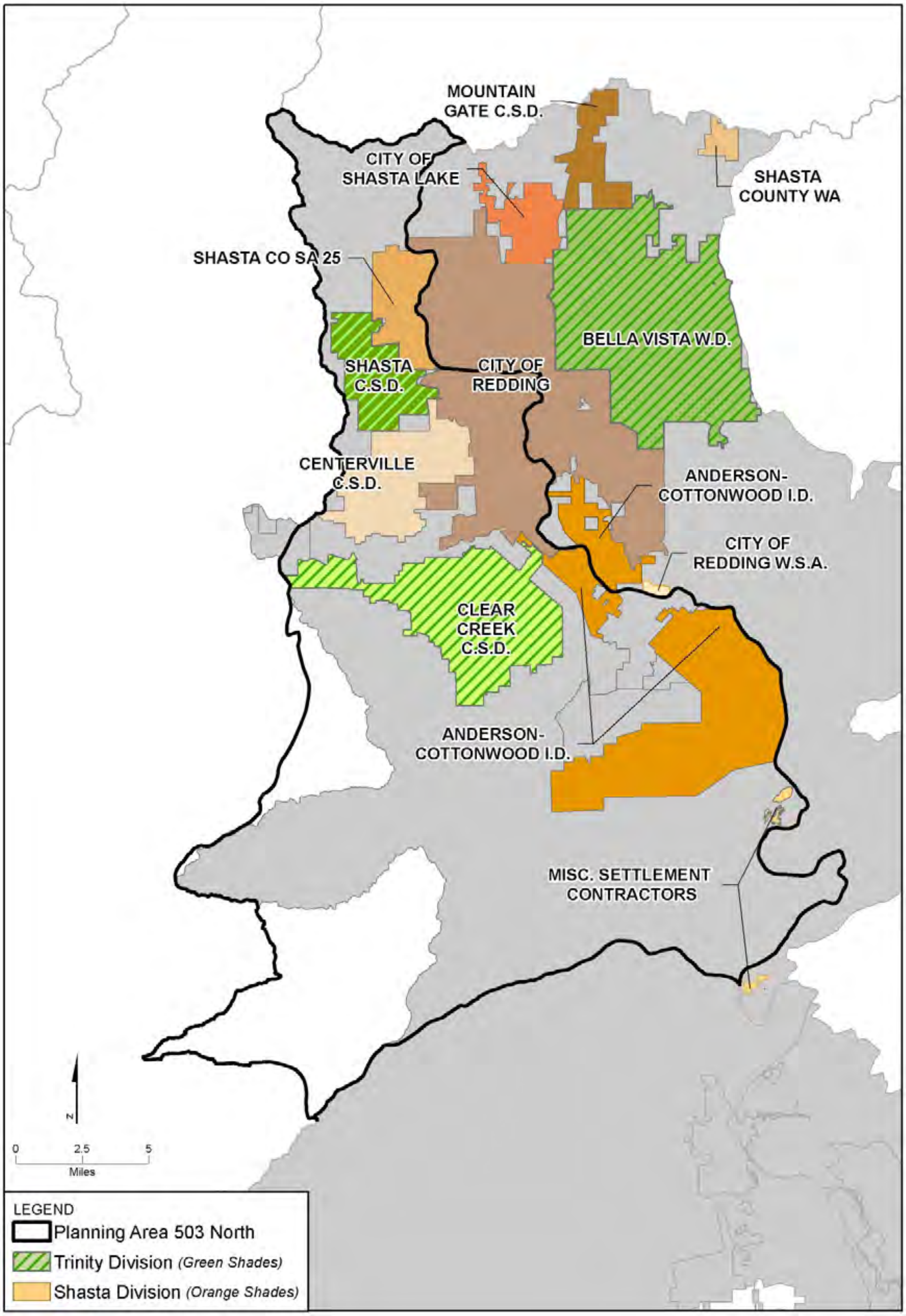
The CVP IRP CalLite model was used to simulate water management in the SWP and CVP systems, with explicit representations of current Delta regulatory requirements and major CVP-SWP and non-project reservoir operations and allocation decisions. The assumptions used in these Baseline simulations included the 2008 U.S. Fish and Wildlife Service and 2009 National Marine Fisheries Service Biological Opinions, State Water Resources Control Board Water Quality Control Plan, State Water Resources Control Board Water Right Decision No. 1641 (D-1641) and other criteria associated with the coordinated operations of the CVP and SWP.

CVP IRP CalLite simulates SWP and CVP operations in the Sacramento Valley, San Joaquin River system, Tulare Lake Region, the Delta, and the SOD export areas. The CVP IRP CalLite model has been set up to perform simulations of the 18-scenario suite for Baseline and somewhat simplified representation of USJRBSI. For each scenario, the CVP IRP CalLite model computes a supply-demand balance within each CVP Division and produces system wide outputs relating to flow, storage, and salinity in the CVP/SWP service areas in the Central Valley and the Delta.

WEAP-CalLite Interaction

The following sections describe the WEAP-CalLite interaction required to perform CVP IRP CalLite simulations using the WEAP-CV output data and how CalLite uses WEAP-CV and CalLite outputs to compute a water balance for each CVP Division.

Agricultural and Urban Demands The WEAP-CV model was used to estimate agricultural and urban demands in each Planning Area. The WEAP simulation does not distinguish between CVP, SWP, and non-project demands. To use this data in the CVP IRP CalLite simulation and to compute demand information for a CVP Division, the demand data produced by WEAP-CV must be disaggregated into different contract types and then mapped to the appropriate CVP Divisions. As an example of how CVP contractor districts relate geographically to Planning Areas, Figure 3-22 depicts the CVP contractors surrounding Planning Area 503 North. The figure shows how each Planning Area can contain multiple CVP contractors, and a CVP contractor can overlap multiple Planning Areas.



Key:
CVP = Central Valley Project

Figure 3-22. CVP Contractor Districts in Planning Area 503 North

A mapping exercise was performed using geographical information system (GIS) to convert the WEAP-CV Planning Area–scale data to CVP Divisions. Conversion of WEAP-CV demand data for use in by the CVP IRP in CalLite involves the following steps:

- Disaggregation of Planning Area data to CalLite nodes by contract type
- Mapping of CalLite node contract type data to CVP Divisions

The disaggregation of demand within each Planning Area is performed by using Microsoft Excel pre-processing spreadsheets that define the percent breakdown of demand types for each land use type in each Planning Area. The breakdown of demand type has been developed using data developed as part of DWR and Reclamation's joint CalSim-III model development effort. A lookup table is used to define the percent of land use for each water demand type in each Planning Area. The following demand types are used:

- CVP: agricultural, municipal and industrial (M&I), Settlement Contractors, Exchange Contractors, and refuges
- SWP: agricultural, M&I, Feather River Service Area
- Non-project: agricultural and M&I

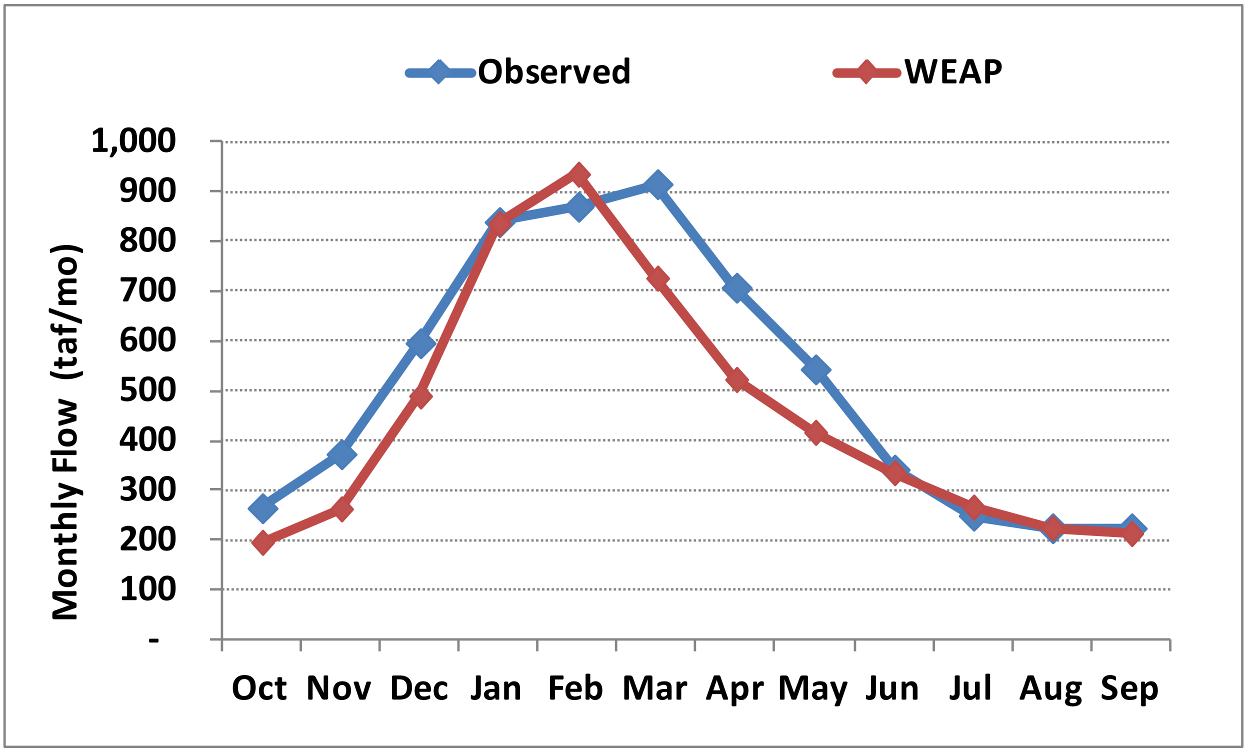
The pre-processing spreadsheets use this information to compute the demand for each demand type in each CalLite node under each scenario. The demand breakdown in each CalLite node is also used to map the CalLite node–scale demand and delivery data to each CVP Division. This is accomplished by identifying the relevant CVP Division of each contractor in each CalLite node and cross-referencing the contract type demand delivery data to the appropriate Division. The total delivery to each CVP Division is then computed as the total for all relevant nodes.

Surface Water and Groundwater Hydrology and Return Flows The CVP IRP CalLite and WEAP-CV models have been enhanced to allow hydrologic and return flow information developed in WEAP-CV to be used as inputs to the CalLite model. The following steps were used to enhance the models:

- The CVP IRP CalLite network was overlain on a map with the Planning Areas, Hydrologic Regions, and the WEAP network.
- The overlay was examined to identify the most appropriate linkage points for integrating rim station and valley floor hydrology, return flows (non-irrigated and irrigated) and surface-groundwater interactions in CVP IRP CalLite and WEAP-CV.
- A data-transfer routine was developed to convert WEAP-CV data to CVP IRP CalLite inputs at each linkage point.

The following sections describe how inputs have been developed at each CVP IRP CalLite node for the rim station locations, for return flows and groundwater-surface water interaction and for the valley floor nodes.

Upper Watershed Hydrology The WEAP-CV model was applied to develop upper watershed runoff values under each scenario. However, a comparison of the WEAP-CV stream flows resulting from a historical simulation with the observed stream flows revealed biases in the modeled flows. As an example, Figure 3-23 shows the difference in monthly values between the WEAP-CV and observed stream flows into Lake Shasta. These biases result from several factors, including spatial and temporal errors in climate model forcings, complex surface water and groundwater interactions, and other complexities normally inherent to hydrologic model parameter calibration. To address these issues, bias corrections of the WEAP-CV stream flows were performed by comparing unimpaired flows varying in time and location for all of the rim inflows used by the CVP IRP CalLite model to better reflect the statistics of the observed stream flows for the historical simulation period. The resulting bias-corrected historical inflows factors were used in the CVP IRP CalLite model to exactly match the annual and monthly averages of the historical observed upper watershed flows. These bias corrections for each inflow location were also used to adjust the upper watershed inflows used for each of the USJRBSI projected future socioeconomic-climate scenarios.



Key:
mo = month
taf = thousand acre-feet
WEAP = Water Evaluation and Planning
WEAP-CV = WEAP model of the Central Valley watershed

Figure 3-23. Comparison of Average Monthly Observed and WEAP-CV Simulated Inflows into Lake Shasta on the Sacramento River Before Adjustment

Valley Floor Hydrology Valley floor hydrology inputs in CVP IRP CalLite were developed using the "Flow to GW No Irrigation" and the "Flow to River No Irrigation" outputs from WEAP-CV. A GIS mapping process was applied to identify the percentage of the flow coming from each WEAP-CV Planning Area that would runoff to each CVP IRP CalLite node and groundwater aquifer. These outputs are mapped to the corresponding CVP IRP CalLite groundwater aquifers and input nodes in the CVP IRP CalLite model.

The irrigation return flow components are dynamically simulated in WEAP-CV and may vary for each scenario. Therefore, the irrigation return flows are computed dynamically in the CVP IRP CalLite model using statistical relationships derived from WEAP-CV results for each Planning Area Reclamation (2013).

Return Flows and Groundwater-Surface Water Interaction
Return flows and groundwater-surface water interaction were also determined dynamically in the CVP IRP CalLite model using equations derived from WEAP-CV results to determine the surface water return flow quantities, surface water-groundwater interactions and groundwater recharge resulting from deliveries in each month. A GIS mapping process was applied to identify the appropriate return flow destinations (i.e., river locations and groundwater aquifers) for each CVP IRP CalLite node. A similar mapping exercise was used to determine the appropriate surface water locations for groundwater-surface water interactions to be implemented for each groundwater aquifer.

Computing a Water Balance for a CVP Division

The water balance for each CVP Division was computed by the CVP IRP CalLite model for the 18 socioeconomic-climate scenarios using the CalLite node-scale demand and hydrology information developed for each scenario with the results of the CVP IRP CalLite simulations. The supply and demand components used in the water balance can be identified by focusing on the inputs and outputs to the local demand node in Figure 3-21. Those that are used to compute supply and demand are listed in Table 3-2 below. The difference between the sum of the supplies and the sum of the demands equals the unmet demand computed by CVP IRP CalLite model. The post-processing routines in CalLite are set up to produce supply and demand information for each CVP Division for each simulation of the 18-scenario suite.

Table 3-2. Components of Supply and Demand Used to Compute Water Balance for CVP Divisions

Supply	Demand
SWP/CVP/non-project deliveries	Urban and agricultural demands
Local inflow and precipitation	Local demand-reduction actions
Local deliveries	
Groundwater pumping	
Local supply-enhancement actions	

Key:
CVP = Central Valley Project
SWP = State Water Project

Application of Additional Performance Assessment Tools

In addition to using metrics available from CVP IRP CalLite, ranges of uncertainty for the Baseline and USJRBSI were evaluated for water quality and temperature, agricultural and urban economics, hydropower, and GHG emmisions metrics. The following tools were used to perform these analyses and generate reporting metric results:

- **Delta water quality –** CVP IRP CalLite produces monthly salinity results at compliance locations in the Bay-Delta system.
- **Urban economics –** The Least Cost Planning Simulation Model (LCPSIM) provides economic results for the San Felipe Division. In addition, the Other Municipal Water Economics Model (OMWEM) is used to perform economic analysis of other urban regions in the remainder of the CVP Service Area.
- **Agricultural economics –** The SWAP model is used to perform economic analysis in agricultural regions in the Central Valley.
- **Water temperature –** The Sacramento River Water Quality Model (SRWQM) and San Joaquin River Water Quality Model (SJRWQM) are used to perform temperature analysis on rivers in the Sacramento and San Joaquin Valleys.
- **Hydropower and GHGs –** LongTermGen (LTGen) and State Water Project Power (SWP_Power) models are used to perform power generation and use analyses for the CVP and SWP systems. These models were enhanced to estimate the GHG emission changes associated with the CVP and SWP pumping and power facilities.

Each of these tools was used to simulate only three selected socioeconomic-climate scenarios for the Baseline and USJRBSI project conditions. The following three scenarios were chosen to reflect a reasonably broad range of potential future uncertainties in both socioeconomic and climate change conditions:

- Current Trends with median temperature change and median precipitation future climate projections (CT-Q5)
- Expansive Growth with higher temperature and lower precipitation than the CT-Q5 scenario (EG-Q2)

- Slow Growth with lower temperature and higher precipitation than the CT-Q5 scenario (SG-Q4)

The following sections provide a brief overview of each of the additional performance assessment tools.

Economic Models A variety of economic modeling tools were applied to assess the sensitivity of agricultural and urban economic conditions in the CVP Service Area to a potential range of 21st century uncertainties in socioeconomic-climate conditions. It is important to note that these simulations were NOT designed to quantify the economic benefits of the USJRBSI project alternatives for the purpose of identifying a preferred project alternative.

Least Cost Planning Simulation Model LCPSIM is an annual time-step urban water service system reliability management model (DWR 2009a). Its objective is to estimate the least-cost water supply management strategy for an area, given the mix of available supplies. The model uses a shortage loss function derived from contingent valuation studies and water agency shortage allocation strategies. It accounts for the ability of shortage management (contingency) measures, including water transfers, to reduce regional costs and losses associated with shortage events. It also considers long-term regional demand reduction and supply augmentation measures in conjunction with regional carryover storage opportunities that can reduce the frequency, magnitude, and duration of those shortage events.

A shortage event, or foregone use, is the most direct consequence of water supply unreliability. Foregone use occurs when, for example, residential users or businesses have established a lifestyle or a level of economic production based on expected availability of water that is not met in a particular year or sequence of years.

Assuming that long-term supply augmentation measures are adopted in order of their cost, with lowest cost measures adopted first, LCPSIM finds the water management strategy that minimizes the sum of the total annual cost of the adopted long-term measures and the total expected annual shortage costs and losses remaining after their adoption. The value of the availability of a supply from a proposed project of future condition, can be determined from the change it produces in this least-cost mix of supply measures and shortages.

The LCPSIM, San Francisco Bay – South model was updated for the CVP IRP for three development scenarios at the 2025, 2055, and 2084 levels of development. Model preparation primarily involved updating model parameters with available population and water portfolio information from Reclamation and DWR's Water Plan Update (2009b). Parameters pertinent to the level of development not available from the Water Plan Update (2009b) were estimated using the existing 2025 and 2055 models. Model preparation also included any necessary adjustment to the model analysis period to accommodate CVP IRP CalLite model outputs.

Other Municipal Water Economics Model Several M&I water providers are not covered by LCPSIM. A set of individual spreadsheet models, collectively called OMWEM, is used to estimate economic benefits of changes in SWP or CVP supplies for potentially affected M&I water providers outside the San Francisco Bay – South region. The model includes CVP M&I supplies north of Delta, SWP and CVP supplies to the Central Valley and the Central Coast, and American River contractors. The model estimates the economic value of M&I supply changes in these areas as the change in cost of shortages and alternative supplies (such as groundwater pumping or transfers).

Data available from 2010 Urban Water Management Plans were used to estimate 2025 water demand and supplies for an average condition and a dry condition, and to identify additional water supply options and their costs. Water demand estimates for 2055 and 2084, at the three development scenarios, are based on population projections developed for the CVP IRP study. For each level of development and development scenario OMWEM uses project water supplies to match supply to demand. If supply is insufficient to meet demand in years categorized as below normal water supply or greater, the model calculates the cost of additional water supplies.

South Bay Water Quality Model South Bay Water Quality Model (SBWQM) is used by the CVP IRP to perform M&I salinity assessment for the portion of the San Francisco Bay Area region from Contra Costa County in the North to Santa Clara County in the South. The model was originally developed and used for the economic evaluation of a proposed expansion of Los Vaqueros Reservoir (Reclamation 2006). It uses estimated relationships between salinity and damages to residential appliances and fixtures to estimate the benefits from changes in salinity. Specific model outputs compare change in average salinity and change in annual salinity costs.

The model inputs include project water supply and chloride concentrations in mg/L from CVP IRP CalLite. Separate calculations were provided for Contra Costa Water District (CCWD) and agencies that use the South Bay Aqueduct. For CCWD, water quality estimates were based on diversion volume and water quality at Old River and Rock Slough. For the other areas, water quality is based on diversion volume and salinity at Banks Pumping Plant. Changes in water quality at the City of Antioch's diversion were used to estimate additional cost of treatment or replacement supply.

The SBWQM was updated for three development scenarios at three levels of development, 2025, 2055, and 2084. Model preparation involved updating available population and water portfolio information from Reclamation and DWR's Water Plan Update (2009b).

Statewide Agricultural Production Model The SWAP model is a regional model of irrigated agricultural production and economics that simulates the decisions of agricultural producers (farmers) in California (Howitt et al. 2012). Its data coverage is most detailed in the Central Valley, but it also includes production regions in the Central Coast, South Coast, and desert areas. The model assumes that farmers maximize profit subject to resource, technical, and market constraints. Farmers sell and buy in competitive markets, and no one farmer can affect or control the price of any commodity. The model selects those crops, water supplies, and other inputs that maximize profit subject to constraints on water and land, and subject to economic conditions regarding prices, yields, and costs.

SWAP incorporates project water supplies (SWP and CVP), other local water supplies, and groundwater. As conditions change within a SWAP region (e.g., the quantity of available project water supply increases or the cost of groundwater pumping increases), the model optimizes production by adjusting the crop mix, water sources and quantities used, and other inputs. It also fallows land when that appears to be the most cost-effective response to resource conditions.

The SWAP model covers 27 agricultural subregions in the Central Valley that are analyzed by the CVP IRP. The SWAP model is used to compare the short or long-run response of agriculture to potential changes in SWP and CVP irrigation water delivery, other surface or groundwater conditions, or other economic values or restrictions. Results from the CVP IRP CalLite model are used as inputs into SWAP through a standardized data linkage tool. Groundwater analysis is used to develop assumptions, estimates, and, if appropriate, restrictions on pumping rates and pumping lifts for use in SWAP. Model output includes intensive and extensive margin production response by agriculture, input use per acre and aggregate input use, respectively.

Water Temperature Models SRWQM and SJRWQM were developed by Reclamation to simulate temperature in the upstream CVP reservoirs and river on the upper Sacramento River system and on the San Joaquin River system. A more detailed description of SRWQM and the calibration performance is included in the calibration report (RMA 2003). The models were developed using integrated HEC-5 and HEC-5Q models. SRWQM simulates mean daily reservoir and river temperatures at Shasta, Trinity, Lewiston, Whiskeytown, Keswick and Black Butte Reservoirs and the Trinity River, Clear Creek, the upper Sacramento River from Shasta to Knights Landing, and Stony Creek based on the flow and meteorological parameters on a 6-hour time step. SJRWQM simulates mean daily reservoir and river temperatures at on all major tributaries and reservoirs in the San Joaquin River system upstream from Vernalis based on flow and meteorological parameters on a 6-hour time step.

Hydropower and GHG Models The hydropower analysis uses spreadsheet post-processors that evaluate the power impacts of flow scenarios from CalSim-II operations studies on a monthly time step. The following post-processor tools are used in the analysis:

- LTGen: analyzes CVP facilities
- SWP_Power: analyzes SWP facilities

The tools estimate average annual energy generation and use at SWP and CVP facilities. For generation facilities, the tools estimate average annual energy generation as well as average annual peaking power capacity. For pumping facilities, the tools estimate average annual energy requirements. The tools also check to determine whether off-peak energy use targets are being met. Transmission losses are estimated for both pumping and generation facilities.

For the CVP IRP, LTGen and SWP_Power have been enhanced to estimate net GHG emissions that are related to energy use at the major project facilities so that a “relative” carbon footprint can be evaluated for each new water management scenario. The net GHG emissions are used as an additional performance metric in the CVP IRP analysis.

Socioeconomic-Climate Scenario Assessment Results

Performance Metrics

Performance metrics provide a common technical basis for analyzing the effects of socioeconomic-climate uncertainties. These analyses were performed using performance metrics related to water supply and demand, water quality (salinity and temperature), hydropower, GHG emissions, urban and agricultural economics. These metrics were quantified using the outputs of the CVP IRP modeling tools for the Baseline (without project) and USJRBSI project as described in the sections below.

Assessment of Potential Socioeconomic–Climate Uncertainties with No Action (Baseline) Conditions

The purpose of the Baseline analyses described in this section is to evaluate the sensitivity of some of the important water management system performance characteristics to a wide range of future uncertainties in socioeconomic and climate conditions potentially occurring in the 21st century. In this regard, the term “Baseline” refers to a future socioeconomic scenario which was simulated without the presence of a USJRBSI with project alternative. The Baseline Conditions simulations are NOT predictions of future conditions rather they are intended to characterize a reasonably large range of uncertainties influencing some of the most significant decision making criteria.

The CVP IRP model package was used to quantify the imbalance between supply and demand in each of the CVP Divisions and to generate other performance metrics for Baseline Conditions across the range of future socioeconomic-climate scenarios. The assumptions used in these Baseline simulations included the 2008 Fish and Wildlife Service and 2009 National Marine Fisheries Service Biological Opinions, State Water Resources Control Board Water Quality Control Plan, D-1641 and other criteria associated with the coordinated operations of the CVP and SWP. The CVP IRP CalLite model assumptions have some differences as compared to those used in CalSim-II for the USJRBSI program primarily due to the simplification inherent in the CVP IRP CalLite implementation of the CVP/SWP system. More detailed information is presented in Reclamation (2013).

Baseline system results have been developed for the following performance metric categories for each of the socioeconomic-climate scenarios:

- Water Supplies
- Applied Water Demands
- CVP and SWP System Operations
- Supplies and Demands in CVP Divisions
- Results of Other Performance-Assessment Tools

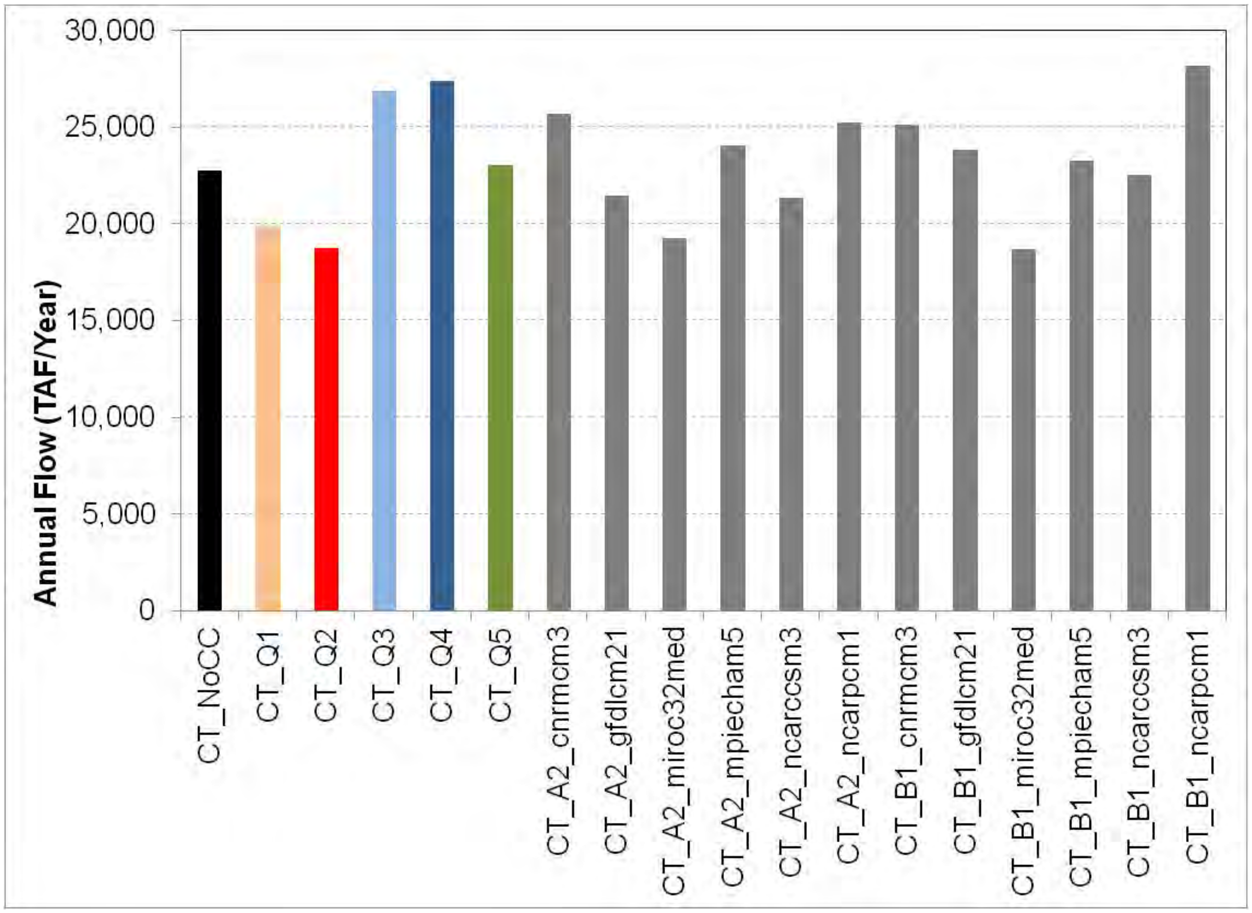
These are described in the sections below.

Water Supplies

Figure 3-24 through 3-27 show the average annual runoff in the Sacramento River system upstream from Hood, the Eastside Streams and the Delta, San Joaquin River system upstream from Vernalis, and Tulare Lake hydrologic region for each of the six projected ensemble informed climate scenarios (Q1,Q2,Q3,Q4,Q5) for the period of water years from 2012 through 2099. Also shown on the figures are results from 6 Global Circulation Models (GCM) selected by the State of California's Climate Action Team as being capable of providing reasonably representative simulations California climate characteristics during the historical period. The 12 future GCM projections were produced by these 6 GCMs by using 2 SRES emissions scenarios, the A2 (higher) and B1 (lower) scenarios. As can be observed, the 12 individual GCM projections are well within the range of the ensemble informed Q1 thru Q5 projections. These individual supply projections are presented here for informational purposes only. The Baseline Conditions and with project analyses described in subsequent sections are based on the ensemble informed projections which include these individual projections in the representative Q1 through Q5 projections.

In general, there is very little difference in water supplies between the different socioeconomic scenarios (CTs, EG, and SG) because urban water demands are relatively insensitive to climate variability and occur primarily in the downstream reaches of the major river systems. However, there are substantial differences in runoff among the different climate scenarios. Under the no climate change (NoCC) scenario, average annual runoff was about 22,739 thousand acre feet (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.

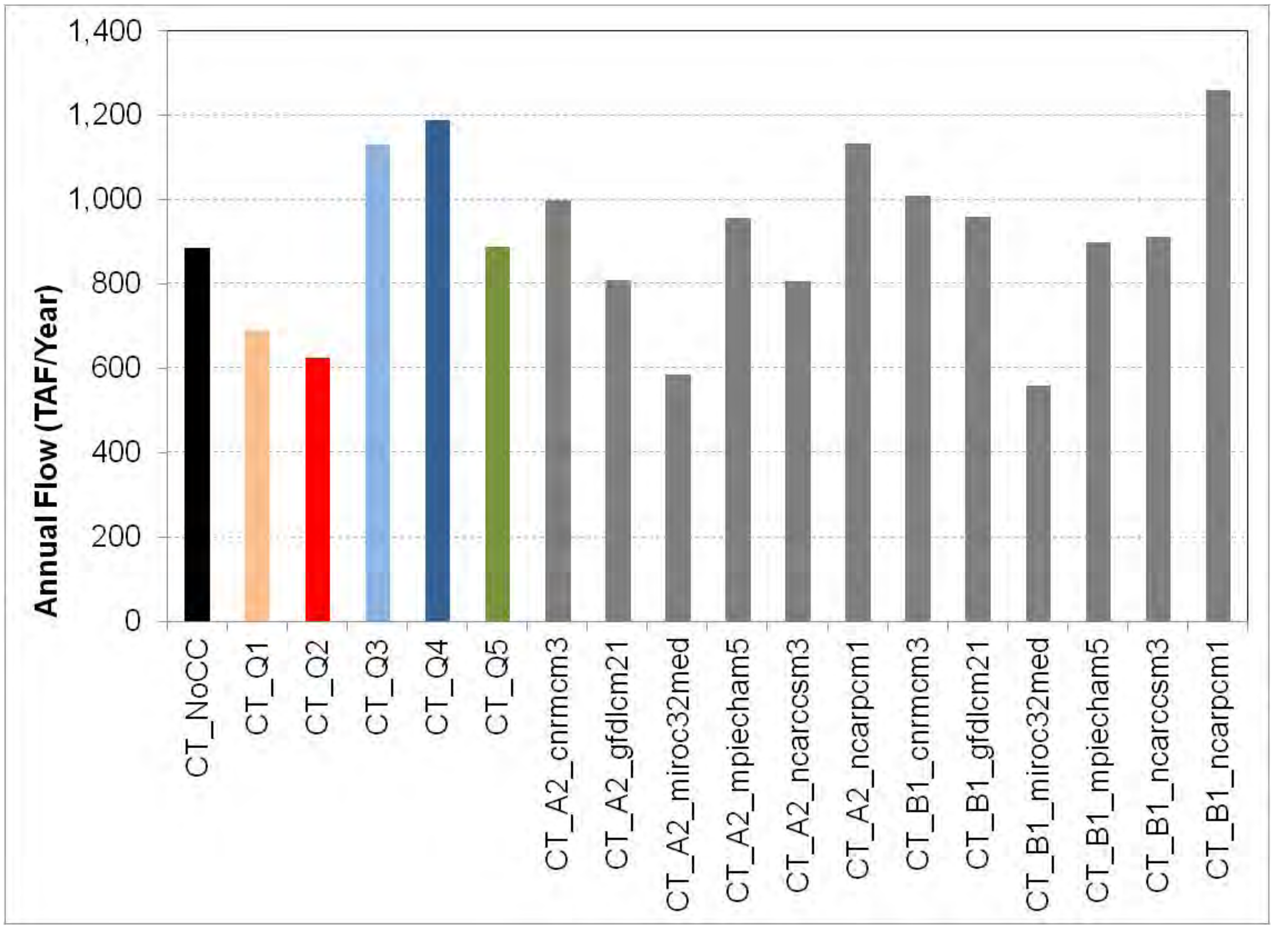
The projected average annual runoff in the Sacramento River system was 23,050 (Q5) to 23,230 (Climate Acton Team (CAT) mean) TAF/year, ranging between 18,715 and 28,190 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was 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.



Key:
TAF = thousand acre feet

Figure 3-24. Average Annual Runoff (TAF/year) in the Sacramento River System for each Scenario

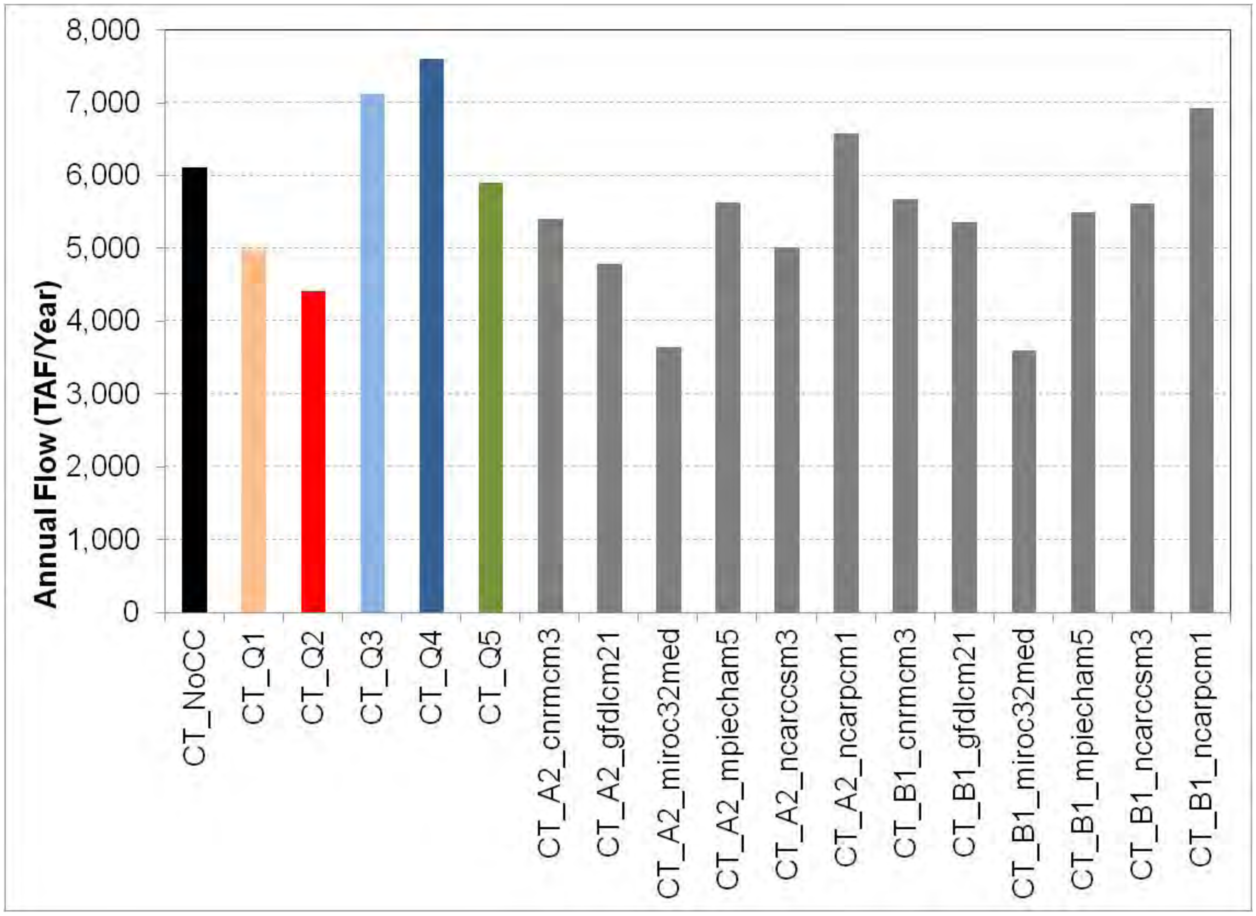
The projected average annual runoff in the East Side streams and the Delta River system was 888 (Q5) to 907 (CAT mean) TAF/year, ranging between 558 and 1,260 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was only slightly 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.



Key:
TAF = thousand acre feet

Figure 3-25. Average Annual Runoff (TAF/year) in the Eastside Streams and Delta for each Scenario

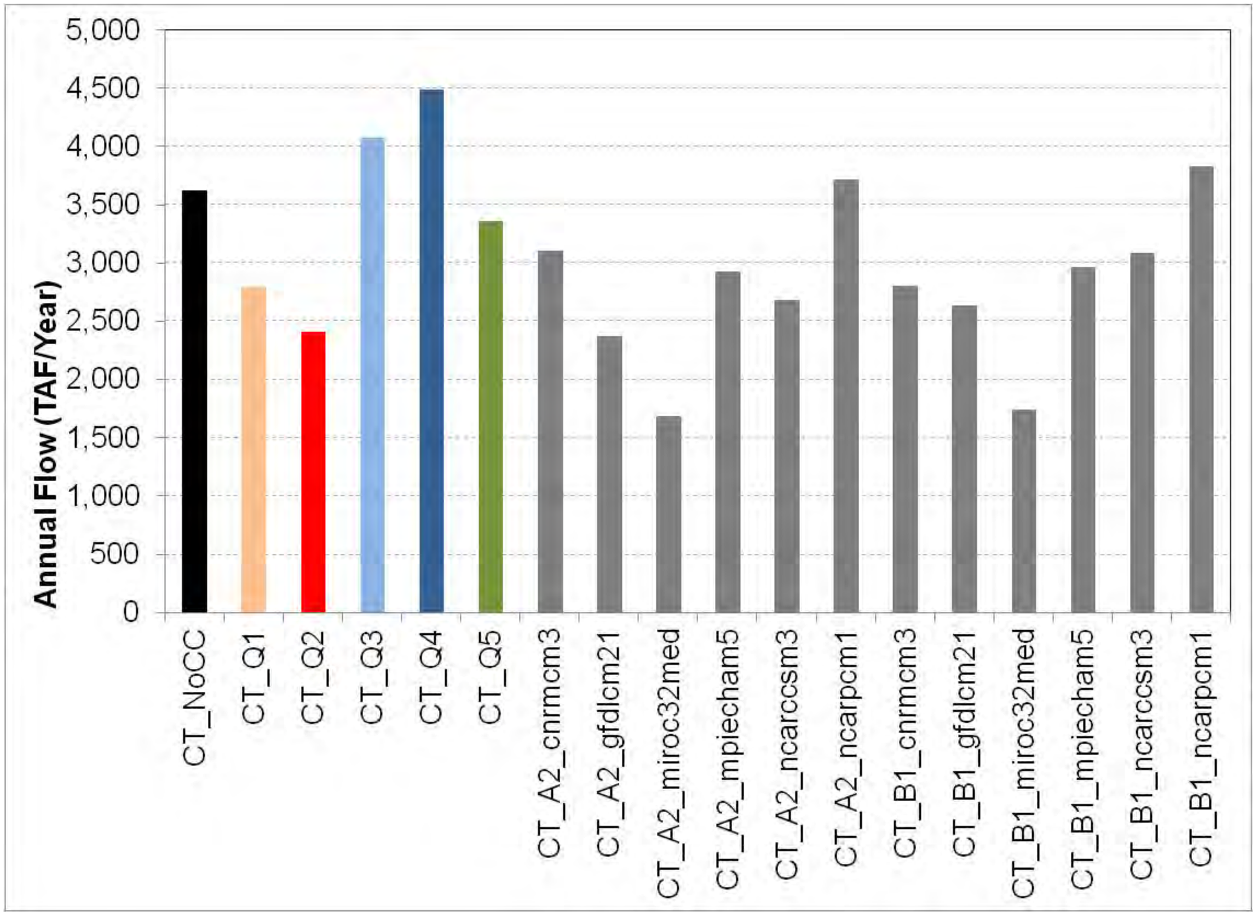
The projected average annual runoff in the San Joaquin River system was 5,899 (Q5) to 5,312 (CAT mean) TAF/year, ranging between 3,604 and 7,609 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was about 4 percent lower than 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.



Key:
TAF = thousand acre feet

Figure 3-26. Average Annual Runoff (TAF/year) in the San Joaquin River System in each Scenario

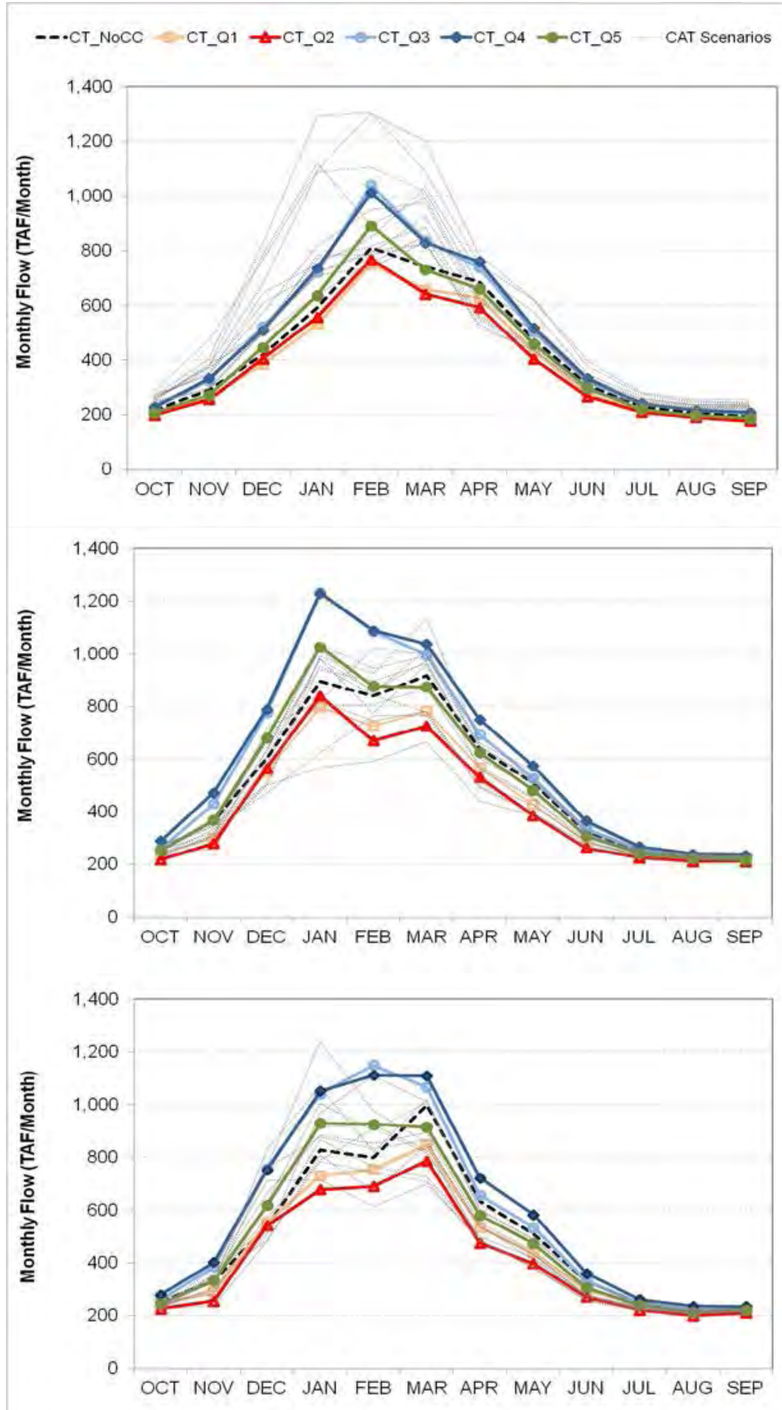
The projected average annual runoff in the Tulare Lake system was 3,358 (Q5) to 2,796 (CAT mean) TAF/year, ranging between 1,683 to 4,487 TAF/year over the simulation period of water years 2012 through 2099. In the median climate scenario (Q5), average annual runoff was about 7.4 percent lower than the 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.



Key:
TAF = thousand acre feet

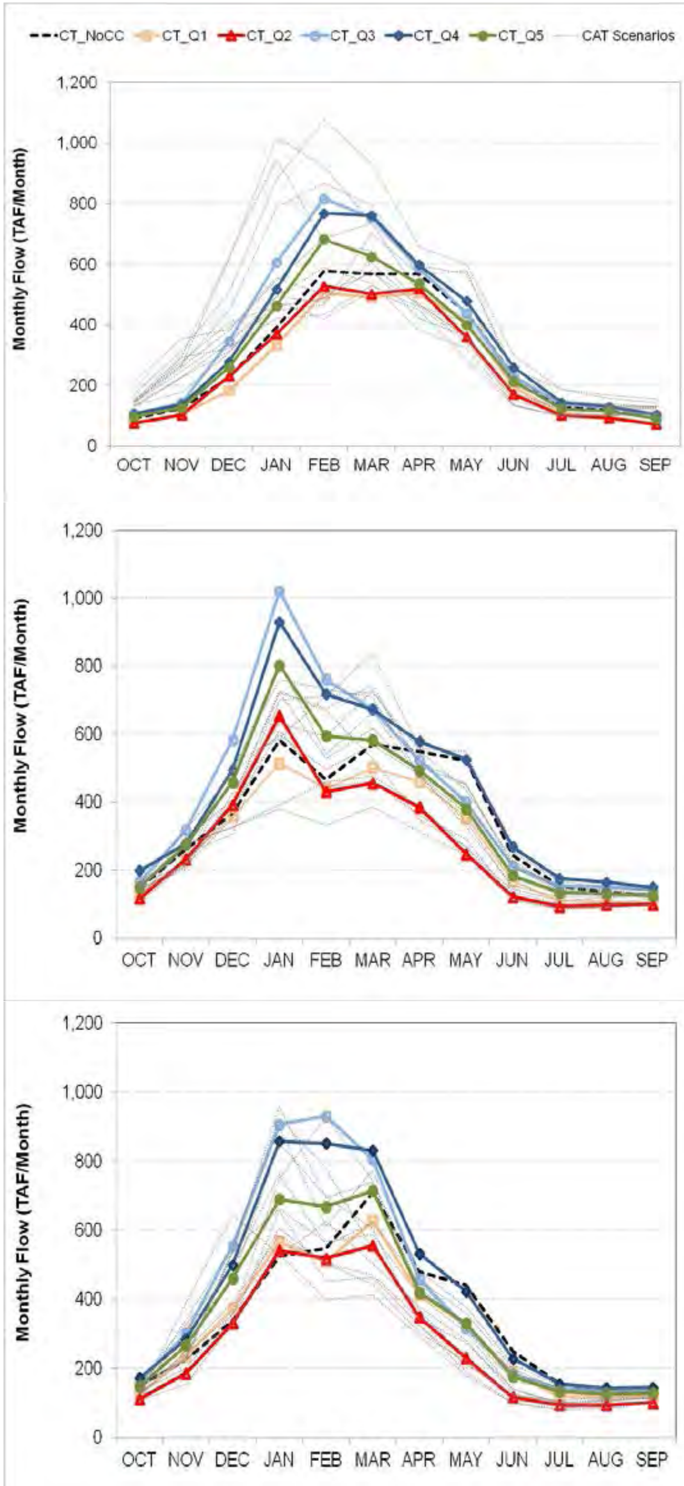
Figure 3-27. Average Annual Runoff (TAF/year) in the Tulare Lake Region in each Scenario

Figure 3-28 through Figure 3-33 show the monthly pattern of inflow to the major reservoirs in the study area. Each basin has a different monthly pattern reflecting the precipitation-runoff characteristics of the basin. In each basin, the climate scenarios exhibit a similar pattern to the central tendency-no climate change (CT_NoCC) scenario but with a shift in runoff from the spring months to the winter months, which results from the occurrence of higher temperatures during winter in all the climate projections causing earlier snowmelt runoff. This seasonal shift is greater in basins where the elevation of the historic snowpack area is lower and therefore more effected by warming induced changes of precipitation from snow to rain. The shift in runoff can be seen most clearly by comparing the pattern of CT_Q5 to CT_NoCC in the Sacramento Valley (e.g., Figure 3-29) with the same scenarios in the Tulare Lake region (e.g., Figure 3-33).



Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.
Key:
TAF = thousand acre feet

Figure 3-28. Average Runoff in each Month (TAF/month) into Shasta Reservoir by Climate Scenario

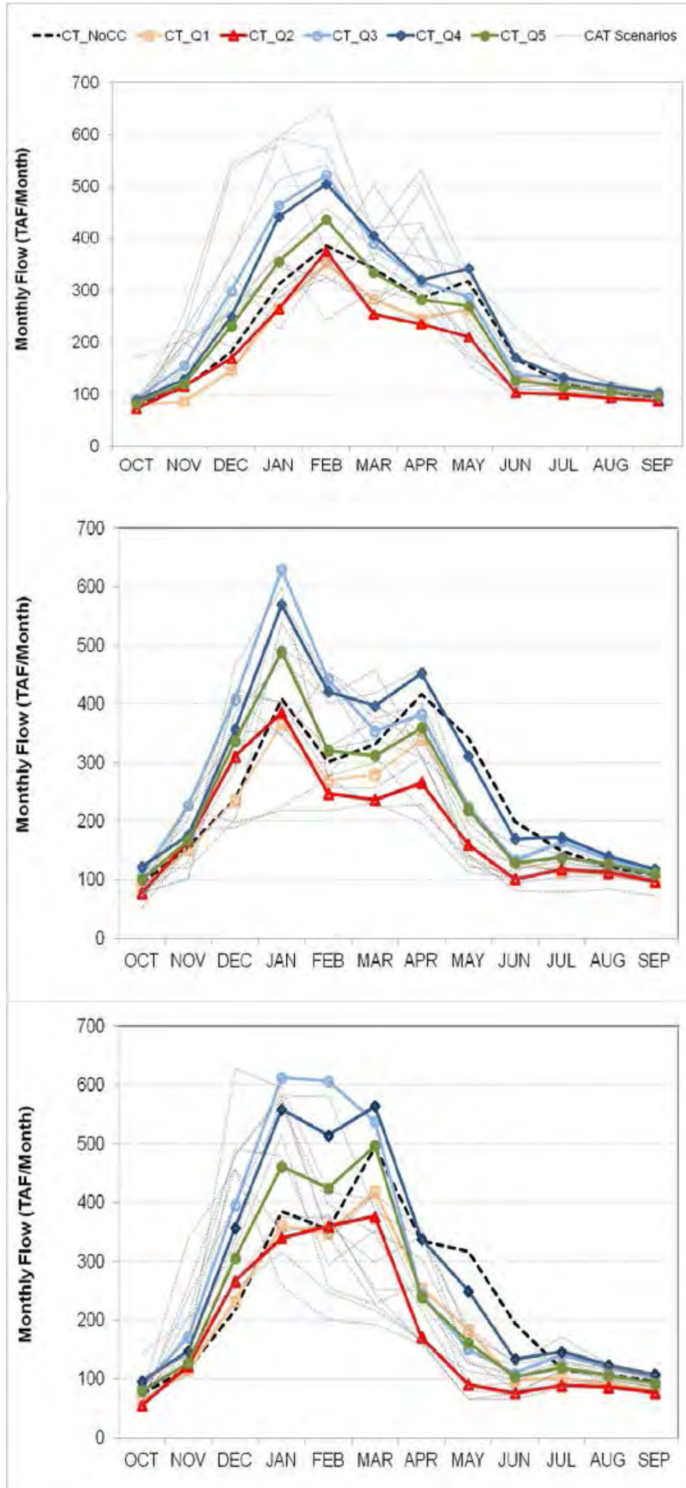


Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.

Key:

TAF = thousand acre feet

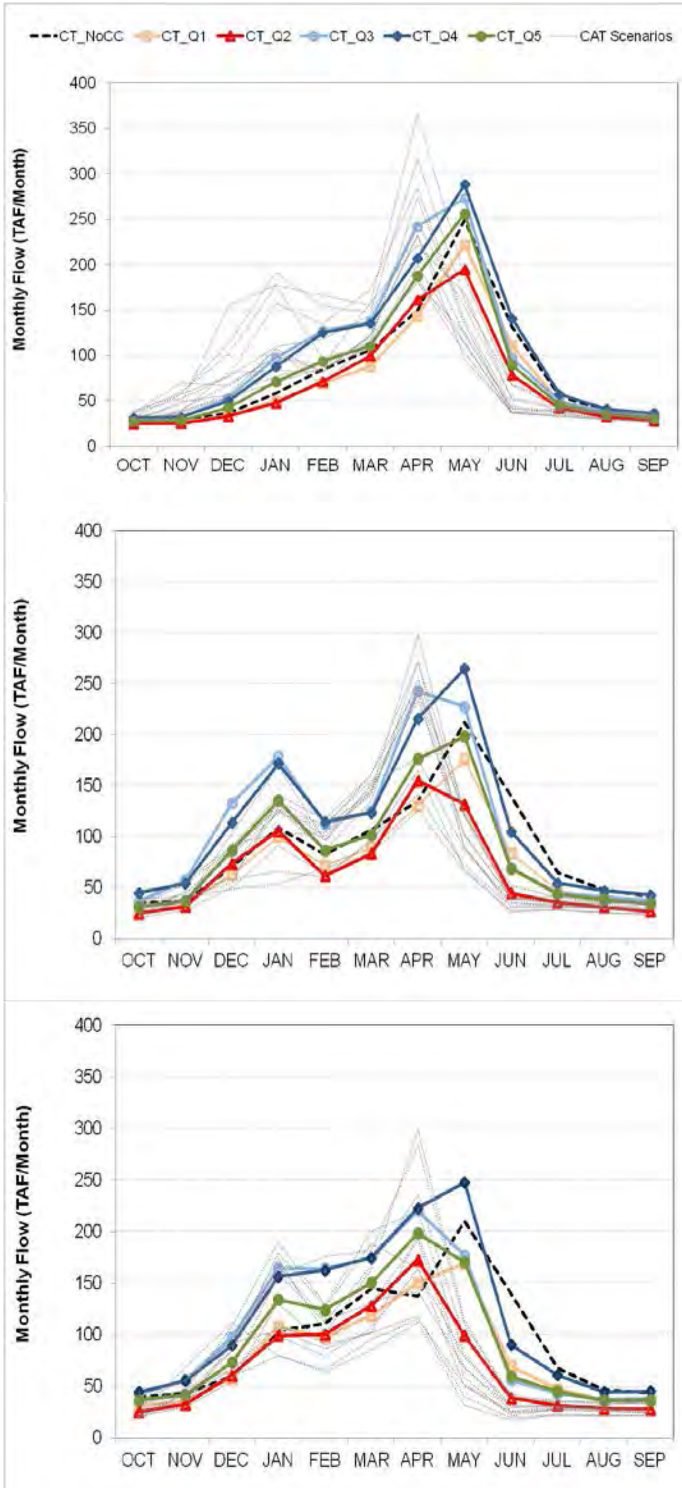
Figure 3-29. Average Runoff in each Month (TAF/month) into Oroville Reservoir by Climate Scenario



Key:
TAF = thousand acre feet

Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.

Figure 3-30. Average Runoff in each Month (TAF/month) into Folsom Lake Reservoir by Climate Scenario

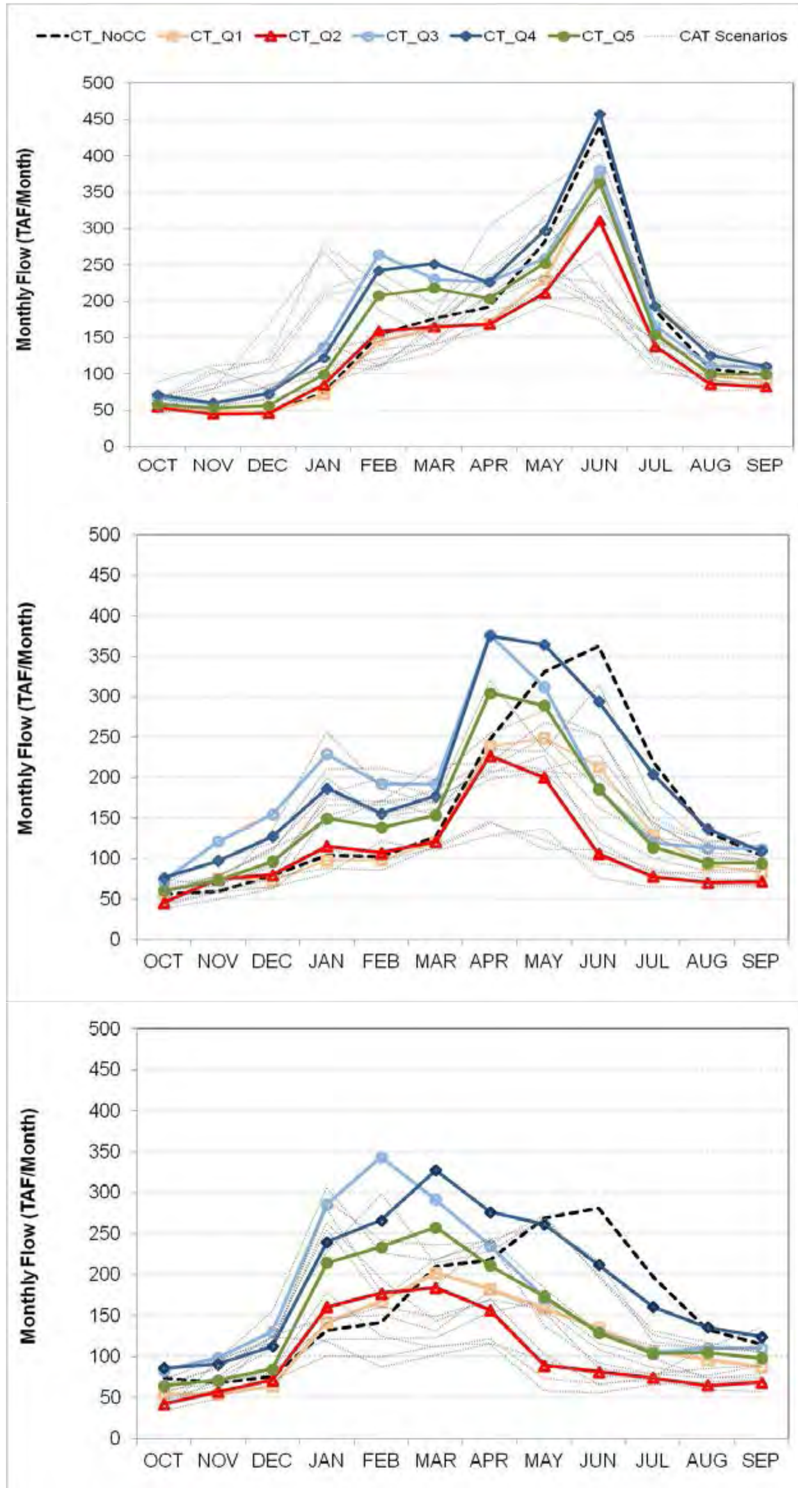


Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.

Key:

TAF = thousand acre feet

Figure 3-31. Average Runoff in each Month (TAF/month) into New Melones Reservoir by Climate Scenario

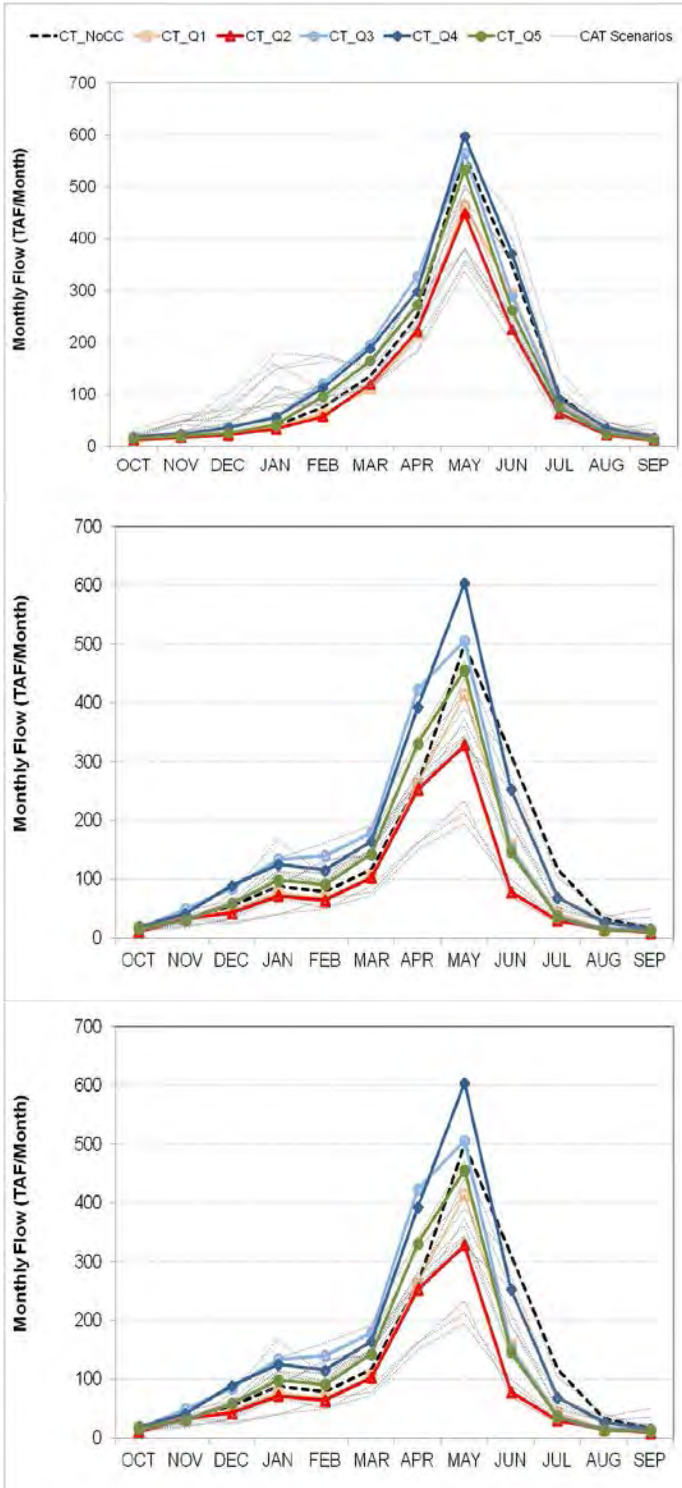


Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.

Key:

TAF = thousand acre feet

Figure 3-32. Average Runoff in each Month (TAF/month) into Millerton Reservoir by Climate Scenario



Note: Top panel: Long-term average over 2012 through 2040, Middle panel: Long-term average over 2041 through 2070, Bottom panel: Long-term average over 2071 through 2099.

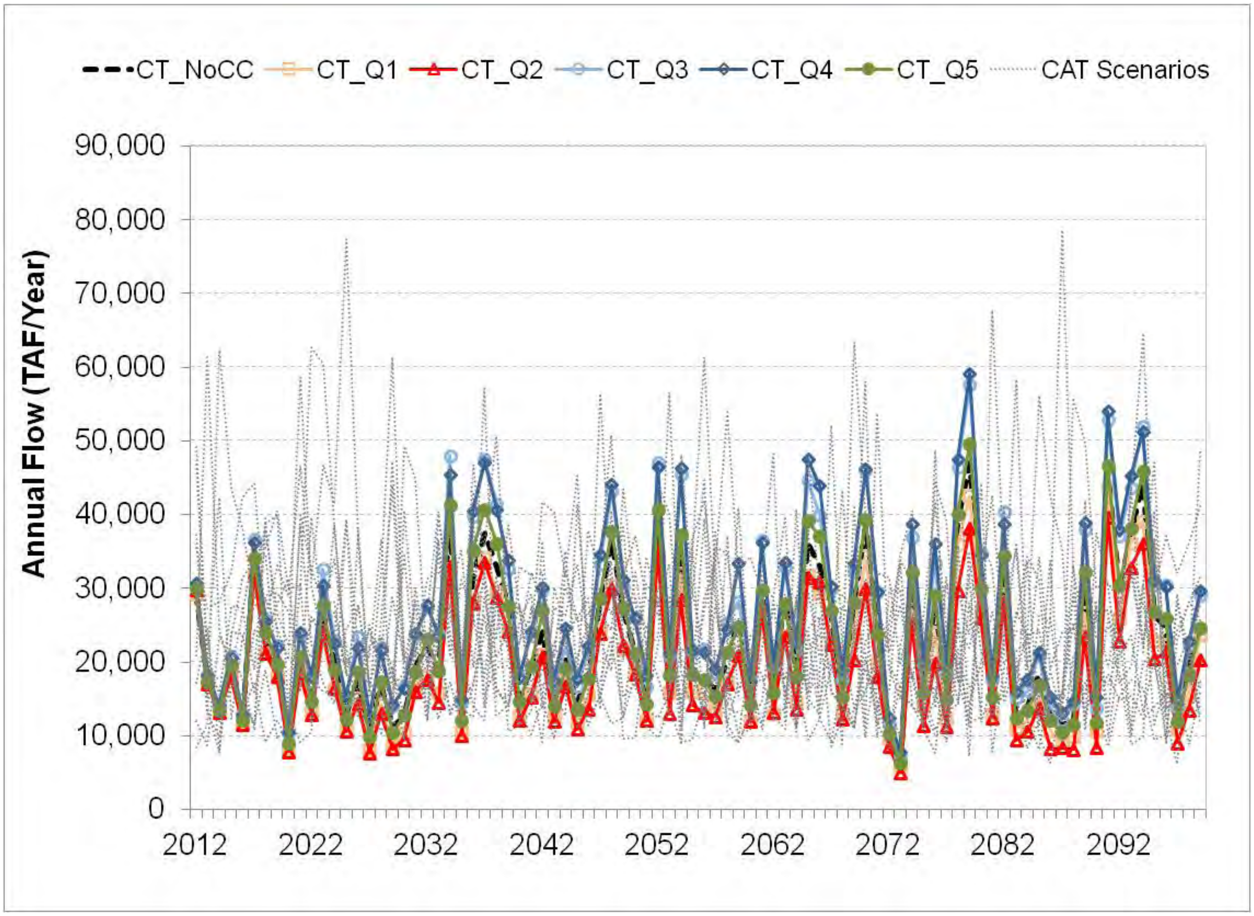
Key:

TAF = thousand acre feet

Figure 3-33. Average Runoff in each Month (TAF/month) into Pine Flat Reservoir by Climate Scenario

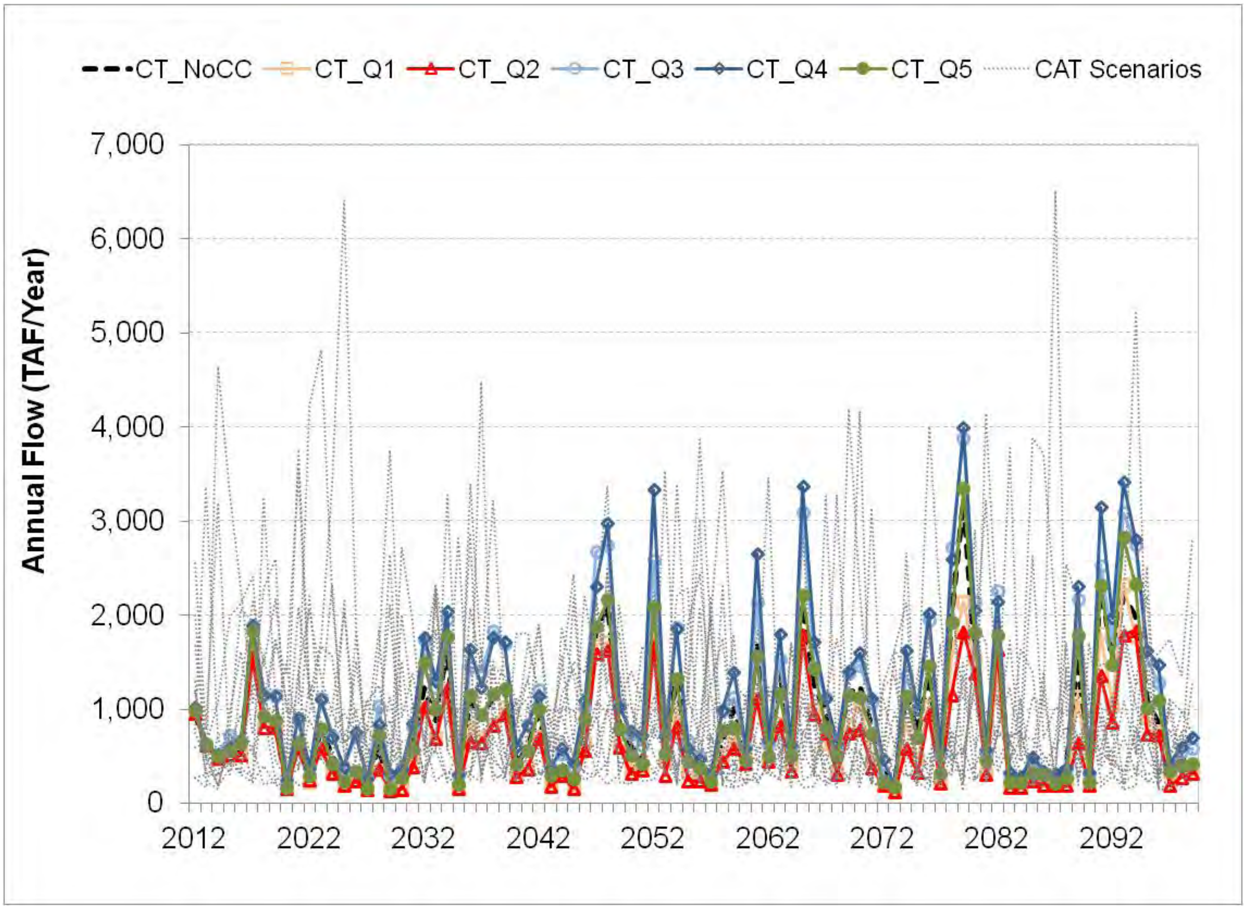
Figure 3-34 through Figure 3-37 show the annual time series of runoff in the Sacramento River system, the Eastside Streams and the Delta, San Joaquin River system, and Tulare Lake regions under each of CTs scenarios during the period from 2012 through 2099. The future time series reflect the same inter-annual variability as the historical period because of the methodology used in developing the projections, with extended drought periods with lower runoff values from 2025-2030 (corresponding to 1929-1934 dry period) and from 2083-2088 (corresponding to 1987-1992 drought), and a very substantial dry period from 2072-2073 (corresponding to 1976-1977 minimum precipitation years). However, as can be observed in the figures, the magnitude of the events is different than the CT_NoCC.

In the Sacramento River system, the mean annual change in flow over the 21st century ranges from -17.6 percent (CT_Q2) to +20.4 percent (CT_Q4) with the central tendency projection (CT_Q5) being +1.4 percent. In the Eastside streams and Delta region, the mean annual change in flow over the 21st century ranges from -29.6 percent (CT_Q2) to +34.0 percent (CT_Q4) with the central tendency projection being +0.2 percent. In the San Joaquin River system, the mean annual change in flow over the 21st century ranges from -27.9 percent (CT_Q2) to +24.5 percent (CT_Q4) with the central tendency projection being +-3.5 percent. In the Tulare Lake region, the mean annual change in flow over the 21st century ranges from -33.4 percent (CT_Q2) to +23.8 percent (CT_Q4) with the central tendency projection being -7.4 percent. Based the central tendency projections there is overall tendency toward declining stream flow from the north to the south.



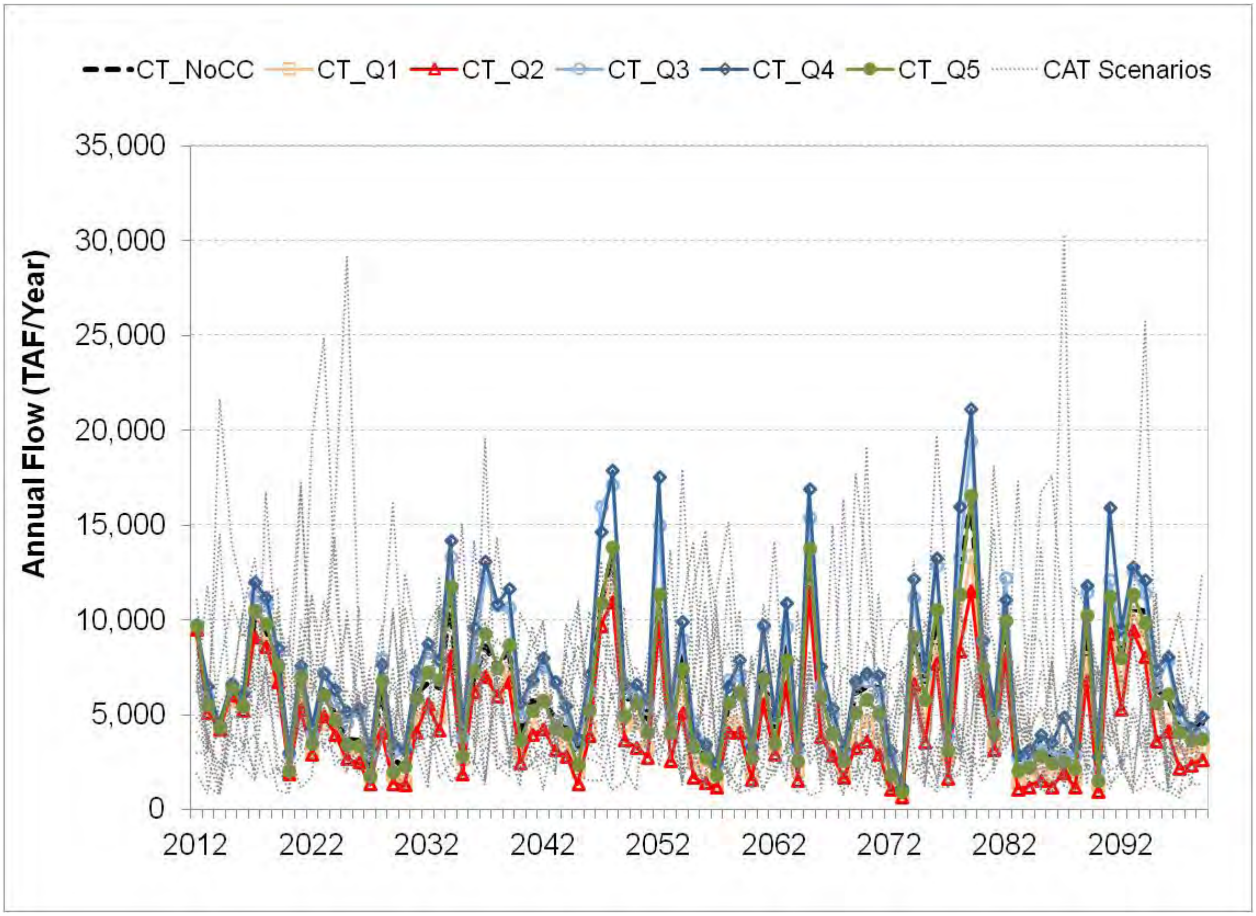
Key:
CAT = Climate Action Team
TAF = thousand acre feet

Figure 3-34. Annual Time Series of Runoff (TAF/year) in the Sacramento River System in each Climate Scenario



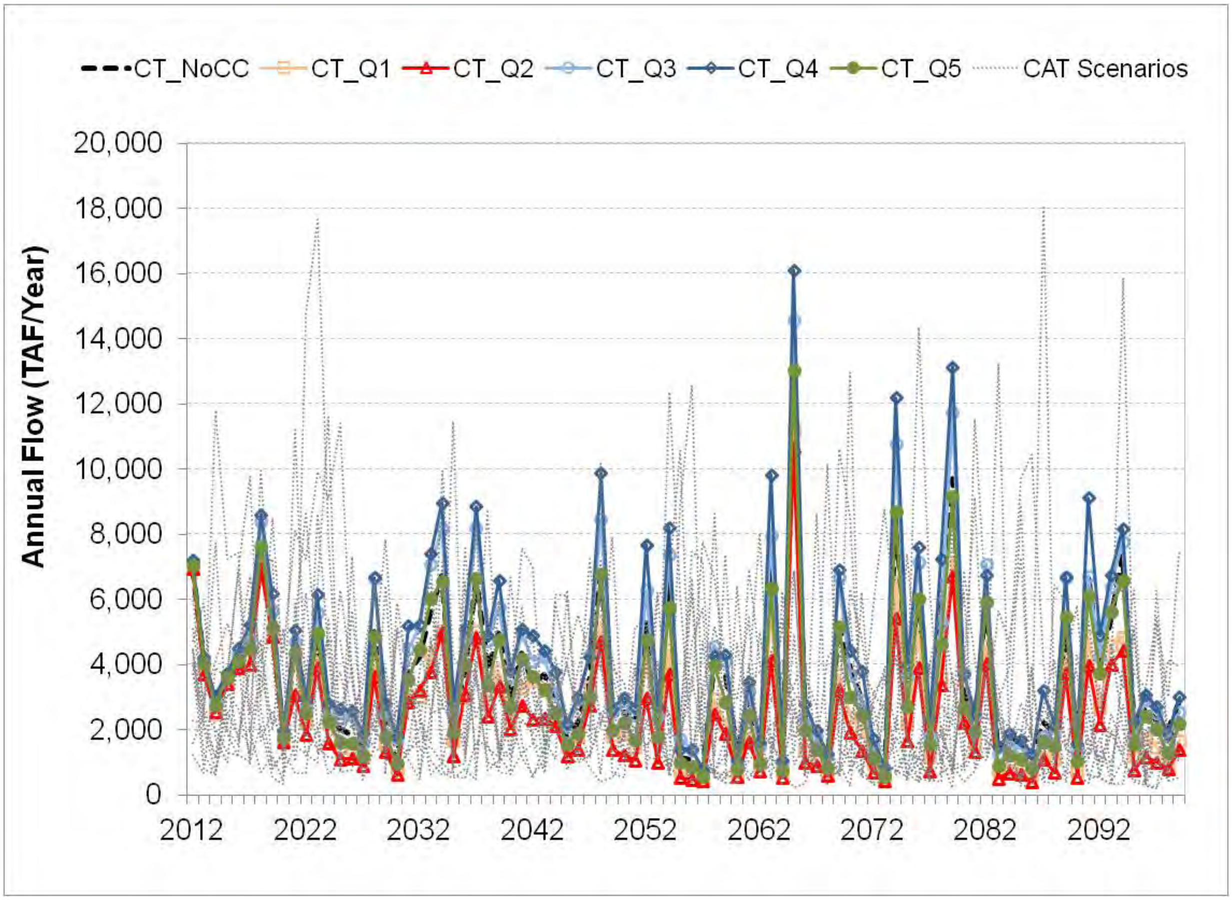
Key:
CAT = Climate Action Team
TAF = thousand acre feet

Figure 3-35. Annual Time Series of Runoff (TAF/year) in the Eastside Streams and Delta in each Climate Scenario



Key:
CAT = Climate Action Team
TAF = thousand acre feet

Figure 3-36. Annual Time Series of Runoff (TAF/year) in the San Joaquin River System in each Climate Scenario



Key:
CAT = Climate Action Team
TAF = thousand acre feet

Figure 3-37. Annual Time Series of Runoff (TAF/year) in the Tulare Lake Region in each Climate Scenario

Applied Water Demands

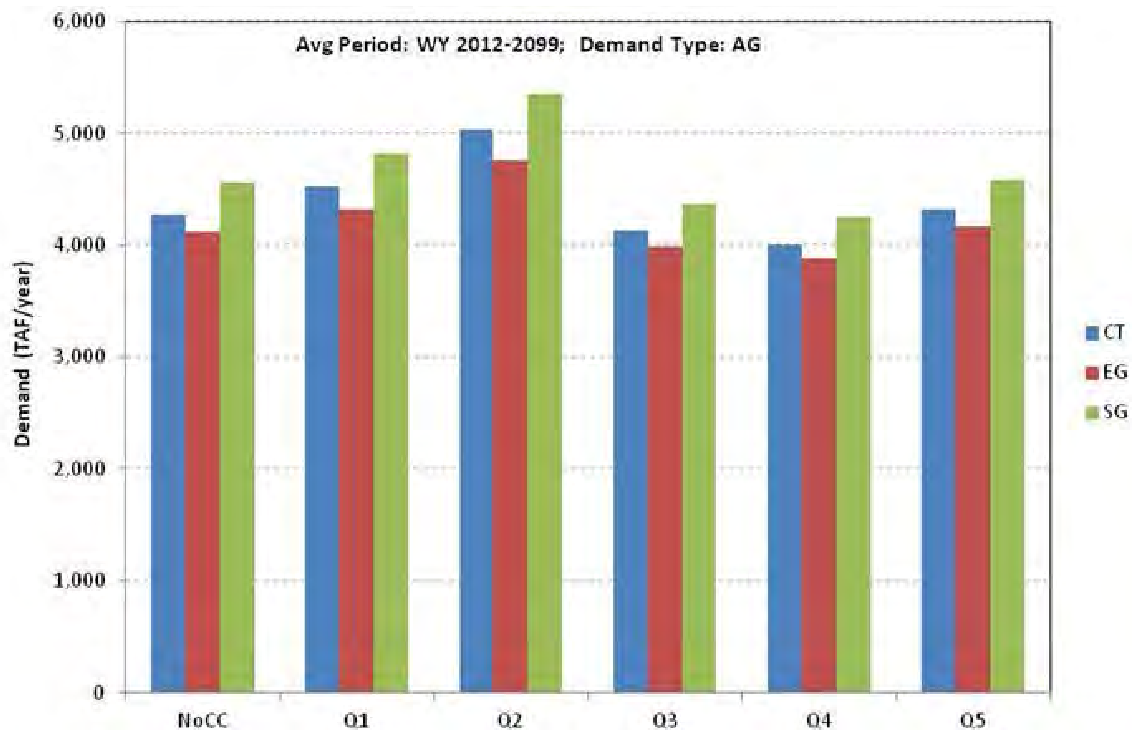
Figure 3-38 through Figure 3-45 show the average annual agricultural and urban applied water demands for the CVP, SWP and non-project water users in the Sacramento River system, the Eastside Streams and the Delta, San Joaquin River system, and Tulare Lake region for each of the socioeconomic-climate scenarios over the projected period of water years from 2012 through 2099. Under NoCC condition, average total average annual demand is about 5.5-5.7 million acre-feet (MAF)/year in the Sacramento River system, 1.4 MAF/year in the Eastside Streams and Delta, 5.8-6.5 MAF/year in the San Joaquin River system, and 14.7-16.3 MAF/year in the Tulare Lake region.

Total agricultural and urban water demands (including CVP, SWP and non-project) vary across both the range of socioeconomic scenarios and across the range of climate scenarios. In all the basins, agricultural demands show a strong relationship with the climate scenarios. Although the magnitudes differ between basins because of differences in crops and acreages, the overall relationship between precipitation and agricultural demand is similar in all the basins. While the median climate scenarios (Q5), have demands that are similar to the no climate change scenario, the drier climate scenarios (Q1 and Q2) have average demands that are higher than the no climate change scenario (ranging from 7-17 percent higher), while the wetter climate scenarios (Q3 and Q4) have average demands that are less than the no climate change scenario (ranging from 9-13 percent lower). Among the socioeconomic scenarios, the EG scenario has lower agricultural demands than the CTs scenario because the assumed rate of urban expansion into agricultural lands is greater in the EG scenario. Conversely, the SG scenario has higher agricultural demands than the CT scenario because of the lesser amount of agricultural to urban land conversion.

In the Sacramento River system, the overall average agricultural demand change including all the socioeconomic scenarios relative to their corresponding NoCC scenarios is about 0-1 percent higher for the central tendency (Q5) and ranges from – 3-7 percent lower in the wetter Q3 and Q4 scenarios to + 5-18 percent higher in the drier Q1 and Q2 scenarios. In the Eastside Streams and Delta system, the overall average agricultural demand change relative to the no climate change scenario is -3 percent in Q5 and ranges from –6-10 percent in the wetter Q3 and Q4 scenarios to + 0-16 percent in the drier Q1 and Q2 scenarios. In the San Joaquin River system, the overall average agricultural demand change relative to the no climate change scenario is - 0-9 percent in Q5 and ranges from – 11-22 percent in the wetter Q3 and Q4 scenarios to + 0-22 percent in the drier Q1 and Q2 scenarios. In the Tulare Lake Region, the overall average agricultural demand change relative to the no climate change scenario is 1-2 percent higher in Q5 and ranges from –12-18 percent lower in the wetter Q3 and Q4 scenarios to +10-20 percent higher in the drier Q1 and Q2 scenarios.

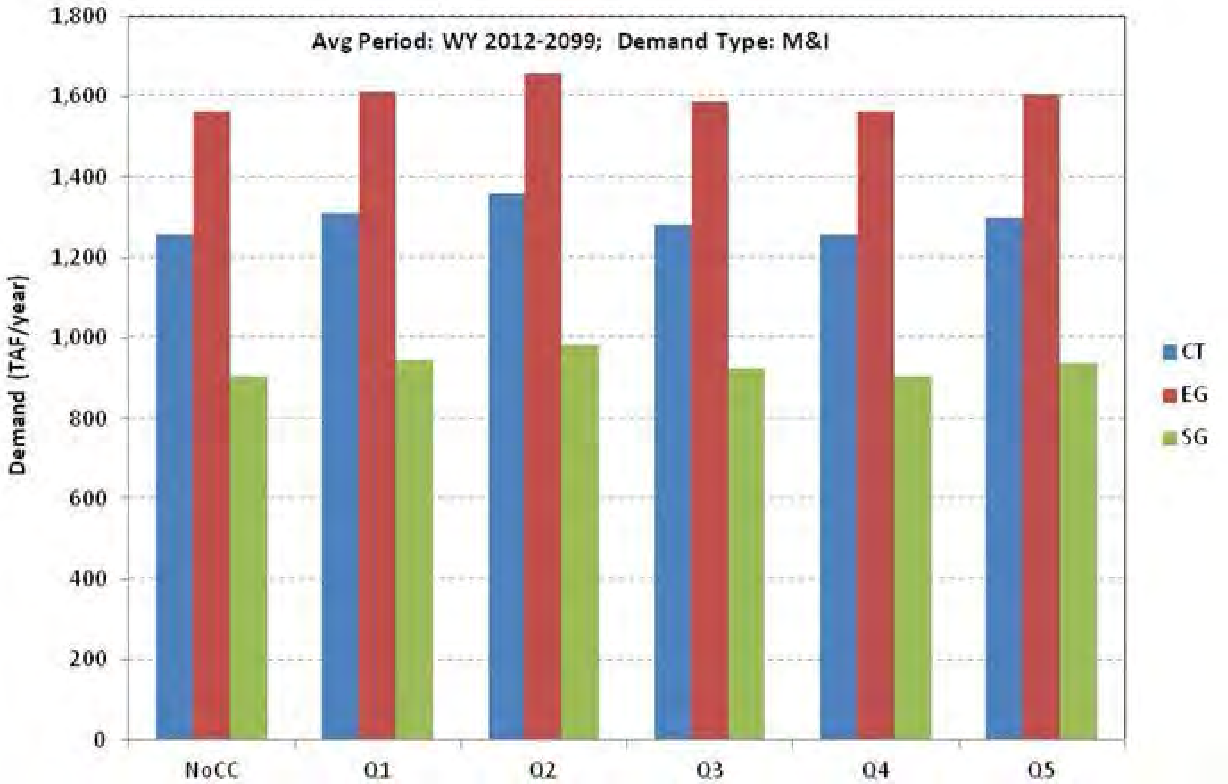
In contrast with agricultural demands, the effect of precipitation variability on urban demands is minimal because it is assumed these demands have a higher delivery priority than agricultural demands. Consequently, the EG scenario has the largest urban demands and the SG scenario the least. Across all climate scenarios and basins, the overall urban demand is about 4.4-4.8 MAF/year the in the CTs socioeconomic scenario and ranges from a low of about 2.9-3.1 MAF/year in SG to a high of about 5.2-5.7 MAF/year in EG.

In the Sacramento River system, the overall average urban demand change relative to the corresponding no climate change socioeconomic scenarios is +3-4 percent for the central tendency Q5 scenario and ranges from +0-2 percent in the wetter Q3 and Q4 scenarios to +3-9 percent in the drier Q1 and Q2 scenarios. In the Eastside Streams and Delta system, the overall average urban demand change is +3-4 percent relative to the no climate change scenario in Q5 and ranges from +0-2 percent in the wetter scenarios to +3-11 percent in the drier scenarios. In the San Joaquin River system, the average Q5 urban demand change is +4-5 percent and ranges from –1 percent to +2 percent in the wetter scenarios to +7-17 percent in the drier scenarios. In the Tulare Lake Region, the average Q5 urban demand change is + 3-4 percent and ranges from 0 percent to -3 percent in the wetter scenarios from -10 percent to 7 percent in the drier scenarios.



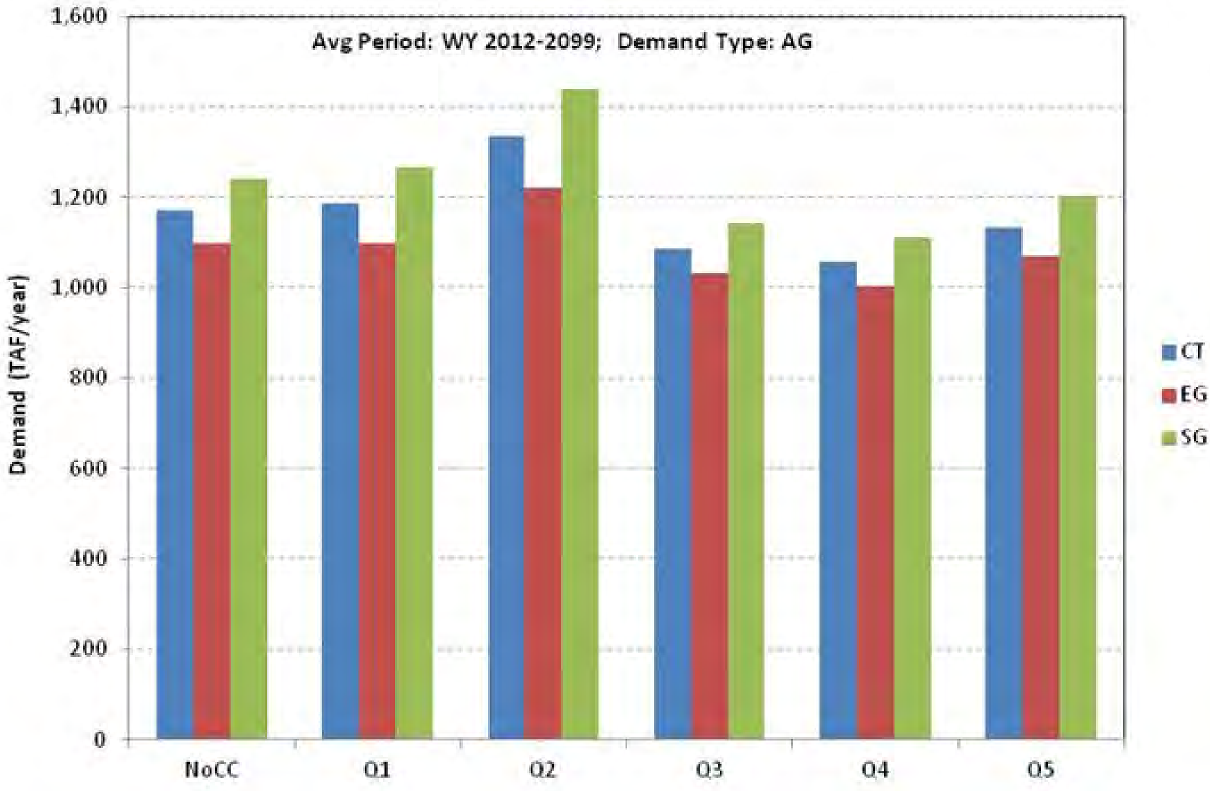
Key:
AG = Agricultural
CT = Current Trend
EG = Expansive Growth
SG = Slow Growth
TAF = thousand acre feet

Figure 3-38. Average Annual Agricultural Applied Water Demand (TAF/year) in the Sacramento River System in each Scenario



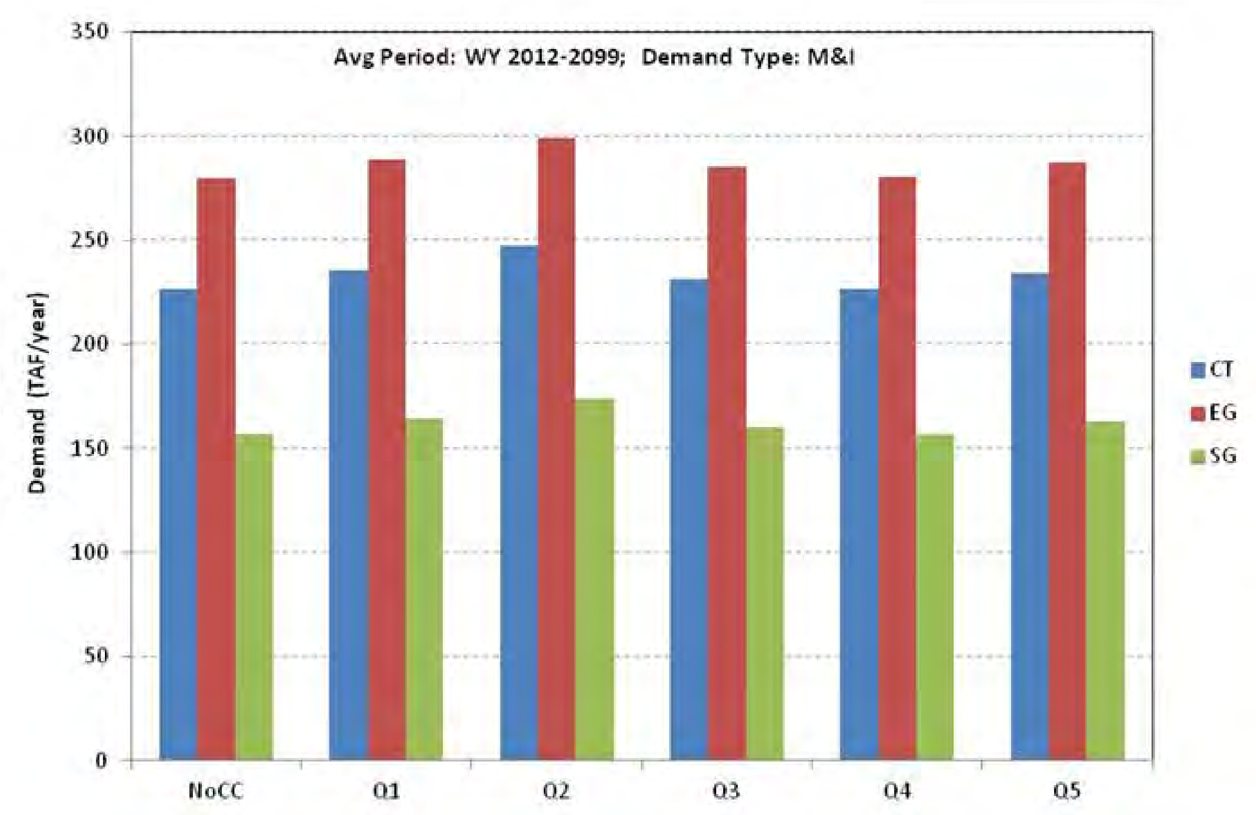
Key:
CT = Current Trend
EG = Expansive Growth
M&I = municipal and industrial
SG = Slow Growth
TAF = thousand acre feet

Figure 3-39. Average Annual Urban Applied Water Demand (TAF/year) in the Sacramento River System in each Scenario



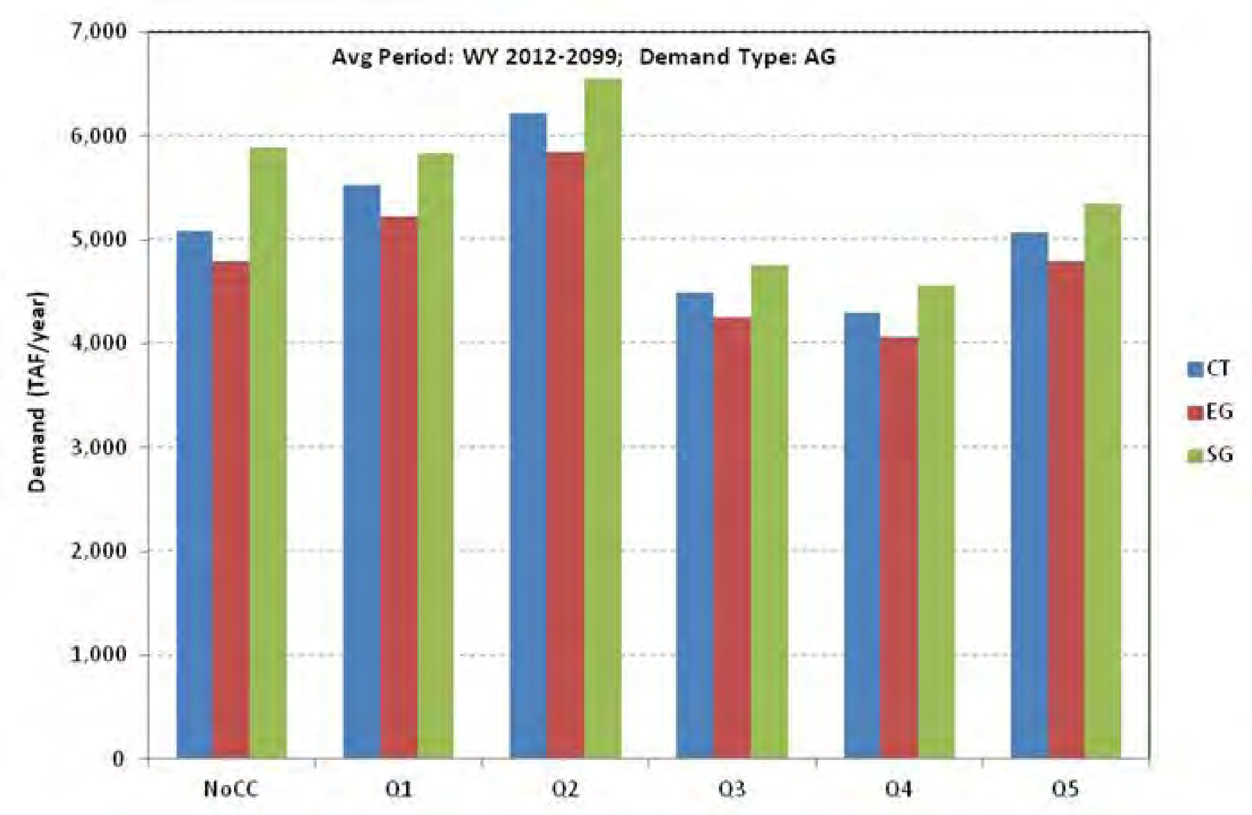
Key:
AG = Agricultural
CT = Current Trend
EG = Expansive Growth
SG = Slow Growth
TAF = thousand acre feet

Figure 3-40. Average Annual Agricultural Applied Water Demand (TAF/year) in the Eastside Streams and Delta in each Scenario



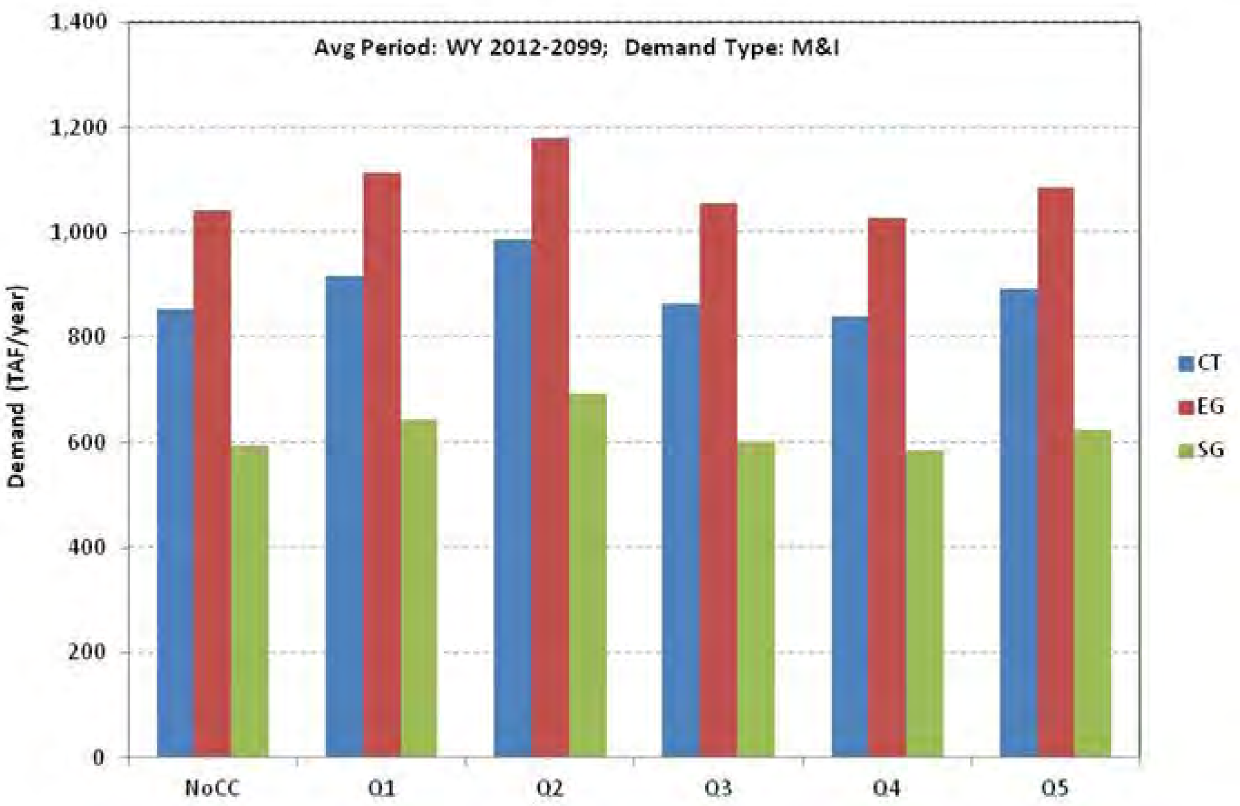
Key:
CT = Current Trend
EG = Expansive Growth
M&I = municipal and industrial
SG = Slow Growth
TAF = thousand acre feet

Figure 3-41. Average Annual Urban Applied Water Demand (TAF/year) in the Eastside Streams and Delta in each Scenario



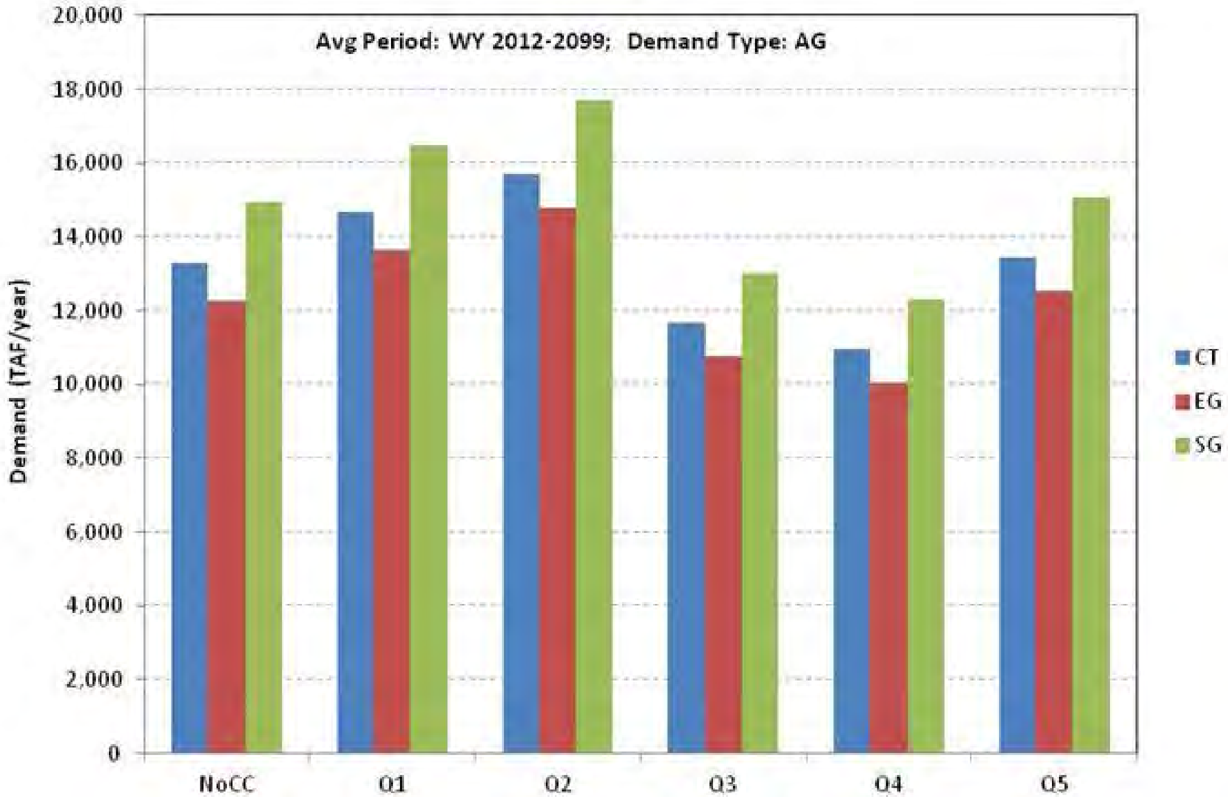
Key:
AG = Agricultural
CT = Current Trend
EG = Expansive Growth
SG = Slow Growth
TAF = thousand acre feet

Figure 3-42. Average Annual Agricultural Applied Water Demand (TAF/year) in the San Joaquin River System in each Scenario



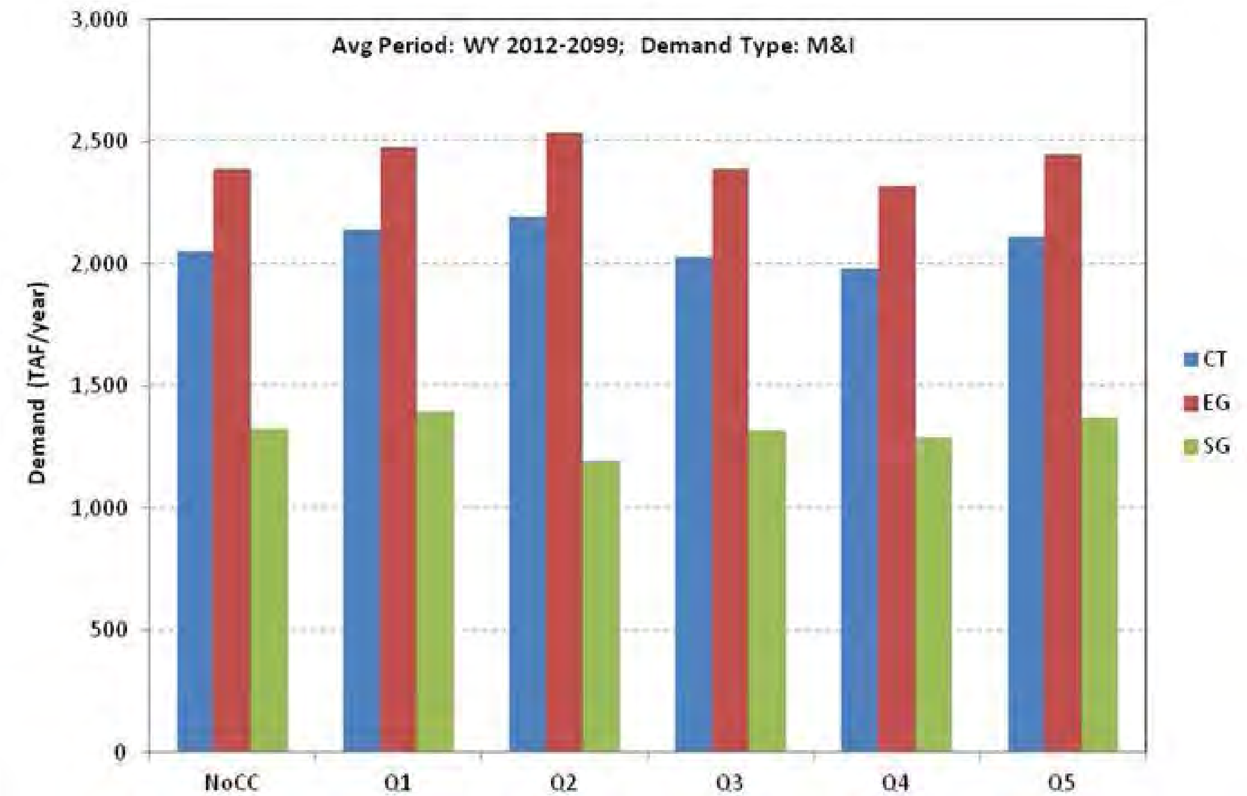
Key:
CT = Current Trend
EG = Expansive Growth
M&I = municipal and industrial
SG = Slow Growth
TAF = thousand acre feet

Figure 3-43. Average Annual Urban Applied Water Demand (TAF/year) in the San Joaquin River System in each Scenario



Key:
AG = Agricultural
CT = Current Trend
EG = Expansive Growth
SG = Slow Growth
TAF = thousand acre feet

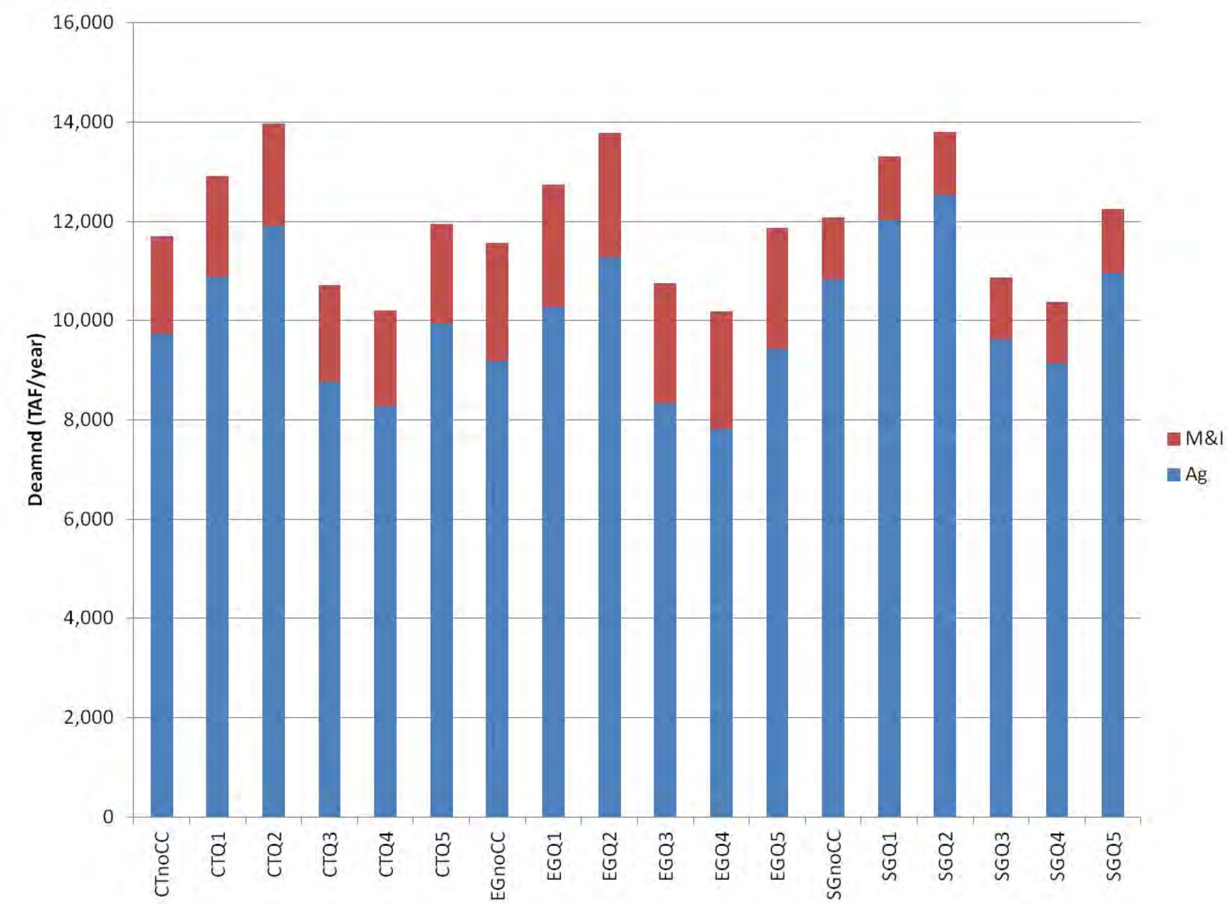
Figure 3-44. Average Annual Agricultural Applied Water Demand (TAF/year) in the Tulare Lake Region in each Scenario



Key:
CT = Current Trend
EG = Expansive Growth
M&I = municipal and industrial
SG = Slow Growth
TAF = thousand acre feet

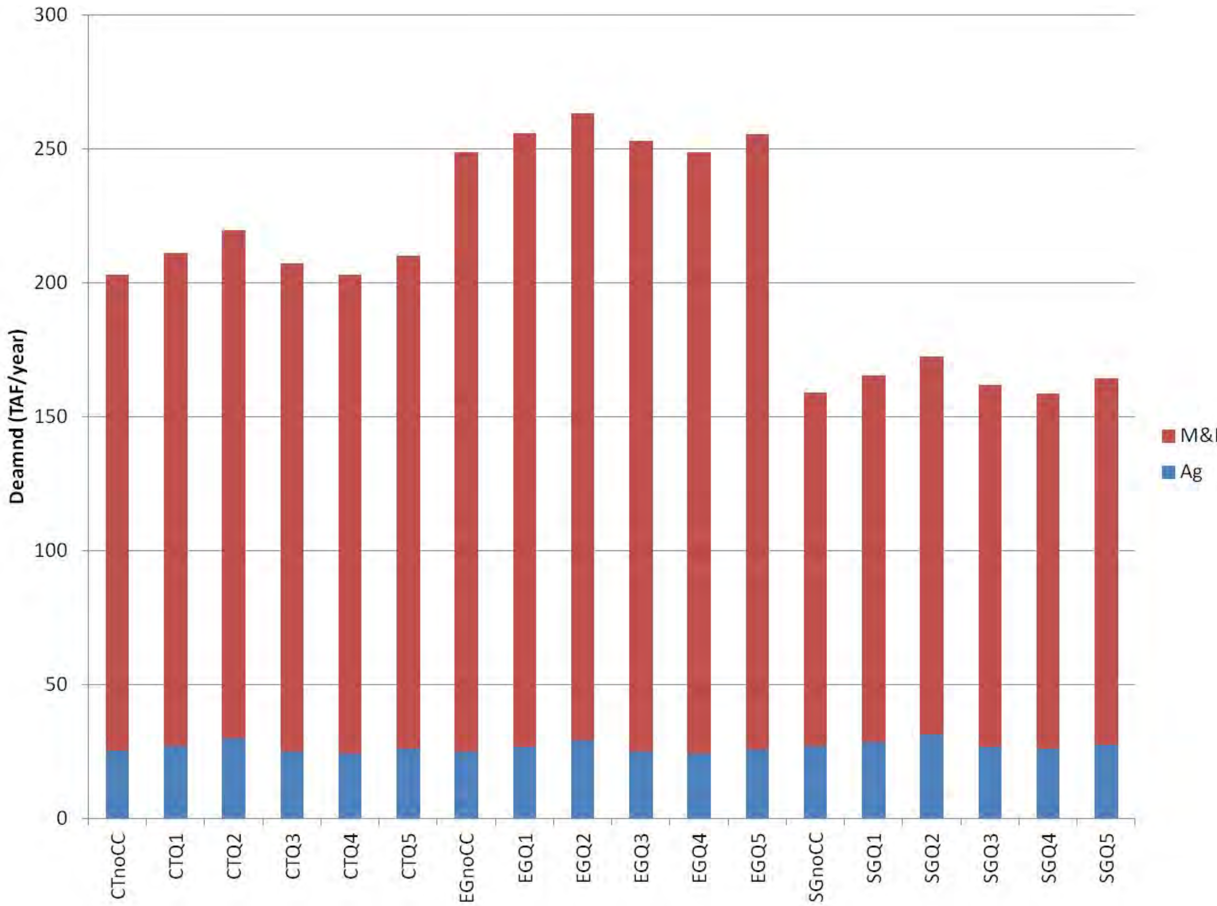
Figure 3-45. Average Annual Urban Applied Water Demand (TAF/year) in the Tulare Lake Region in each Scenario

Figure 3-45 through Figure 3-54 show the average annual agricultural and urban demand in each socioeconomic-climate scenario for the total CVP service area and within each CVP Division. Total average annual demands in the CVP service area range from about 10-14 MAF/year across the range of future scenarios. Among the Divisions, the largest demands are in the Friant Division, with total demands of about 4-6 MAF/year across the range of scenarios. The American River and San Felipe Divisions have much higher urban demands than agricultural demands and consequently show the highest total demands in the EG scenario and the lowest total demands in the SG scenarios as the changes in demands are driven primarily by changes in population. The other Divisions have more agricultural demands than urban demands and therefore show little differences in total demands between socioeconomic scenarios, as changes in agricultural demand are offset by corresponding changes in urban demand.



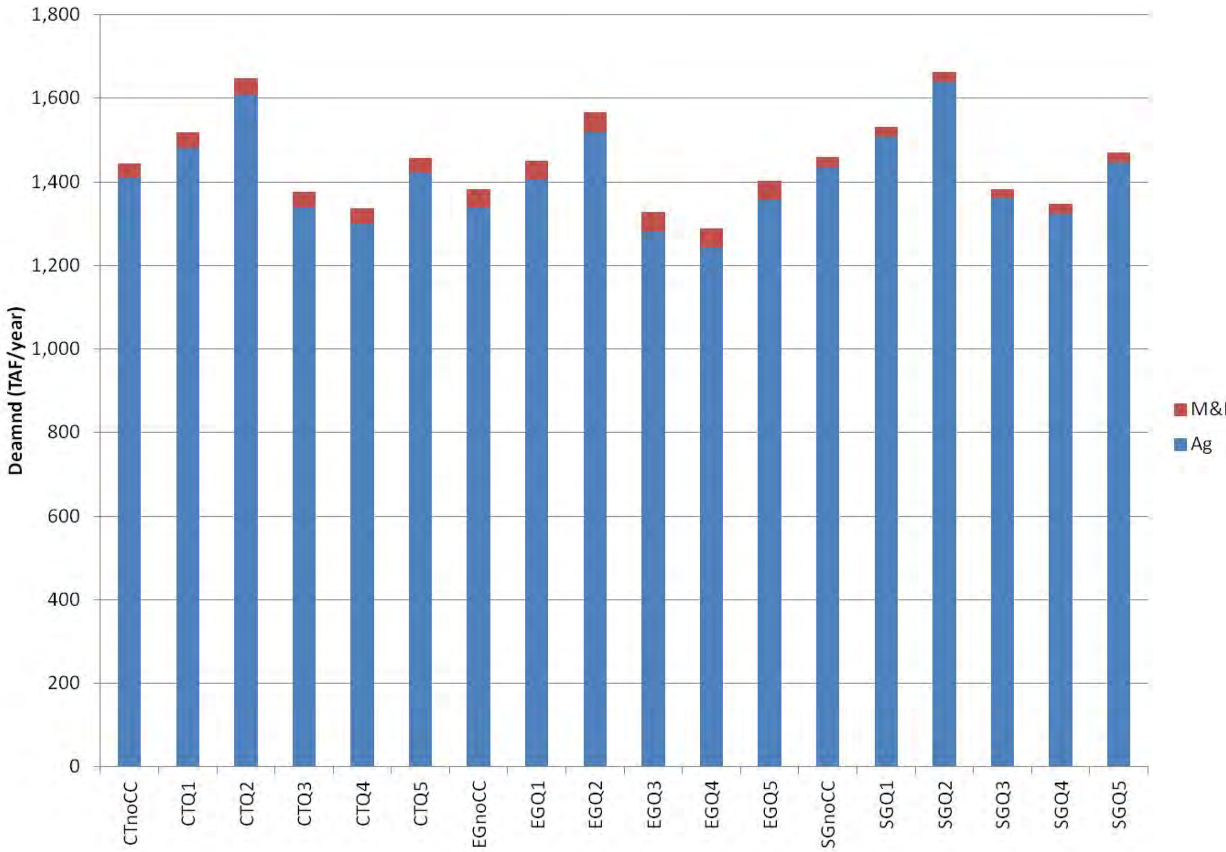
Key:
Ag = agricultural
CVP = Central Valley Project
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-45. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the CVP Service Area



Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-46. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the American River Division

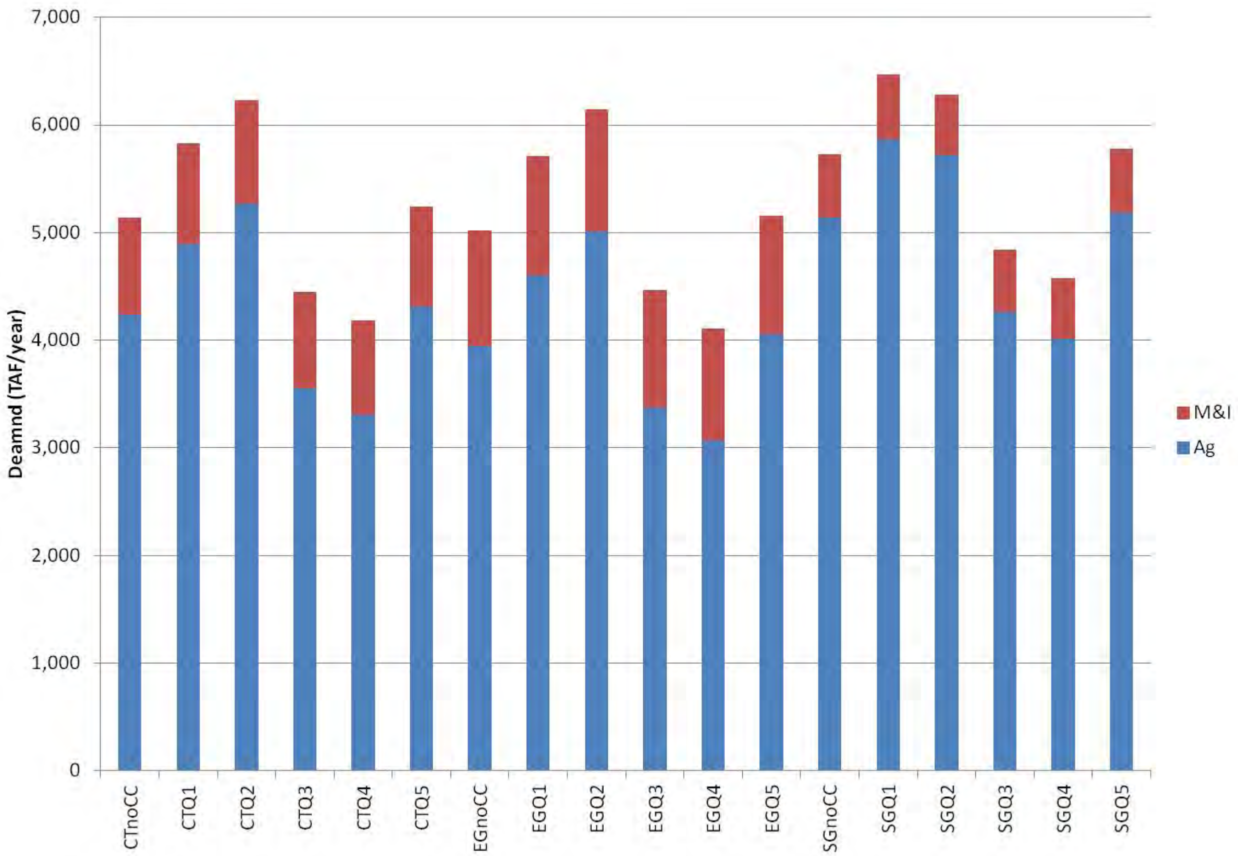


Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-47. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Delta Division

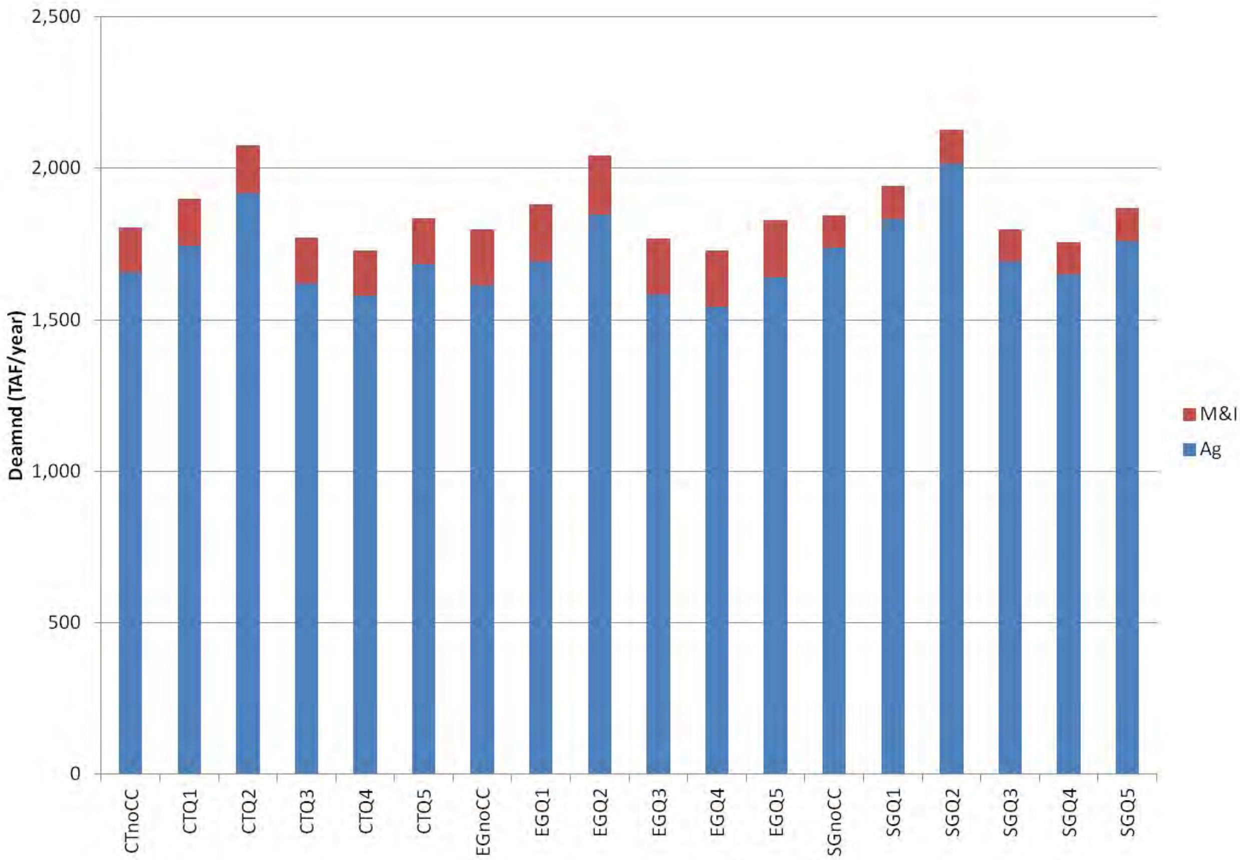
Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-48. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Eastside Division



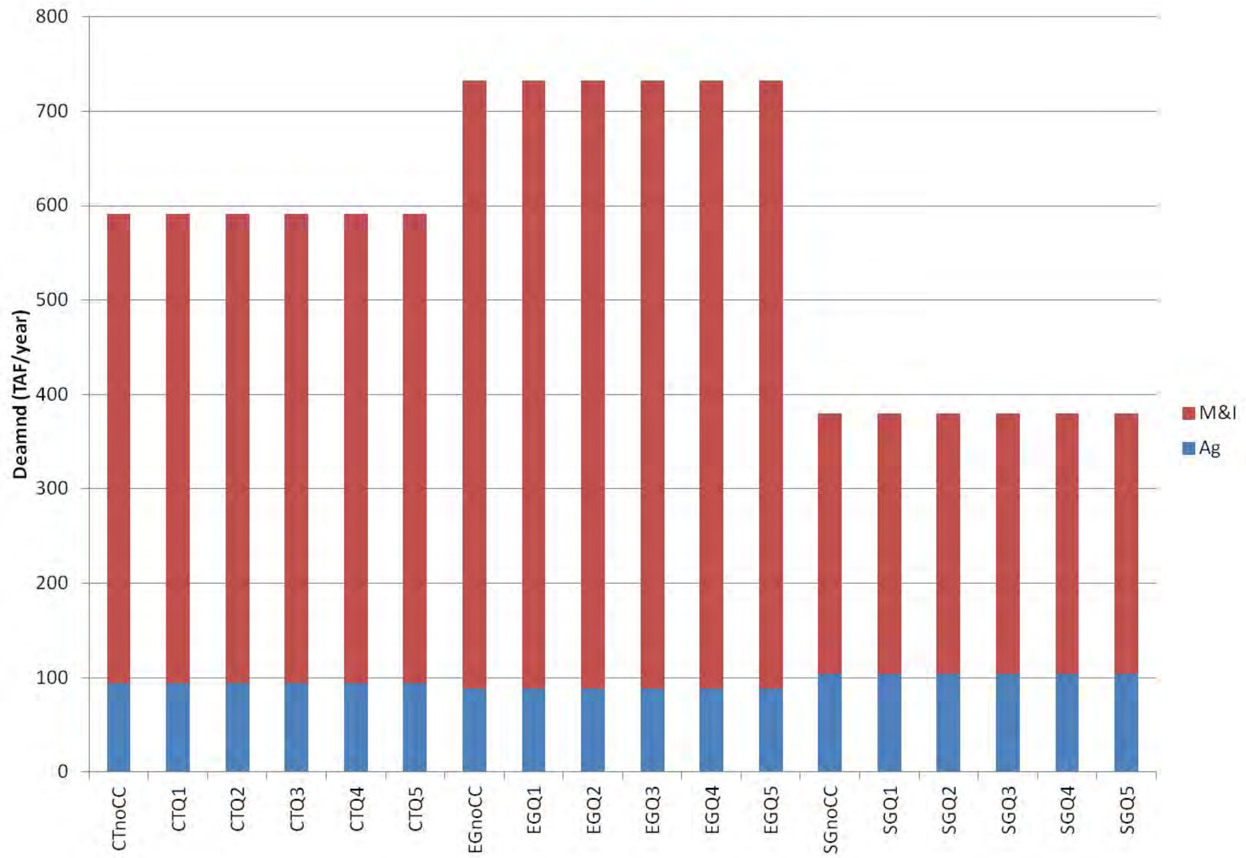
Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-49. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Friant Division



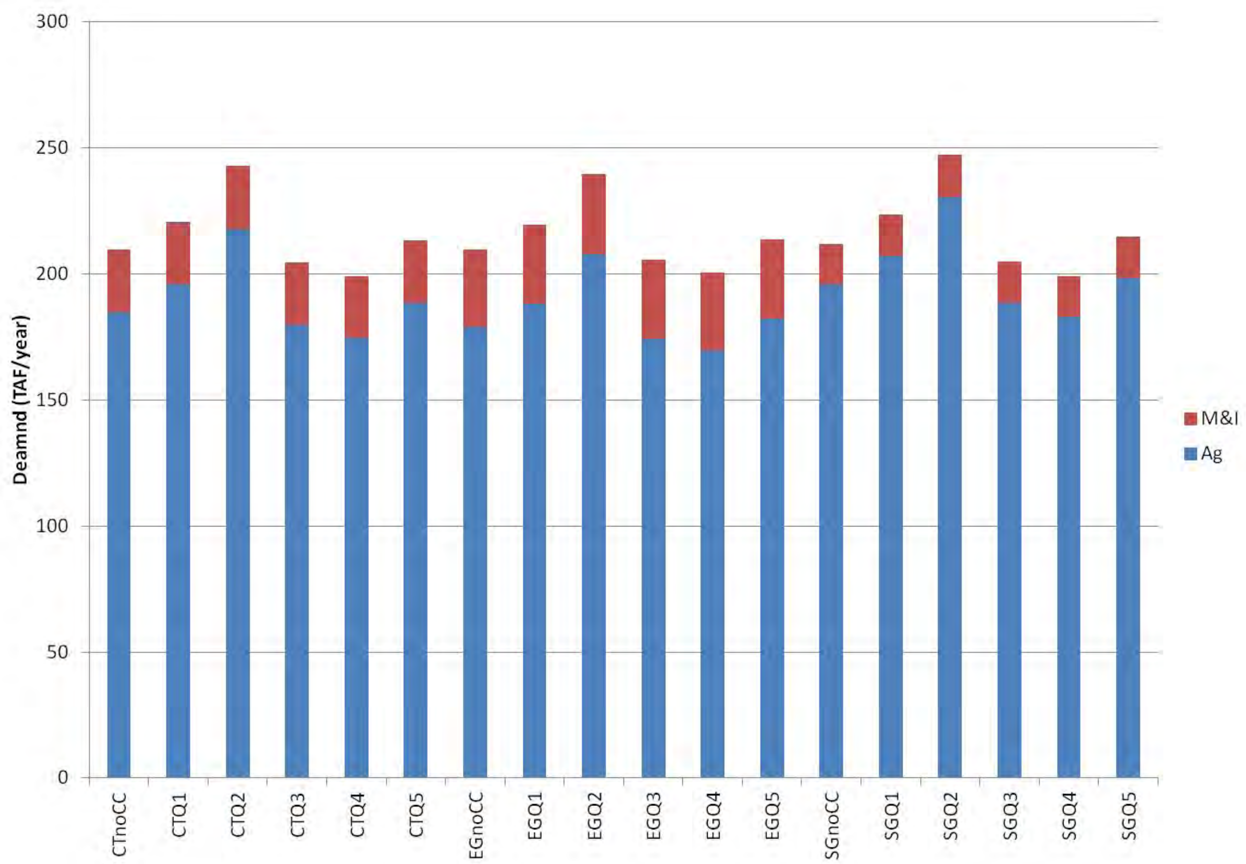
Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-50. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Sacramento River Division



Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-51. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the San Felipe Division

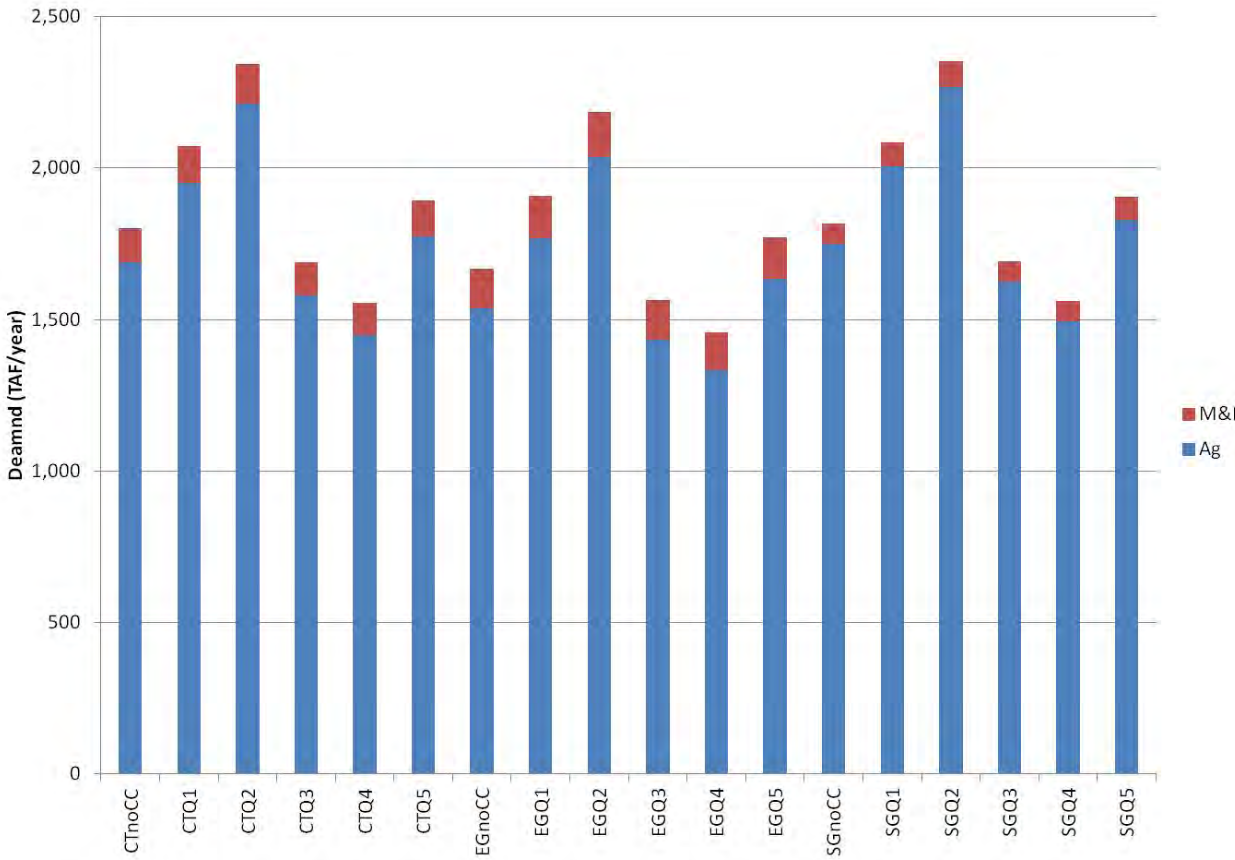


Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

Figure 3-52. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Shasta Division

Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

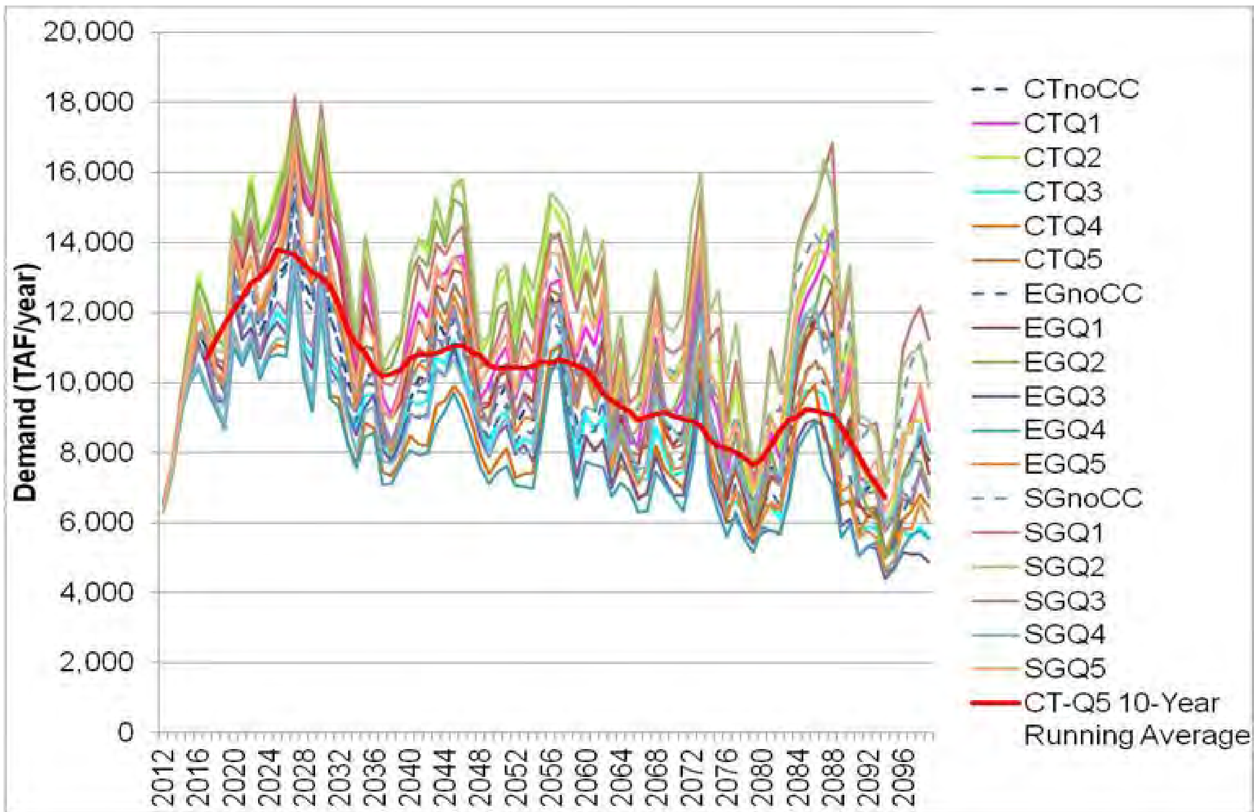
Figure 3-53. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the Trinity Division



Key:
Ag = agricultural
M&I = municipal and industrial
TAF = thousand acre feet

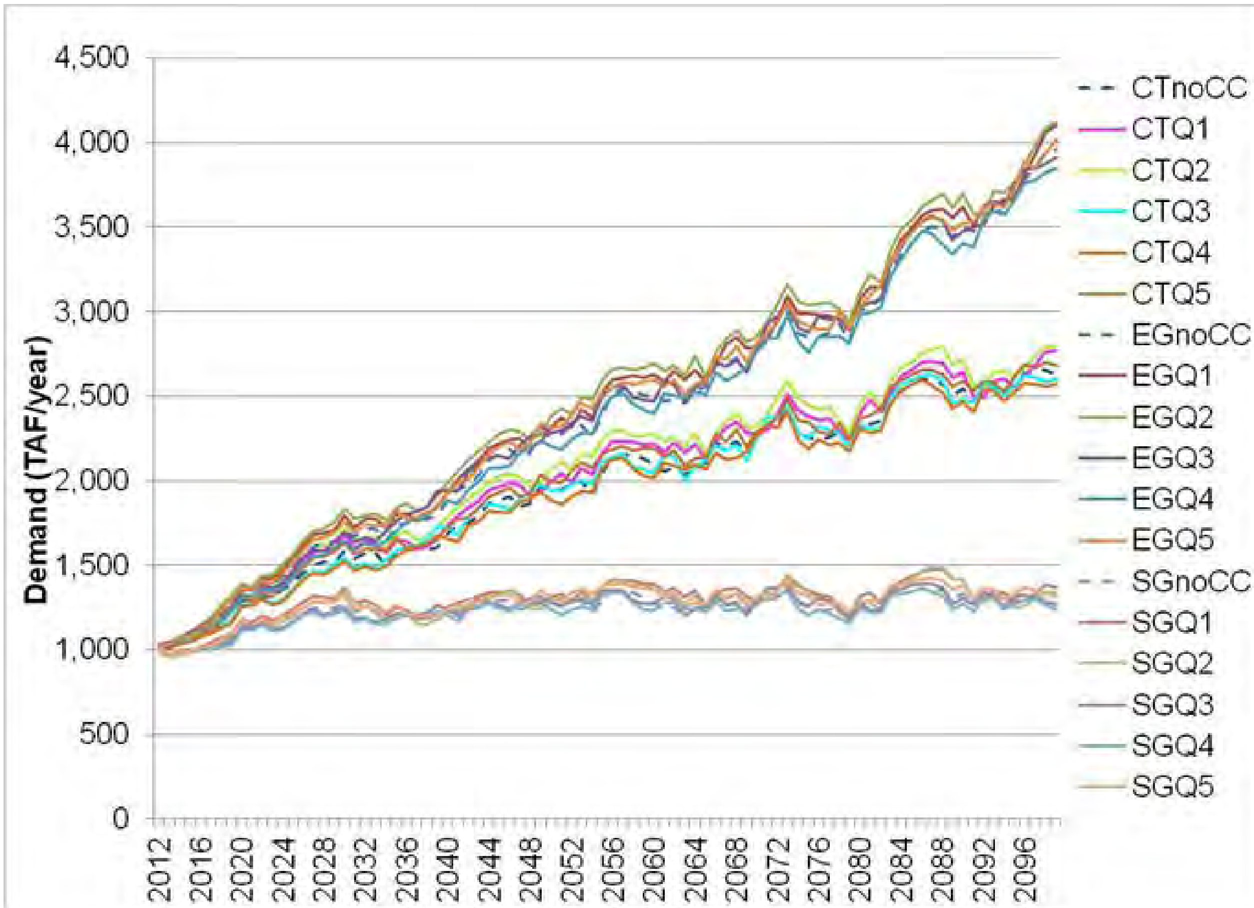
Figure 3-54. Average Annual Agricultural (Ag) and Urban (M&I) Demands (TAF/year) in the West San Joaquin Division

Figure 3-55 and Figure 3-56 present the annual time series of projected total agricultural and urban demands within the all CVP Service Areas for the eighteen socioeconomic-climate scenarios. As shown on Figure 3-55, there is both short term variability and longer term trends in agricultural water demands. For the agricultural demands it is assumed that there are no changes in the crop types being grown and that changes in acreage are only associated with the socioeconomic scenarios. However, as irrigated acreage declines during the 21st century, results from the SWAP model were used to simulate which crops farmers would continue to irrigate assuming future crop selections are made to obtain optimum economic benefits. The short term variability is highly correlated with the variability in annual precipitation. In years of low precipitation, demand is higher while in years of high precipitation agricultural demands decrease. The longer term trends include both a period of increasing demands during the early 21st century followed by declining demands in the latter half of the century. These changes occur across all the future socioeconomic-climate scenario projections. However, it is also important to note that the rapid increase in demands during the early 21st century is partly an artifact of using the historical period precipitation record to create the projected future climate. A better method would be to simulate droughts and wet periods throughout the simulation period. However, this approach was not implemented in this study.



Key:
CVP = Central Valley Project
TAF = thousand acre feet

Figure 3-55. Annual Time Series of Agricultural Applied Water Demand (TAF/year) in the CVP Service Area in each Scenario



Key:
CVP = Central Valley Project
TAF = thousand acre feet

Figure 3-56. Annual Time Series of Urban Applied Water Demand (TAF/year) in the CVP Service Area in each Scenario

There are several projected changed climatic conditions that contribute to the long term trends. Increased temperatures during the growing season can have multiple and opposing effects on crop growth, yield and ET. In general as temperatures rises, the rate of plant transpiration increases due an increase in the VPD which is the difference between the saturated vapor pressure in the plant's leaves and the surrounding atmosphere. However, many plants can adapt to increased VPD by reducing their growth and stomatal openings to mitigate this heat stress. This adaptation ability varies between different crops and even amongst crop cultivars. The magnitude of the VPD is also affected by changes in atmospheric humidity. For the climate projections used in this study, both the VPD and atmospheric humidity (dew point temperature is a good indicator) were projected to increase throughout the 21st century. Although atmospheric humidity was projected to increase which would tend to reduce the VPD, the nonlinear nature of effect of temperature on the saturation vapor pressure in the plant's leaves was greater than the potentially offsetting increase in humidity. Increasing temperature may also effect plant growth by causing plants to grow faster. For annual plants like many agricultural crops, the faster growth results in a shorter growth period which reduces the total growing season ET. The yield of many agricultural crops is also negatively affected by overly rapid growth because of inadequate time for seed development. In contrast, increased temperature, providing it is not excessive, extends the growth period for perennial crops such as alfalfa, grasses and some trees which tends to increase total ET. Thus, these temperature related phenological changes can have significant and opposite effects on different types of agricultural crops. The average Tmax and Tmin daily average temperatures and VPD associated with the climate projections were presented previously in Figure 3-11, Figure 3-12, and Figure 3-15, respectively. As shown, there is a steadily upward trend projected for both Tmax, Tmin and VPD during the 21st century.

Rs is also a major climatic factor affecting plant growth, yield and ET. As solar radiation increases, ET, growth and yield also generally increase. However, unlike temperature, Rs was projected to decrease during the 21st century. This decrease in Rs is associated with projected increases in atmospheric humidity and cloudiness. These changes are reflected in the rising Tdew shown on Figure 3-14. Consequently, this projected climatic change would tend to reduce the rate of crop growth, yield and ET during the 21st century. The projected changes in solar radiation are shown on Figure 3-13.

CO_2 is an important GHG which effects crop growth, yield, and ET. As CO_2 concentrations increase, most agricultural crops respond by reducing the conductance of the stomatal openings in their leaves which reduces their transpiration rate. The magnitude of the reduction depends somewhat on whether the plant uses the C3 or C4 photosynthetic pathway to assimilate CO_2. In C3 crops such as wheat, stomatal conductance is reduced by an average of 22 percent when CO_2 concentrations increase from 366 to 567 parts per million (ppm) (current global average concentrations are ~ 385 ppm). For C4 crops such as corn, the average reduction in stomatal conductance was about 30 percent. Based on data from the Free Air Carbon Exchange (FACE) experiments, Ainsworth and Long (2005) reported an overall average reduction in stomatal conductance of between 20 – 22 percent when CO_2 concentrations were increased from 360 to 600 ppm. Furthermore, CO_2 effects on crop yield differ between C3 and C4 crops. For C3 crops, increasing CO_2 tends to increase crop growth. For C4 crops, growth is less affected because the C4 photosynthetic pathway is more efficient and consequently growth is not significantly affected.

In this study, CO_2 concentrations were based on global emission scenarios developed for the Intergovernmental Panel on Climate Change (IPCC) Forth Assessment Report (IPCC 2007) and are described in the Special Report on Emissions Scenarios (IPCC 2000). The projected concentrations vary between the scenarios and increase over time. The warmer scenarios (Q2 and Q3) have higher CO_2 concentrations than the less warm (Q1 and Q4) scenarios. The central tendency, Q5, projection is intermediate between these extremes. The Q5 concentrations increase from approximately 370 ppm at the beginning of the 21st century to about 650 ppm by the late 21st century. The maximum concentrations simulated reach 700 ppm by 2099. The projected CO_2 concentrations associated with each of the climate projection are presented on Figure 3-16.

As shown on Figure 3-55, agricultural demands are projected to increase in the early to middle 21st century because of rising temperatures and increased VPD. During this period, the decreases in Rs intensity and increases in CO_2 concentrations are not yet of sufficient magnitude to offset the temperature and VPD effects on ET and yield. However in the latter half of the 21st century as projected Rs continues to decrease and CO_2 concentrations continue to increase to levels of between 600 to 700 ppm, the ET of many agricultural crops being grown in the Central Valley will decline despite the rising temperatures and increasing VPDs. As indicated on Figure 3-55, the overall average CVP Service Area agricultural demands increase from about 6.5 MAF in 2012 to approximately 7.5 MAF in 2099 and range from a minimum of 5.5 to a maximum of 11.2. Over the entire 21st century, the demands range from a minimum of 4.4 to a maximum of 18.2 MAF.

In contrast to the agricultural demands, urban demands are strongly correlated with the socioeconomic scenarios and show only slight variations with changing short term variability and longer term climatic trends. Because the urban demands are mostly indoor M&I, they tend to change steadily over time with the growth in population and expansion in commercial activities. As shown on Figure 3-56, urban demand is only slightly changed under Slow Growth conditions but does increase significantly under the Current Trends and Expansive Growth scenarios. By the end of the 21st century, the overall average of all the socioeconomic scenario urban demands in the CVP service areas is 2.7 MAF and ranges from 1.2 MAF (SG) to 4.1 MAF (EG).

CVP and SWP System Operations

CVP and SWP Project Storage

Figure 3-56 through Figure 3-69 are exceedence plots of storage at the end of May and at the end of September in Shasta, Folsom, Oroville, New Melones, Friant, CVP San Luis and SWP San Luis reservoirs under each uocioeconomic-climate scenario. For example, the 50 percent probability of exceedence may be interpreted as the average storage volume over the entire 21st century period. The end of May storage typically represents the water supply available for meeting agricultural, urban and environmental water demands while end of September storage is an indicator of carryover storage that is reserved to meet demands in subsequent years. By the end of May, the majority of precipitation that will develop in a water year as already fallen and the end of September generally signals the end of large amounts of irrigation demand. In some instances, reservoir storage reaches 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. 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.

As seen on the figures, the reservoir storage results reveal only a limited amount of variability between the different socioeconomic scenarios but differ significantly between the different climate scenarios. However, reservoir storages typically are higher under the EG scenario because over time agricultural demands which are the largest demand type decrease the most in this scenario because it assumes the most conversion of agricultural land to urban land.