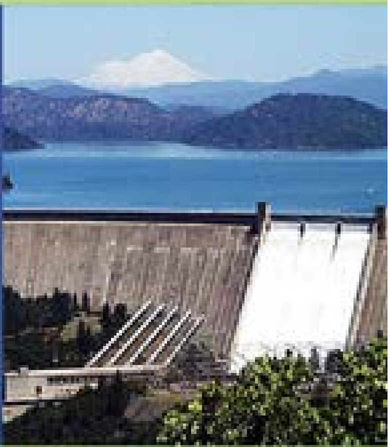
RECLAMATION

Managing Water in the West

Summary Report

Central Valley Project Integrated Resource Plan



U.S. Department of the Interior
Bureau of Reclamation
Mid-Pacific Region

TABLE OF CONTENTS

Tables

Figures

Table of Contents - Continued

BACKGROUND

The Central Valley Project Integrated Resource Plan (CVP IRP) study continues and expands on the long-range planning activities of the Central Valley Project Yield Feasibility Investigation by addressing future uncertainties in climate as well as changing socioeconomic conditions. To better understand future challenges, the CVP IRP study focuses on providing more comprehensive assessments of potential climatic and socioeconomic uncertainties for the entire CVP Service Area and each of the CVP Divisions. The study explores various portfolios of system-wide and local water management actions that might be employed to adapt to potential twenty-first century challenges. These strategies are evaluated against key CVP performance criteria to compare their potential effectiveness under a broad range of future socioeconomic-climate uncertainties, and to identify tradeoffs among various delivery reliability, water quality, environmental, hydropower, and urban and agricultural economic performance characteristics. Finally, it is envisioned that the CVP IRP will serve as an important background document for the Sacramento-San Joaquin River Basins Study (SSJRBS), which received funding under the WaterSMART grant program.

STUDY APPROACH

The CVP IRP study employed a scenario-based analytical approach. Existing operational, hydrologic, water quality, hydropower, urban and agricultural economic models were integrated into a suite of decision support tools for assessing the effects of future socioeconomic-climate uncertainties on CVP and its Divisions. Future socioeconomic-climate uncertainties were characterized by combining three potential socioeconomic and six representative climate futures to form 18 future scenarios. Each scenario was simulated with conditions continuously changing from present day to the end of the 21st century.

The current trends, slow and expansive growth socio-economic scenarios based on population and land use changes developed for the California Water Plan through year 2050 were extended to year 2100 using other North American population projections. Transient future climate projections were developed from an ensemble of 112 bias corrected spatially downscaled global climate model (GCM) simulations. One historical and five statistically representative future temperature and precipitation projections were developed to characterize the central tendency and the range of the ensemble uncertainty including projections representing drier, less warming; drier, more warming; wetter, more warming; and wetter, less warming conditions than the median projection. The observed natural variability in the historic climate between 1915 and 2003 was used to create the same inter-annual variability in the projected climates. Transient sea level rise projections corresponding with projected climate change were also developed for the Sacramento-San Joaquin Delta.

Figure 1 shows an example of the five transient temperature and precipitation projections used in the CVP IRP study to represent climate uncertainty in the 21st century. The central tendency (Q5) includes ensemble members between the 25th to 75th percentiles of temperature and precipitation change relative to the historic climate. The Q1 through Q4 projections each include the 10 ensemble members closest to the 10th and 90th percentile of changes to capture a significant range of the uncertainty in the 112 member ensemble.

In addition to assessing the impacts of future climate change on water supply, an important objective of CVP IRP study was to evaluate the corresponding effects of climate change on water demands. For this purpose, projections of changes in solar radiation, atmospheric humidity and wind speed were developed to evaluate changes in crop evapotranspiration (ET). These meteorological conditions were not readily available from GCM simulations. Consequently, an analysis of long-term historic observations at four representative California Irrigation Management System meteorological stations was performed to develop the information necessary to estimate solar radiation, atmospheric humidity and wind speed from the projections of future temperature and precipitation. Carbon dioxide (CO2) also has significant effects on both crop ET and yield. Projected changes in CO2 were obtained directly from the proportion of individual projections included in each of the statistically representative climate projections.

The modeling approach involved first simulating the effects from projected climate change on the evapotranspiration (ET) and yields of the major agricultural crops grown in Central Valley of California. For each socioeconomic-climate scenario, these projected crop ETs along with urban and environmental demands were used as inputs to an integrated hydro-climate model (WEAP-CV) to simulate snowpack accumulation and runoff; reservoir operations and river flows; surface water diversions and return flows; and groundwater recharge and pumping. These hydrological responses to socioeconomic-climate scenarios were then used as inputs to the CVP IRP CalLite model. This model was used to simulate the coordinated operations of the CVP and State Water Project (SWP) as well as other Central Valley non-project water management systems

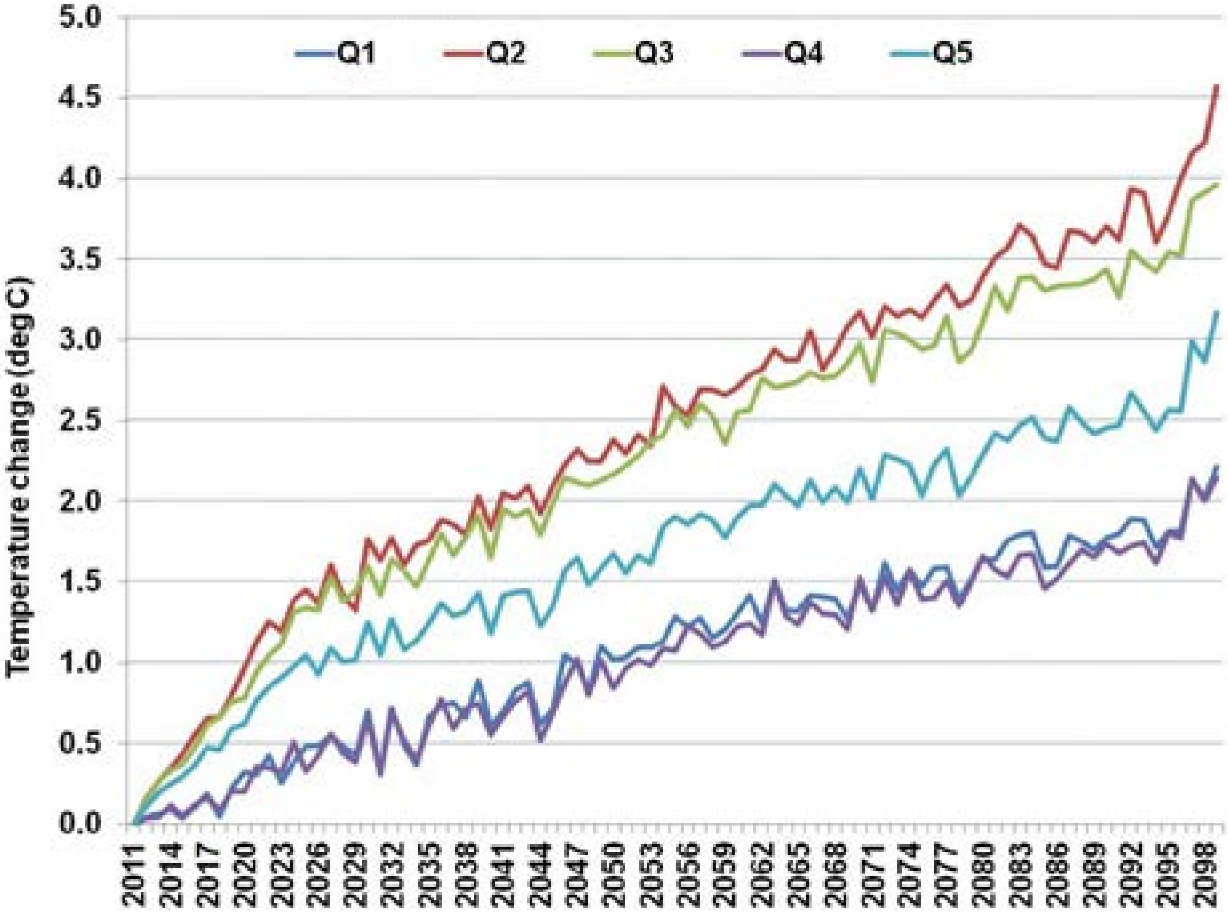


Figure 1a. Projected changes in Temperature in Ensemble-Informed Transient Climate Scenarios between 2012 and 2099 for a Representative Grid Cell in the American River Basin (Example). Q5 represents the central tendency. 10th – 90th percentile projections include Q1 (drier, less warming), Q2 (drier, more warming), Q3 (wetter, more warming) and Q4 (wetter, less warming). Note: Appendix I. explains the acronyms and abbreviations used in the figures.

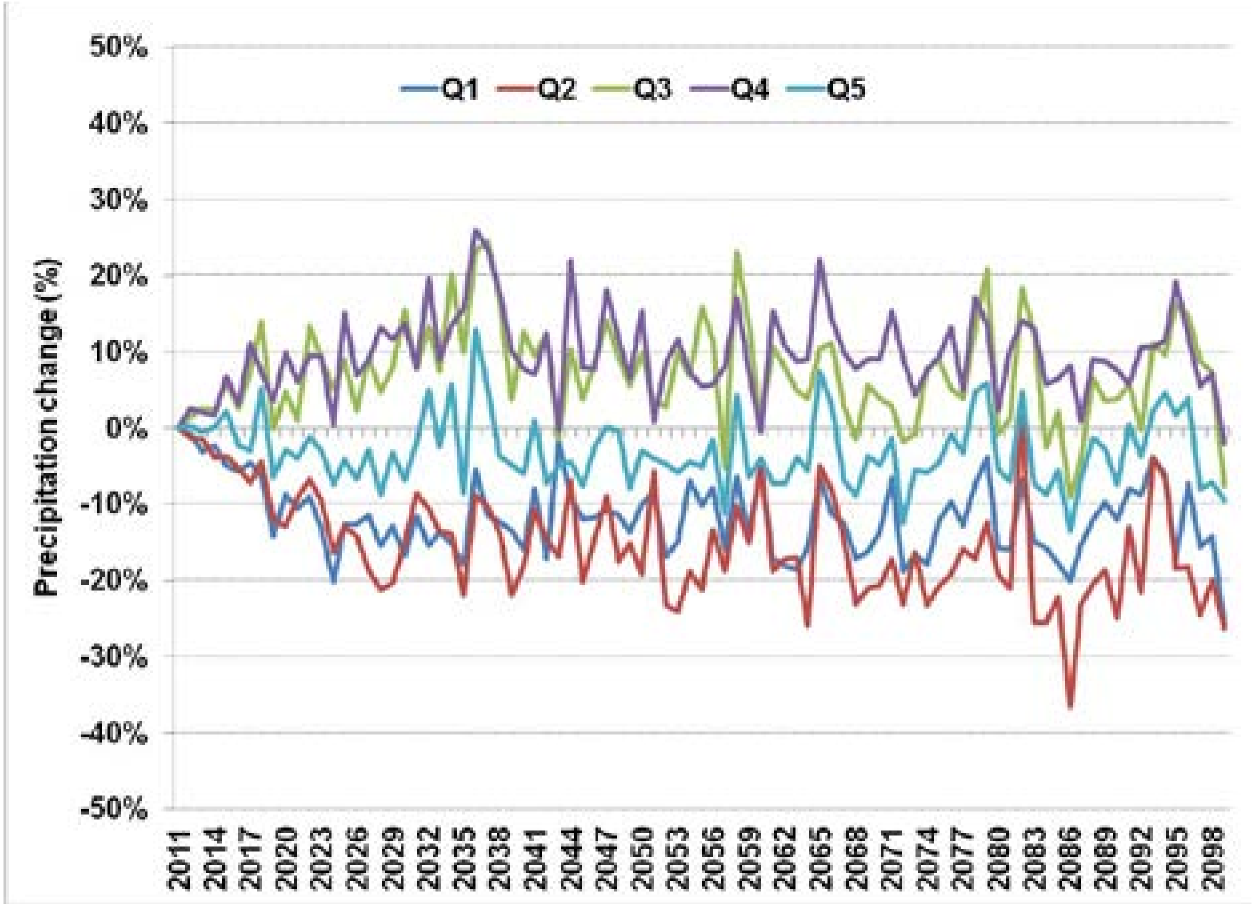


Figure 1b. Projected changes in Precipitation in Ensemble-Informed Transient Climate Scenarios between 2012 and 2099 for a Representative Grid Cell in the American River Basin (Example). Q5 represents the central tendency. 10th – 90th percentile projections include Q1 (drier, less warming), Q2 (drier, more warming), Q3 (wetter, more warming) and Q4 (wetter, less warming). Note: Appendix I. explains the acronyms and abbreviations used in the figures.

under current regulatory requirements. The CVP IRP CalLite model is a screening tool, which was specially developed to quantify the impacts of changes in hydro-climate on water supplies and demands in the CVP Service Area and its Divisions. By design, it also facilitates analyses of the effectiveness of a wide variety of potential changes in management and infrastructure on imbalances between future surface and ground water supplies and CVP-SWP water demands. The CVP IRP CalLite model was also designed to interface with existing river water temperature (Sacramento and San Joaquin) and Delta water quality (salinity), hydropower (CVP and SWP) and municipal (Central Valley and South Bay) and agricultural economics (SWAP) models to evaluate key CVP-SWP performance metrics. A new greenhouse gas (GHG) model was also developed to evaluate the effects of potential changes in hydropower generation on CVP-SWP GHG emissions.

CLIMATE IMPACTS ON WATER SUPPLIES AND DEMANDS

Model runs were performed to estimate the projected annual time series of surface water runoff in the Sacramento River system upstream of Hood and in the San Joaquin River system upstream of Vernalis for each of the 18 transient socioeconomic-climate scenarios from 2012 to 2099. Figure 2 shows projected runoff for each of the 5 climate change scenarios under current trends growth (CT) as well as a no climate change (noCC) condition. The 10-year moving average for the central tendency (Q5) climate projection is also shown.

Figure 2, does not show surface water flow projections for the slow growth (SG) and expansive growth (EP) scenarios to allow the graph to be readable. In general, differences in river flows among the different socioeconomic scenarios associated with the same climate projection are small because the flow impact is limited to the overall impact of changed water demands under the various socioeconomic scenarios. As explained in more detail in the demand discussion starting on page 10, the more robust growth scenarios result in increased demands for urban water supplies. However, urban growth is assumed to be accompanied by conversion of some agricultural to urban land resulting in a corresponding decrease in agricultural water demands. The offsetting nature of urban and agricultural demands coupled with the fact that urban demands are a relatively small component of total water demands explains the negligible overall impact of the socioeconomic scenarios on river flows. However, there are substantial differences in flows among the different climate projections. A general trend toward increasing high flow magnitude occurs in both river systems during the twenty-first century. These projected time series reflect the inter-annual variability of the historical period because of the methodology used in developing the projections. Figure 3 shows the changes in annual flow for the 5 representative climate projections relative to the historic climate assuming the CT socioeconomic scenario. While the central tendency (Q5) projected flows are only slightly different than historic flows, the wetter projections (Q3, Q4) result in increased river flows in both the Sacramento and San Joaquin rivers whereas flows in the drier projections (Q1, Q2) are less than in historic period.

Figure 4 shows the simulated monthly period average flows in the Sacramento River and San Joaquin River basins for each projected climate from 2012 through 2099 assuming the CT socioeconomic scenario. Each basin has a different monthly pattern reflecting their differences in hydro-climate, topography and terrestrial conditions. In both basins, the magnitude of flows reflects the projected precipitation. The wetter projections (Q3,Q4) have flows greater than historic conditions especially in the Fall and Winter months whereas the drier projections (Q1,Q2) have less. The central tendency projection (Q5) is similar to the historic (CT No CC) but with increased early water year flows. In the generally lower elevation, rainfall dominated Sacramento River basin, the climate projections have a similar pattern to the no climate change scenario. In higher elevation, more snowpack affected San Joaquin basin, a projected shift in runoff from the spring months to the winter months occurs. This projected shift occurs because higher future temperatures during the winter season result in more precipitation occurring as rainfall along with earlier snowmelt runoff. This shift in timing becomes more pronounced during the 21st century as temperature increases become larger (not shown).

Figure 5 shows the annual time series of projected applied agricultural water demands within the CVP Service Area for each the 18 socioeconomic-climate scenarios. Unlike water supplies, demands are significantly affected by both the socioeconomic scenarios and projected climate change. In all the socioeconomic scenarios, there is an assumption that some agricultural land is converted to urban uses. The magnitude of these assumed land use changes increase over time with

Sacramento River

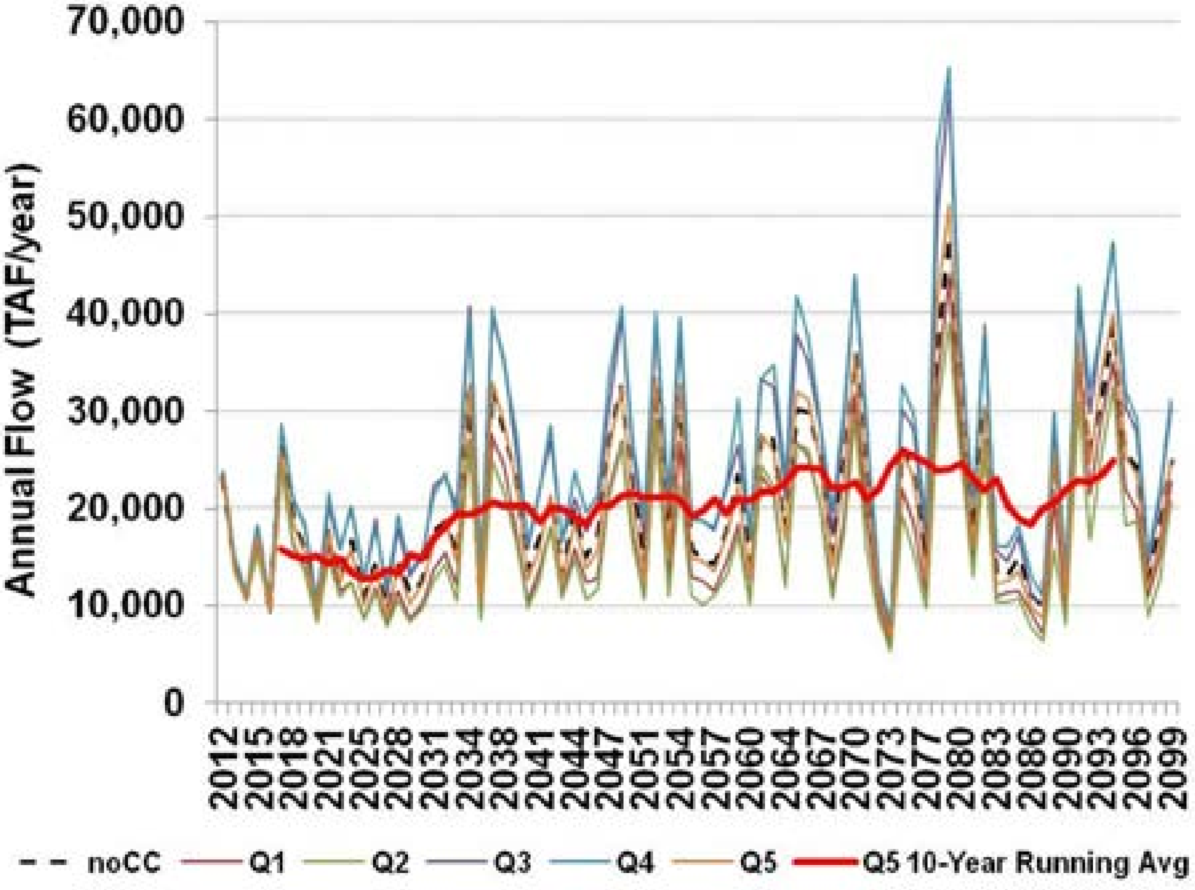


Figure 2a. Annual Time Series from 2012 to 2099 of Surface Water Flows in TAF/yr for the Sacramento River for each Climate Scenario under Current Trends (CT) socioeconomic scenario

San Joaquin River

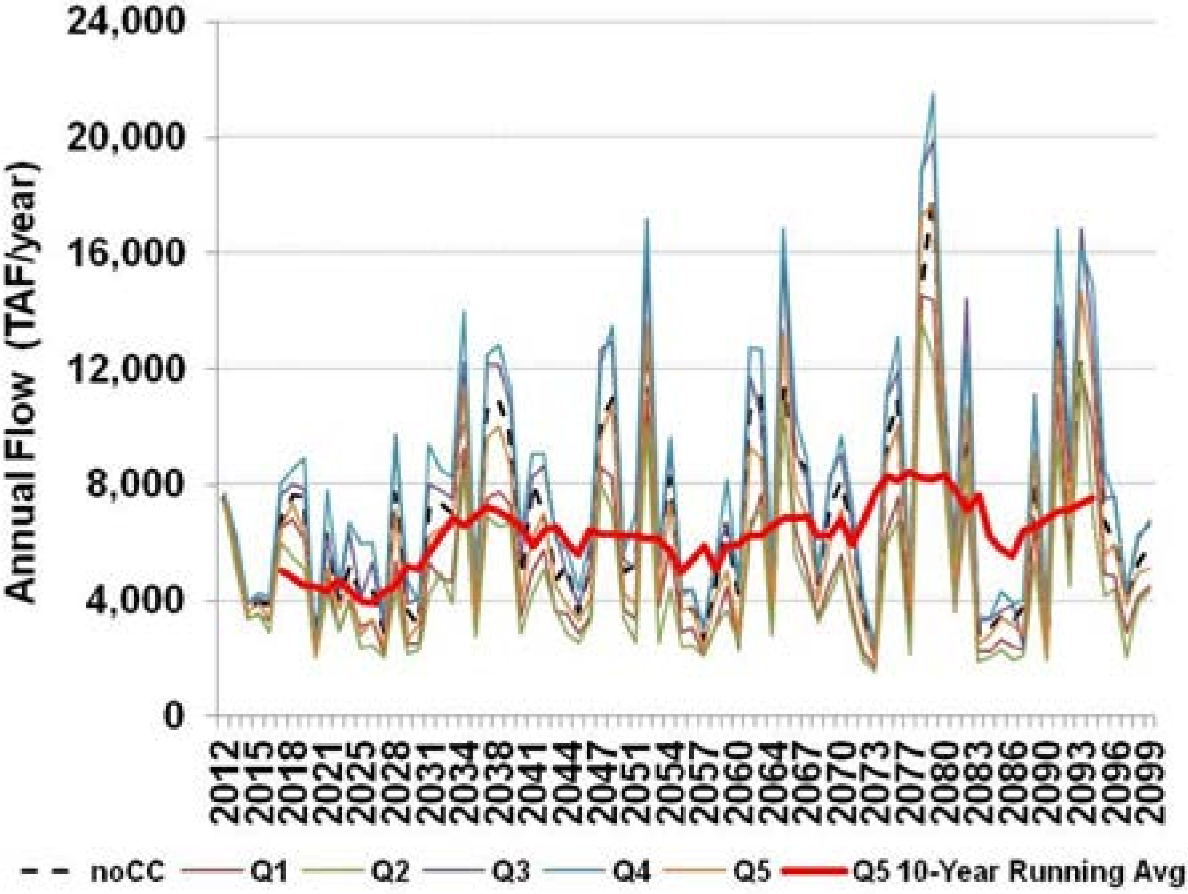


Figure 2b. Annual Time Series from 2012 to 2099 of Surface Water Flows in TAF/yr for the San Joaquin River for each Climate Scenario under Current Trends (CT) socioeconomic scenario

Sacramento River

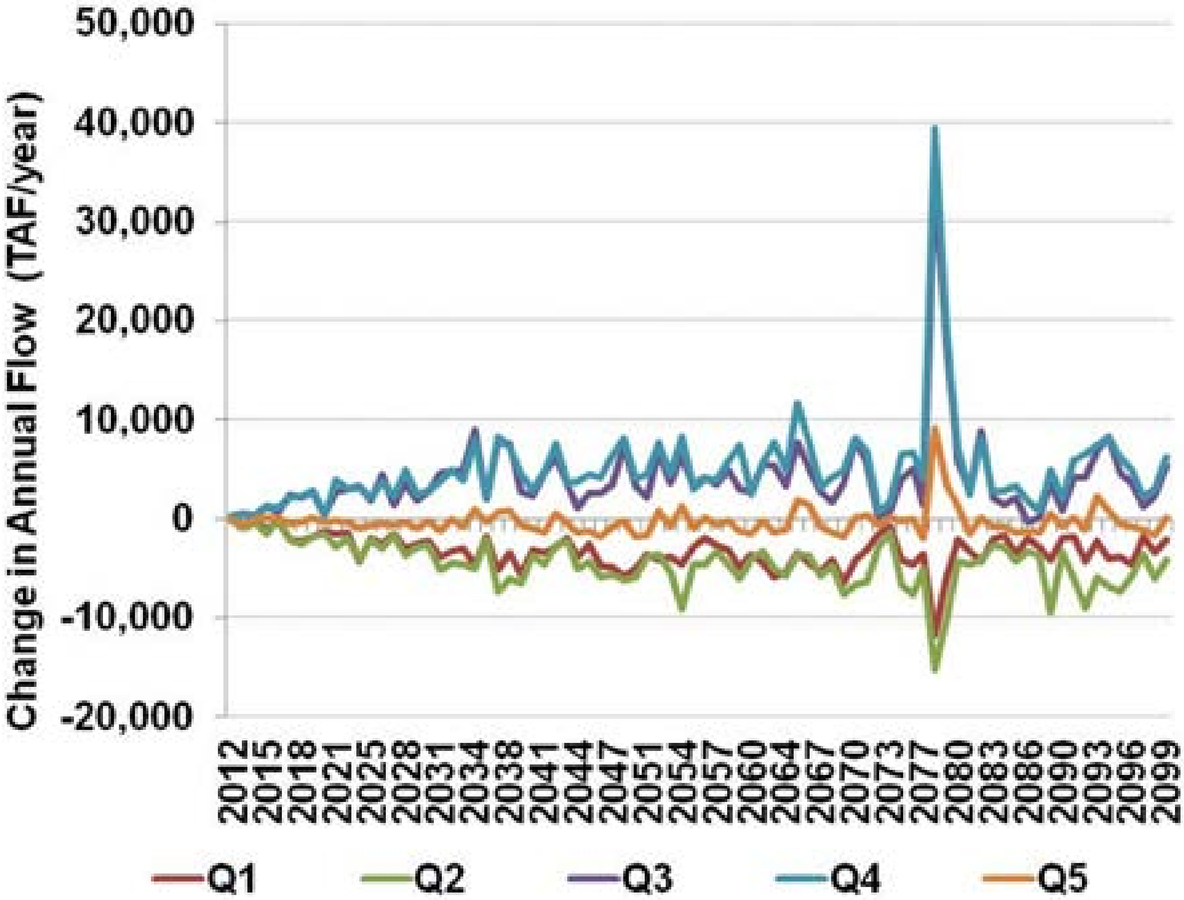


Figure 3a. Projected Changes in Annual Surface Water Flows in TAF/yr between 2012 and 2099 in the Sacramento River for each Climate Scenario Relative to the Historic Period Simulation (1915-2003).

San Joaquin River

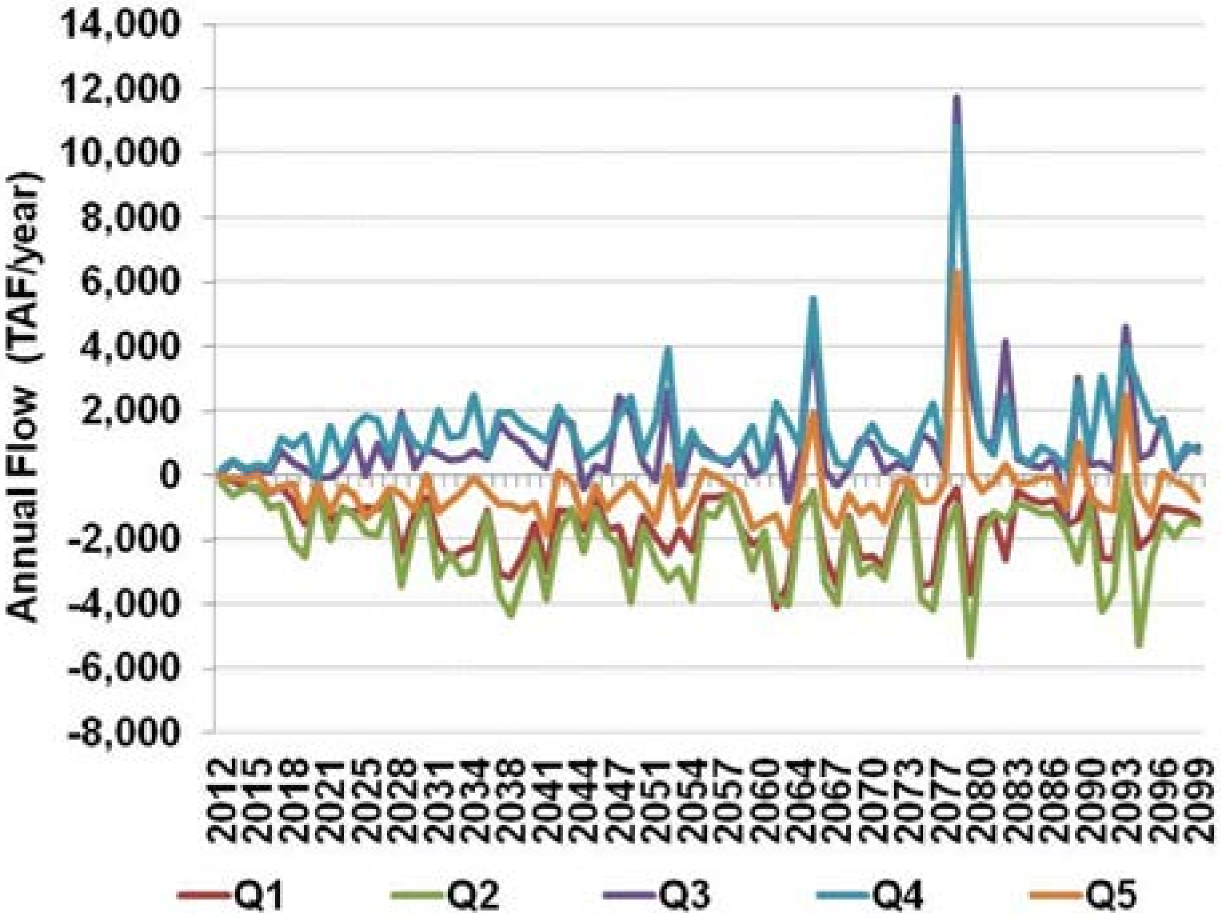


Figure 3b. Projected Changes in Annual Surface Water Flows in TAF/yr between 2012 and 2099 in the San Joaquin River for each Climate Scenario Relative to the Historic Period Simulation (1915-2003).

Sacramento River

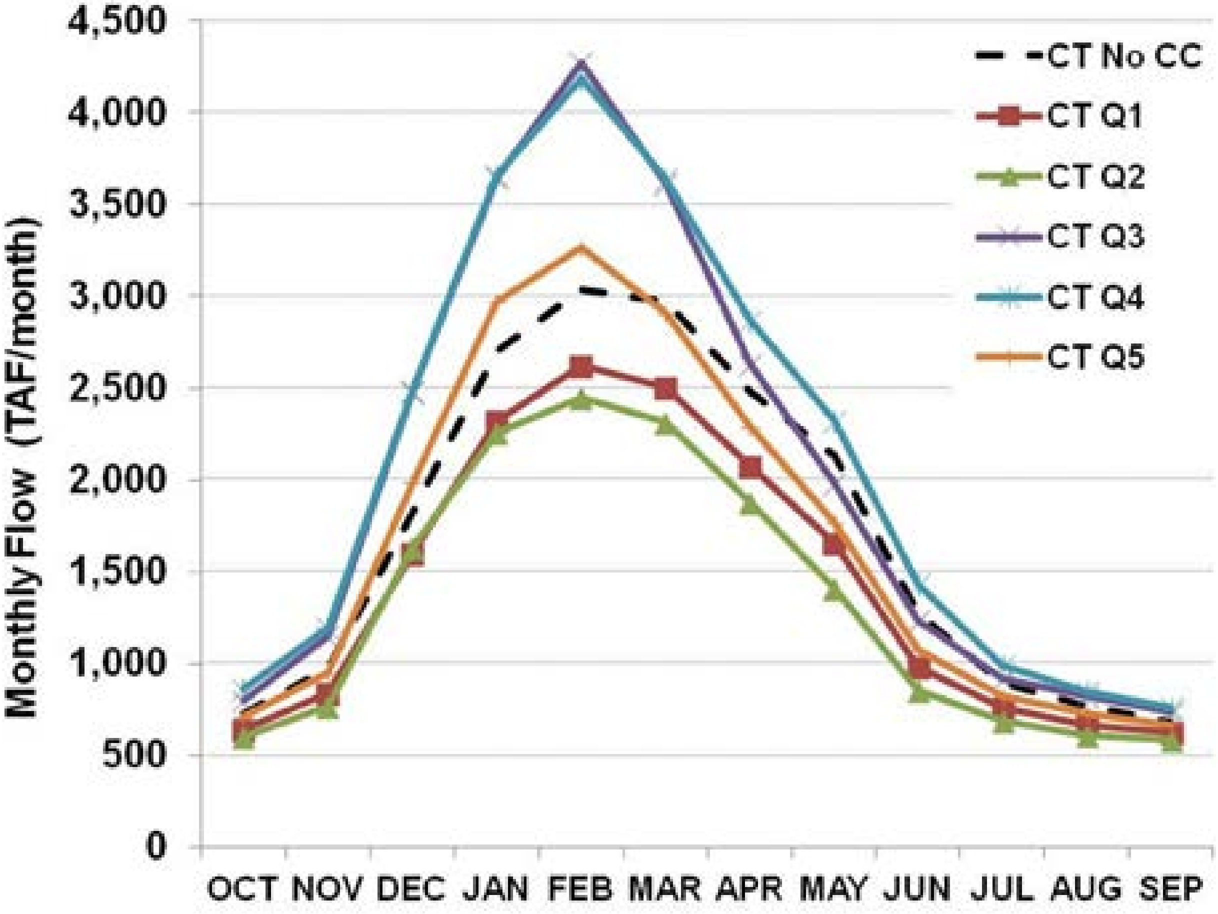


Figure 4a. Simulated Period Average Monthly Runoff in the Sacramento River Basin for each Climate Scenario

San Joaquin River

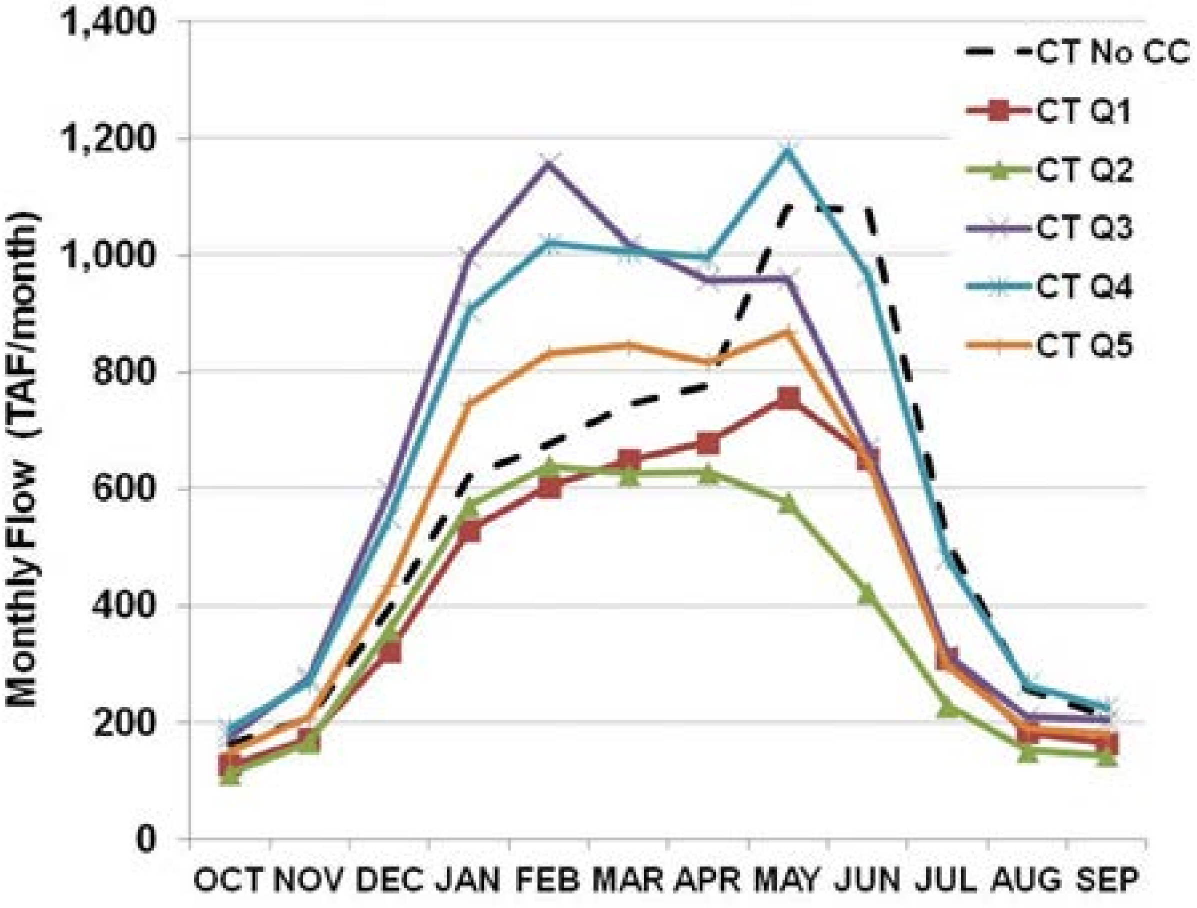


Figure 4b. Simulated Period Average Monthly Runoff in the San Joaquin River Basin for each Climate Scenario

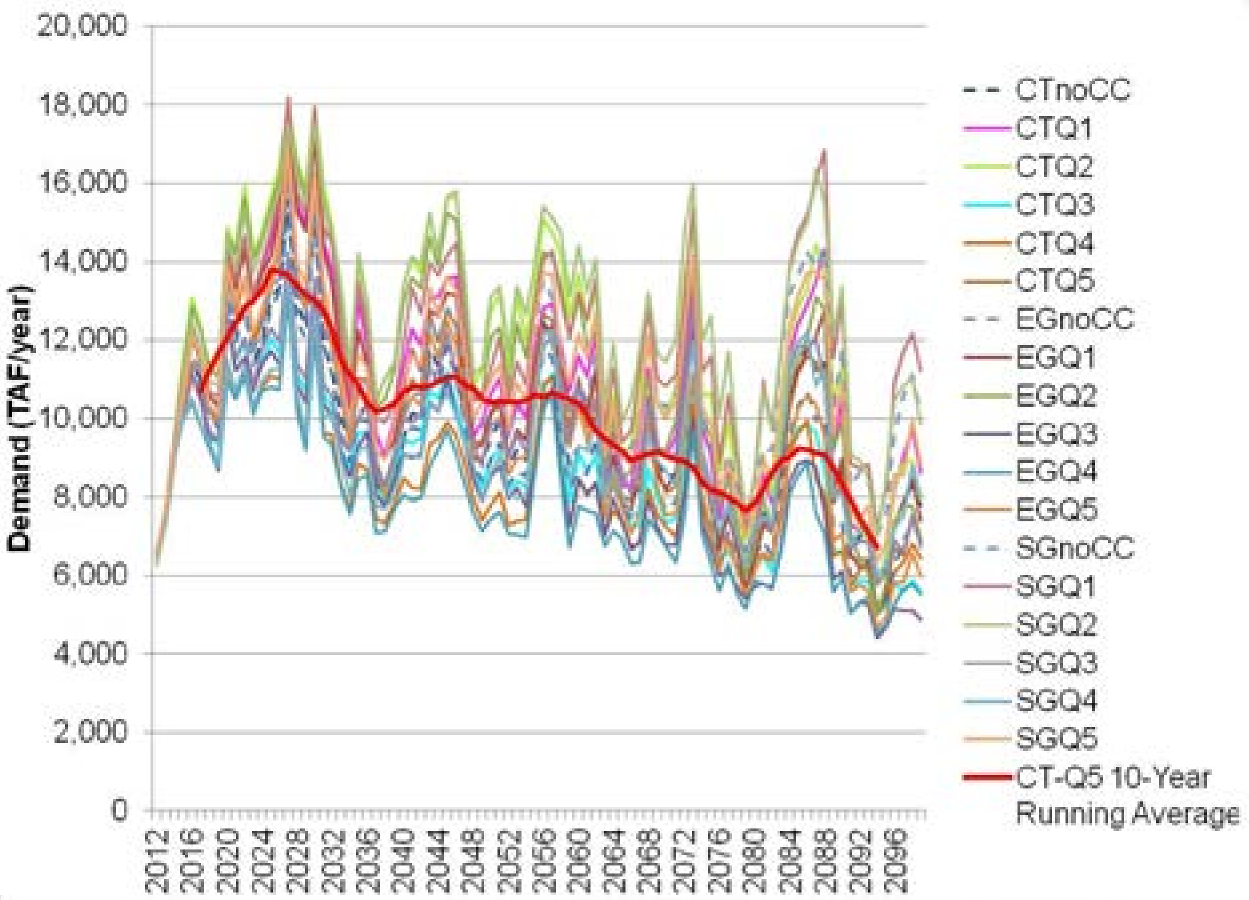


Figure 5. Annual Applied CVP Agricultural Water Demand in TAF/yr for each Socioeconomic-Climate Scenario.

the least change occurring in the Slow Growth (SG) scenario and the most in the Expansive (EG) scenario. Projected climate change also affects agricultural water demands. Changes in temperature, solar radiation, atmospheric humidity, wind speed and carbon dioxide have different crop-specific effects on the water needs of the major crops grown in the Central Valley.

For example, increased temperature may result in increased crop ET until a crop's optimum temperature range is exceeded resulting in reduced growth and a corresponding decline in water use. However, increasing carbon dioxide can both stimulate crop growth and reduce transpiration thereby increasing a crop's water use efficiency. Furthermore, climate change can also affect the rate of crop growth as well as planting and harvest dates. For annual crops, a shorter growing season due to more rapid growth may result in less water use whereas for perennial crops a longer growing season due to increased early and late season temperatures may result in more water use. In the CVP IRP study, these complex relationships were simulated to determine the net effect of the socioeconomic-climate scenarios on agricultural water demands by assuming that there would be no changes in the current mixture of crops and cultivars as well as planting dates and management practices. However, as irrigated acreage declines during the 21st century due to urban growth, results from the State Wide Agricultural Production (SWAP) model were used to simulate which crops farmers would continue to irrigate assuming future crop selections are made to obtain optimum economic benefits. Consequently, the CVP IRP study results may be interpreted as an assessment of the need for the development of effective strategies to adapt for current crop characteristics, management practices and technologies.

In general, the applied agricultural water demands decrease during the 21st century because of both the assumed reductions in irrigated land area and the effects of climate change on crop growth and ET. Both of these factors contribute to the overall decrease in agricultural water demands by the end of the 21st century. Because the agricultural applied water demands reflect the objective of maintaining optimum soil moisture conditions throughout the growing season by irrigating whenever precipitation is not sufficient to meet optimum crop water requirements, the drier climate projections (Q1,Q2) result in higher agricultural water demands. It is important to note that the rapid increase in agricultural water demands in the early 21st century shown on Figure 5 is an artifact of several factors including the use of the 20th century historical climate (1930's drought period) to characterize inter-annual climate variability in developing the transient 21st century projections, higher agricultural land use in the early 21st century and the limited amount of climate change that has occurred prior to and during this period. If a similar drought in the late 21st century had been simulated, the magnitude of applied water demands would have been reduced.

Figure 6 presents the annual time series of projected total urban demands within the CVP Service Area for the 18 socioeconomic-climate scenarios. In contrast to agricultural demands, urban demands in the CVP Service Area are strongly correlated with the socioeconomic scenarios and show only slight variations with projected climate change. Because the urban demands are driven largely by population, they tend to change steadily over time with the growth in population and expansion in commercial activities. Urban demand is only slightly changed under Slow Growth (SG) conditions but increases significantly under the Current Trends (CT) and Expansive Growth (EG) scenarios.

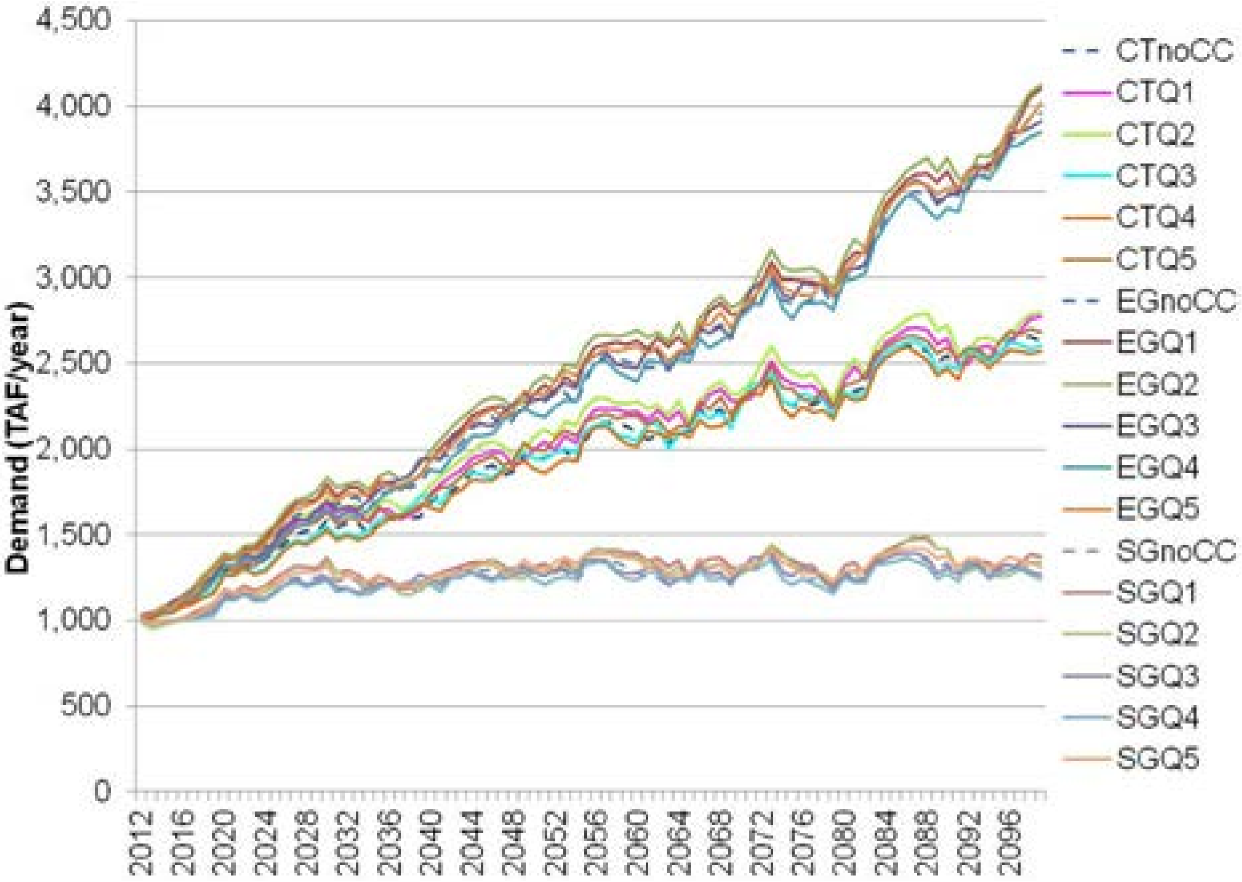


Figure 6. Annual Time Series of Urban Water Demands from 2012 to 2099 in the CVP Service Area in Each of the Socioeconomic (CT,SG, EG) and Climate projections (noCC, Q1, Q2, Q3, Q4, Q5) scenario combinations.

COMPARISON OF PROJECTED WATER SUPPLIES AND DEMANDS

A comparison of projected water supplies and demands in the CVP Service Area was performed to characterize the occurrence and potential range of unmet demands in the CVP Service Area. 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.

Figure 7 shows annual time series of groundwater, surface water, local project supplies, and unmet demands for four socioeconomic-climate scenarios, selected to represent the central tendency (CT-Q5), upper (EG-Q2), and lower (SG Q4) range of potential future unmet demands. The no climate change simulation (CT-noCC) is also included for comparative purposes. Over the twenty-first century, average annual unmet demands ranged from 2.7 to 8.2 MAF/year across the range of the 18 socioeconomic-climate scenarios. These unmet demands occurred predominantly in the South-of-Delta Divisions (San Felipe, West San Joaquin, and Friant). In general, unmet demands decrease as the rate of growth and climate warming are reduced and when precipitation is wetter than historic. Such conditions contribute to both reduced overall demands and increased supplies of both surface and groundwater.

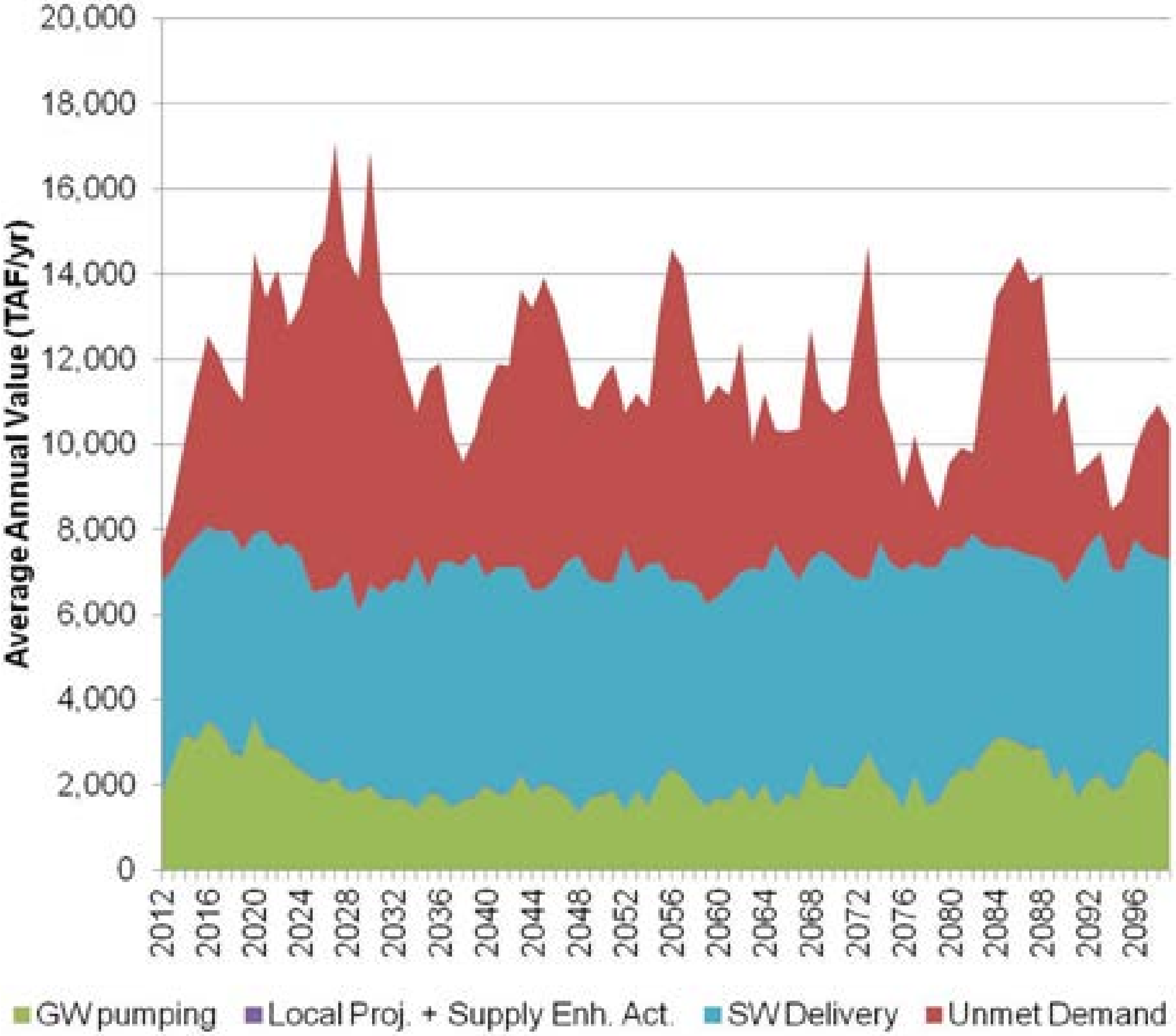


Figure 7a. Annual Time Series of Unmet Water Demands from 2012 to 2099 in the CVP Service Area for Selected Socioeconomic-Climate Scenarios - Current Trends – No Climate Change (CT-noCC) - Average Unmet Demand – 4.2 MAF

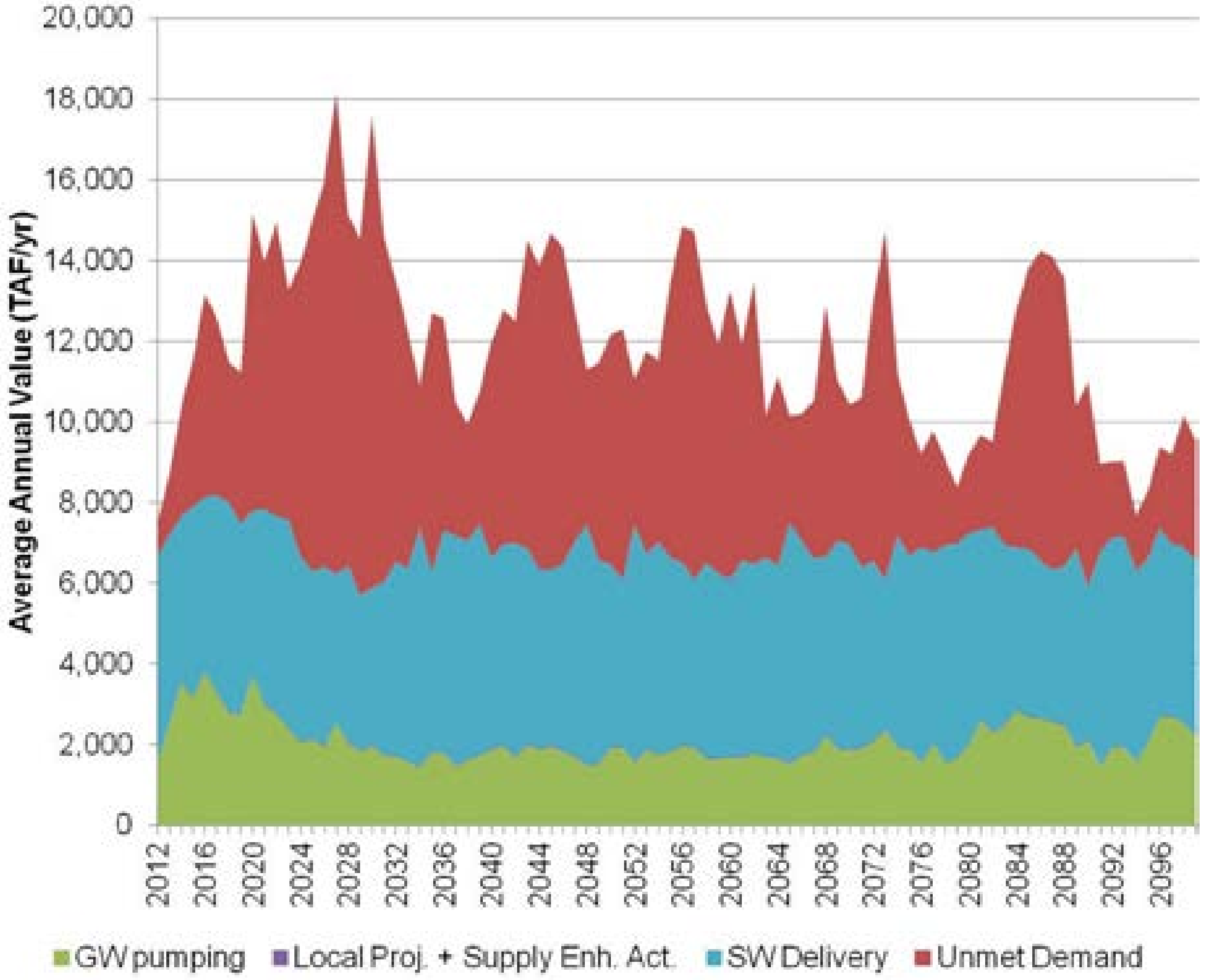


Figure 7b. Annual Time Series of Unmet Water Demands from 2012 to 2099 in the CVP Service Area for Selected Socioeconomic-Climate Scenarios - Current Trends – Central Tendency (CT-Q5) - Average Unmet Demand – 5.1 MAF

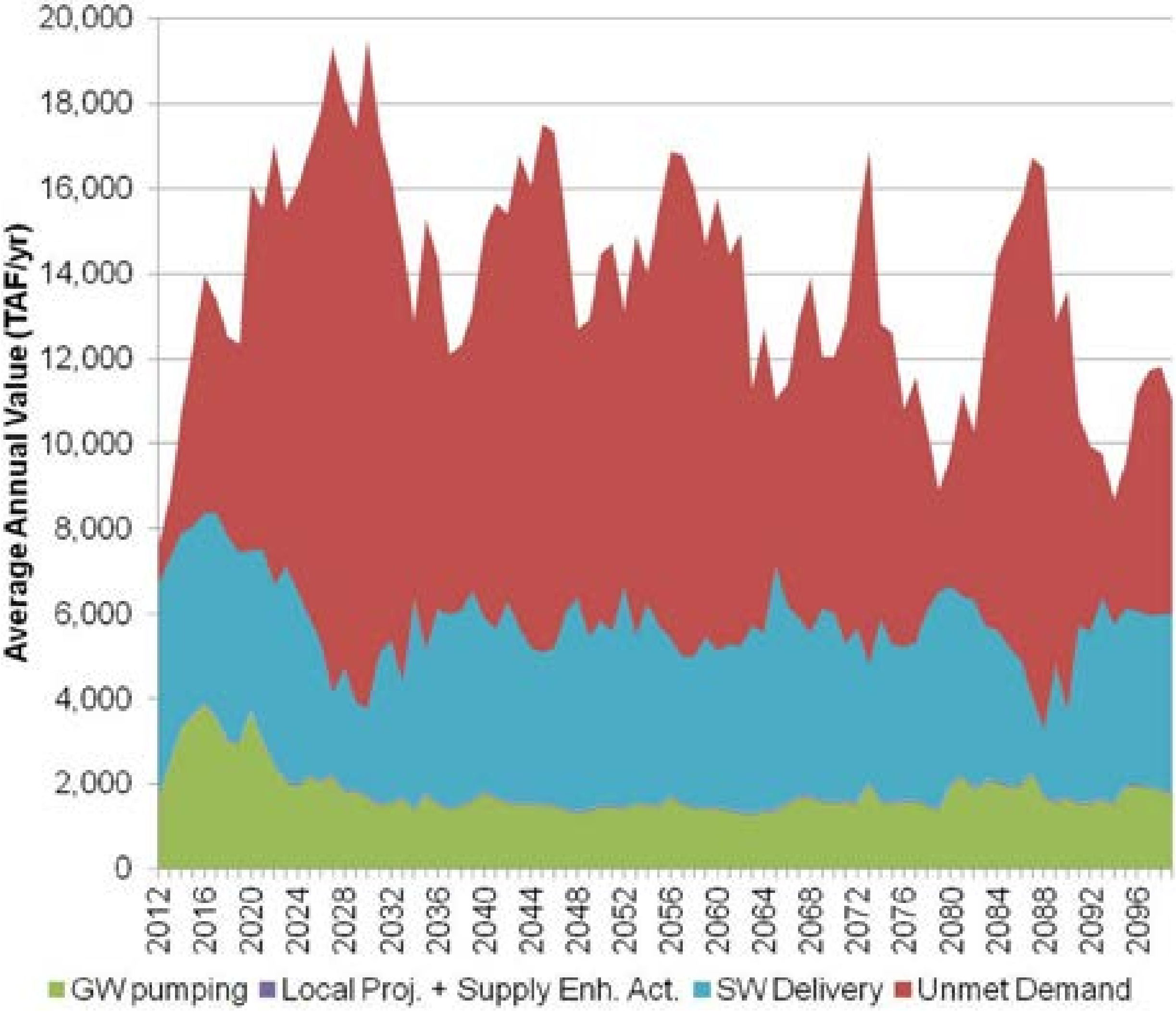


Figure 7c. Annual Time Series of Unmet Water Demands from 2012 to 2099 in the CVP Service Area for Selected Socioeconomic-Climate Scenarios - Expansive Growth – More Warming, Drier (EG-Q2) - Average Unmet Demand – 7.9 MAF

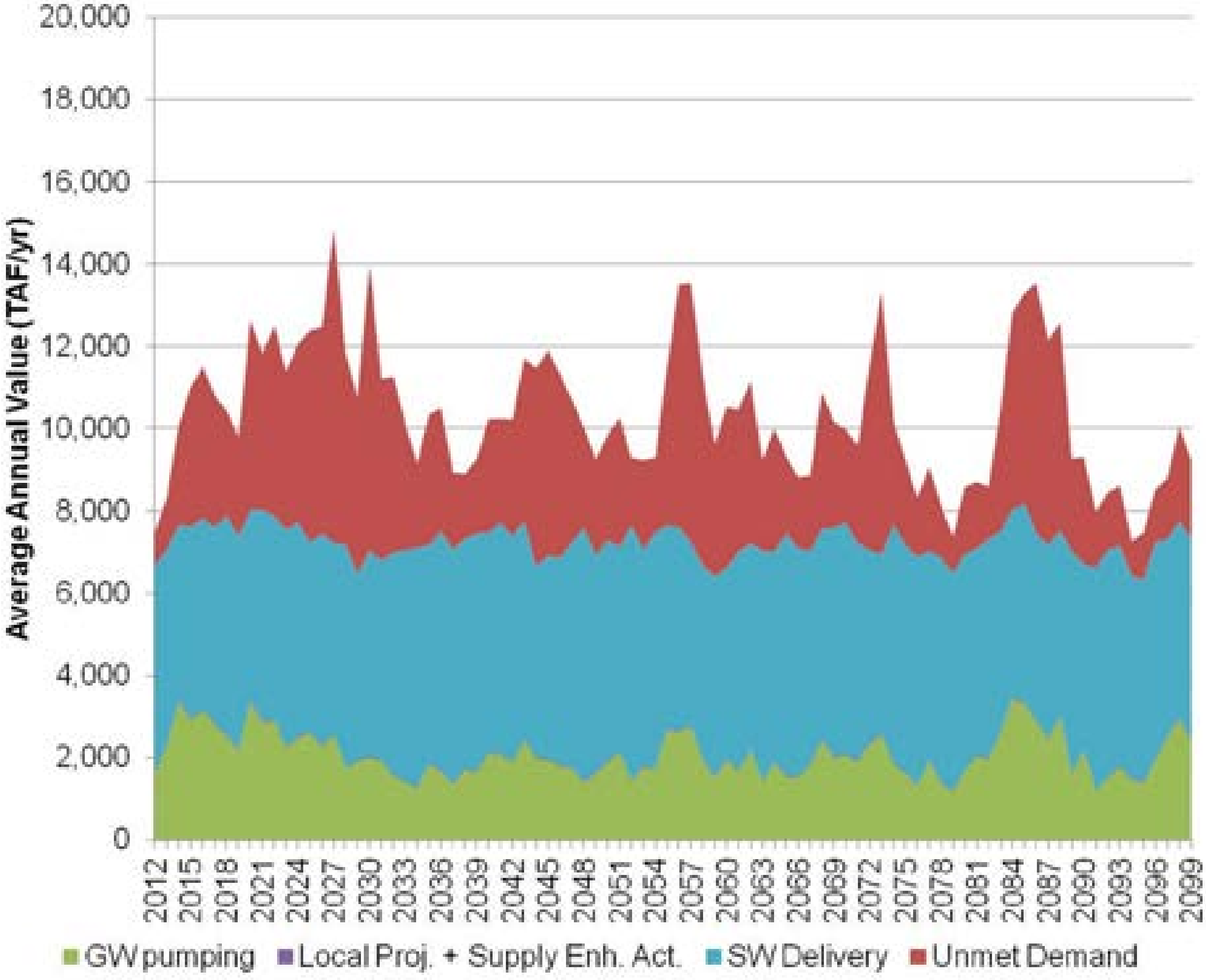


Figure 7d. Annual Time Series of Unmet Water Demands from 2012 to 2099 in the CVP Service Area for Selected Socioeconomic-Climate Scenarios - Slow Growth – Less Warming, Wetter (SG-Q4) - Average Unmet Demand – 3.2 MAF

PERFORMANCE OF POTENTIAL FUTURE WATER MANAGEMENT ACTIONS

The CVP IRP study included the analysis of a variety of potential water management actions that were grouped into thematic portfolios designed to achieve particular objectives. These portfolios were analyzed by simulating each one using the 18 socioeconomic-climate scenarios to characterize the range of their potential effectiveness relative to future socioeconomic-climate uncertainties and to assess what tradeoffs relative to key CVP performance metrics might occur. In the CVP IRP study, no attempt was made to find an optimum combination of actions nor to make recommendations relative to future implementation. In addition, the CVP IRP modeling tools were developed and applied with intent of characterizing the effects of socioeconomic-climate uncertainties on the CVP Service Area. As such, the results presented below are for informational purposes only.

Four thematic portfolios of water management actions were analyzed including:

- Portfolio A: Aggressive Local Actions
- Portfolio C: Delta Conveyance and North-of-Delta Storage
- Portfolio D: Delta Conveyance and South-of-Delta Storage
- Portfolio E: Aggressive Local Actions, Enhanced Environmental Flows, and North-of-Delta Storage

(An additional portfolio, Portfolio B focusing on North-of-Delta Storage was also developed but is not included in this summary because those actions are included in the composite Portfolios C and E). The actions that are included in each of the portfolios are shown in Table 1.

Table 1. Simulation Suites and Assumptions Inlcuded in Each Portfolio

	Portfolio			
Assumption	A	C	D	E
Baseline assumptions	X	X	X	X
Local actions				
Modest Ag and M&I Conservation	X	X	X	X
Municipal Recycling and Desalination	X			X
Aggressive Ag and M&I Conservation	X			X
Systemwide Actions				
Delta Conveyance		X	X	
Shasta Lake Enlargement		X		X
North-of-Delta Offstream Storage		X		X
South-of-Delta SW or GW Storage			X	
Enhanced Environmental Flows				X

Notes: GW = groundwater | M&I = municipal and industrial | SW = surface water

The Local Water Management Actions included additional conservation measures above the Baseline conservation conditions. However, it is important to note that no assessment was made of whether or not such actions could actually be achieved. The Modest Demand Reduction actions included full implementation of a 20-percent reduction in urban applied water demand with a 5-percent reduction in agricultural applied water demand to be achieved by 2020 and continue at the same level through 2100. The Aggressive Demand Reduction actions included these reductions plus additional water use efficiency measures to achieve a 40-percent reduction in urban demand and a 10-percent reduction in agricultural demand by 2050, and a 60-percent reduction in urban demand and a 15-percent reduction in agricultural demand by 2100. Municipal Water Recycling was also included in the Local Actions. These supply enhance¬ments were applied only in the San Felipe and Friant Divisions because these are the only Divisions that have significant unmet urban demands in the Baseline. In the Sacramento River Division, 65 TAF of additional municipal recycling and 35 TAF of desalination were assumed to be implemented by 2100. In the Friant Division, 100 TAF of municipal recycling was assumed to be implemented by 2100. In both cases, linear increases were assumed to occur throughout the 21st century.

The System-wide Water Management Actions included both changes in infrastructure and operations. The Enhanced Delta Conveyance Action includes assumptions that were developed solely for the purpose of the CVP IRP socioeconomic-climate scenario effects analysis and do not reflect Reclamation's policy regarding the Bay Delta Conservation Plan (BDCP) planning program.

The Enhanced Delta Conveyance Action assumptions include the following:

- 9,000-cfs capacity Division facility at Hood
- No minimum South Delta pumping
- 10,300-cfs Banks PP capacity
- Bypass flow controlled by Rio Vista flow requirements
- Shared SWP and CVP beneficiaries

The Shasta Lake Enlargement Action assumed a 634 TAF increase in reservoir storage with the primary objectives being to (1) increase survival of anadromous fish populations in the Sacramento River upstream of the Red Bluff Diversion Dam; and (2) increase water supply reliability for agricultural, M&I, and environmental purposes in the CVP Service Area.

The North-of-Delta Offstream Storage Action assumed a 1.8 MAF increase in offstream storage in the Sacramento Valley with the primary objectives being (1) provide ecological benefits to the Sacramento River, (2) ecological and water quality benefits to the Delta through outflow augmentation and (3) water supply reliability benefits to local users, CVP-SWP water contractors and wildlife refuges.

The South-of-Delta Storage Action was simulated to represent potential options for additional surface storage, groundwater storage, or conjunctive use management opportunities within the South-of-Delta CVP and SWP Service Areas. It was assumed that new storage would only be filled after existing SWP-CVP San Luis accounts were full, and that water would be released from this new South-of-Delta storage prior to releasing storage from existing San Luis Reservoir accounts. The assumed maximum simulated storage increases were 972 TAF for the CVP and 1,067 TAF for the SWP water contractors.

The Enhanced Environmental Flow Action provides additional flows beyond existing regulatory requirements for improving environmental conditions in the Sacramento Valley and Delta by requiring additional upstream reservoir releases and operational changes including:

- Unimpaired flows below Shasta Lake, Lake Oroville, and Folsom Lake are used as minimum instream flow requirements.
- A Delta outflow requirement of 60 percent of total unimpaired flow in each month from February through June was applied by reducing Delta exports.
- Offramps based on monthly reservoir storage can be applied to limit the required reservoir releases.

In the sections below, the results for each portfolio are compared. To give an overview of the range of results associated with the different socioeconomic-climate scenarios, the performance analysis results are shown for the same four socioeconomic-climate scenarios for which unmet demand results were shown above. The "Baseline" simulations represent current conditions without any additional management actions.

Unmet Demands in the CVP Service Area

Figure 8 shows the average annual unmet demands in thousands of acre-feet per year (TAF/yr) for the Baseline and each of four Portfolios using on four socioeconomic-climate scenarios selected to characterize the reasonable range of potential future uncertainties during the 21st century. All four portfolios show significant reductions in unmet demands relative to the Baseline. The largest reductions in unmet demands occur with implementation of the Portfolio "Aggressive" urban and agricultural local water conservation and recycling actions. When aggressive conservation actions are combined with increased North of Delta storage and enhanced environmental flows (Portfolio E) unmet demand reductions are slightly less reduced because of increased Delta outflows. Although not as large, Portfolios C and D which include only "modest" demand-reduction actions combined with increased storage and enhanced Delta conveyance also show reductions in unmet demands.

The Delta Conveyance - South of Delta storage portfolio (D) results in slightly increased unmet demands relative to the Delta Conveyance - North of Delta storage portfolio (C) largely due to the lessor amount of total storage capacity represented in the Portfolio D.

For all portfolios and the Baseline, projected unmet demands increase under the current trends central tendency climate scenario (CT_Q5) relative to the no climate change (CT_noCC) scenario. Even larger increases occur in the Expansive Growth and drier climate scenario (EG_Q2) scenario whereas in the Slow Growth wetter climate scenario (SG_Q4) unmet demands are less than in the no climate change scenario.

Delta Exports and Outflows

Figures 9 and 10 show the average annual Delta exports and outflows in TAF/yr for the Baseline and each portfolio. In all the socioeconomic-climate scenarios, the aggressive local demand-reduction and supply-enhancement actions (Portfolio A) result in little change in either exports or outflows relative to Baseline conditions. Both Portfolios C and D which combine modest conservation with increased storage and enhanced Delta conveyance result in significant increases in Delta exports and some reductions in Delta outflows whereas the enhanced environmental flows in Portfolio E result in reductions in exports and increases in outflows.

For the Baseline and all portfolios, Delta exports and outflows in projected central tendency (CT_Q5) scenario were slightly reduced relative to the no climate change (CT_noCC) scenario. In the Baseline as well as all the portfolios, both Delta exports and outflow were greatest in the wettest scenario (SG_Q4) and least in the driest scenario (EG_Q2).

Delta Salinity

The X2 metric is used as a measure of the effect of ocean salinity on Delta water quality. It indicates the location of the 2 parts per thousand salinity concentration measured in kilometers (km) from the Golden Gate Bridge. Larger values indicate increased Delta salinity. Figure 11 shows the average simulated X2 positions from February to June for the Baseline and portfolios. In all the socioeconomic-climate change scenarios, the local water demand reductions actions in Portfolio A result in very little change in X2 relative to the Baseline conditions. Both of the portfolios with increased storage and enhanced conveyance in (C and D) result in increases in X2 location whereas the enhanced environmental flows in Portfolio E decrease the X2 location.

For the Baseline and all the portfolios, X2 location increased under the central tendency socioeconomic-climate scenario (CT_Q5). Even larger X2 increases occur under the drier climate projection (EG_Q2) whereas in the wetter climate projection (SG_Q4) the X2 position is similar to the no climate change location despite the effects of sea level rise in SG_Q4.

Water Temperature

Water temperatures in the Sacramento and San Joaquin River were simulated for each of the portfolios and socioeconomic scenarios. Water temperatures in the San Joaquin River were essentially unaffected by any of the Portfolio

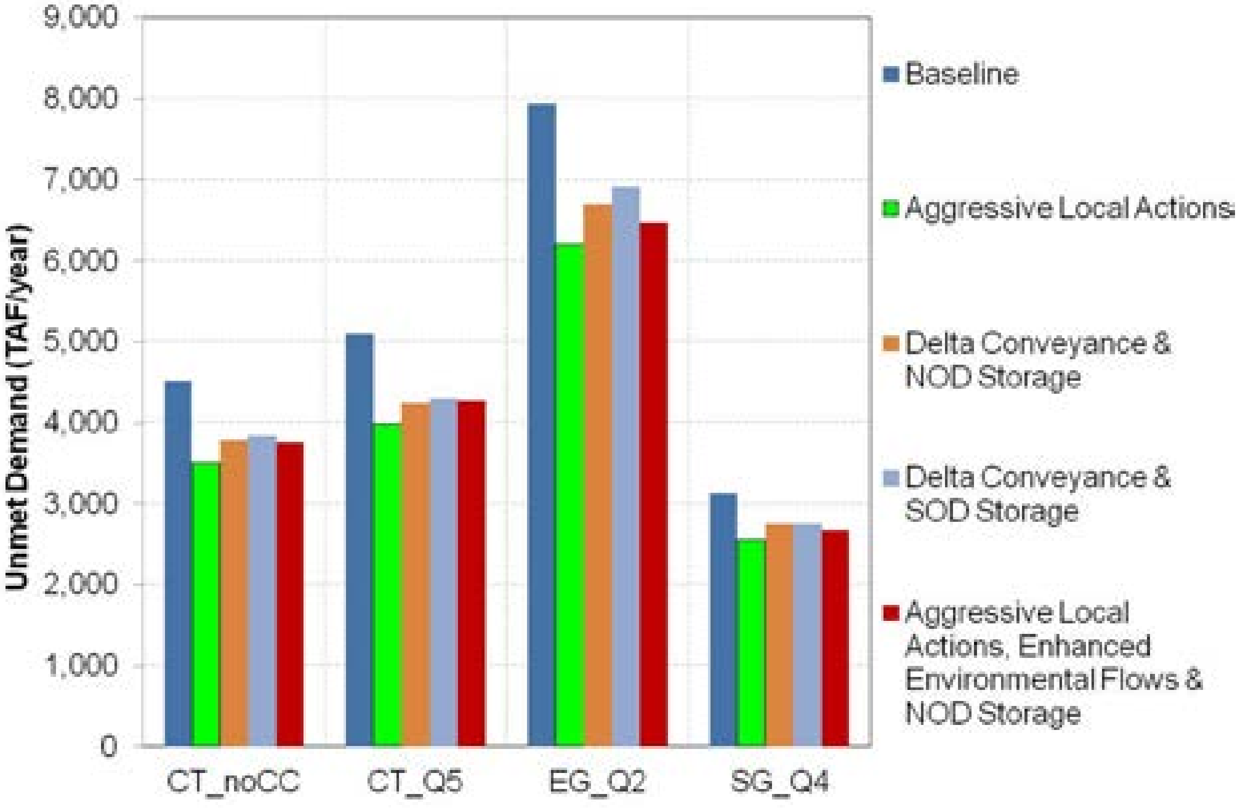


Figure 8. Average Annual Unmet CVP Demands for each Portfolio and Scenario

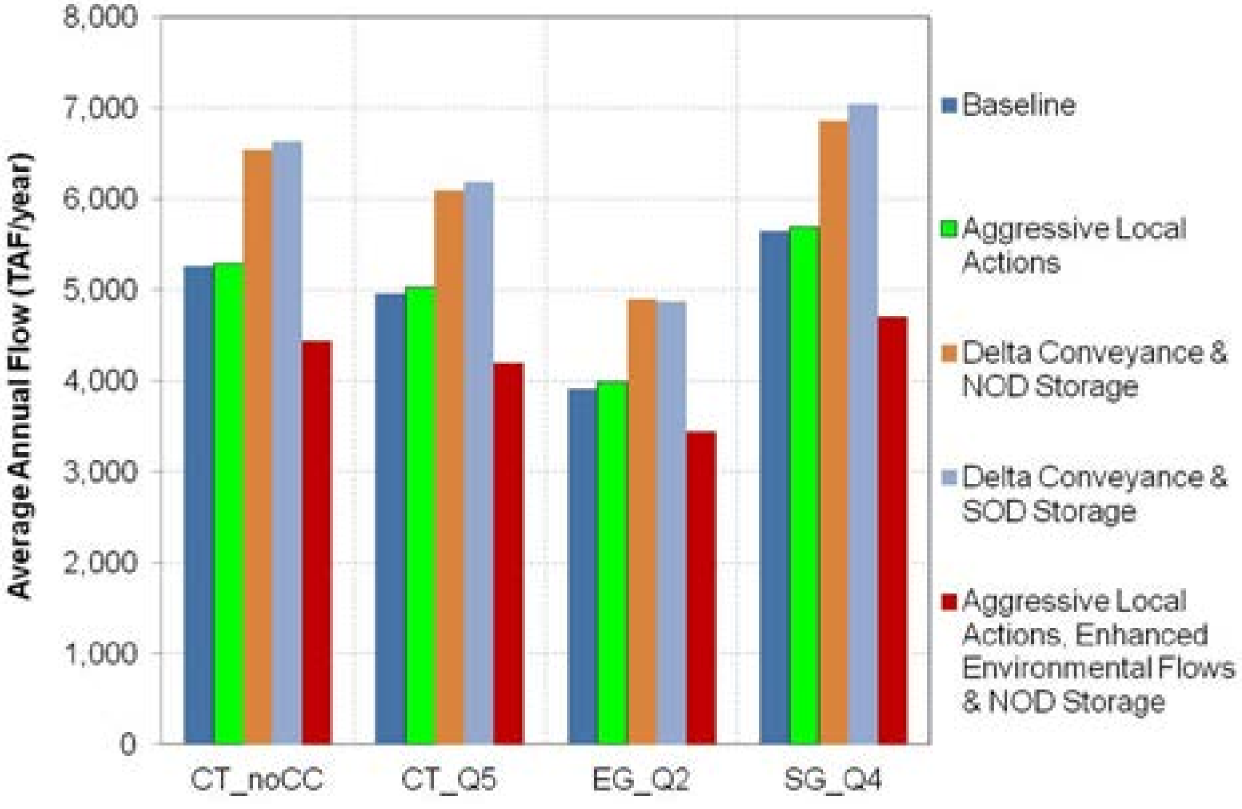


Figure 9. Average Annual Total Delta Exports (TAF/yr) for each Portfolio and Scenario.

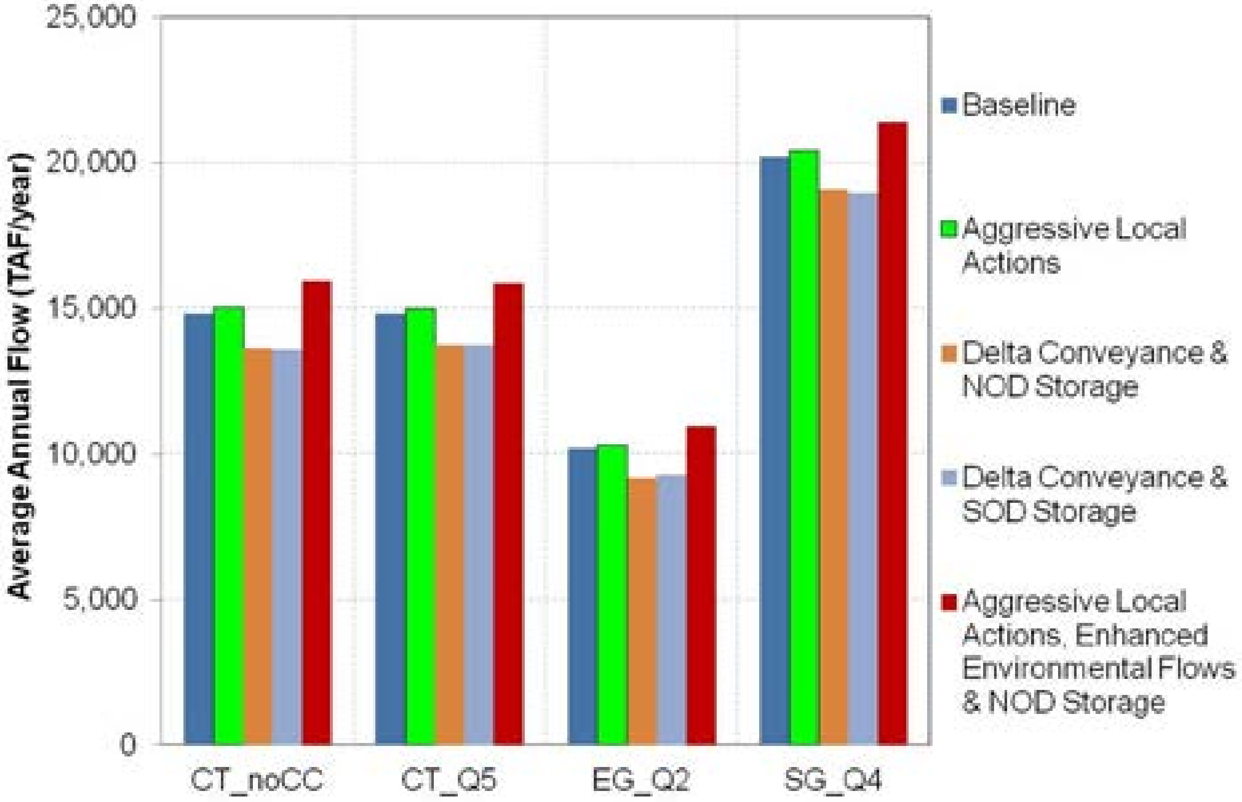


Figure 10. Average Annual Delta Outflows (TAF/yr) for each Portfolio and Scenario.

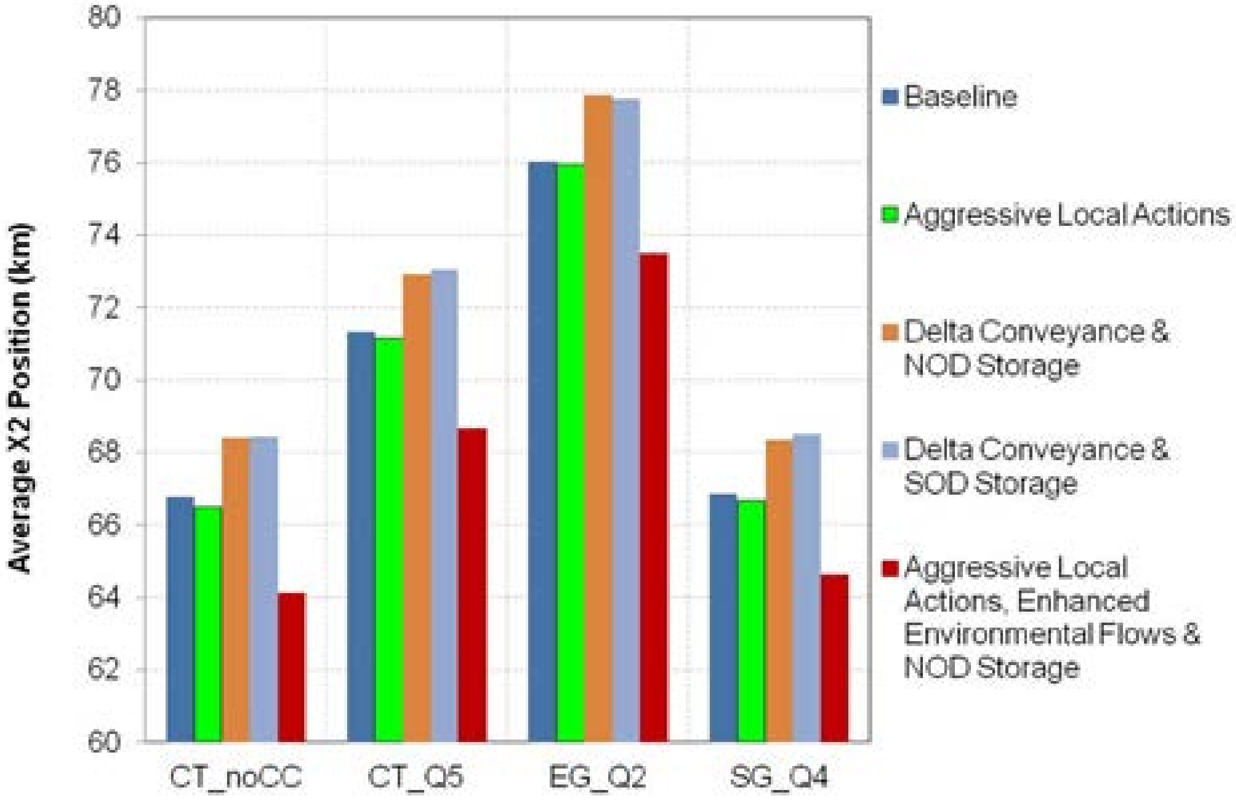


Figure 11. Average Annual February-to-June X2 Locations for each Portfolio and Scenario.

actions. Changes in mean daily July through September water temperatures in the Sacramento River at Jelly's Ferry are shown on Figure 12 for each of the Portfolios. Relative to their Baselines, the increased North of Delta storage actions in Portfolio C provide the largest reductions in water temperatures. Both the aggressive local demand reductions actions (Portfolio A) and South of Delta storage increases (Portfolio D) do provide some reductions in water temperature at this location. Despite including increased North of Delta storage, the enhanced environmental flows result in some slight increases in water temperatures.

The largest decreases in water temperature occur in the drier climate (EG_Q2) because the additional storage in Portfolio C results in greater increases cold water pool relative to the Baseline under drier conditions. The largest increases in water temperature occur under the wetter SG_Q5 scenario because increased releases for enhanced environmental flows (Portfolio E) reduce the cold water pool relative to the Baseline more significantly under these conditions.

Hydropower Generation and Greenhouse Gas Emissions

Figure 13 shows the average annual change in net hydropower generation in Gigawatthours per year (GWh/yr) for each portfolio relative to their respective Baseline condition. Figure 14 shows the corresponding changes in mean annual GHG emissions expressed as metric tons of carbon dioxide equivalents per year (mtCO2e/yr). Because hydropower generation essentially occurs without significant GHG emissions, reductions in hydropower may increase the use of fossil fuel based power generation resulting in potential increases in GHG emissions. Since SWP system produces less power than it uses, any further reduction in its power generation is accompanied by increased GHG emissions.

For all the socioeconomic-climate scenarios, Portfolio E is the only portfolio that results in a net increase in hydropower generation. This net increase occurs primarily because there are reduced Delta export and conveyance pumping associated with the enhanced environmental flows for both CVP and SWP systems. This export reduction also reduces GHG emissions. There are only very slight reductions in hydropower generation associated with the aggressive local demand reduction actions in Portfolio A. The increased storage and enhanced Delta conveyance portfolios (C and D) both result in reduced net hydropower generation and corresponding increases in GHG emissions due to increased export pumping. Portfolio D has the greatest net power reductions because of the additional pumping required to store water in the south of Delta region. Overall changes are not as large for the CVP as for the SWP system because it is already a net consumer of power in the Baseline. Across the range of socioeconomic-climate scenarios, larger increases in generation and reductions in emissions occur in the wetter SG_Q4 scenario than in the drier EG_Q2 scenario with the central tendency (CT_Q5) being intermediate in magnitude.

Economic Benefits

Urban water supply and salinity costs as well as agricultural economic benefits throughout the CVP Service Area were evaluated to compare the potential effects of changing socioeconomic-climate conditions on each of portfolios during the early (2025), mid (2055) and late (2085) 21st century. It should be clearly noted that the economic benefits reported here are not a thorough analysis of benefits nor are the costs of implementing the actions included in the analysis.

Figure 15 shows the change in average annual benefits in each portfolio relative to their Baselines. The largest increases in benefits occur with the increased storage and enhanced Delta conveyance portfolios (C and D). The Portfolio A aggressive local demand reduction actions show little effect on economic benefits whereas the enhance environmental flows (Portfolio E) results in decreased benefits. Depending on the portfolio actions, benefits either increase or decrease continuously during the century. The largest changes (both positive or negative) occur in the Expansive Growth drier climate (EG_Q2) scenario and the least change occurs in the wetter scenario (SGQ4) reflecting the increased value of water in high growth conditions and reduced supply availability.

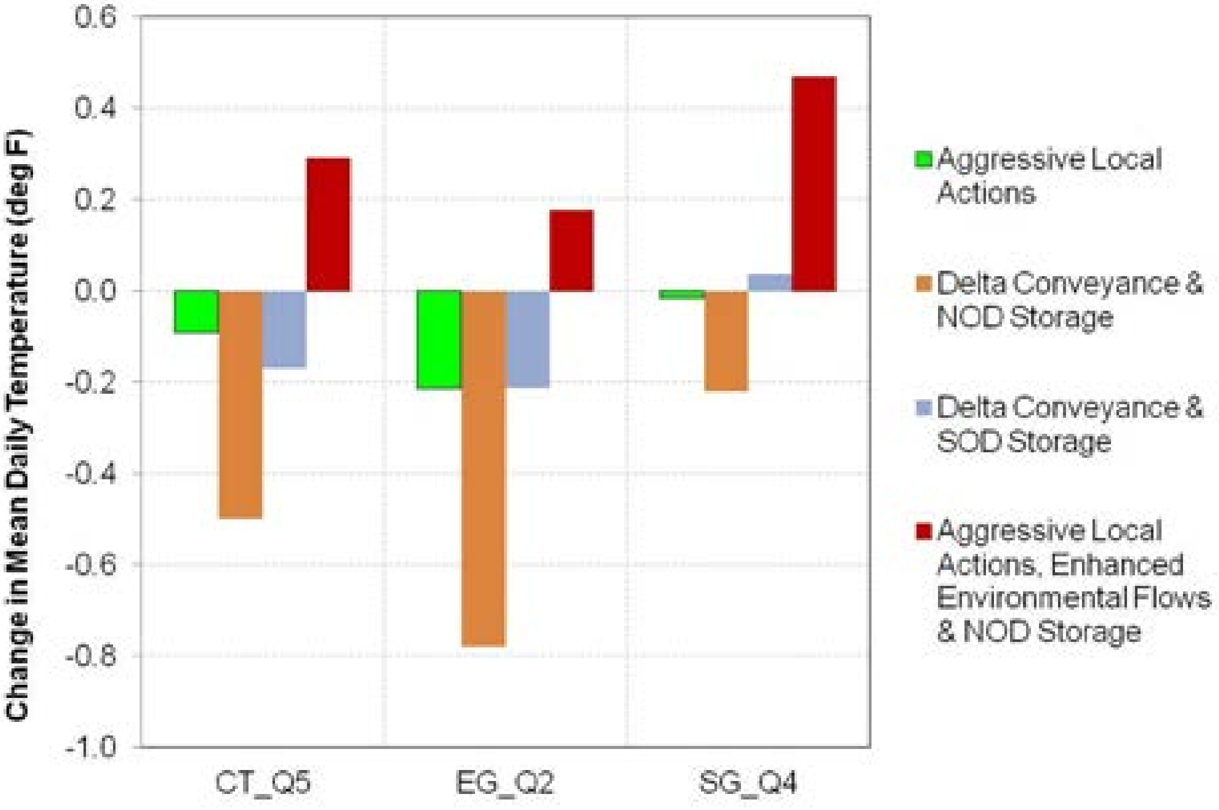


Figure 12. Change in Mean Daily Temperature on Sacramento River at Jelly's Ferry from July to September for each Portfolio and Scenario Relative to their Baselines.

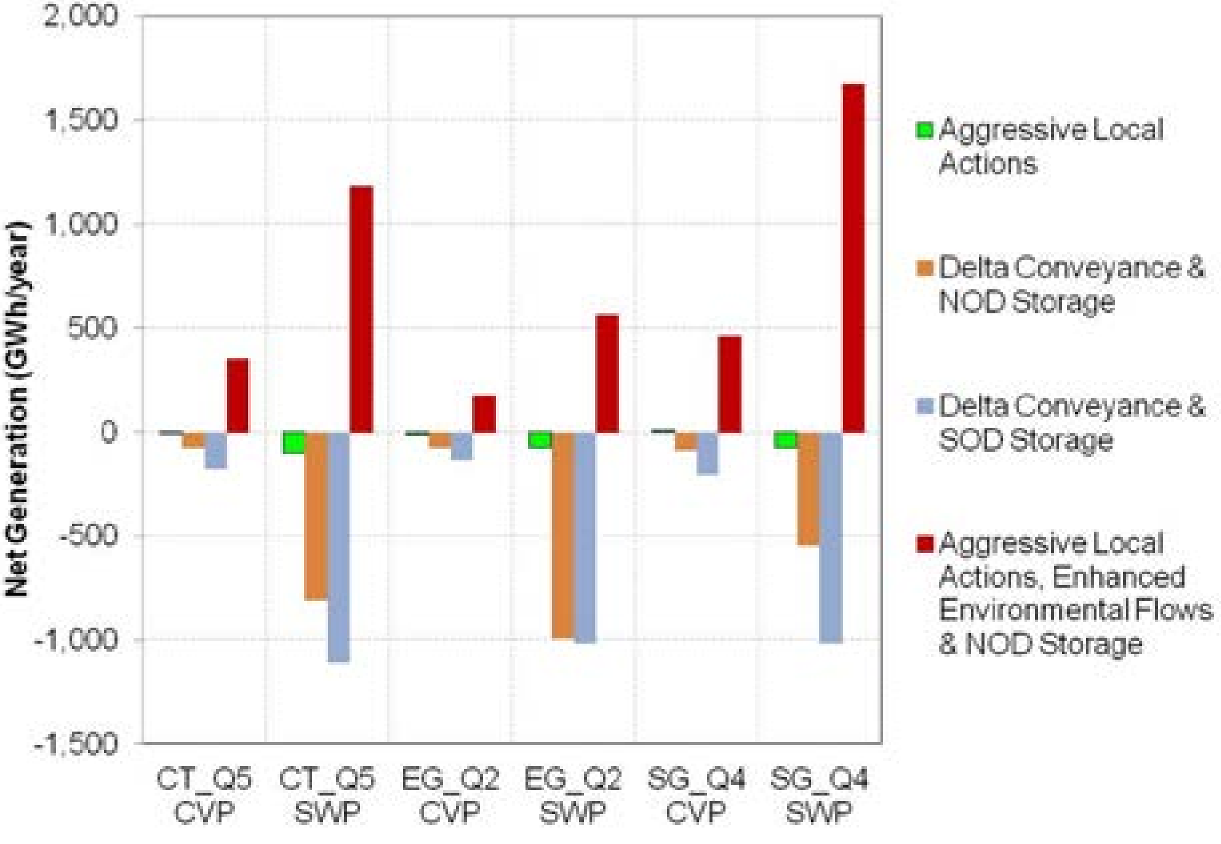


Figure 13. Change in Net Hydropower Generation in CVP and SWP systems for each Portfolio and Scenario Relative to their Baselines.

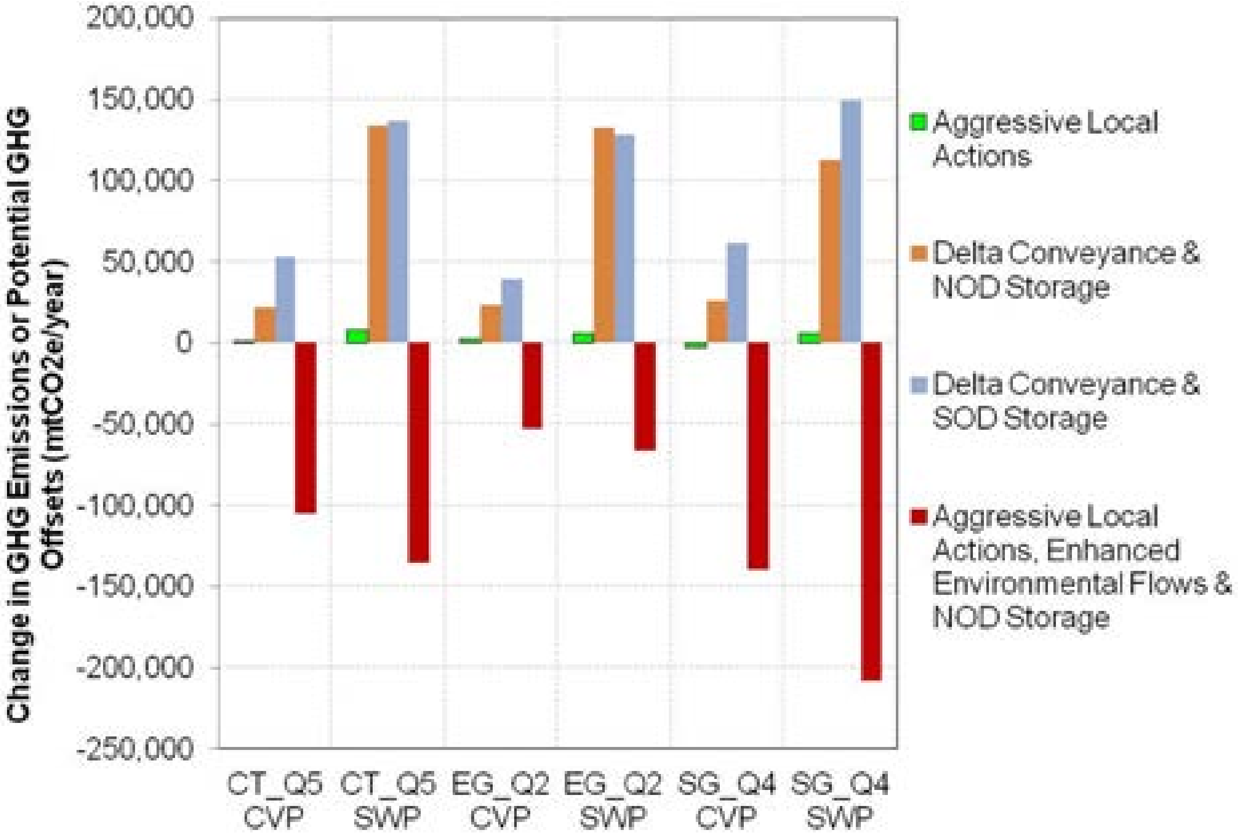


Figure 14. Change in Net GHG emissions in CVP and SWP systems for each Portfolio and Scenario Relative to their Baselines.

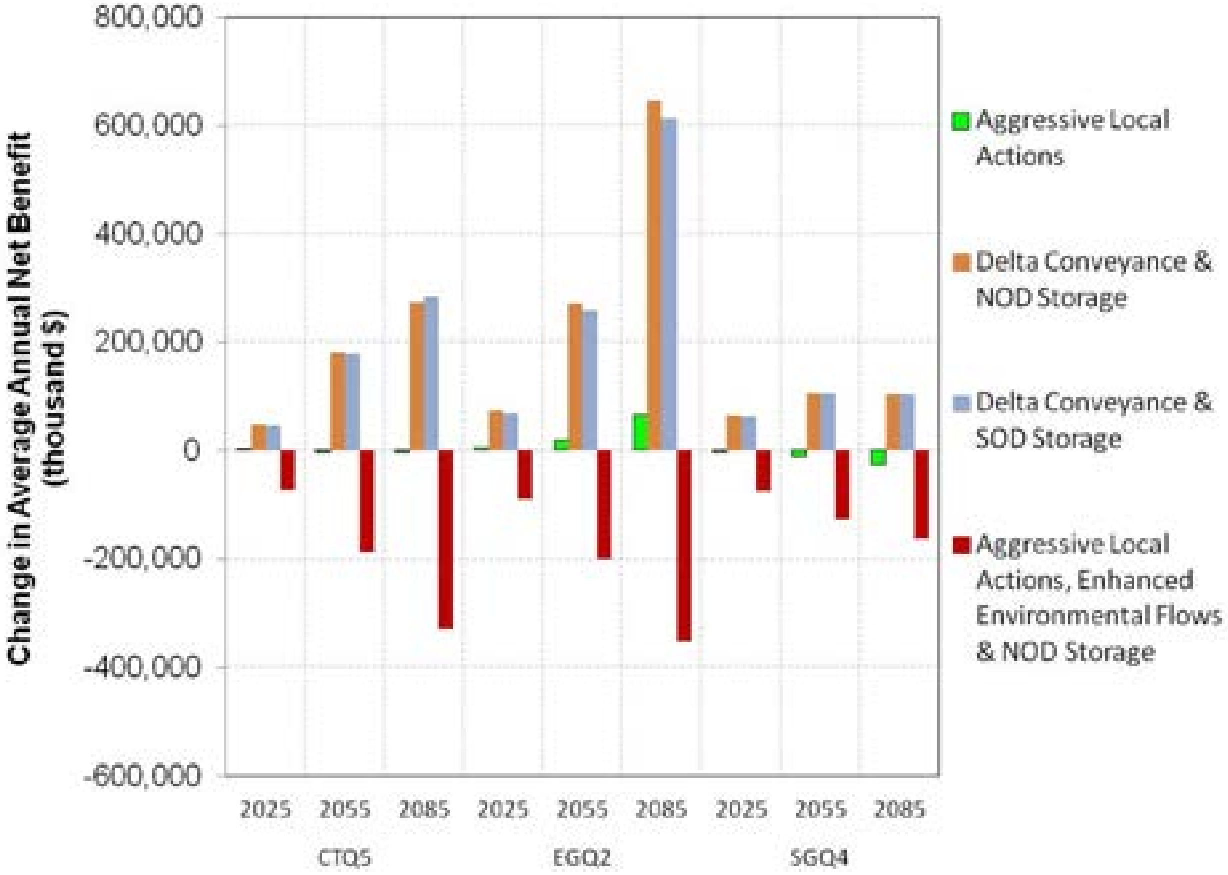


Figure 15. Changes in Average Annual Agricultural and Urban Economic Benefits in the CVP Service Area for each Portfolio and Scenario Relative to their Baselines.

PORTFOLIO TRADEOFFS

The results of portfolio performance assessments above were compared to evaluate tradeoffs among the portfolios. However, it should be noted that other potentially significant parameters such as the costs and feasibility of implementing these portfolios were not evaluated.

- Portfolio A: Aggressive Local Reduction and Supply Enhancements
  - Portfolio A would provide reductions in unmet demands in the CVP Service Area, with little change in the other performance metrics as compared to the Baseline.
- Portfolio C: Delta Conveyance and North-of-Delta Storage
  - Portfolio C would provide increases in Delta exports, reductions in unmet demands in the CVP Service Area (though less than in Portfolio A), increased economic benefits, and modest improvement in upper Sacramento River water temperatures. However, these benefits would come with reduced Delta outflow, increased salinity in the Delta, reduced net hydropower generation, and increased GHG emissions.
- Portfolio D: Delta Conveyance and South-of-Delta Storage
  - Portfolio D would provide similar benefits and impacts to Portfolio C, with the exception that smaller water temperature benefits on the upper Sacramento River would be realized.
- Portfolio E: Aggressive Local Actions, Enhanced Environmental Flows, and North-of-Delta Storage
  - Portfolio E would provide increases in Delta outflow, improvements in Delta salinity, reductions in unmet demands in the CVP Service Area (though less than in Portfolio A), increased net hydropower generation, and reduced GHG emissions. These benefits would come with reduced Delta exports and reduced economic benefits.

CVP IRP STUDY LIMITATIONS

The CVP IRP study provides new valuable information for long-range planning purposes regarding the impacts of future climatic and socioeconomic uncertainties on the CVP Service Area and its Divisions. The CVP IRP study also examines the potential benefits and tradeoffs among several portfolios of water management actions, addressing some identified challenges confronting the CVP in the 21st century. However, there are limitations that should be kept in mind when considering the results of these analyses.

- The CVP IRP study is a screening-level analysis that simulated the most important components of the CVP water management system by using simplified representations of the CVP, SWP, and local project operations within the Central Valley. In addition, although the scope of the analysis covered supplies and demands within the CVP Service Area, the effects of potential actions on SWP and non-project contractor's unmet demands were not analyzed.
- The analyses used the WEAP-CV and CVP IRP CalLite models, which are simplified models in which much of the complexity of the system has been aggregated as compared to more complex models such as CALSIM II. CVP IRP CalLite model captured the most prominent aspects of the Central Valley hydrology and system operations, but simulated hydrology and water management within specific sub-basins has limited detail. Therefore, the model did not simulate some aspects of CVP operations such as Cross Valley Canal deliveries or Central Valley Project Improvement Act (b)(2) operations. In addition, the model included simplified representations of some of the water management actions as compared to CALSIM II.
- Although the analytical approach addressed a broad range of performance metrics related to the Central Valley water management system, it did not address some aspects of California water management that could be considered important metrics for assessment of impacts and development of robust adaptation strategies. In particular, the costs of implementing each action were not considered in the CVP IRP analysis.
- The CVP IRP study was only able to analyze a limited number of potential water management actions. This allowed for only a limited assessment of tradeoffs to be performed among different portfolios of actions. Furthermore, no attempt was made to determine which combinations of actions might be optimum with regard to various performance metrics.

Despite these limitations, the CVP IRP study does provide a solid foundation for future reconnaissance-level analyses of the Central Valley water management system. The limitations described above are intended to identify what additional improvements in the analytical approach and modeling tools would benefit the Mid Pacific Region's long range planning activities.

ACRONYMS AND ABBREVIATIONS USED IN FIGURES

Δ°C	change in temperature in degrees Centigrade
Δ%P	percent change in precipitation
Avg	average
CT	Current Trends
CVP	Central Valley Project
EG	Expansive Growth
GHG	greenhouse gas
GW	Groundwater
GWH/yr	Annual Electric Generation in Gigawatthours
IRP	Integrated Resource Plan
km	kilometer
M&I	municipal and industrial
max	maximum
min	minimum
MJ/m2	mega-joules per square meter
mtCO2e/year	metric tons of CO2 equivalents
noCC	no climate change
Q1	drier, less warming
Q2	drier, more warming
Q3	wetter, more warming
Q4	wetter, less warming
Q5	ensemble median
SG	Slow Growth
SW	surface water
SWP	State Water Project
TAF	thousand acre-feet
taf/mo	thousand acre-feet per month
TAF/year	thousand acre-feet per year

On the Front Cover: Generic photo of fish with a photo strip showing agriculture, an energy transmission tower, and the Shasta Dam; *On the Back Cover*: Generic photograph of riparian habitat