

SECTION 5 - BASELINE CONDITION ANALYSIS

In this section, the effects of potential future socioeconomic-climate changes on the CVP Divisions are presented. The CVP IRP modeling tools were 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 scenarios. In Appendix A, the Baseline assumptions used for the CVP IRP CalLite model simulations are described in more detail. The Baseline assumptions reflect the requirements of the 2008 Fish and Wildlife Service and 2009 National Marine Fisheries Service Biological Opinions, along with other assumptions related to demands, water rights, facilities, regulatory standards, and operations criteria of the SWP and CVP systems. The CVP IRP CalLite model assumptions have minor differences compared to those used in many CALSIM II studies. These differences are primarily due to the simplifications necessary to make the CVP IRP CalLite model computationally efficient.

Baseline system results were developed for the following performance metric categories for each of the 18 socioeconomic-climate scenarios:

- Water supplies
- Applied water demands
- CVP and SWP system operations
- Supplies and demands in CVP Divisions
- Other performance assessments

The Baseline results for these metrics are described in the following sections.

5.1 Water Supplies

Figures 5-1 through 5-4 show the average annual runoff in the Sacramento River system upstream of Hood, the East Side streams and the Delta, the San Joaquin River system upstream of Vernalis, and the Tulare Lake region for each of the socioeconomic-climate scenarios

over the simulation period of water years 2012 through 2099. In general, there was very little difference in water supplies among the different socioeconomic scenarios. However, there were substantial differences in runoff among the different climate scenarios. Under the no climate change condition, average annual runoff was about 20.5 million acre-feet per year (MAF/year) in the Sacramento River system, 1.3 MAF/year in the East Side streams and the Delta, 6.7 MAF/year in the San Joaquin River system, and 3.4 MAF/year in the Tulare Lake region, for a total of 31.9 MAF/year. In the median climate scenario (Q5), average annual runoff in each region was only slightly less than the no climate change condition. However, the drier climate scenarios (Q1 and Q2) had average annual runoff that was substantially lower (ranging from 19–26 percent) than the no climate change scenario, and the wetter climate scenarios (Q3 and Q4) had average runoff that was substantially higher (ranging from 16–22 percent) than the no climate change scenario. Overall, average annual runoff for the entire water system ranged from a low of about 23.7 MAF/year in Q2 to a high of about 39.0 MAF/year in Q4 (a difference of about 64 percent).

Figures 5-5 through 5-8 show the average runoff in each month in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region for each Current Trends scenario. Figures 5-9 through 5-13 show the same information for the inflows into each of the major CVP and SWP reservoirs. Each basin has a different monthly pattern reflecting the difference in hydroclimate and terrestrial conditions within the basin. In each basin, the climate scenarios exhibited a similar pattern to the no climate change scenario, but with a shift in runoff from the spring months to the winter months. This projected shift occurs because higher temperatures during winter cause earlier snowmelt runoff. This seasonal shift is greater in basins where the elevations of the historical snowpack areas are lower and, therefore,

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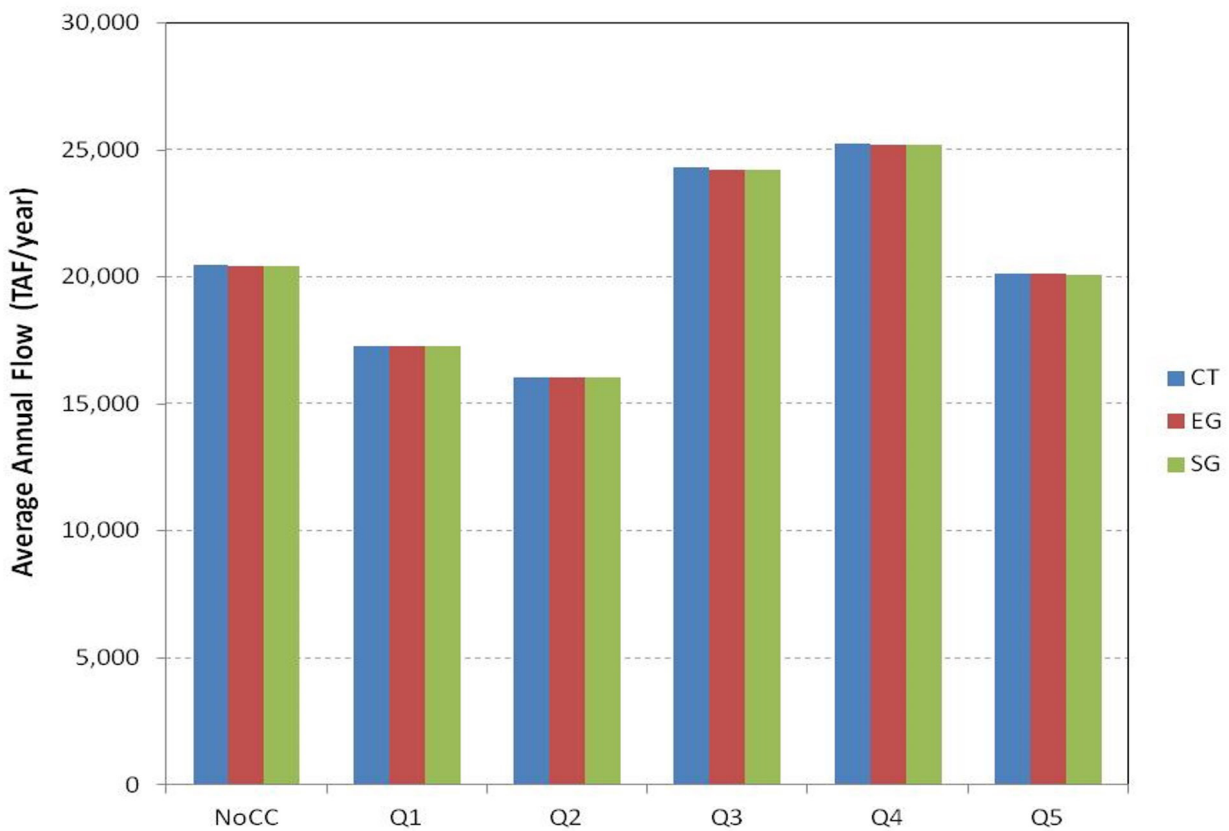


Figure 5-1. Average Annual Runoff in the Sacramento River System in Each Scenario

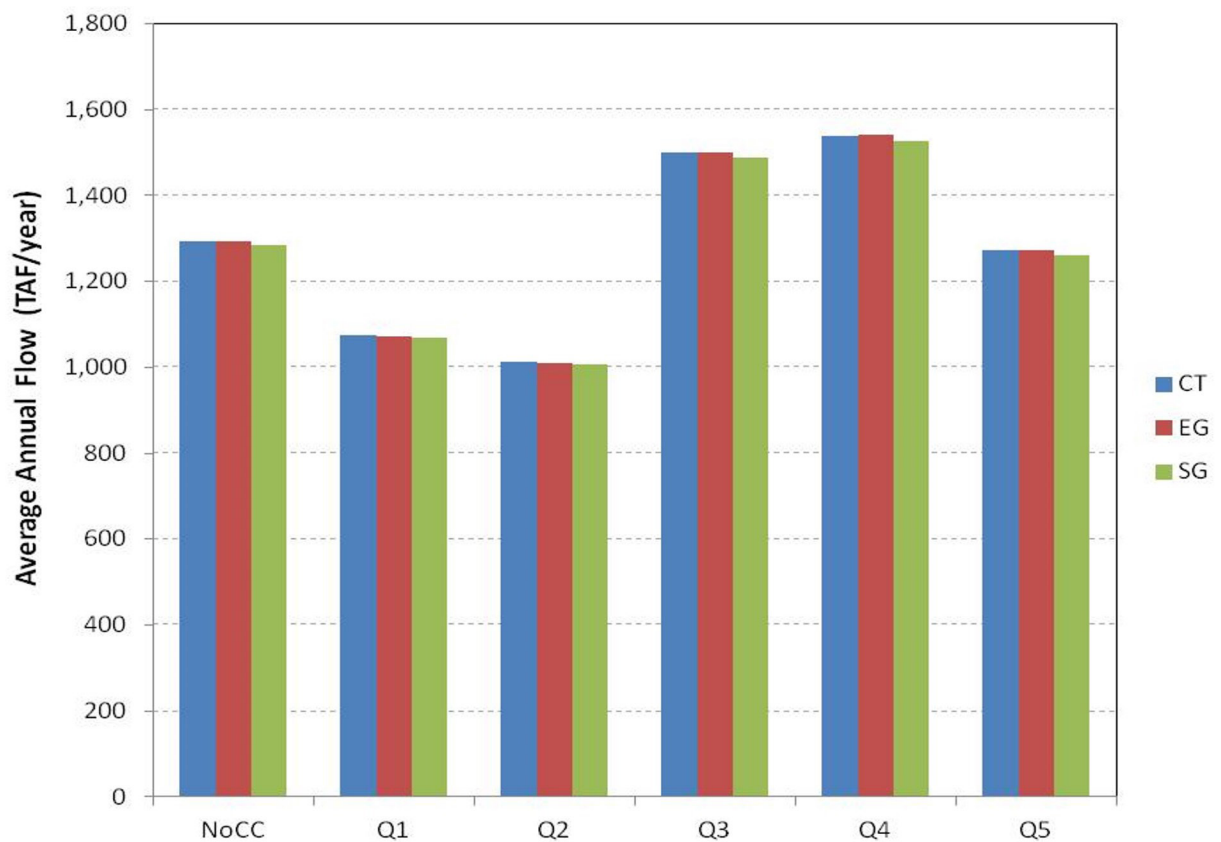


Figure 5-2. Average Annual Runoff in the East Side Streams and Delta in Each Scenario

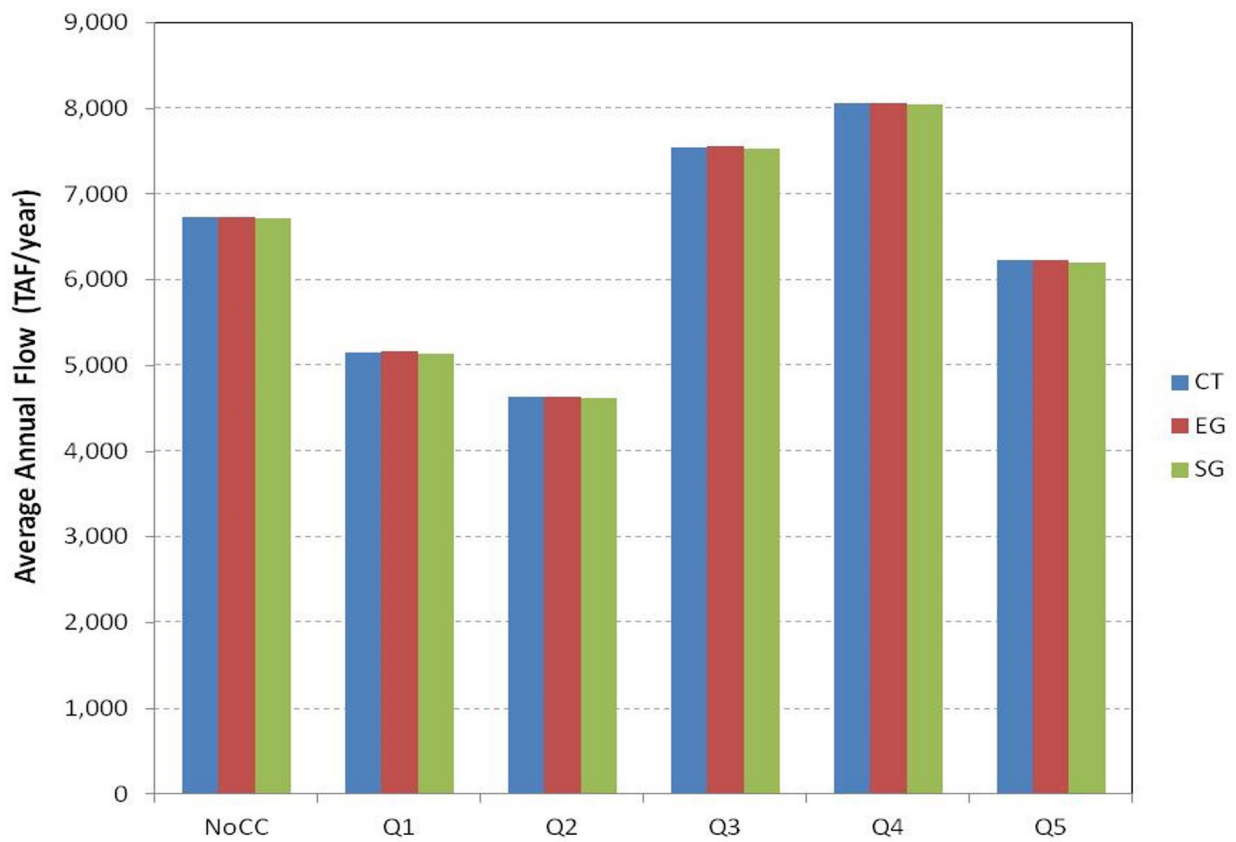


Figure 5-3. Average Annual Runoff in the San Joaquin River System in Each Scenario

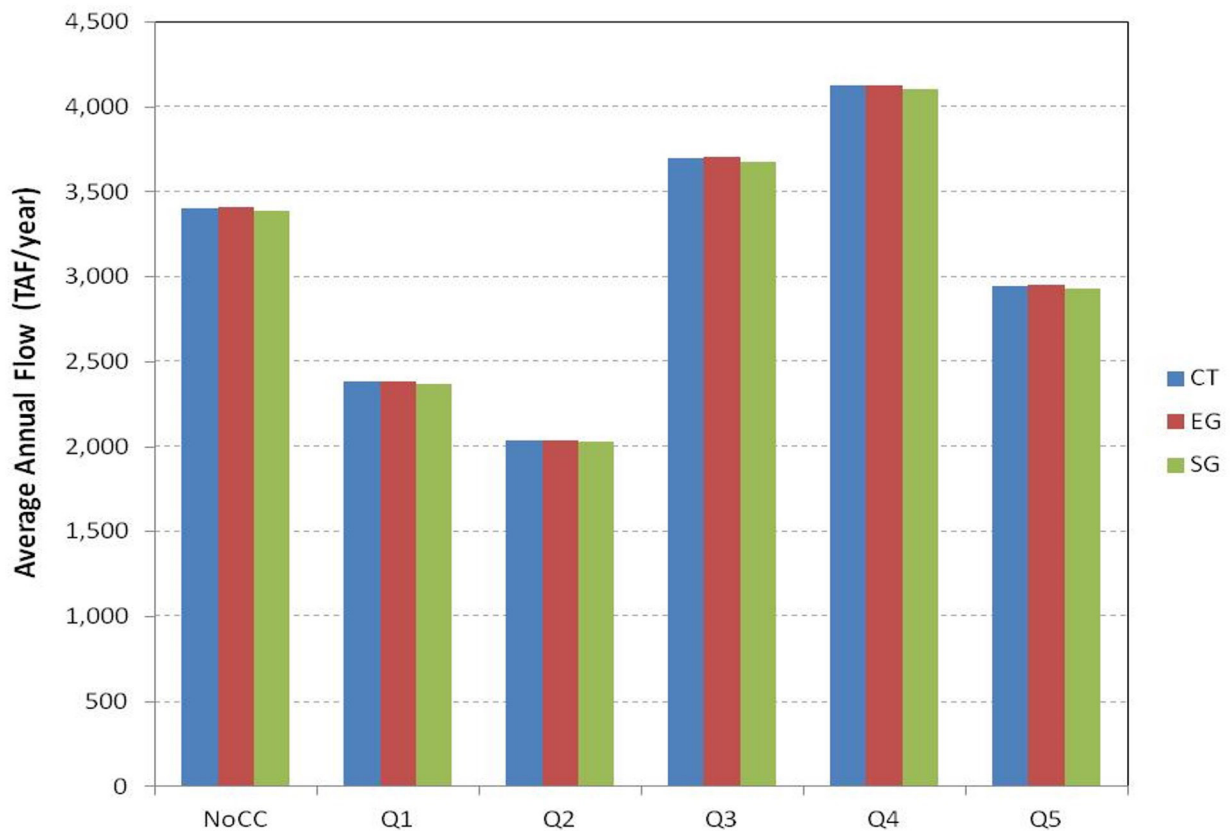


Figure 5-4. Average Annual Runoff in the Tulare Lake Region in Each Scenario

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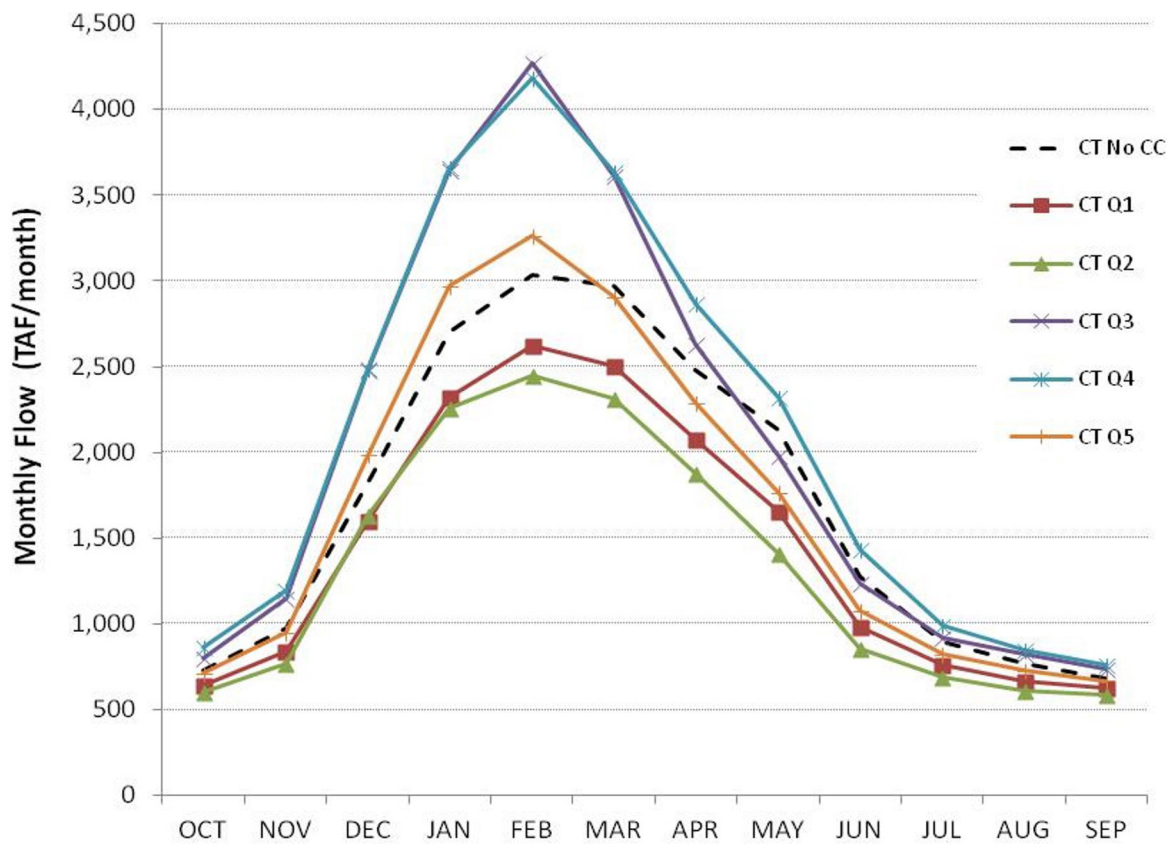


Figure 5-5. Average Runoff in Each Month in the Sacramento River System in Each Climate Scenario

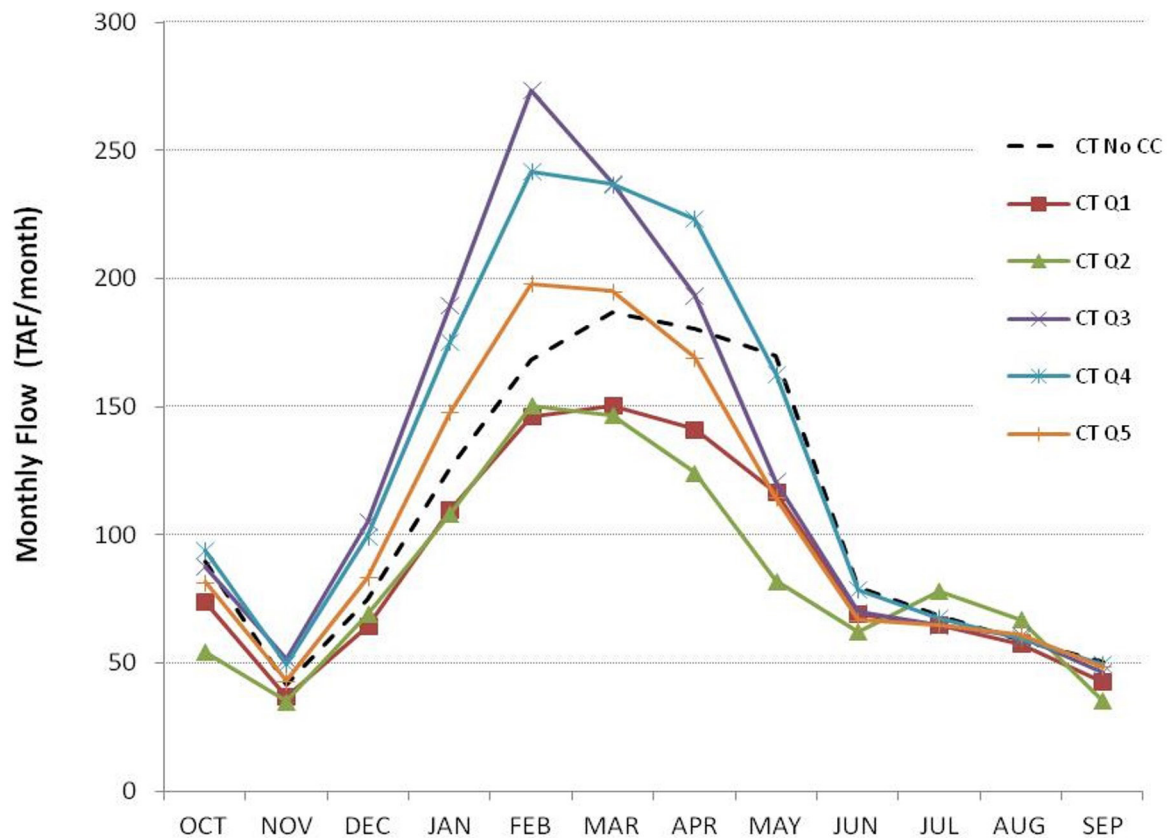


Figure 5-6. Average Runoff in Each Month in the East Side Streams and Delta in Each Climate Scenario

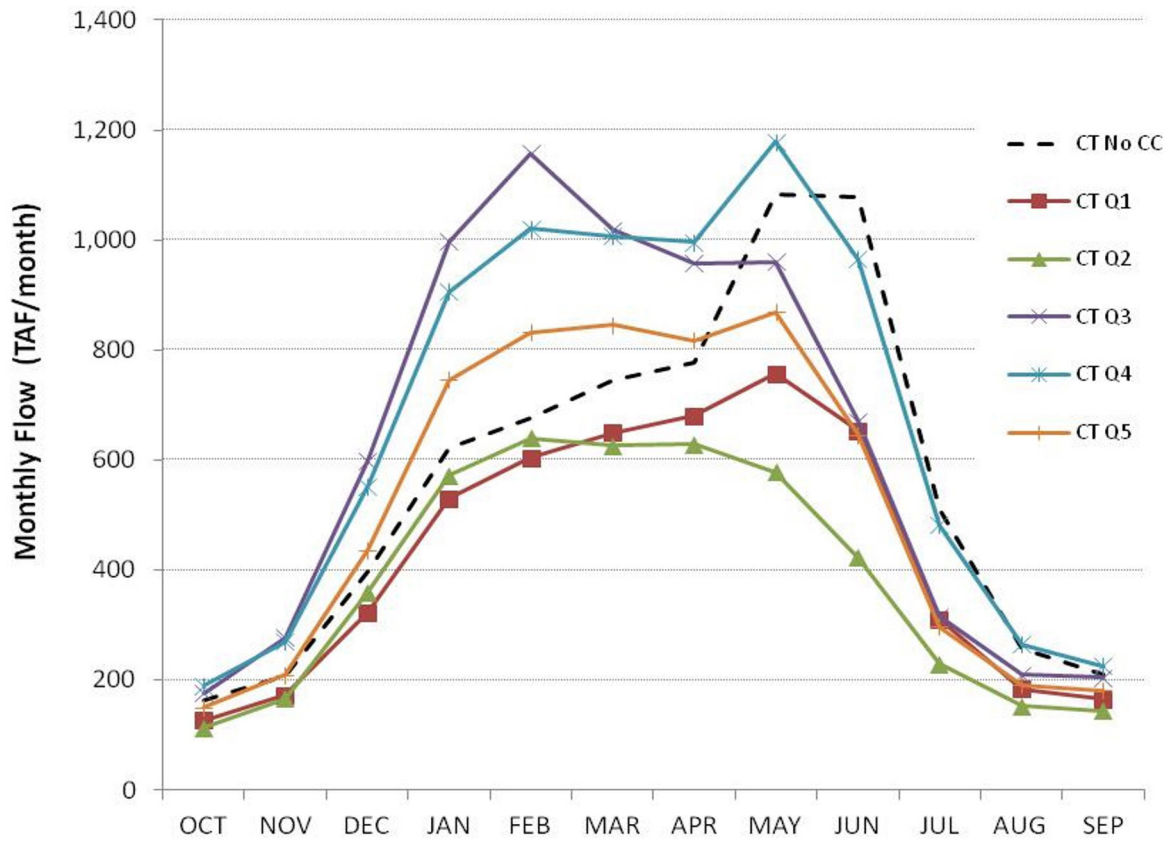


Figure 5-7. Average Runoff in Each Month in the San Joaquin River System in Each Climate Scenario

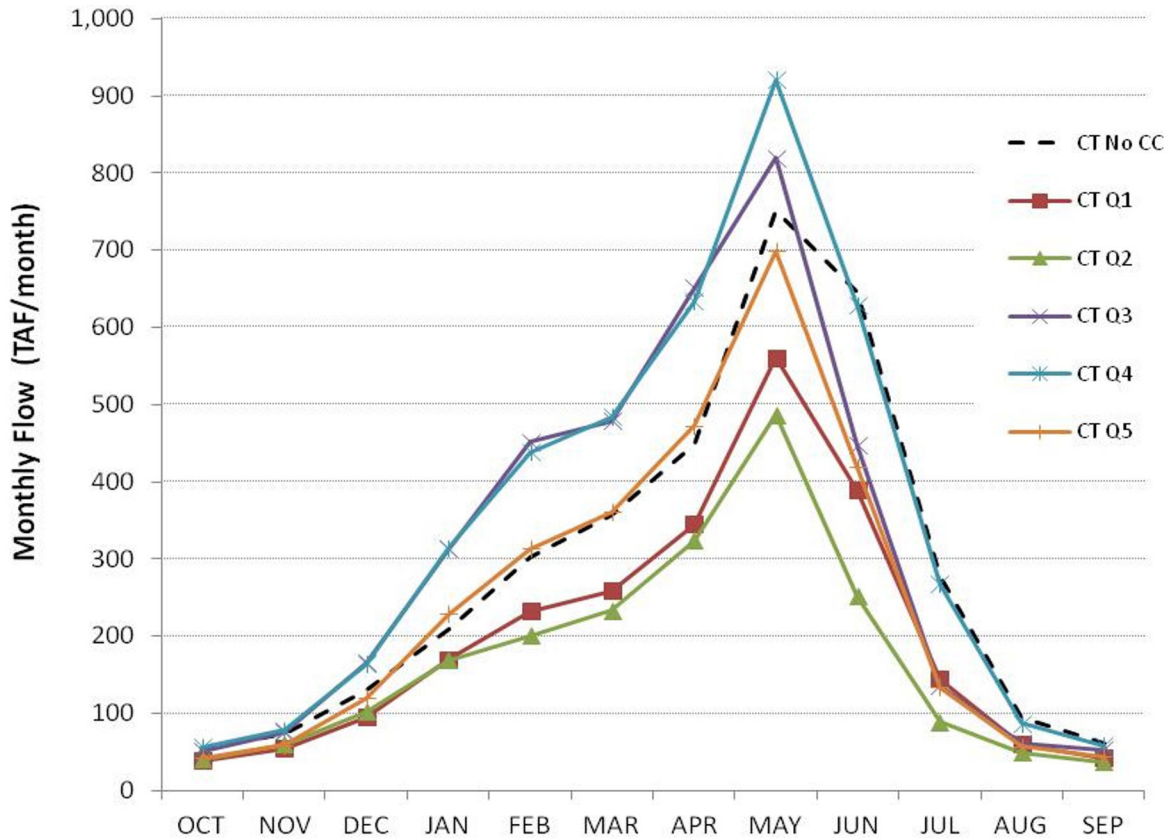


Figure 5-8. Average Runoff in Each Month in the Tulare Lake Region in Each Climate Scenario

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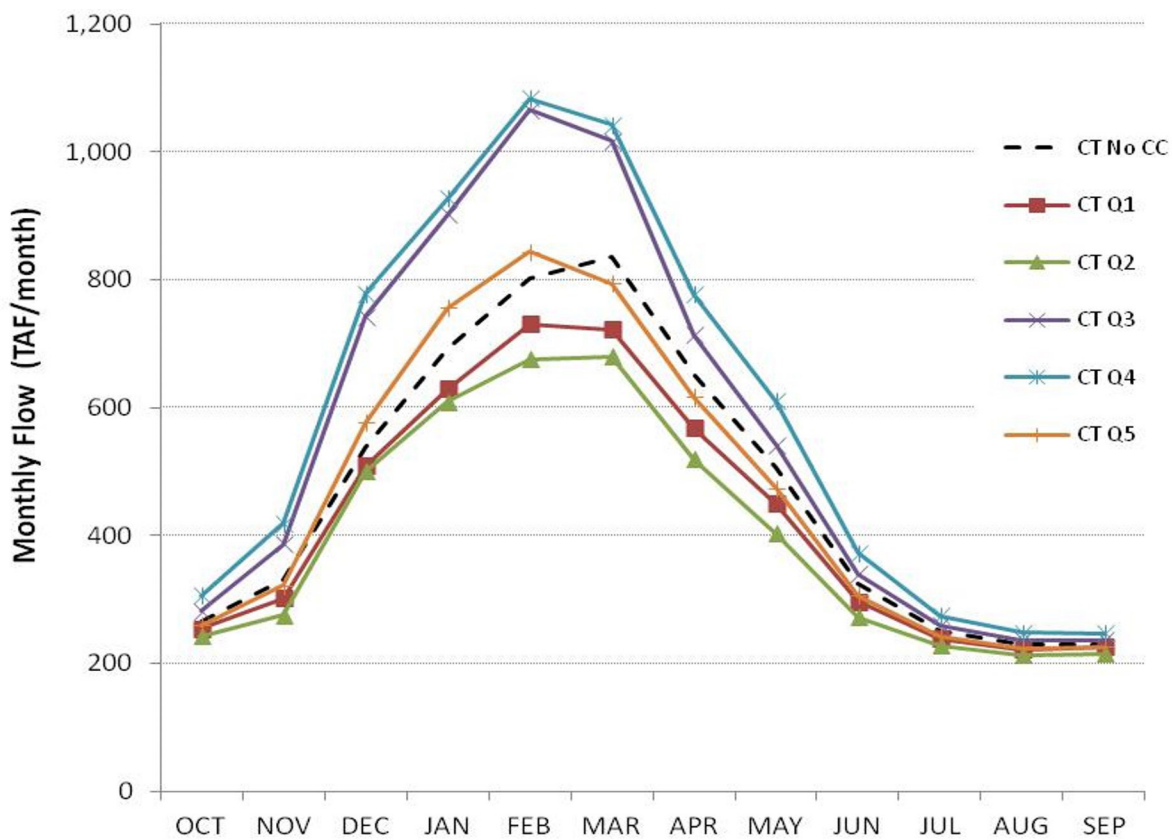


Figure 5-9. Average Runoff in Each Month into Lake Shasta in Each Climate Scenario

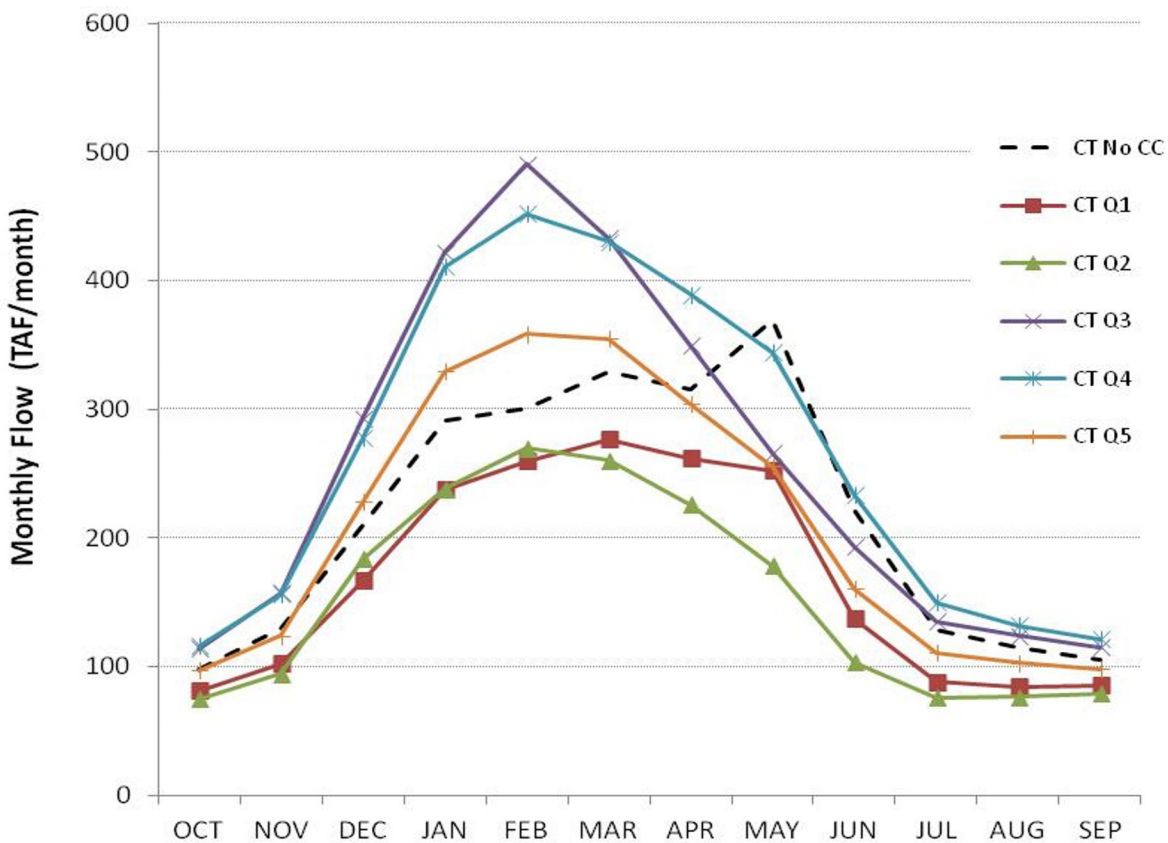


Figure 5-10. Average Runoff in Each Month into Folsom Lake in Each Climate Scenario

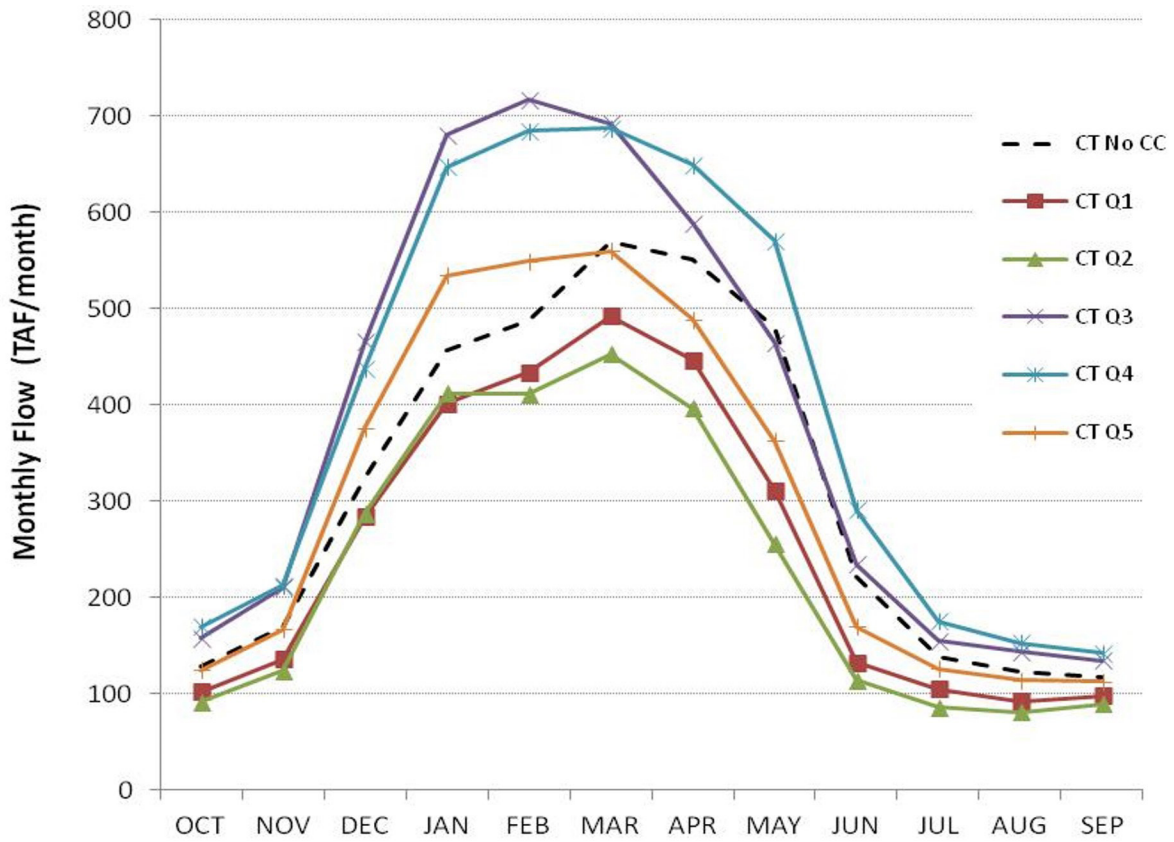


Figure 5-11. Average Runoff in Each Month into Lake Oroville in Each Climate Scenario

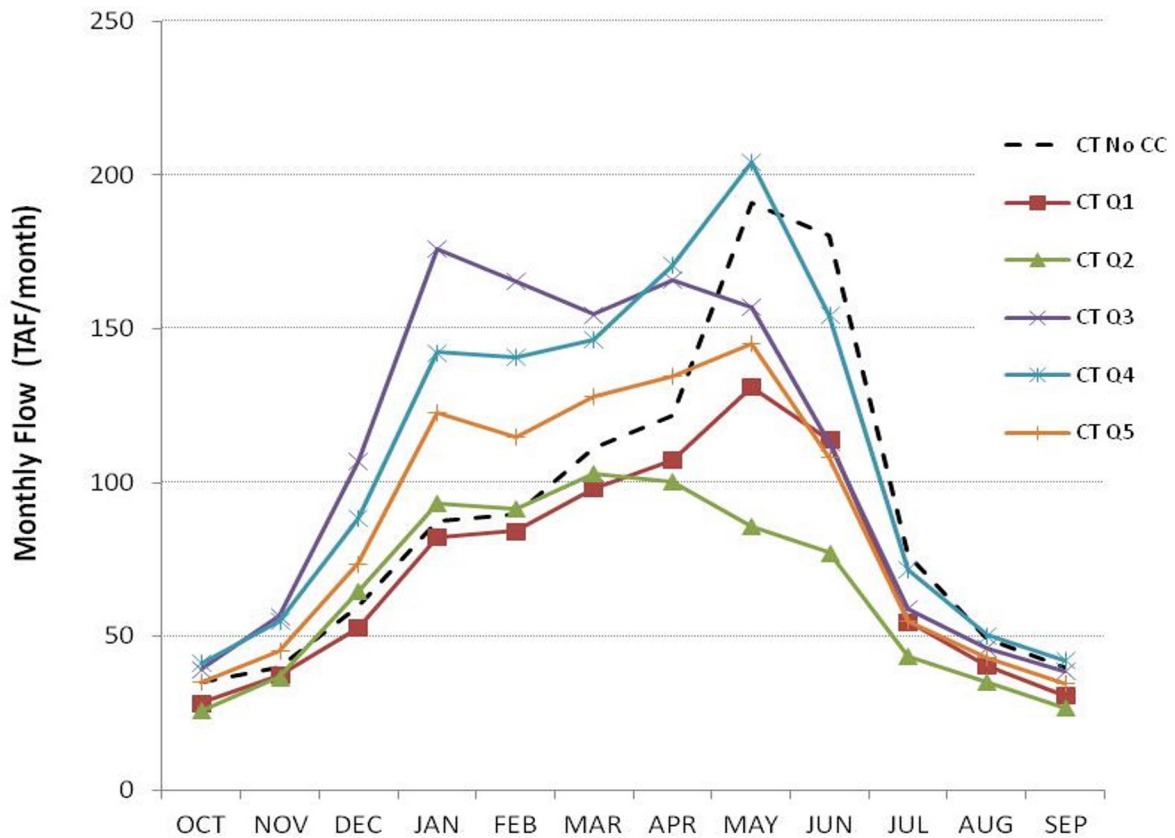


Figure 5-12. Average Runoff in Each Month into New Melones Reservoir in Each Climate Scenario

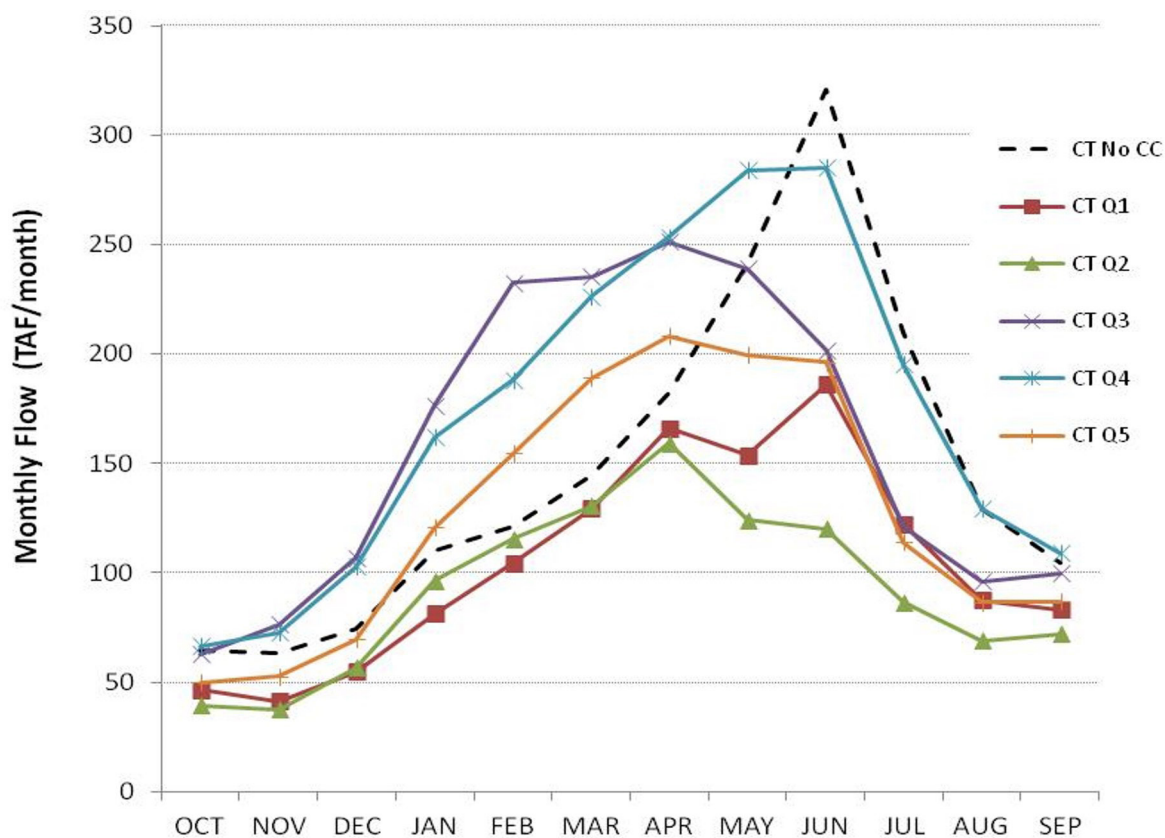


Figure 5-13. Average Runoff in Each Month into Millerton Lake in Each Climate Scenario

more susceptible to warming-induced changes in precipitation from snow to rain.

Figures 5-14 through 5-17 show the annual time series of runoff in the Sacramento River system, the East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake regions under each of Current Trends scenarios from water years 2012 through 2099. These future time series reflect the same inter-annual sequence as the historical period because of the methodology used in developing the projections, with extended drought periods of lower runoff values from 2025–2030 (corresponding to the 1929–1934 dry period) and from 2083–2088 (corresponding to the 1987–1992 drought), and a very substantial dry period from 2072–2073 (corresponding to the 1976–1977 low precipitation years). However, as can be observed on the figures, the magnitude of the events differs from historical conditions.

5.2 Applied Water Demands

Figures 5-18 through 5-25 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 East Side streams and the Delta, the San Joaquin River system, and the Tulare Lake region for each of the socioeconomic-climate scenarios over the projected period of water years from 2012 through 2099. Under the no climate change condition, average total annual demand is about 5.5–5.7 MAF/year in the Sacramento River system, 1.4 MAF/year in the East Side streams and the 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) varied across both the range of socioeconomic scenarios and across the range of climate scenarios. In all of the basins, agricultural demands showed a strong relationship with the climate scenarios. Although the magnitudes differed among basins because of differences in crops and acreages, the overall relationship between precipitation and agricultural demand was similar in all of the basins. Although the median climate scenarios (Q5) had demands

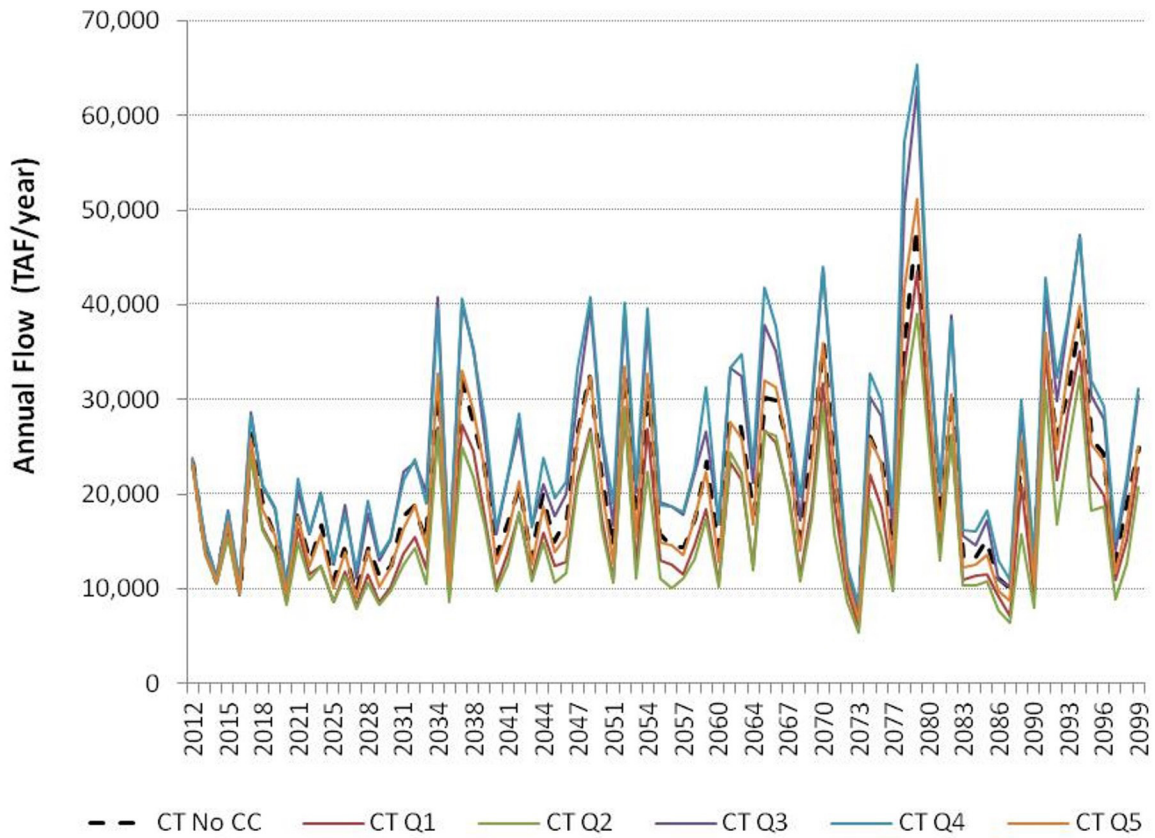


Figure 5-14. Annual Time Series of Runoff in the Sacramento River System in Each Climate Scenario

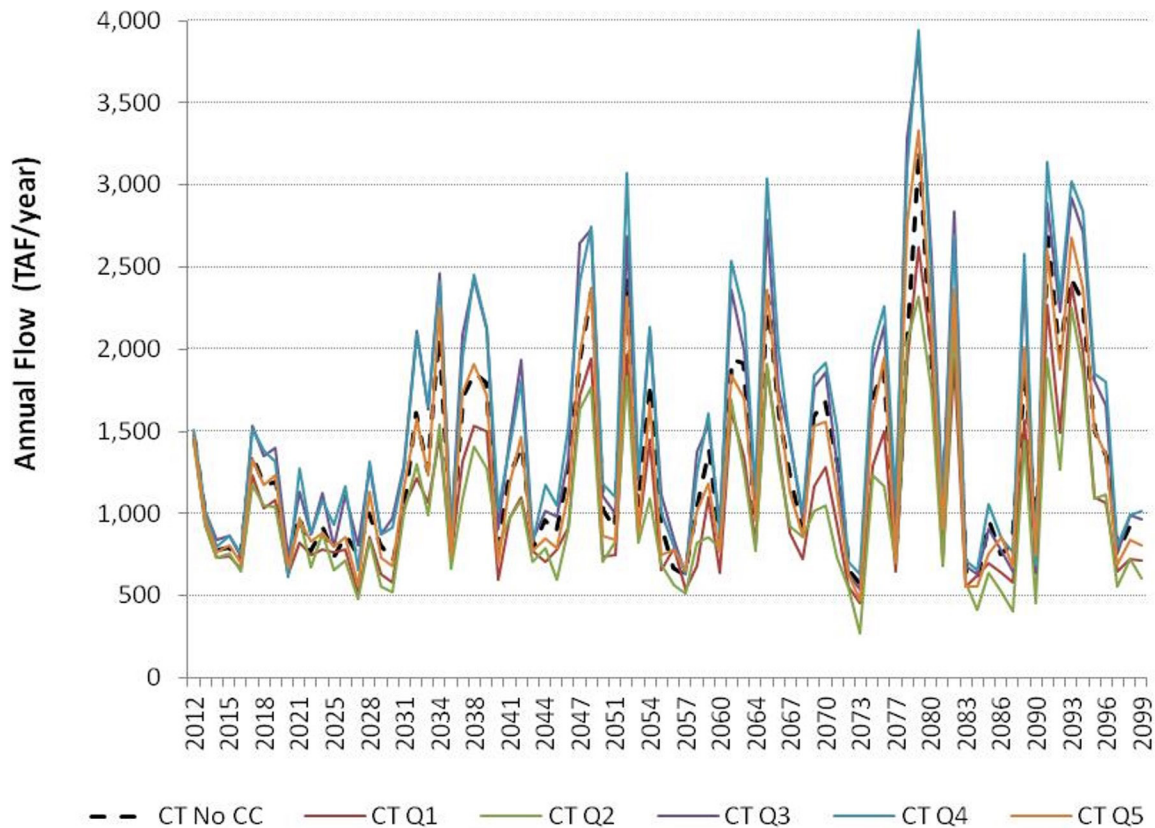


Figure 5-15. Annual Time Series of Runoff in the East Side Streams and Delta in Each Climate Scenario

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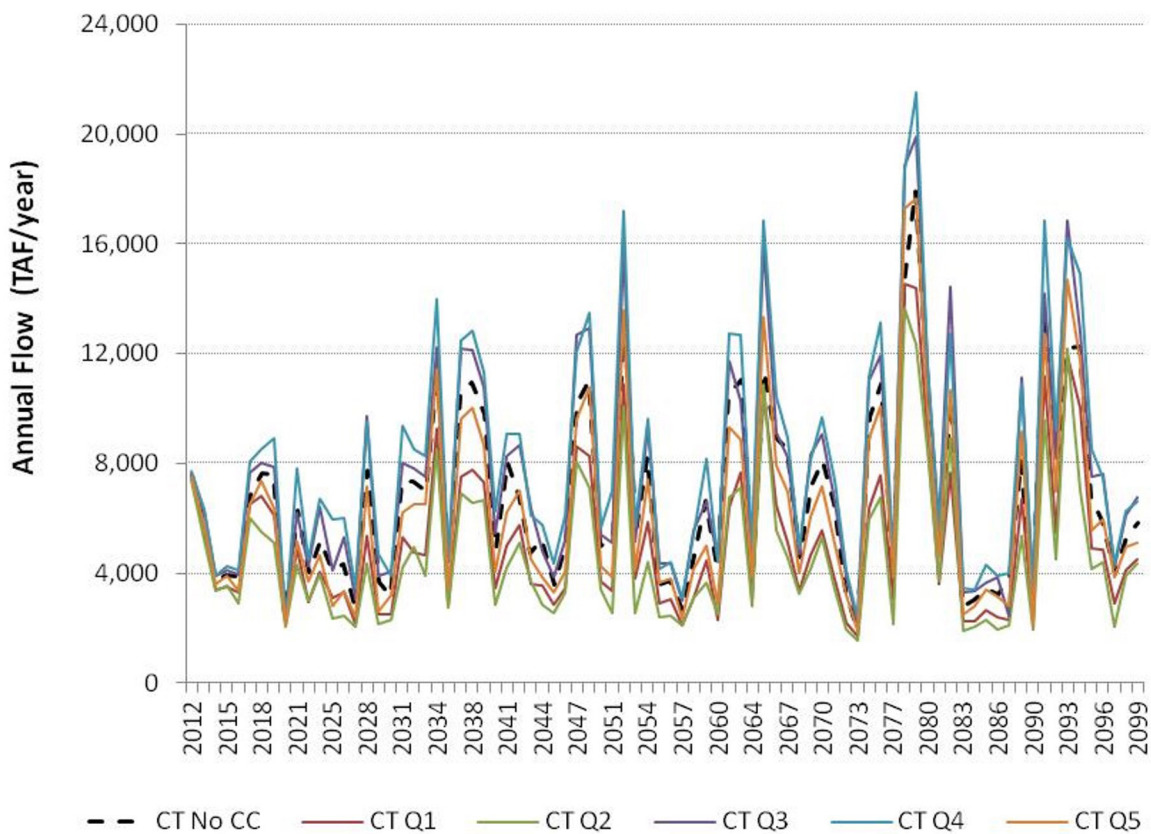


Figure 5-16. Annual Time Series of Runoff in the San Joaquin River System in Each Climate Scenario

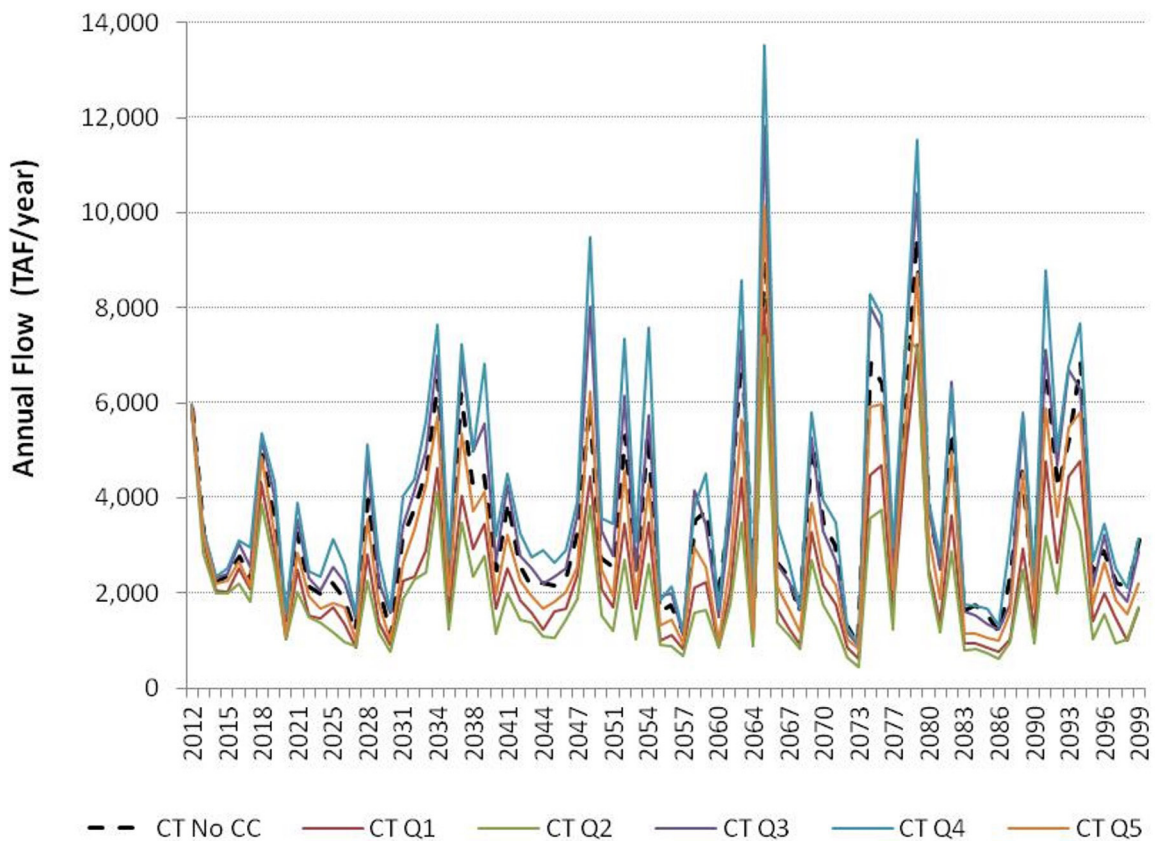


Figure 5-17. Annual Time Series of Runoff in the Tulare Lake Region in Each Climate Scenario

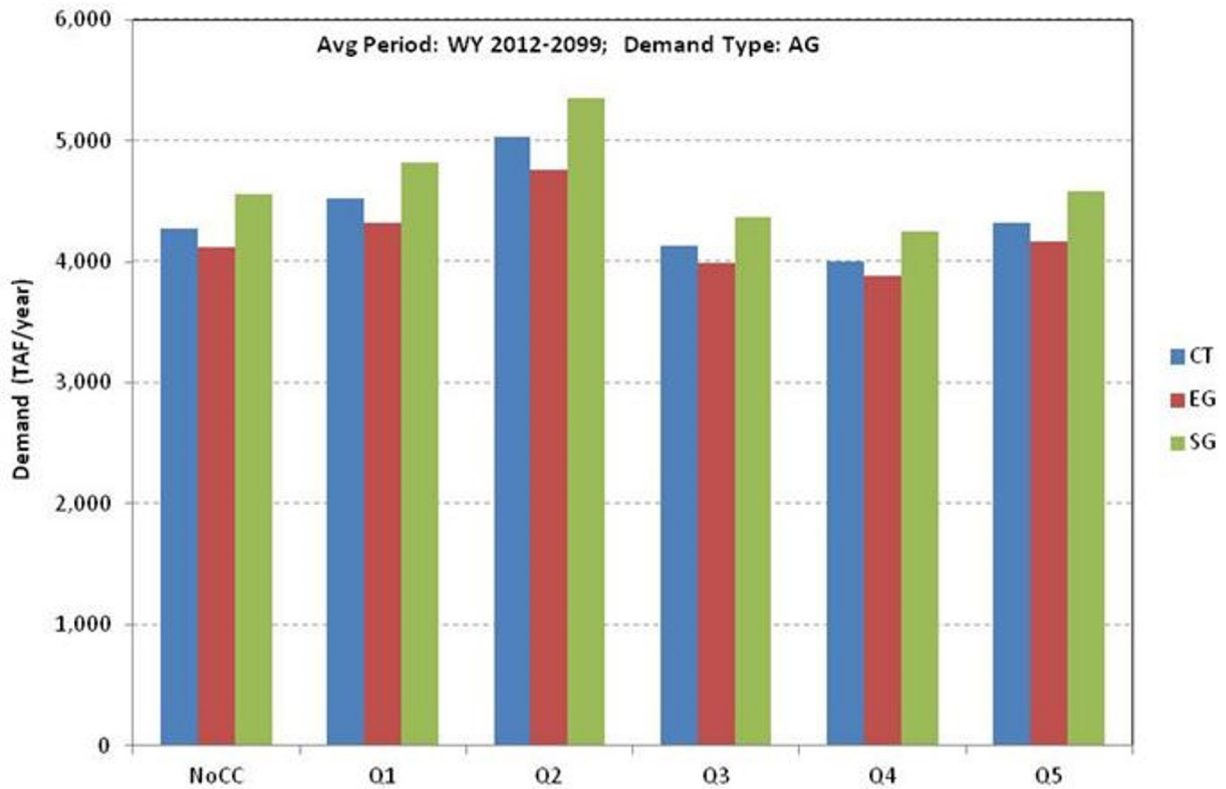


Figure 5-18. Average Annual Agricultural Applied Water Demand in the Sacramento River System in Each Scenario

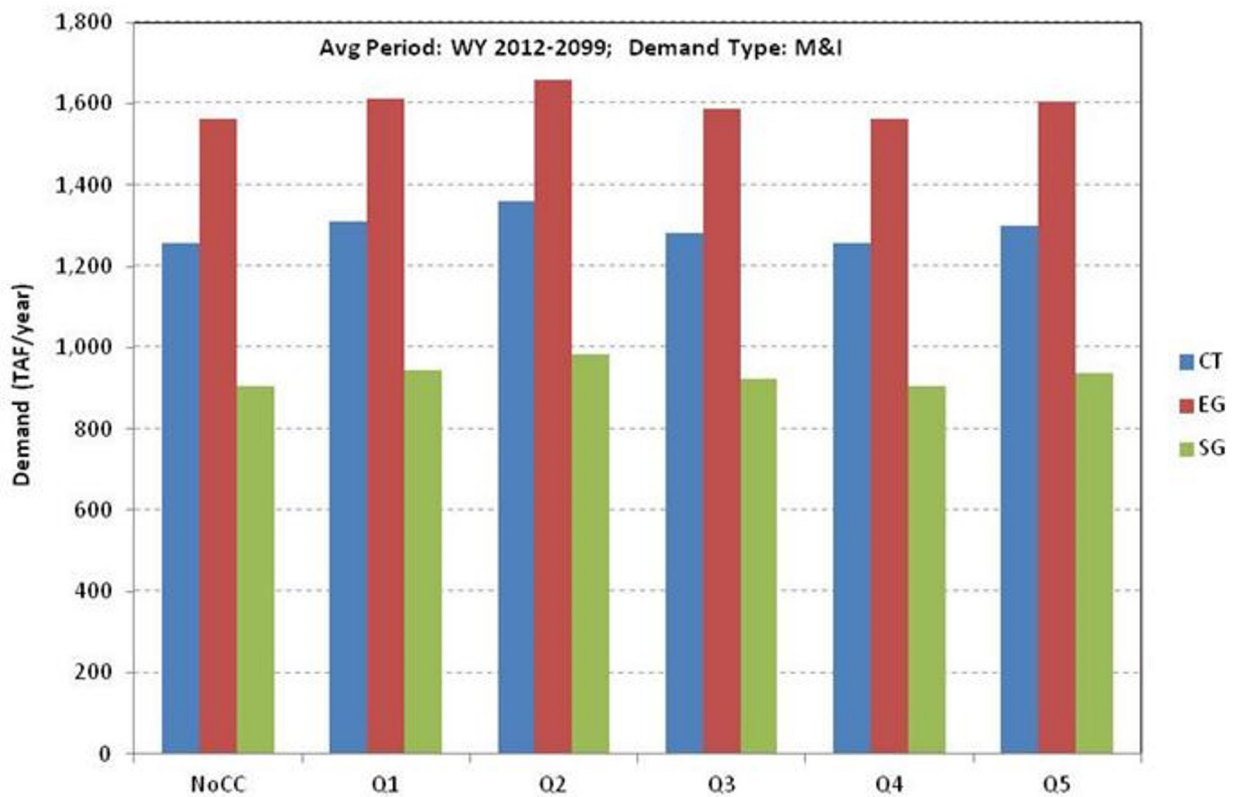


Figure 5-19. Average Annual Urban Applied Water Demand in the Sacramento River System in Each Scenario

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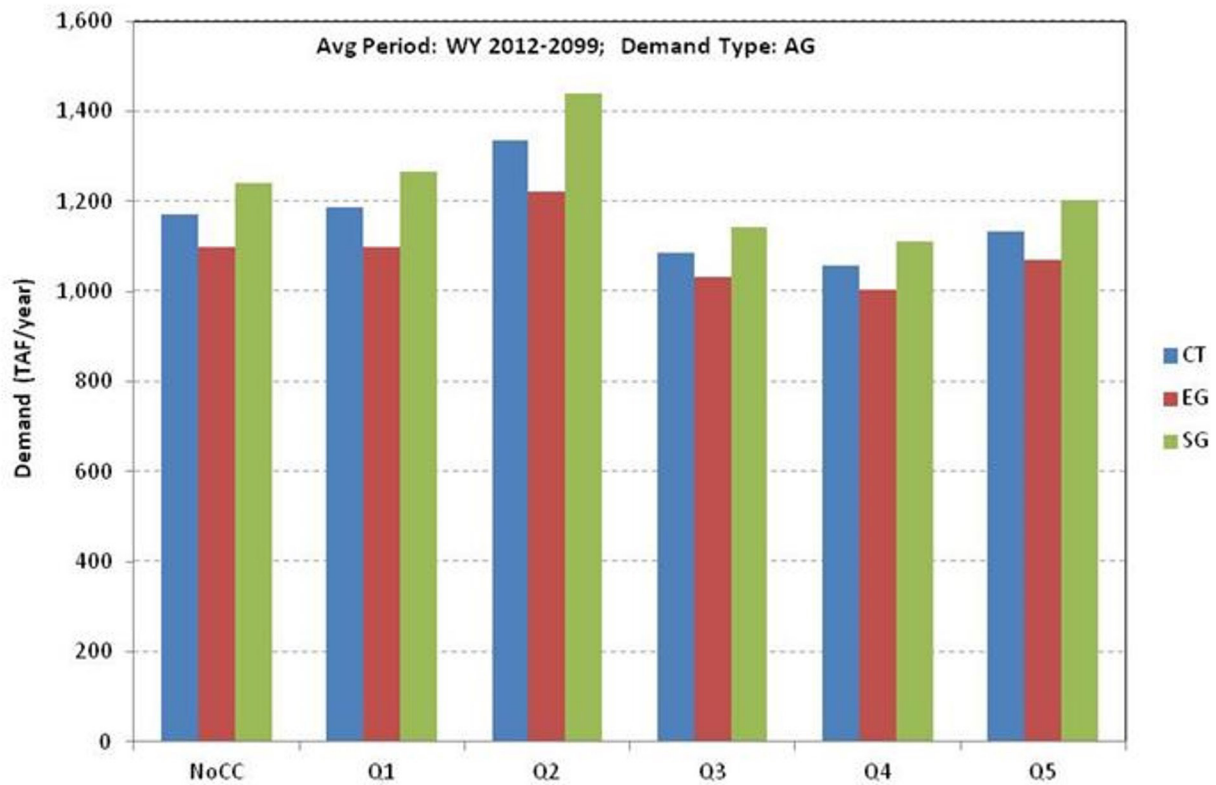


Figure 5-20. Average Annual Agricultural Applied Water Demand in the East Side Streams and Delta in Each Scenario

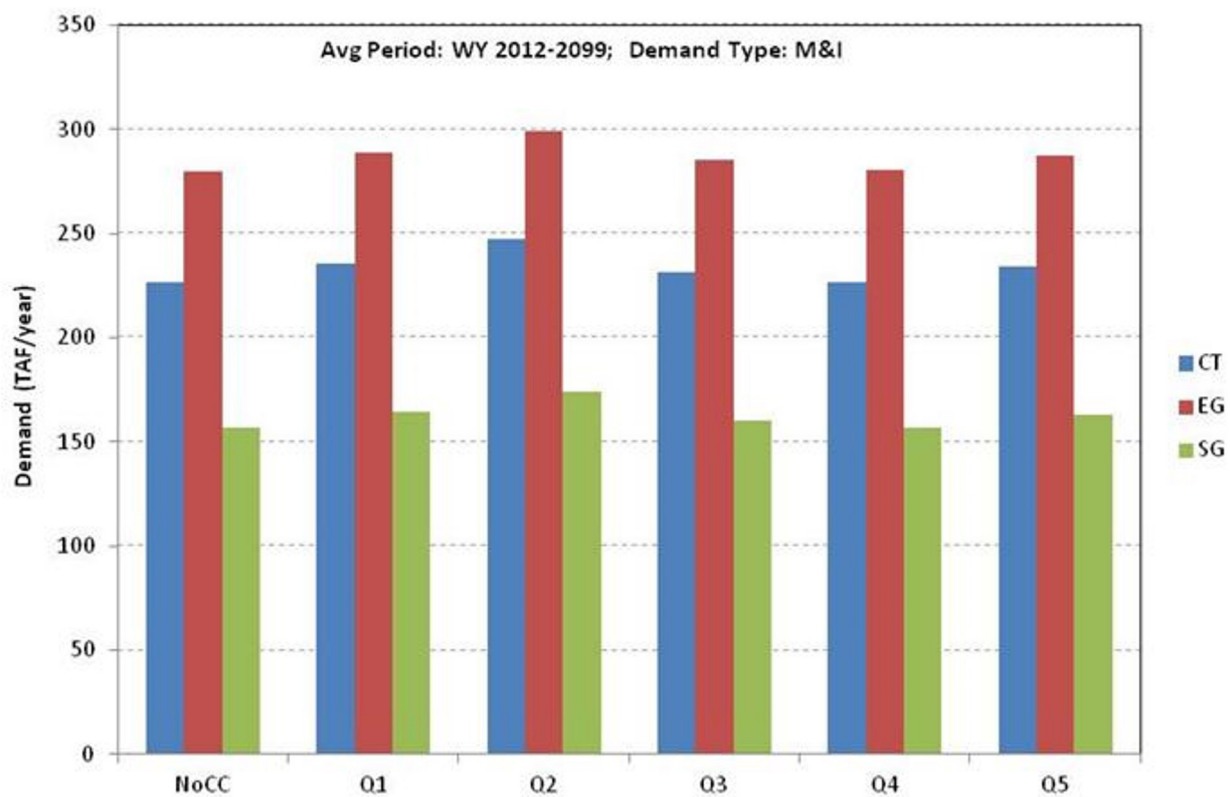


Figure 5-21. Average Annual Urban Applied Water Demand in the East Side Streams and Delta in Each Scenario

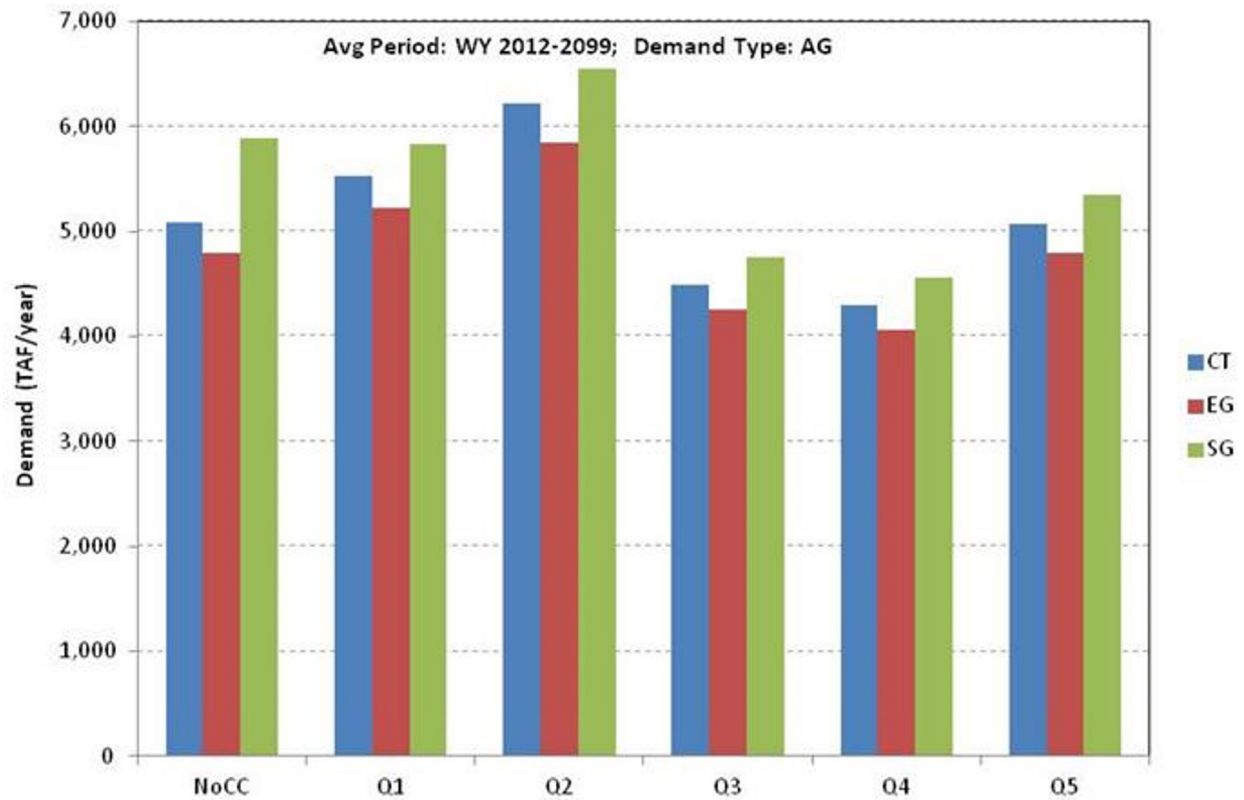


Figure 5-22. Average Annual Agricultural Applied Water Demand in the San Joaquin River System in Each Scenario

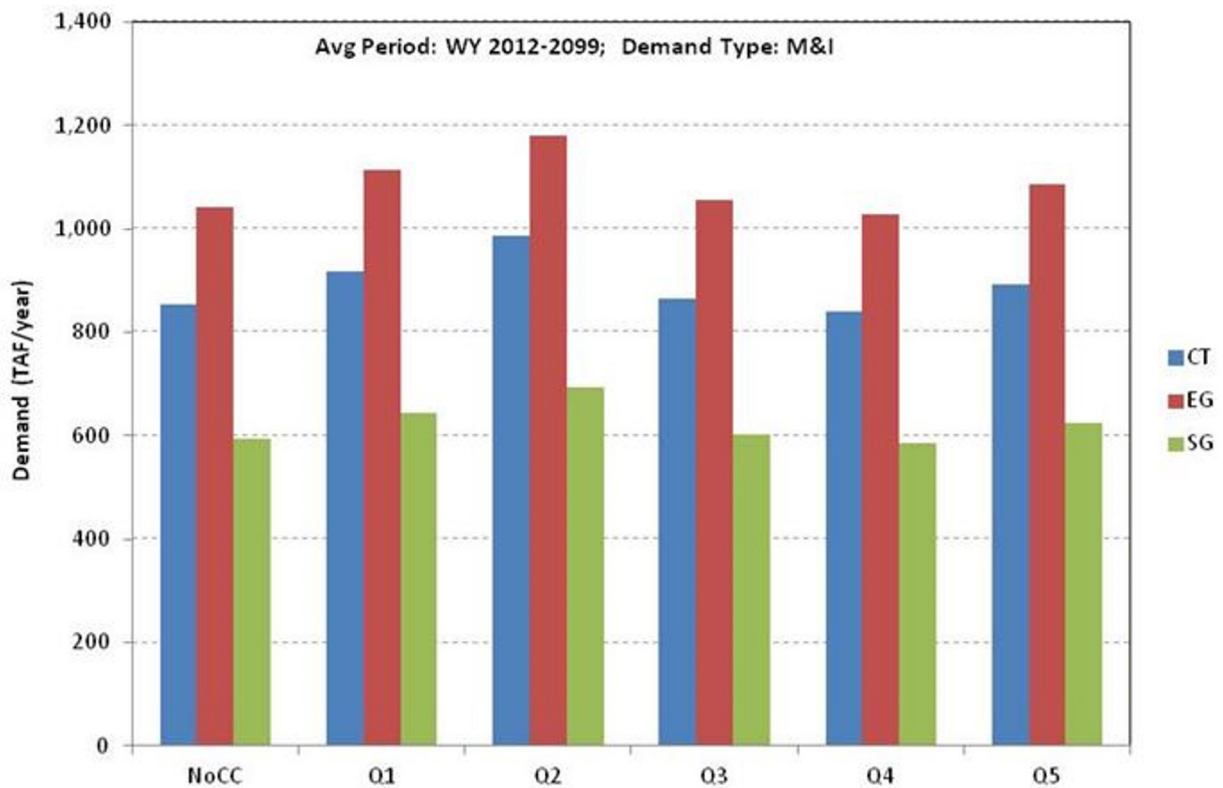


Figure 5-23. Average Annual Urban Applied Water Demand in the San Joaquin River System in Each Scenario

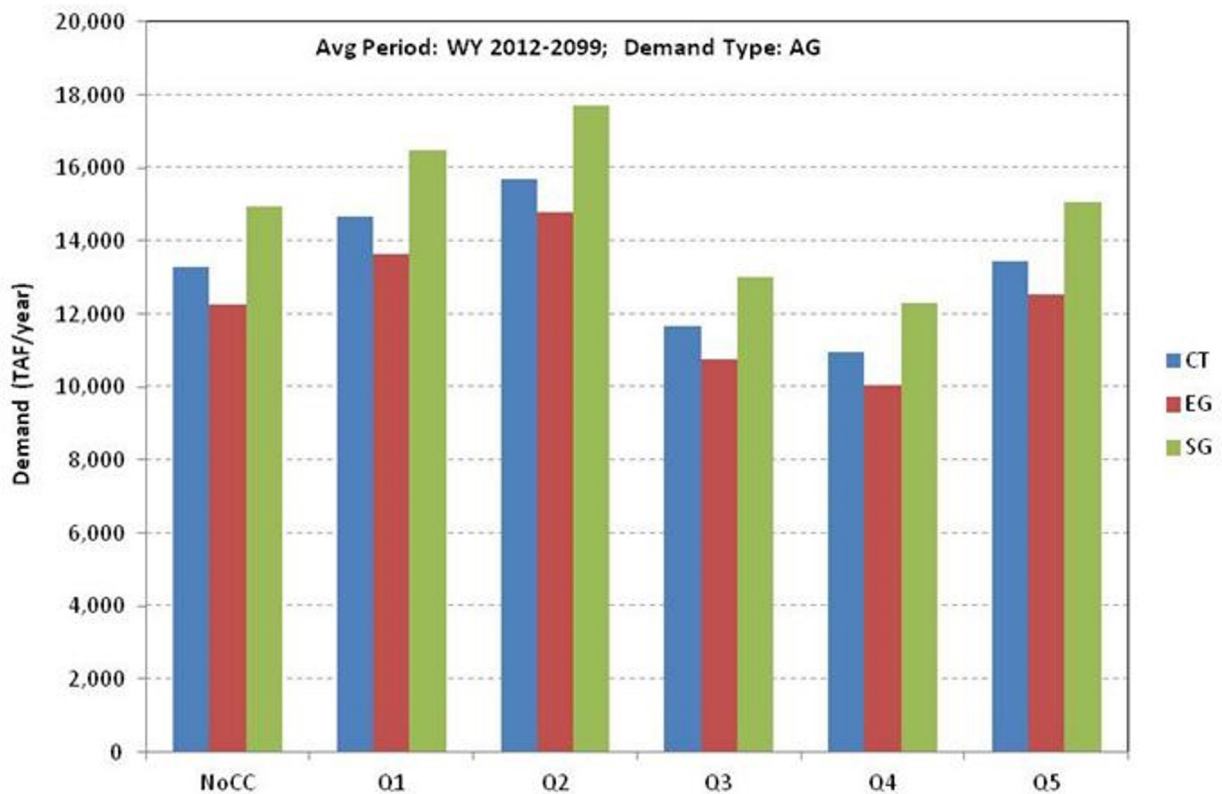


Figure 5-24. Average Annual Agricultural Applied Water Demand in the Tulare Lake Region in Each Scenario

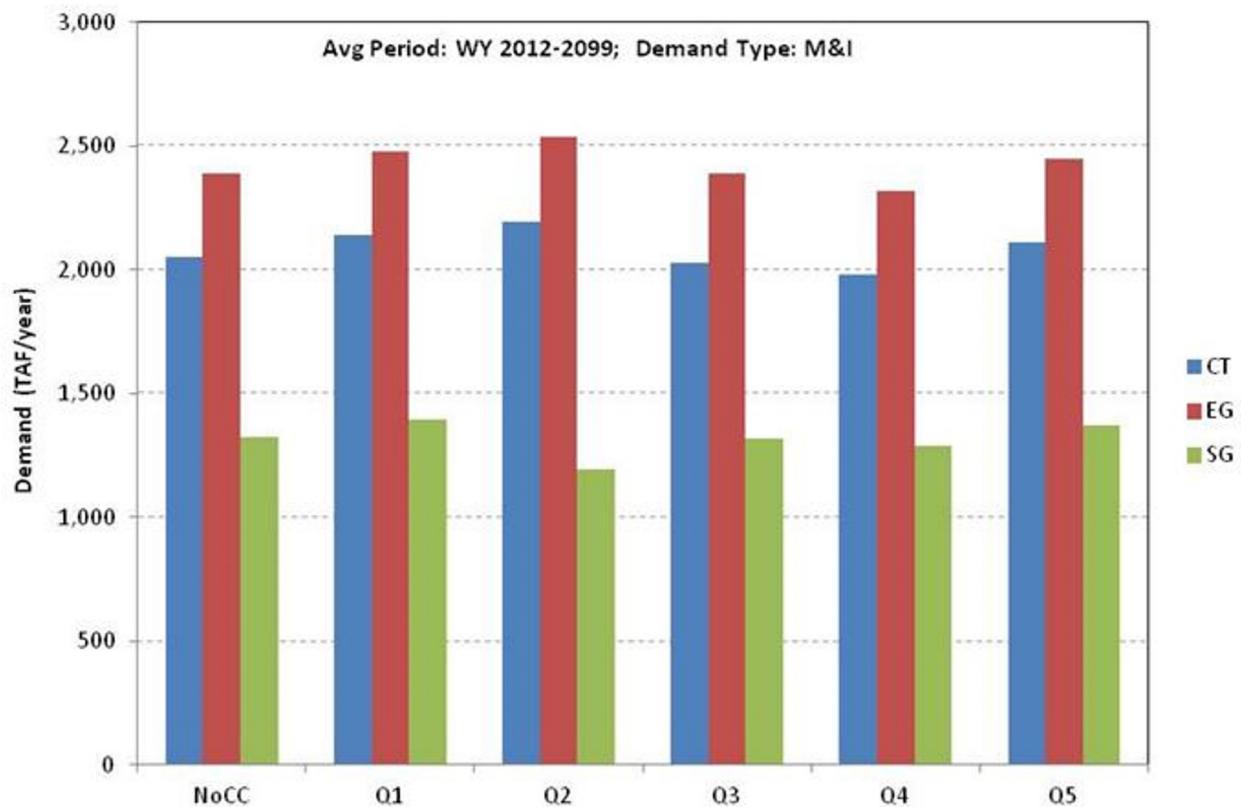


Figure 5-25. Average Annual Urban Applied Water Demand in the Tulare Lake Region in Each Scenario

that were similar to the no climate change scenario, the drier climate scenarios (Q1 and Q2) had average demands that were higher than the no climate change scenario (ranging from 7–17 percent), and the wetter climate scenarios (Q3 and Q4) had average demands that were less than the no climate change scenario (ranging from 9–13 percent). Among the socioeconomic scenarios, the Expansive Growth (EG) scenario had lower agricultural demands than the Current Trends (CT) scenario because the assumed rate of urban expansion into agricultural lands was greater in the Expansive Growth scenario. Conversely, the Slow Growth (SG) scenario had higher agricultural demands than the Current Trends scenario because of the smaller amount of land conversion.

In the Sacramento River system, the overall average agricultural demand change, including all the socioeconomic scenarios relative to their corresponding no climate change scenarios, was about 0–1 percent for the central tendency (Q5) and ranged from -3–7 percent in the wetter Q3 and Q4 scenarios to +5–18 percent in the drier Q1 and Q2 scenarios. In the East Side streams and the Delta system, the overall average agricultural demand change relative to the no climate change scenario was -3 percent in Q5 and ranged 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 was 0–9 percent in Q5 and ranged 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 was 1–2 percent in Q5 and ranged from -12–18 percent in the wetter Q3 and Q4 scenarios to +10–20 percent in the drier Q1 and Q2 scenarios.

In contrast with agricultural demands, the effect of precipitation variability on urban demands was minimal because it was assumed these demands have a higher delivery priority than agricultural demands. Consequently, the Expansive Growth scenario had the largest urban demands and the Slow Growth scenario the least. Across all climate scenarios and basins, the overall urban demand was about 4.4–4.8 MAF/year in the Current Trends socioeconomic scenario and ranged from a low of

about 2.9–3.1 MAF/year in Slow Growth to a high of about 5.2–5.7 MAF/year in Expansive Growth.

In the Sacramento River system, the overall average urban demand change relative to the corresponding no climate change socioeconomic scenarios was +3–4 percent for the central tendency Q5 scenario and ranged from +0–2 percent in the wetter Q3 and Q4 scenarios to +3–9 percent in the drier Q1 and Q2 scenarios. In the East Side streams and the Delta system, the overall average urban demand change is +3–4 percent relative to the no climate change scenario in Q5 and ranged 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 was +4–5 percent and ranged 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 was 3–4 percent and ranged from 0–3 percent in the wetter scenarios to -10 percent to 7 percent in the drier scenarios.

Figures 5-26 through 5-35 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 ranged from about 10–14 MAF/year across the full range of future socio-economic-climate scenarios. Among the Divisions, the largest demands were 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 had much higher urban demands than agricultural demands and, consequently, show the highest total demands in the Expansive Growth scenario and the lowest total demands in the Slow Growth scenarios, because these changes in demands are driven primarily by changes in population. The other Divisions had more agricultural demands than urban demands and, therefore, show small differences in total demands among socioeconomic scenarios, as changes in agricultural demand were offset by corresponding changes in urban demand.

Figures 5-36 and 5-37 present the annual time series of projected total agricultural and urban demands within the all CVP Service Areas for the 18 socioeconomic-climate scenarios. As shown on Figure 5-36, there is both short-term

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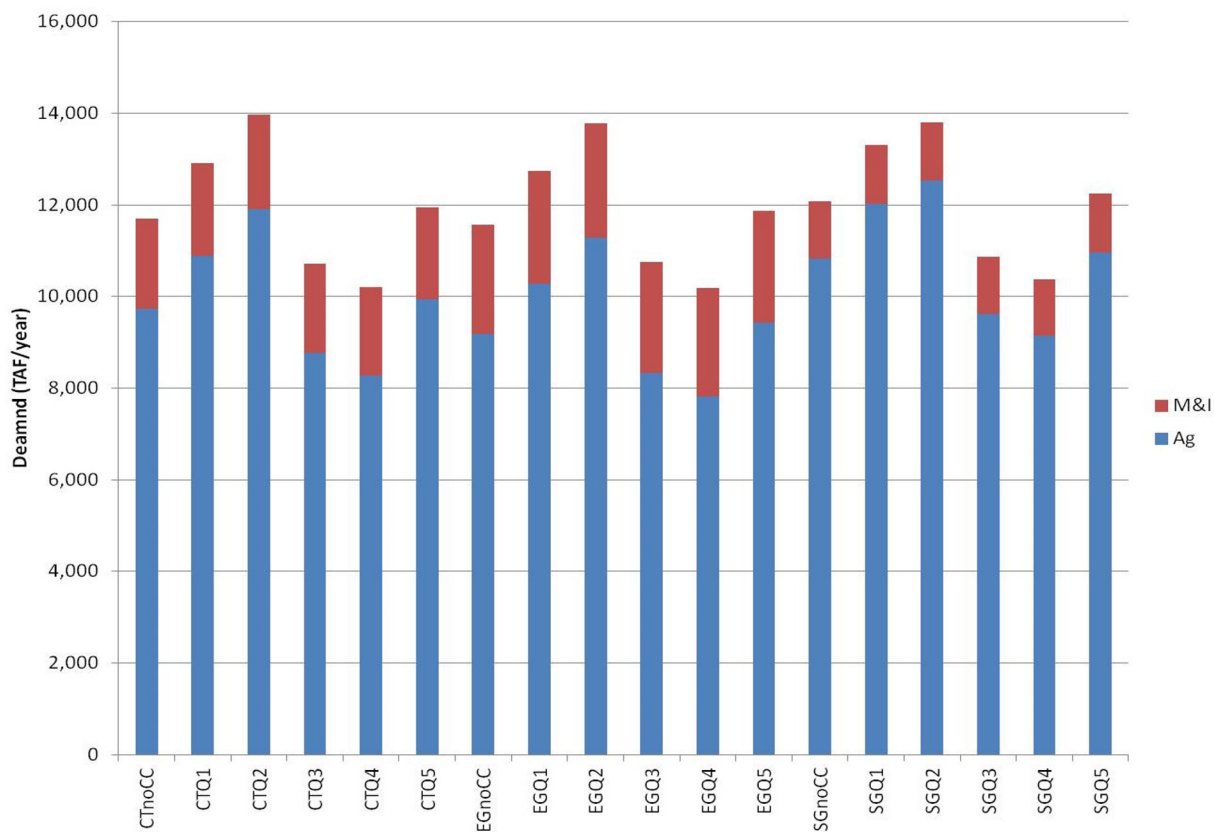


Figure 5-26. Average Annual Agricultural and Urban Demands in the CVP Service Area

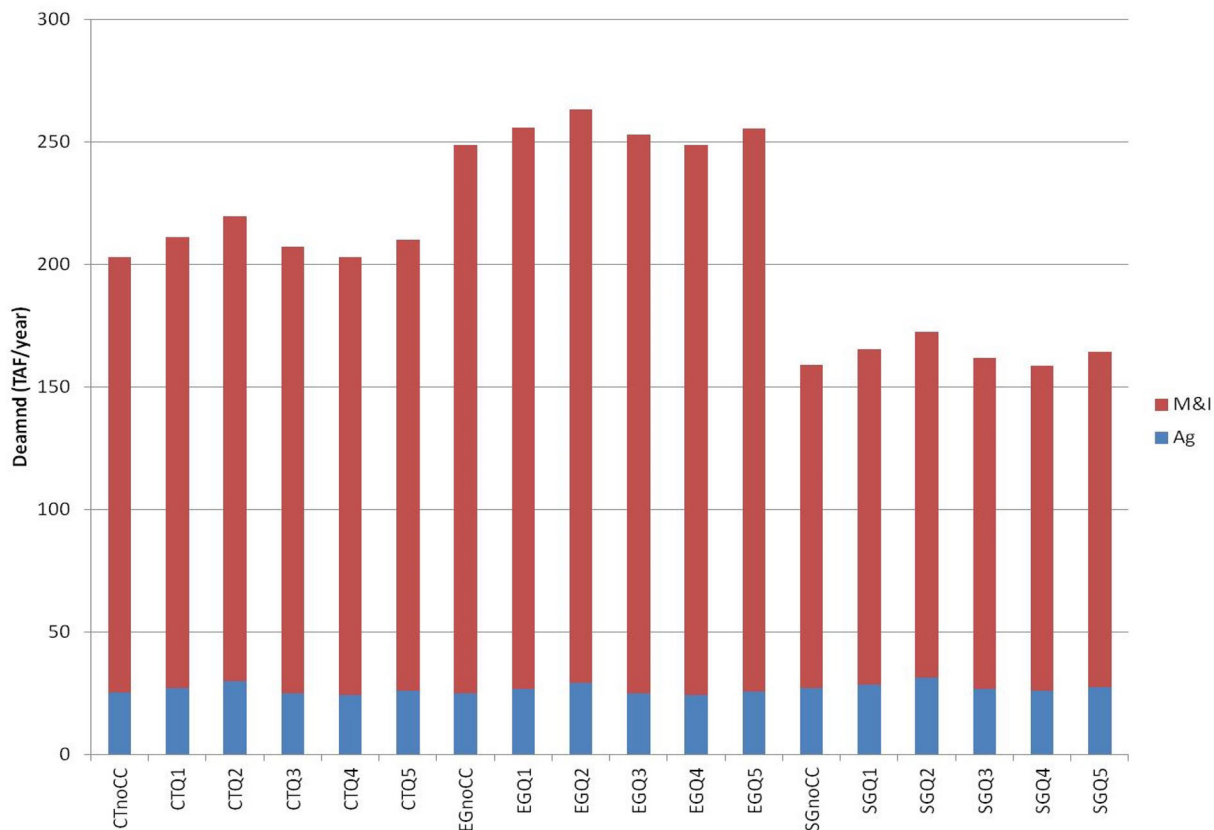


Figure 5-27. Average Annual Agricultural and Urban Demands in the American River Division

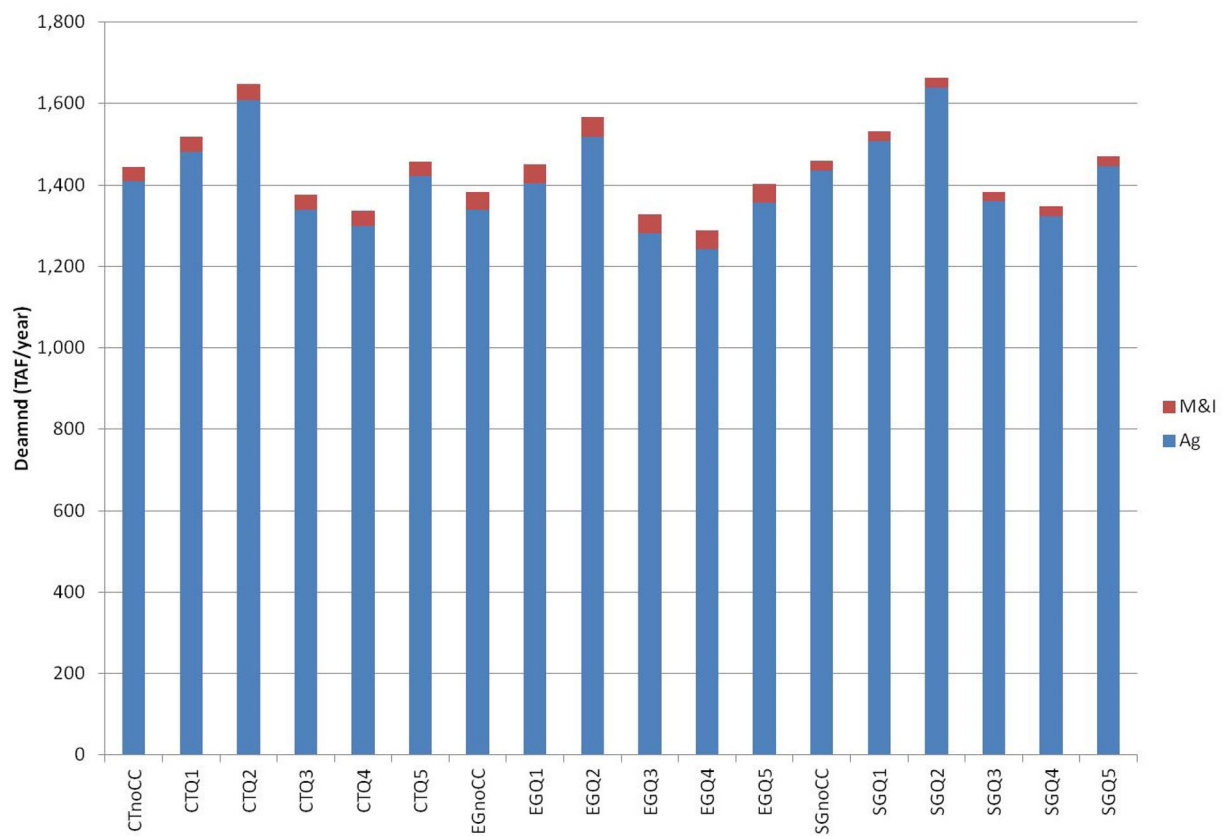


Figure 5-28. Average Annual Agricultural and Urban Demands in the Delta Division

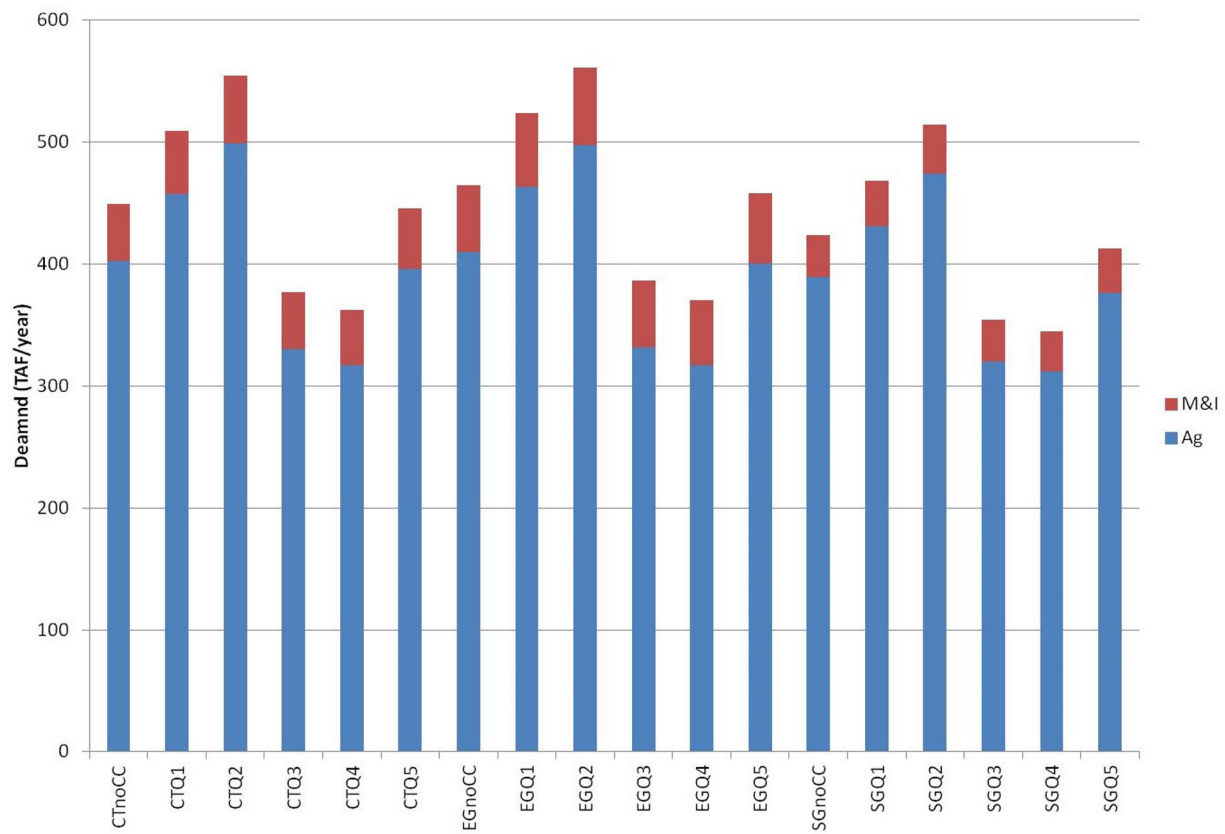


Figure 5-29. Average Annual Agricultural and Urban Demands in the East Side Division

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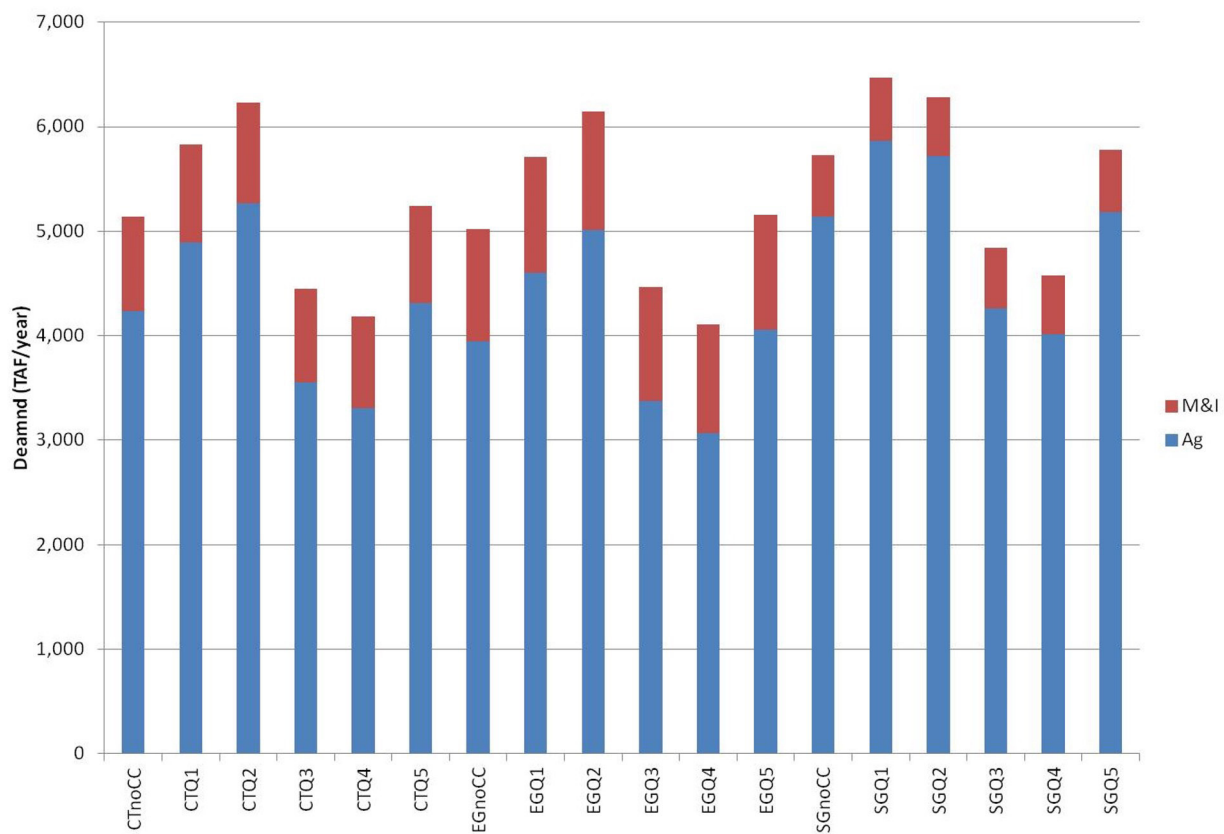


Figure 5-30. Average Annual Agricultural and Urban Demands in the Friant Division

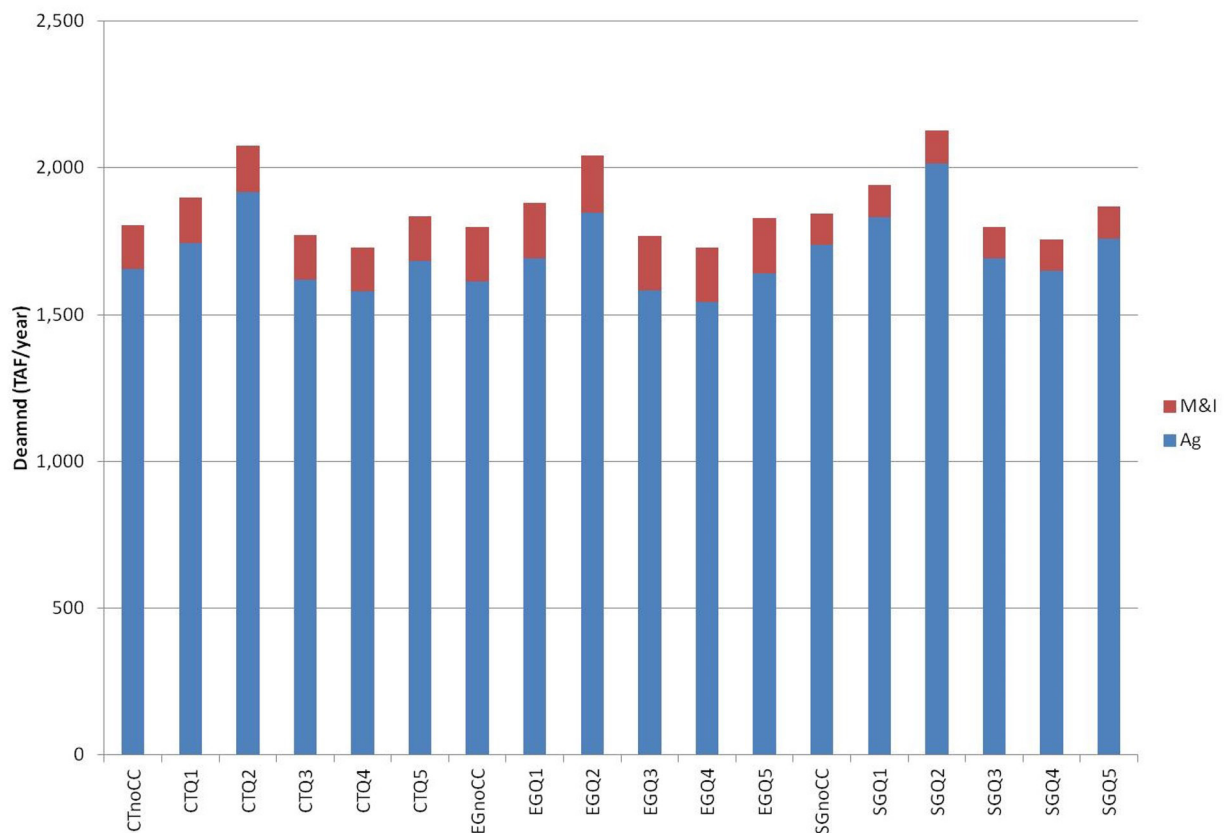


Figure 5-31. Average Annual Agricultural and Urban Demands in the Sacramento River Division

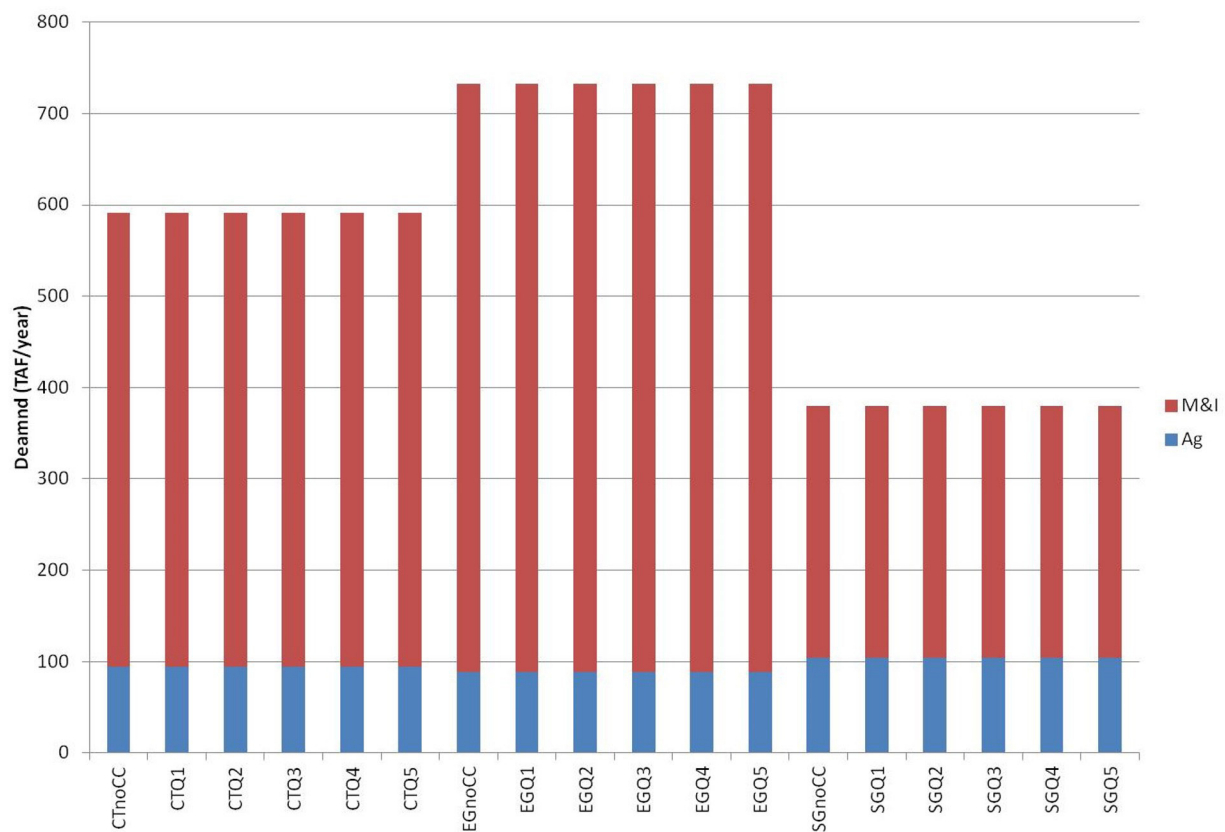


Figure 5-32. Average Annual Agricultural and Urban Demands in the San Felipe Division

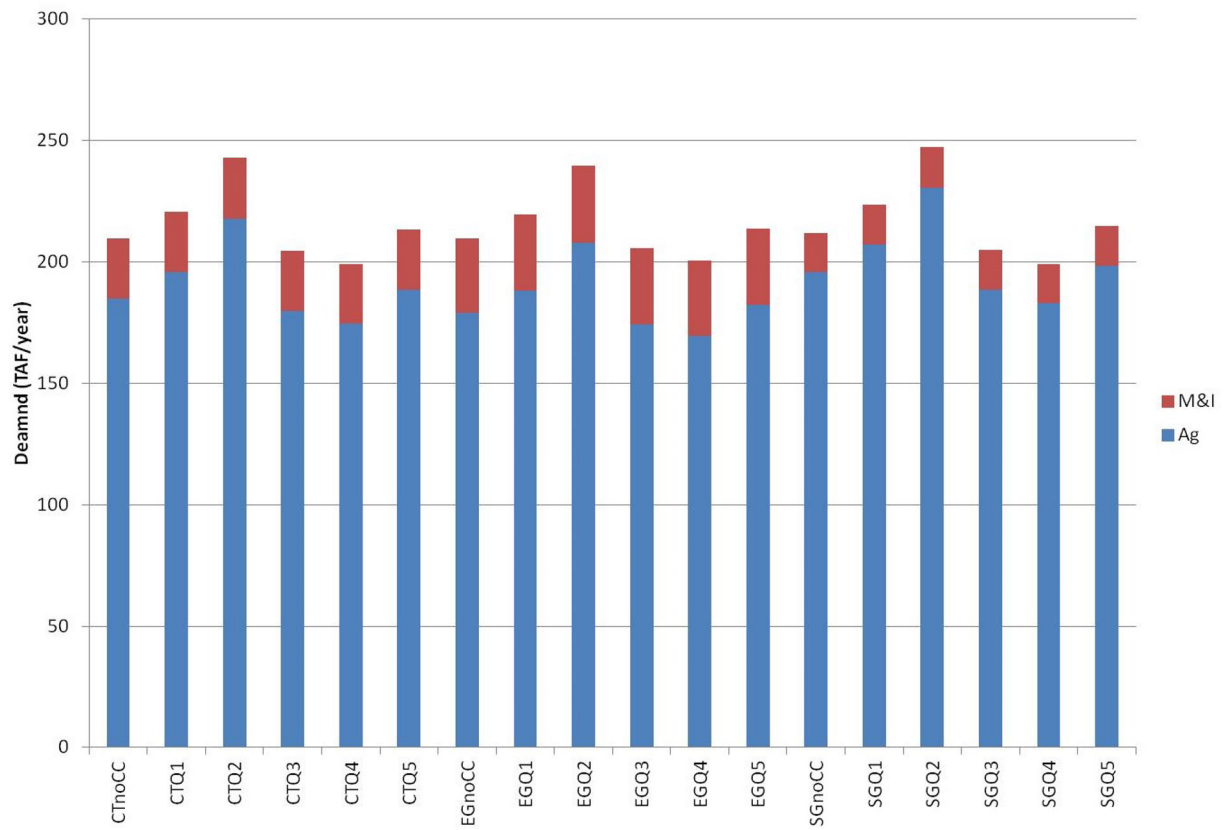


Figure 5-33. Average Annual Agricultural and Urban Demands in the Shasta Division

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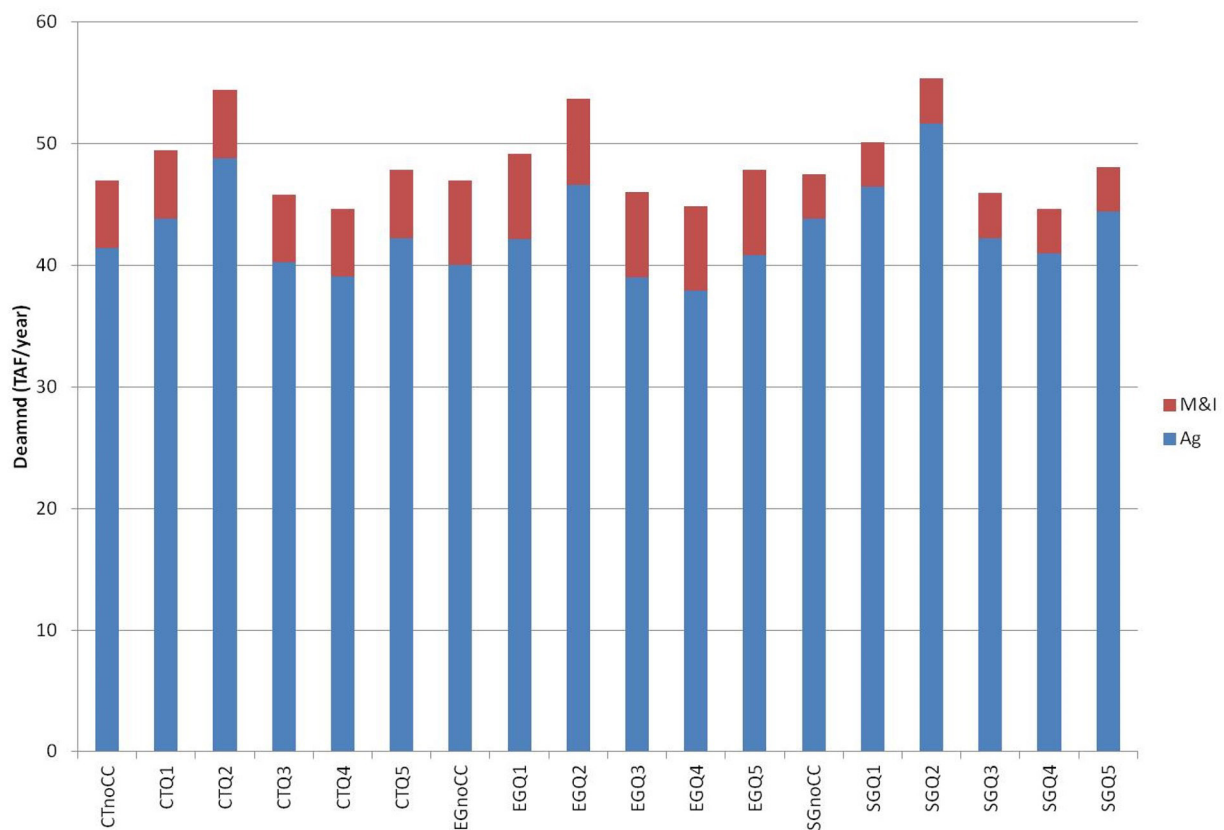


Figure 5-34. Average Annual Agricultural and Urban Demands in the Trinity Division

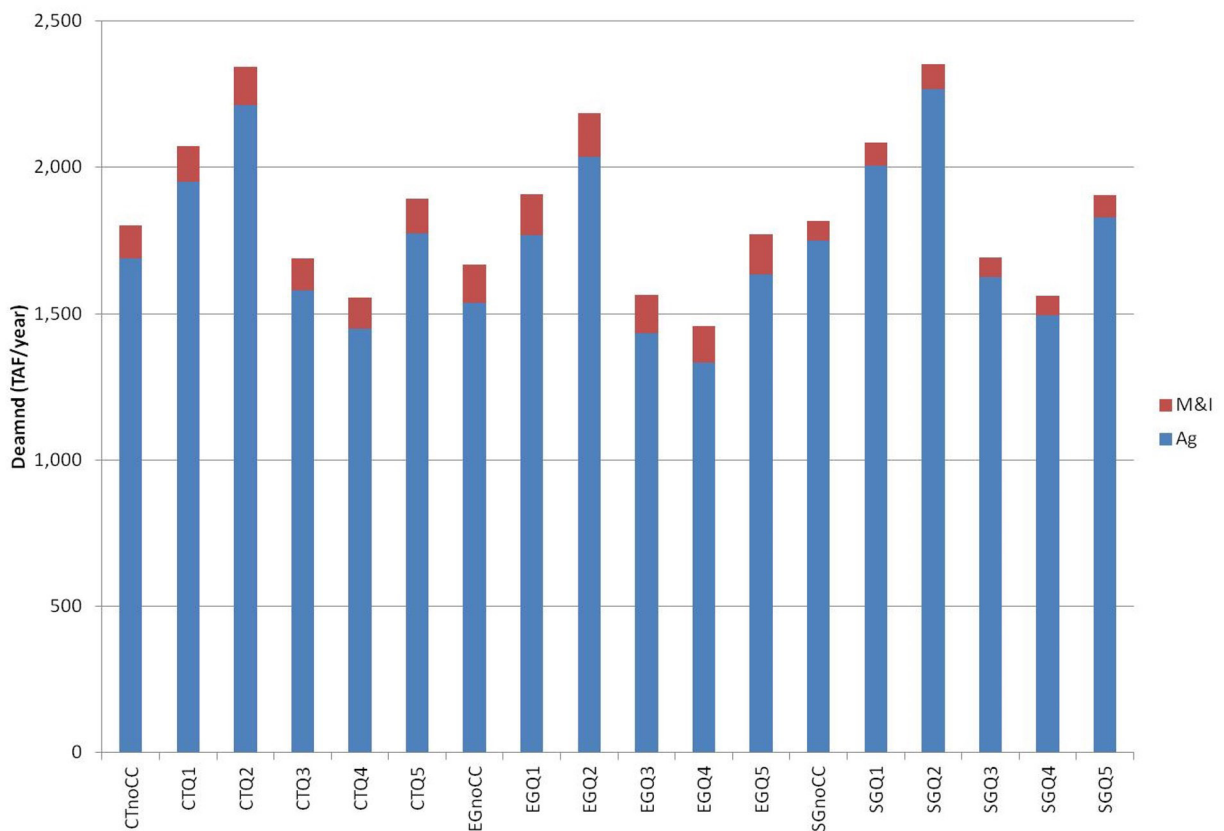


Figure 5-35. Average Annual Agricultural and Urban Demands in the West San Joaquin Division

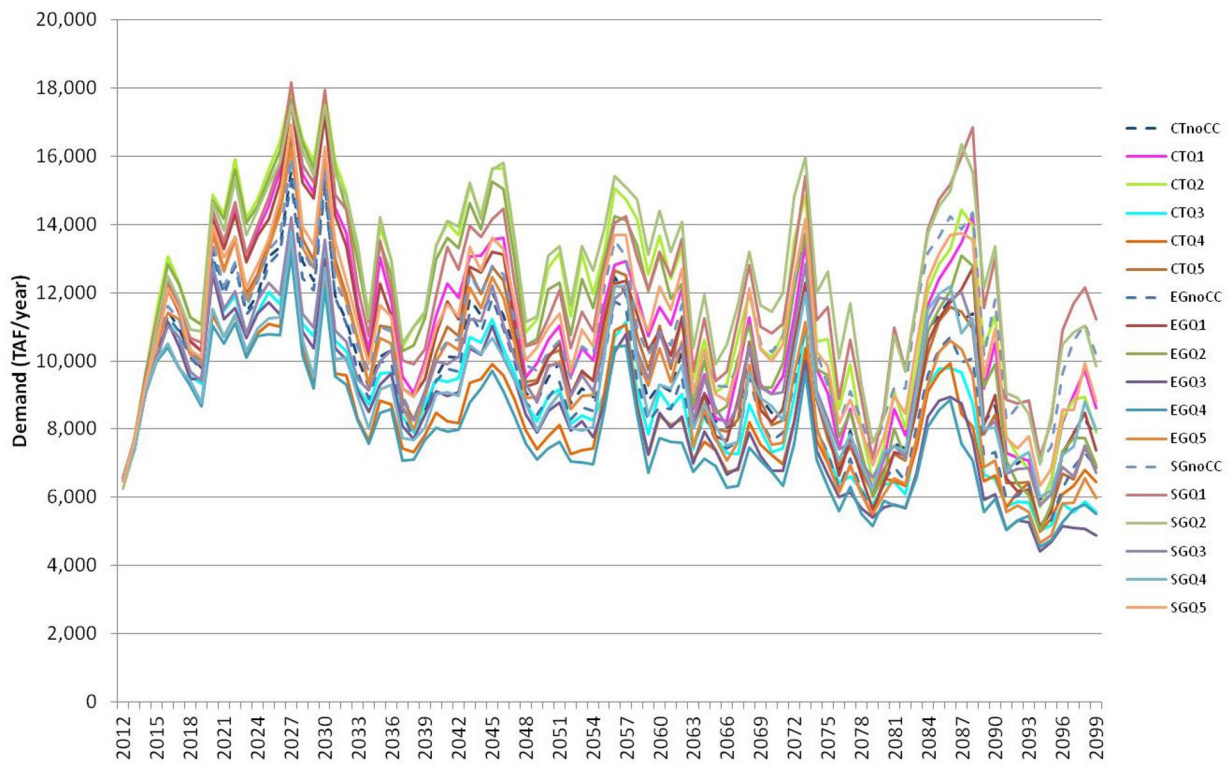


Figure 5-36. Annual Time Series of Agricultural Applied Water Demand in the CVP Service Area in Each Scenario

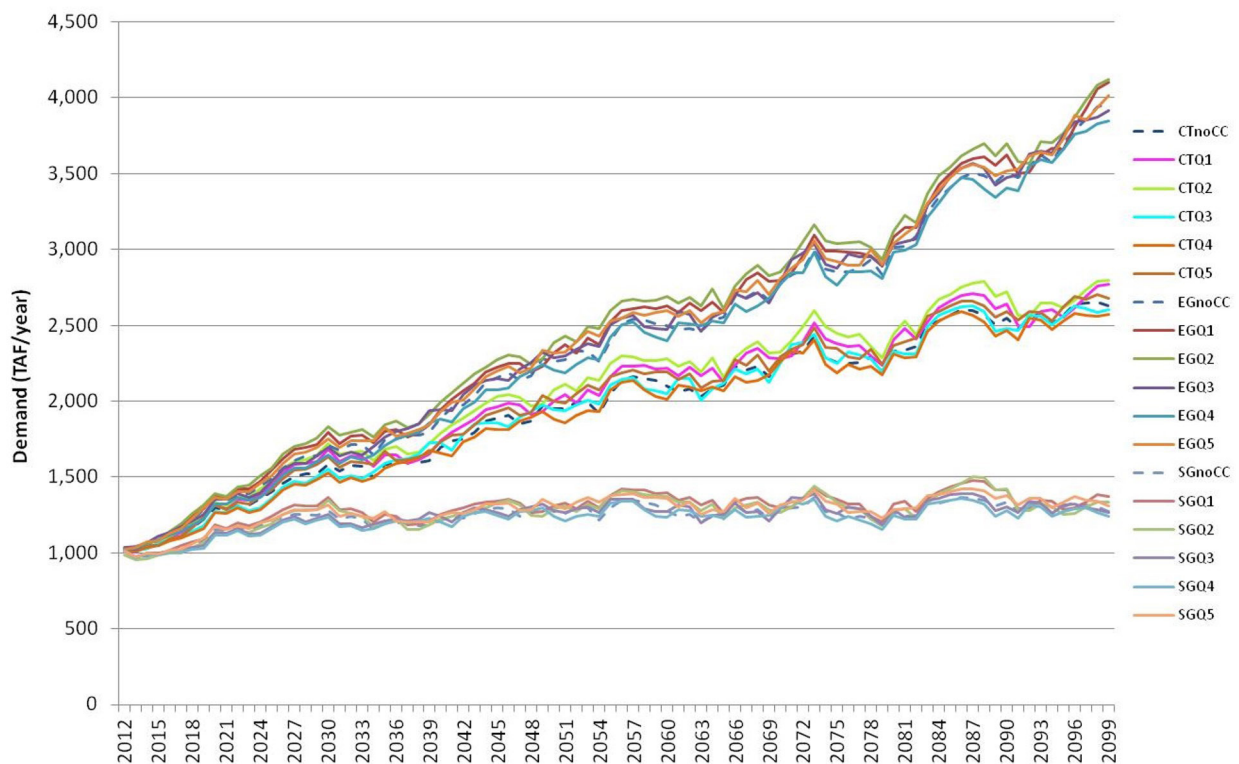


Figure 5-37. Annual Agricultural Applied Water Demand in the CVP Service Area in Each Scenario

variability and longer-term trends in agricultural water demands. For the agricultural demands, it was assumed that there were no changes in the types of crops being grown and that changes in acreage were only associated with the socioeconomic scenarios. The short-term demand variability was highly correlated with the variability in annual precipitation. In years of low precipitation, demand is higher; and in years of high precipitation, agricultural demands decrease. The longer-term trends include both a period of increasing demands during the early twenty-first century followed by declining demands in the latter half of the century. These changes occurred across all the future socioeconomic-climate scenario projections. However, it is also important to note that the rapid increase in demands during the early twenty-first century is partly an artifact of the historical sequence of inter-annual variability used as the basis for projecting future climate. A suggested improvement to this method in further study is to re sample the historical sequence to simulate droughts and wet periods at different times during the twenty-first century.

Several projected changed climatic conditions contribute to these longer-term trends. Increased temperatures during the growing season can have multiple and opposing effects on plant growth and ET. In general, as temperatures increase, the rate of plant transpiration increases because of an increase in the VPD, which is defined as 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 rate and stomatal openings to mitigate this heat stress. This adaptation ability varies among different crops and even among crop cultivars. In addition, 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 were estimated to increase throughout the twenty-first century. Although projected atmospheric humidity was estimated to increase, 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 also affects plant growth by causing plants to grow faster. For annual plants, such as 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 temperatures cause the growth period for perennial crops such as alfalfa, grasses, and some trees to increase, which tends to increase growth period ET. Thus, these temperature-induced phenological changes could have significant and counter-balancing 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 on Figures 3-12, 3-13, and 3-16, respectively. As shown, there is a steadily upward trend projected in Tmax, Tmin, and VPD during the twenty-first century. Therefore, these projected changes would tend to result in increased ET and yields until crop-specific tolerances are exceeded. When climatic conditions exceed these limits, resulting decreases in both crop ET and yields may be expected to occur unless adaptations in crops types occur.

R_s is also a major climatic factor affecting plant growth, yield, and ET. As R_s increases, ET and yield typically increase. However, unlike temperature, R_s was projected to decrease slightly during the twenty-first century. This decrease in R_s is associated with projected increases in atmospheric humidity (Tdew is a good indicator of atmospheric humidity). These changes are reflected in the rising Tdew shown on Figure 3-15. The projected changes in R_s are shown on Figure 3-14. Consequently, this projected climatic change would tend to reduce plant growth, yield, and ET during the twenty-first century.

CO_2 is another changing climatic condition that affects both crop growth and ET. As CO_2 concentrations increase, many plants respond by reducing the conductance of the stomatal openings in their leaves, which reduces their transpiration rate. The magnitude of the reduction can depend 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 approximately 385 ppm). For C4 crops such as corn, the average reduction in stomatal conductance is about 30 percent. On the basis of data from the Free Air Carbon Exchange

experiments, Ainsworth and Long (2005) reported an overall average reduction in stomatal conductance of between 20 and 22 percent when CO₂ concentrations were increased from 360 to 600 ppm. Furthermore, CO₂ effects on crop yields differ between C3 and C4 crops. For C3 crops, increasing CO₂ 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, CO₂ concentrations were based on global emission scenarios developed for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007), which are described in the Special Report on Emissions Scenarios (IPCC, 2000). The projected concentrations varied among the emissions scenarios and increase over time. The warmer scenarios Q2 and Q3 had higher CO₂ concentrations than the less warm Q1 and Q4 scenarios. The central tendency, Q5, projection was intermediate among these extremes. The Q5 concentrations increased from approximately 360 ppm at the beginning of the twenty-first century to about 650 ppm in the late twenty-first century. The maximum concentrations simulated reach approximately 700 ppm by 2099. The projected CO₂ concentrations associated with each of the climate projections are presented on Figure 3-16. On the basis of these projections, the effects of CO₂ on crop ET and yield would tend to be similar and not especially significant until the latter half of the twenty-first century when significant reductions in ET and increases in yield could occur for crops that can tolerate the effects of increased temperature.

As shown on Figure 5-36, agricultural demands were projected to increase in the early to middle twenty-first century primarily because of rising temperatures and increased VPD. During this period, the decreases in Rs intensity and increases in CO₂ concentrations were not yet of sufficient magnitude to offset the temperature and VPD affects on ET. However, in the latter half of the twenty-first century, as projected Rs continues to decrease and CO₂ concentrations continue to increase to levels of between 600 and 700 ppm, the ET of many agricultural crops currently being grown in the Central Valley was projected to decline despite the rising temperatures and increasing VPDs. The average simulated total

CVP Service Area agricultural demand increased from about 6.5 million acre-feet (MAF) in 2012 to approximately 7.5 MAF in 2099, and ranged from a minimum of 5.5 MAF to a maximum of 11.2 MAF. Over the entire twenty-first century, these demands ranged from a minimum of 4.4 MAF to a maximum of 18.2 MAF.

In contrast to the agricultural demands, urban demands were strongly correlated with the socioeconomic scenarios and showed only slight variations with changing short-term climate variability and longer-term climatic trends. 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. In addition, the simulation of outdoor urban demands did not include changes in climate other than temperature and precipitation. As shown on Figure 5-37, urban demand was only slightly changed under Slow Growth conditions but does increase significantly under the Current Trends and Expansive Growth scenarios. By the end of the twenty-first century, the overall average of all the socioeconomic scenario urban demands in the CVP Service Areas was 2.7 MAF and ranged from 1.2 MAF (Slow Growth) to 4.1 MAF (Expansive Growth).

5.3 CVP and SWP System Operations

5.3.1 CVP and SWP Project Storage

Figures 5-38 through 5-51 are exceedance 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 for each of the socioeconomic-climate scenarios. For example, the 50 percent probability of exceedance may be interpreted as the median storage volume over the entire twenty-first century period. The end of May storage typically represents the water supply available for meeting agricultural, urban, and environmental water demands; and the end of September storage is an indicator of the “carryover” storage that is reserved to meet demands in subsequent years. In some of the drier climate projections (Q1 and Q2), reservoir storage reached a minimum volume (dead pool) below which releases cannot be made. Typically, the CVP and SWP systems are operated to maintain sufficient carryover storage to meet

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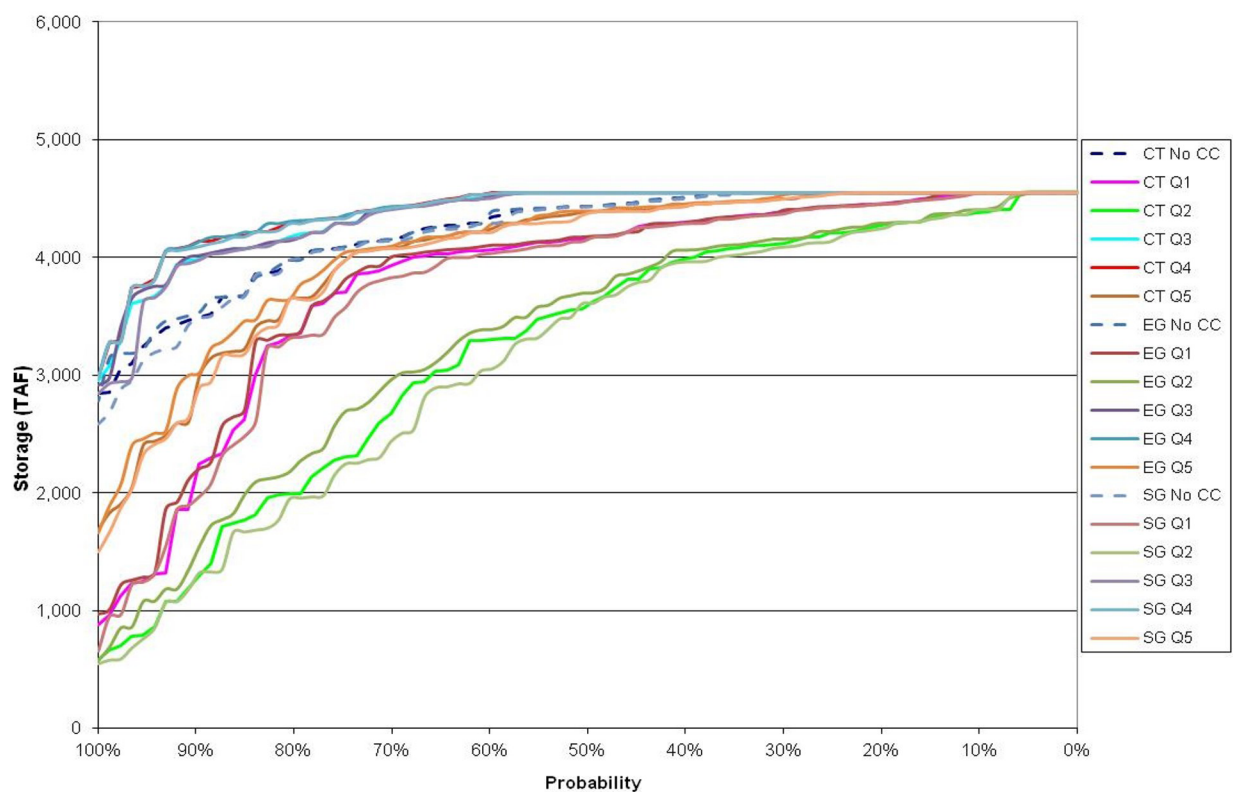


Figure 5-38. Exceedance of Lake Shasta End-of-May Storage in the Baseline in Each Scenario

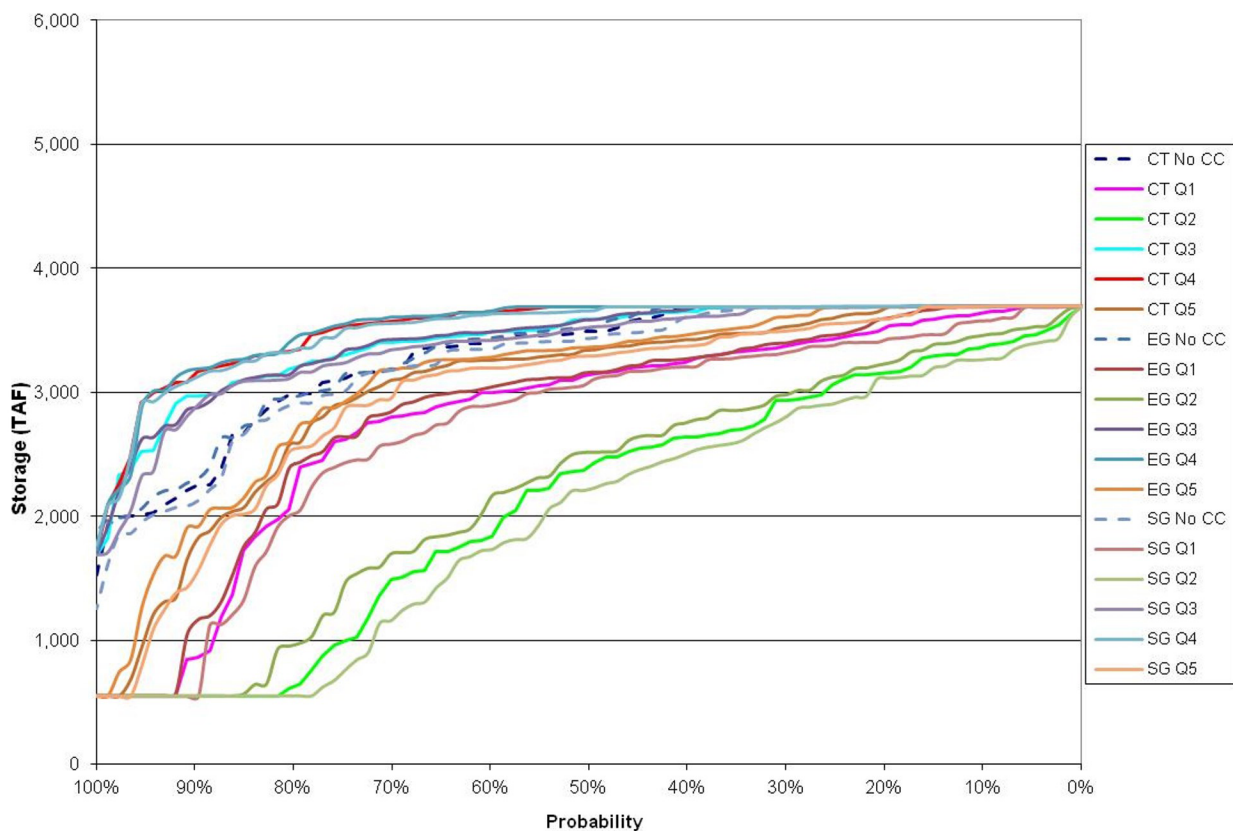


Figure 5-39. Exceedance of Lake Shasta End-of-September Storage in the Baseline in Each Scenario

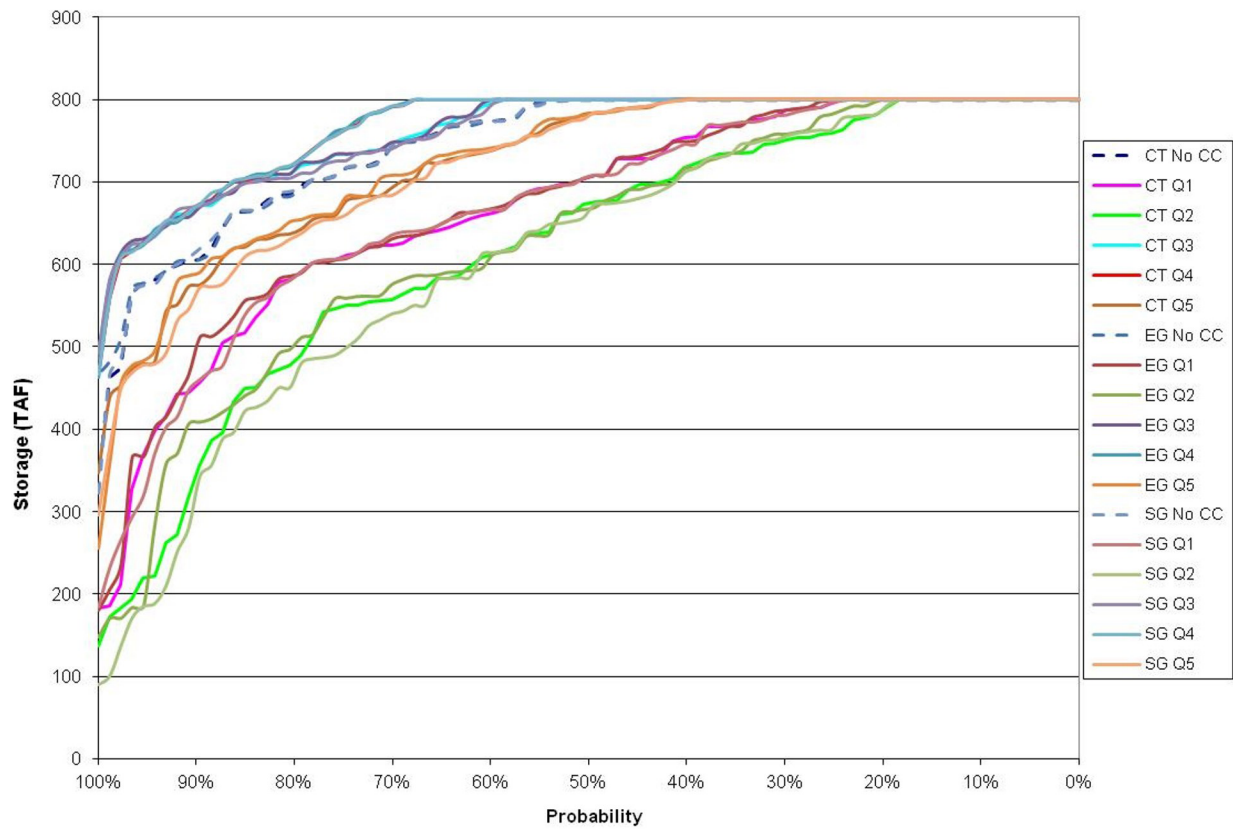


Figure 5-40. Exceedance of Folsom Lake End-of-May Storage in the Baseline in Each Scenario

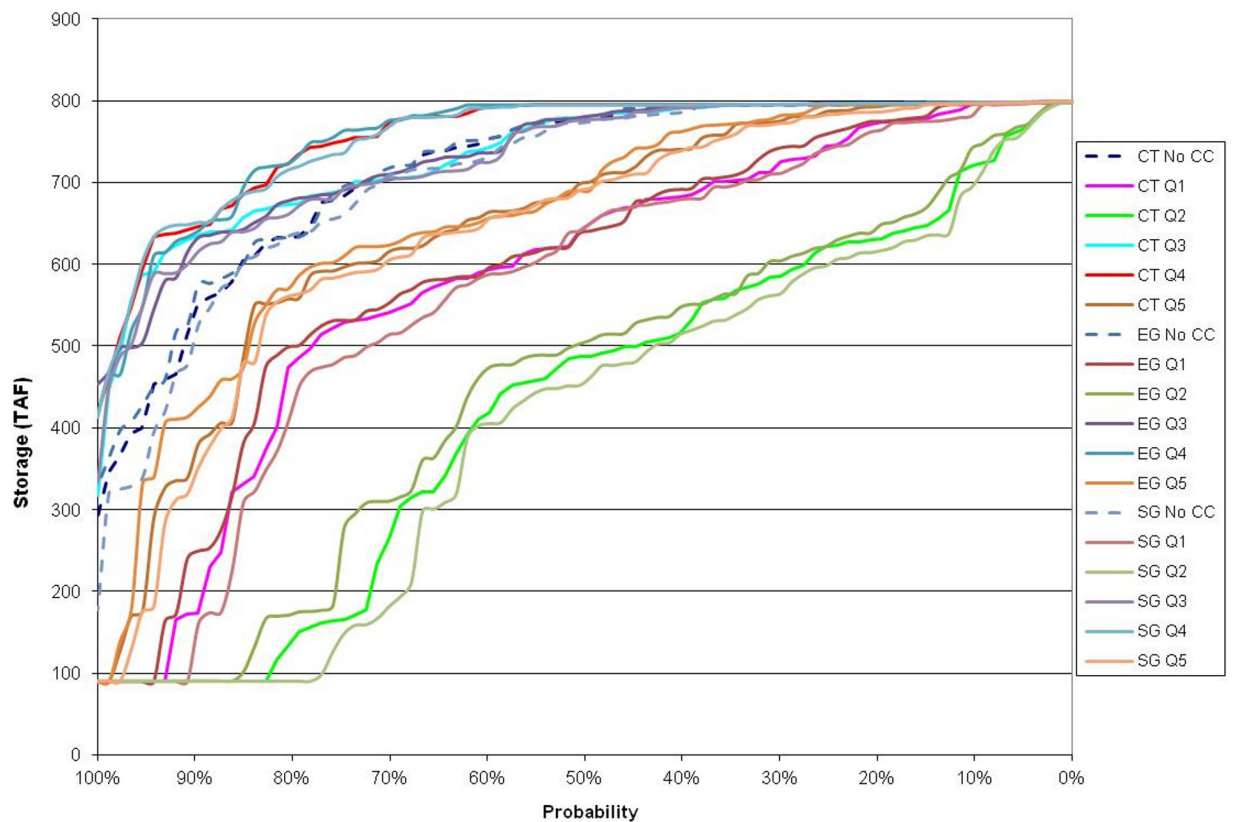


Figure 5-41. Exceedance of Folsom Lake End-of-September Storage in the Baseline in Each Scenario

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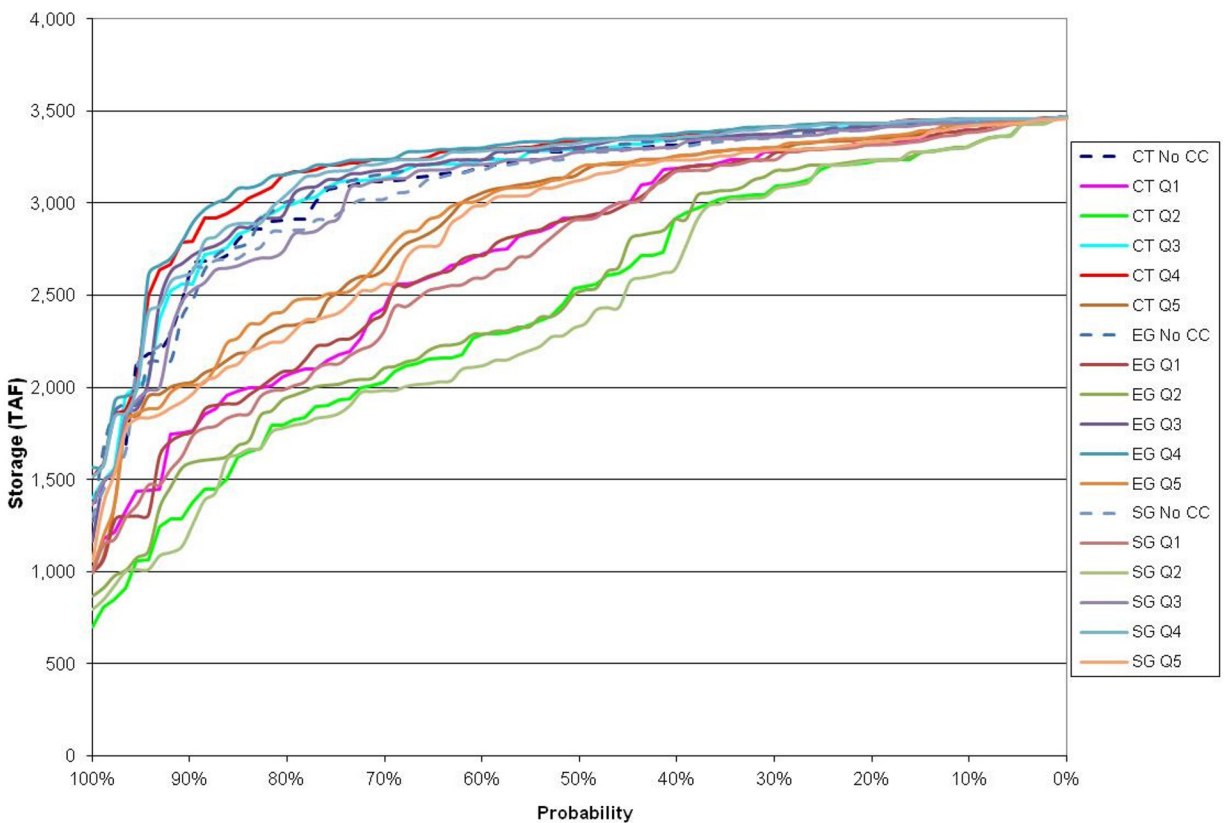


Figure 5-42. Exceedance of Lake Oroville End-of-May Storage in the Baseline in Each Scenario

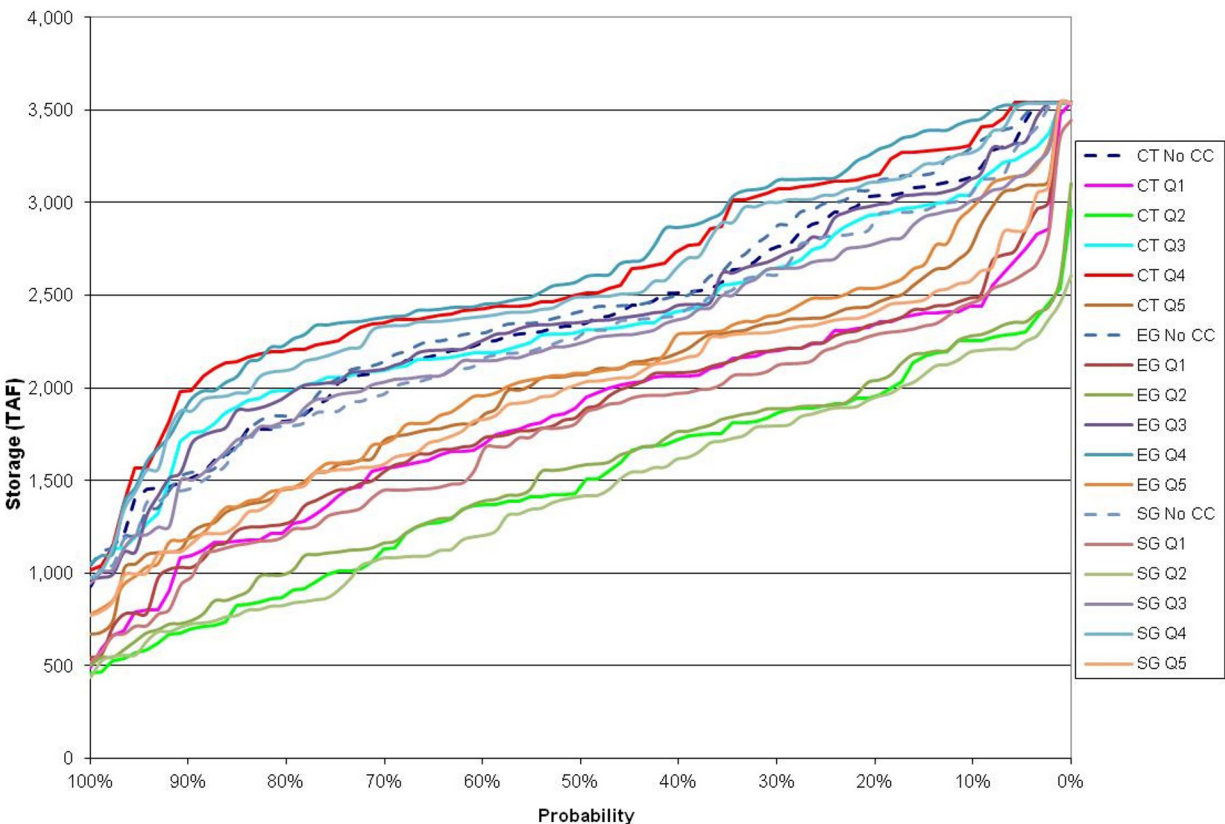


Figure 5-43. Exceedance of Lake Oroville End-of-September Storage in the Baseline in Each Scenario

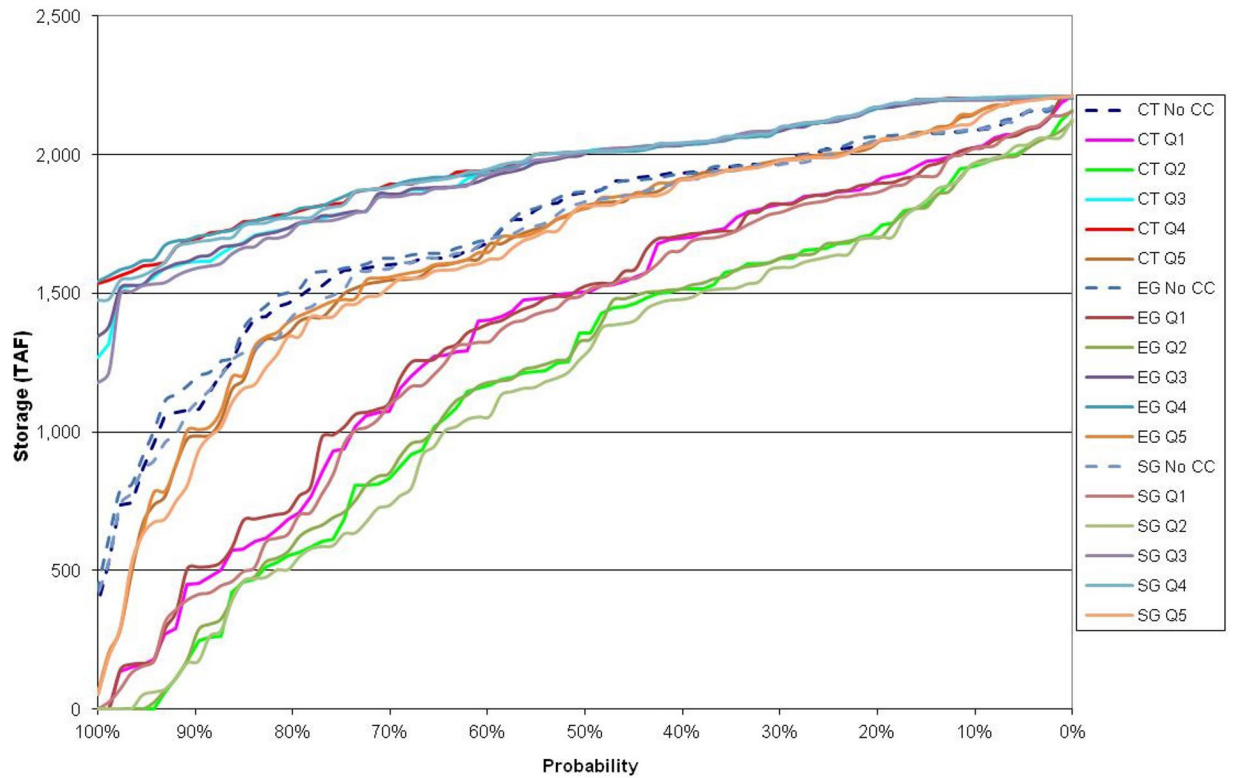


Figure 5-44. Exceedance of New Melones End-of-May Storage Baseline

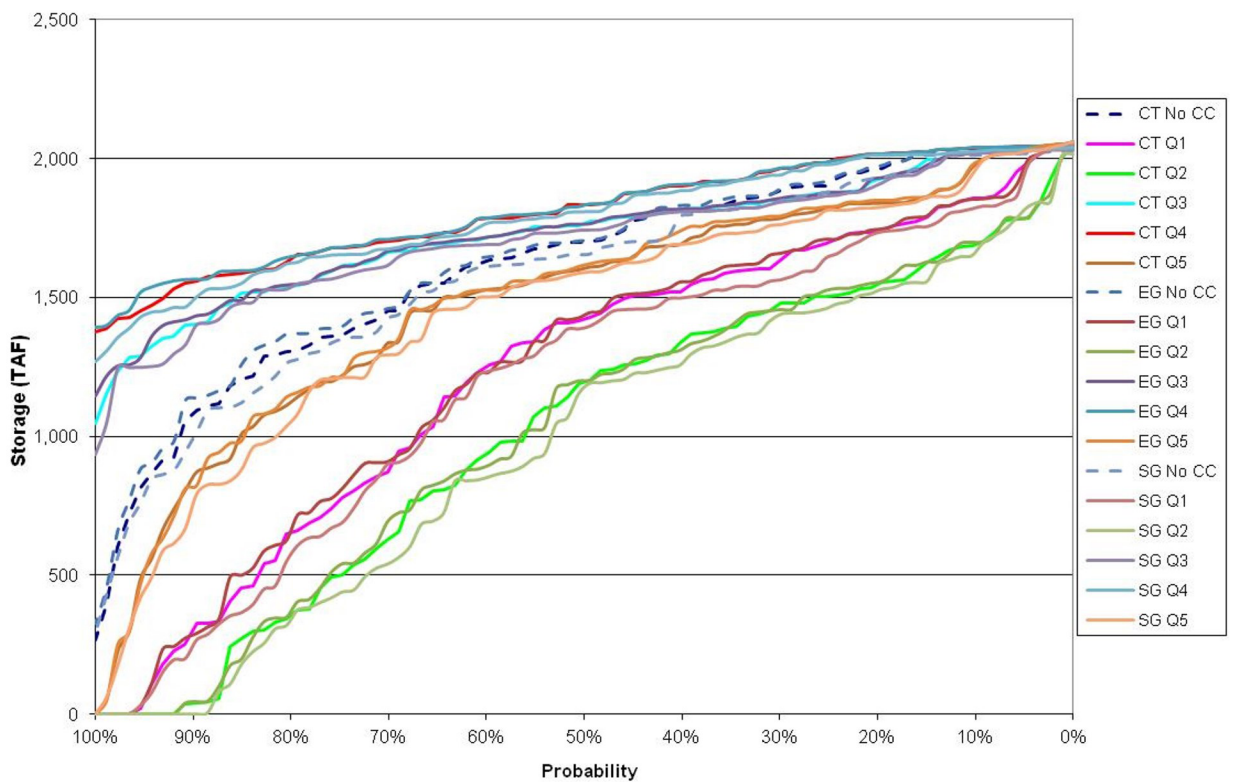


Figure 5-45. Exceedance of New Melones End-of-September Storage Baseline

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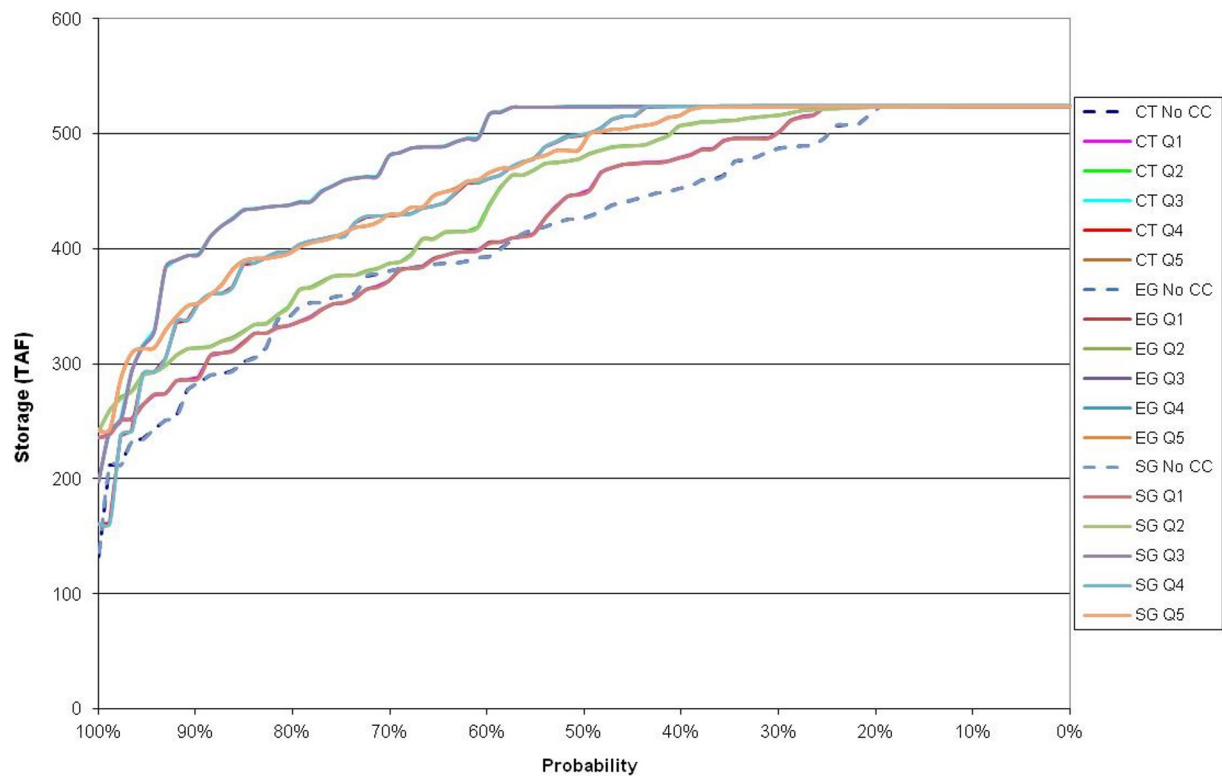


Figure 5-46. Exceedance of Millerton End-of-May Storage Baseline

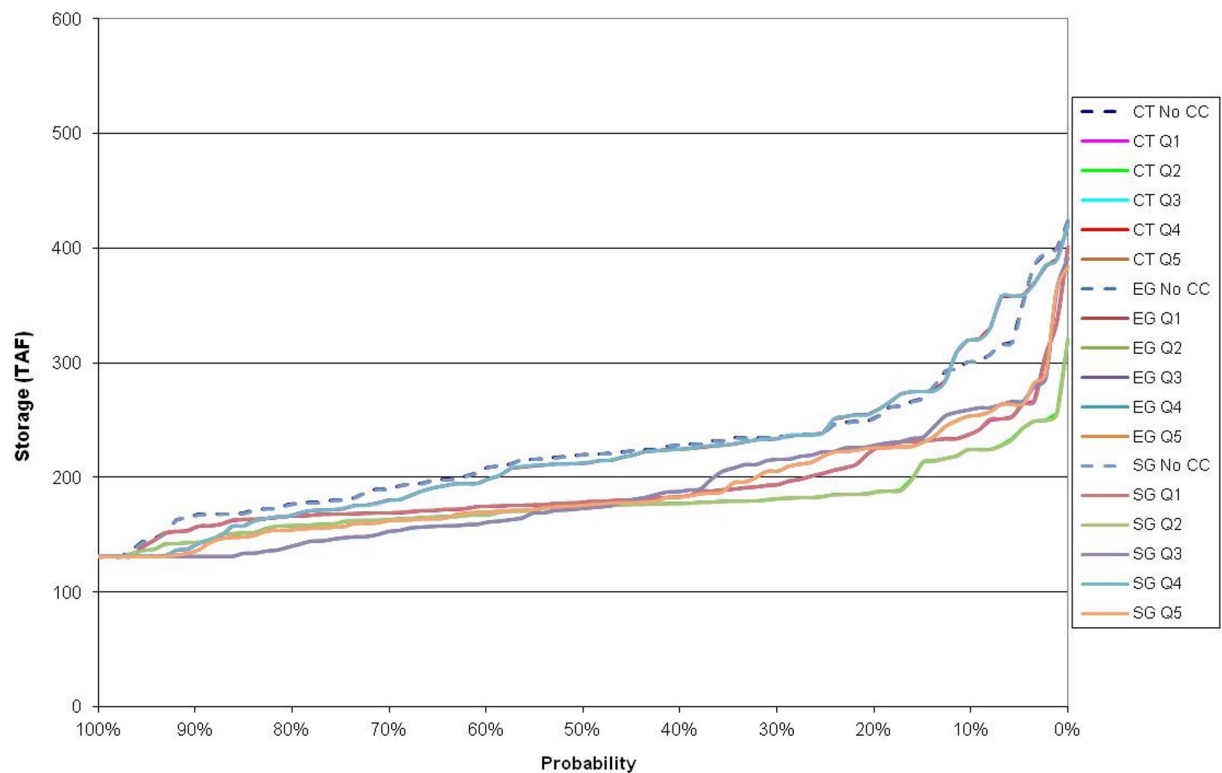


Figure 5-47. Exceedance of Millerton End-of-September Storage Baseline

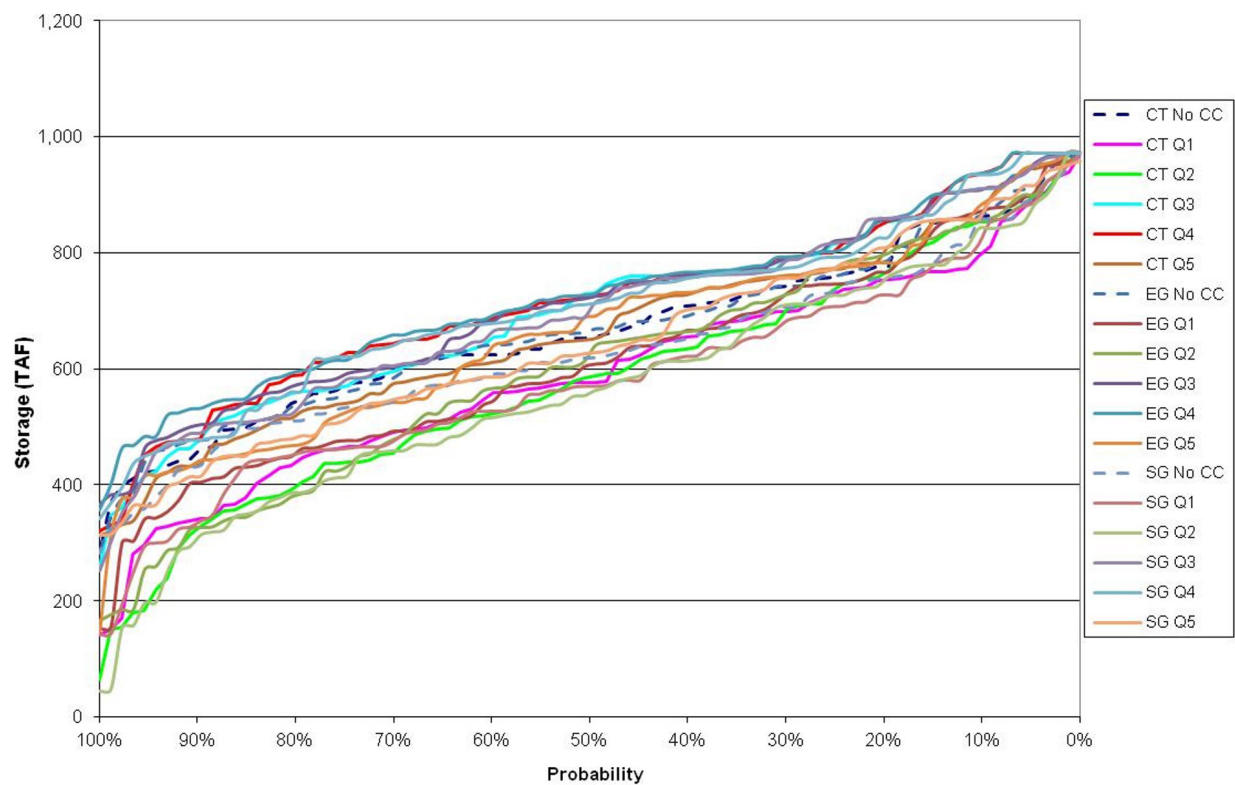


Figure 5-48. Exceedance of CVP San Luis End-of-May Storage Baseline

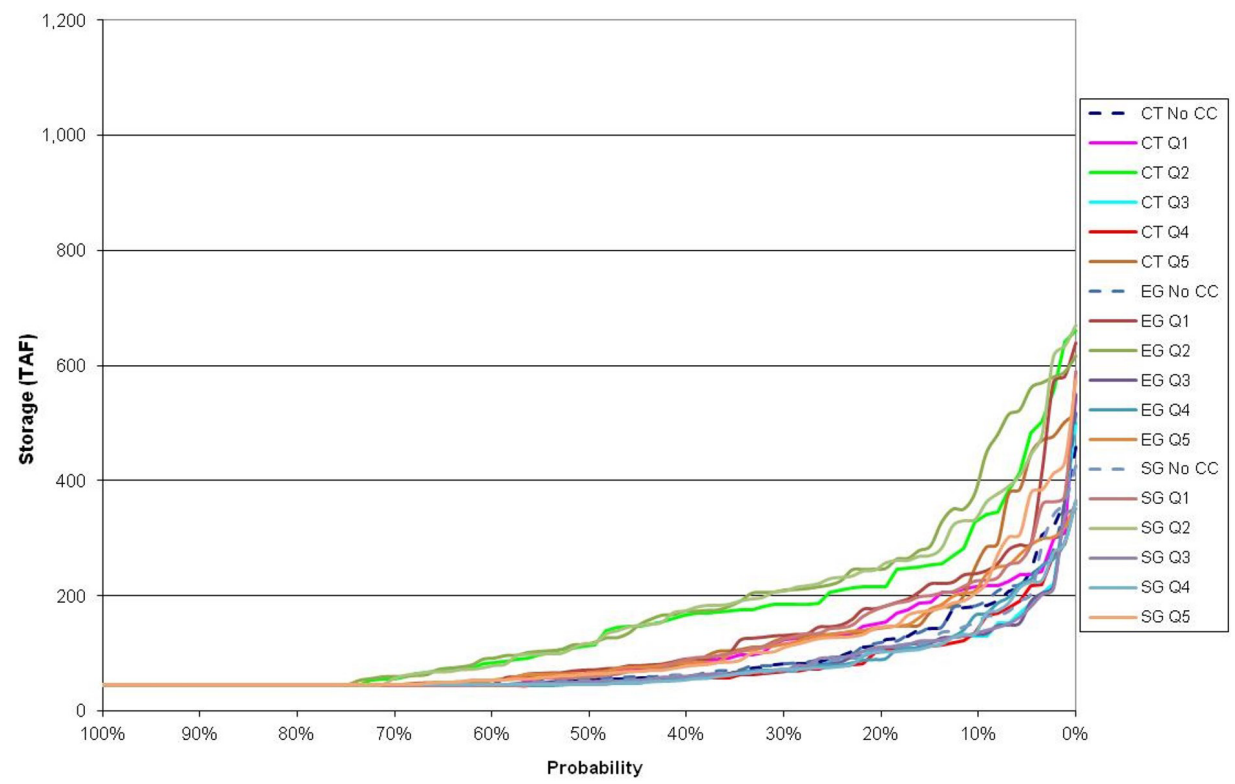


Figure 5-49. Exceedance of CVP San Luis End-of-September Storage Baseline

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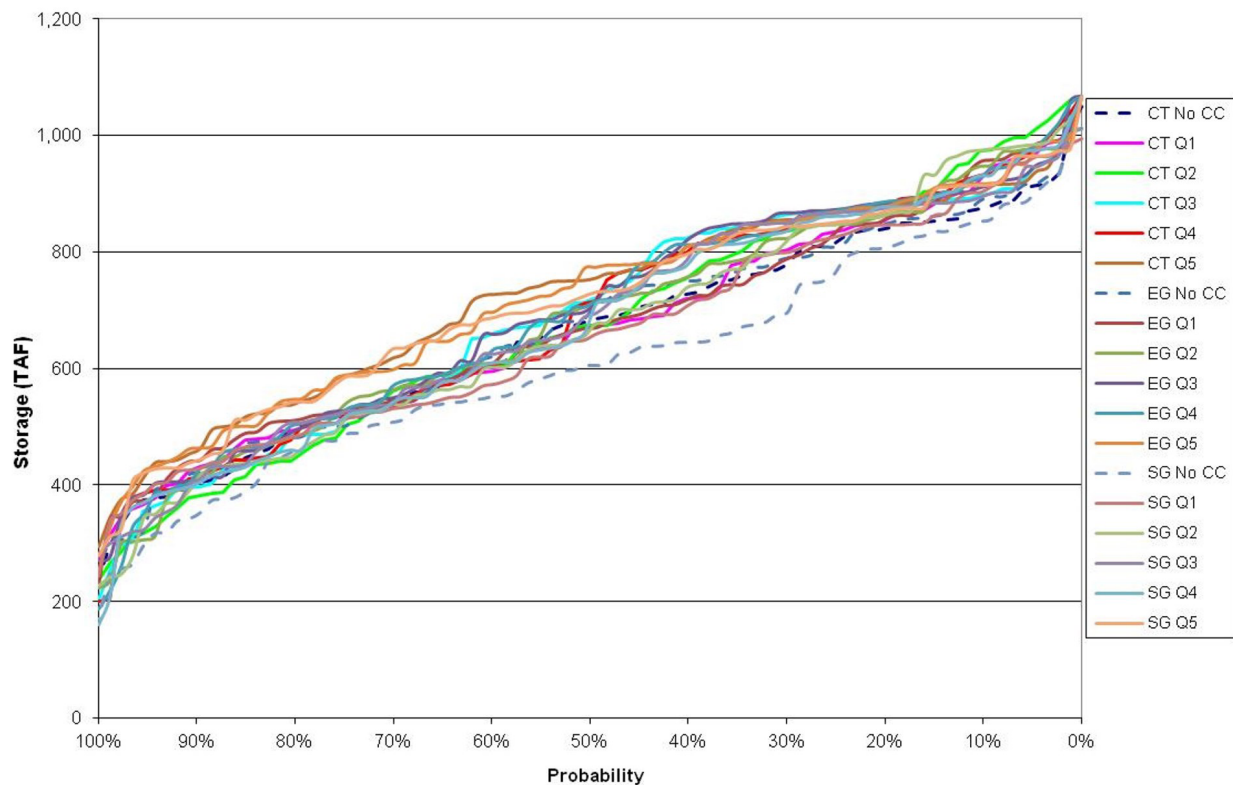


Figure 5-50. Exceedance of SWP San Luis End-of-May Storage Baseline

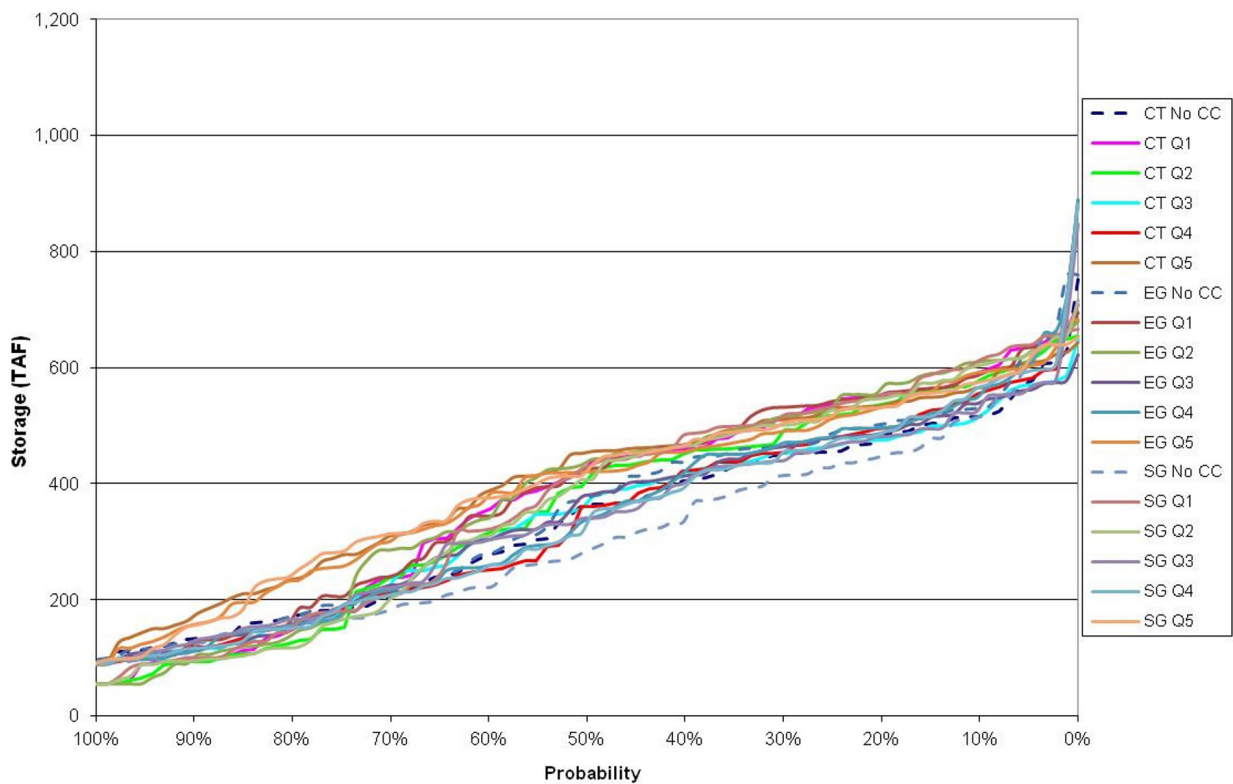


Figure 5-51. Exceedance of SWP San Luis End-of-September Storage Baseline

demand requirements during drought periods of several years. In the CVP IRP simulations, the reservoir operating rules have not been adjusted to account for the projected hydrologic conditions under climate change. Therefore, the dead pool results presented in these figures do not reflect how the CVP and SWP systems would actually be operated under future changes in climate but, rather, may be viewed as indicators of the potential need for adaptation under some of the projected future climates should such conditions actually occur.

Because of the effects of climate change, the differences in storage results among the socioeconomic-climate scenarios became greater as the simulation moved through the twenty-first century. As examples, Figures 5-52 and 5-53 show the average storage in each year in the six Current Trends scenarios in Lake Shasta and Lake Oroville. Although the storage trends for the six scenarios were very similar in the first few years of the simulation, the variability among scenarios grew greater as the transient simulation moved toward the latter part of the century.

As shown on the figures, the reservoir storage results revealed only a limited amount of variability among the different socioeconomic scenarios, but differed significantly among the different climate scenarios. However, reservoir storages were somewhat higher under the Expansive Growth scenario because over time, agricultural demands, which are the largest demand type, decreased the most in this scenario because it assumed the most conversion of agricultural land to urban lands.

The median climate scenario (Q5) had storage levels very close to the no climate change scenarios in Lake Oroville and a moderate amount lower than the no climate change scenario in Shasta, Folsom, and New Melones Reservoirs. In Millerton Lake, the storage was greater in all five climate change scenarios than in the no climate change scenario in May, and lower in all five climate change scenarios than in the no climate change scenario in September. This reflects the greater shifts in monthly timing of projected inflows into Millerton than in the other climate scenarios. In all five reservoirs, the storage levels in both May and September were higher under the wetter climate scenarios (Q3 and Q4) than

under the no climate change scenarios, with the highest storage levels in the wetter, less warming scenario (Q4). Conversely, the storage levels in both months were lower under the drier climate scenarios (Q1 and Q2) than under the no climate change scenarios, with the lowest storage levels in the drier, more warming scenario (Q2). All five reservoirs were at dead storage in some proportion of years at the end of September under climate scenario Q2, with Lake Shasta the most likely to be at dead storage in about 20 percent of all years. In most of these reservoirs, dead storage conditions also occurred, but less frequently under the Q1 and Q5 scenarios. As noted previously, the actual operation of these reservoirs in the drier scenarios would more than likely be adapted to maintain end-of-September carry-over storage greater than the amounts simulated here.

5.3.2 CVP and SWP Delta Exports and Delta Outflow

Figures 5-54 through 5-59 are annual exceedance and box plots of CVP and SWP exports at Banks PP and C. W. Jones Pumping Plant (Jones PP), and of total Delta exports. Figures 5-60 and 5-61 show the same information for Delta outflow. The box plots depict the mean, median, 25th and 75th percentile, minimum, and maximum values for the annual flows at these same locations in each of the socioeconomic-climate scenarios. Like the reservoir storage results, the Delta export and outflow results were very similar with respect to the different socioeconomic scenarios but differed significantly among the different climate scenarios. Banks and Jones pumping and Delta outflow were all lower under climate scenarios Q5, Q1, and Q2 than under the corresponding no climate change scenarios, with the lowest flows occurring in the warmer-drier Q2 scenario. Conversely, the annual flows at all three locations were greater under climate scenarios Q3 and Q4 than under their corresponding no climate change scenarios, with the highest flows occurring in the less warm-wetter Q4 scenario. The drier climate scenarios (Q1 and Q2) showed a greater difference in Delta exports relative to the no climate change scenarios than did the wetter climate scenarios (Q3 and Q4) because exports in the wetter climate scenarios were frequently limited by CVP SWP conveyance capacities and Delta regulatory requirements. Total exports were about 1.4 to 1.5 MAF/year lower, and Delta outflow was about 4.5 to 5.0 MAF/ year lower under Q2 than under

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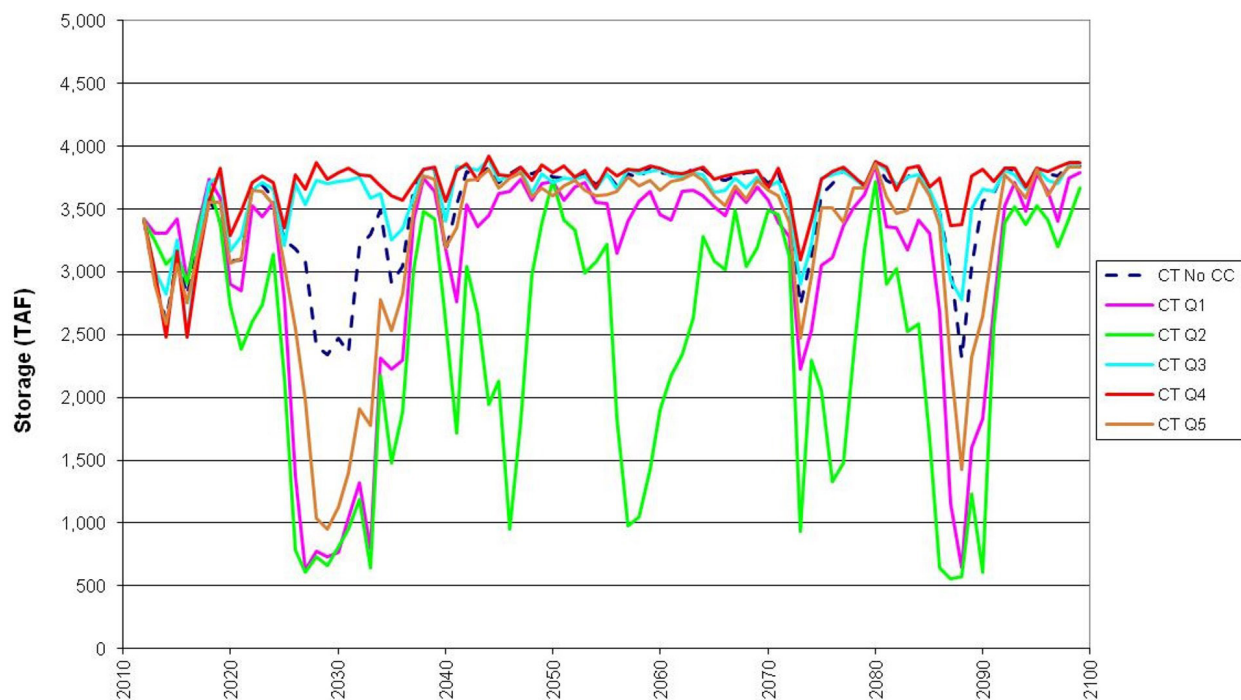


Figure 5-52. Time Series of Average Storage in Each Year in Lake Shasta in the Baseline

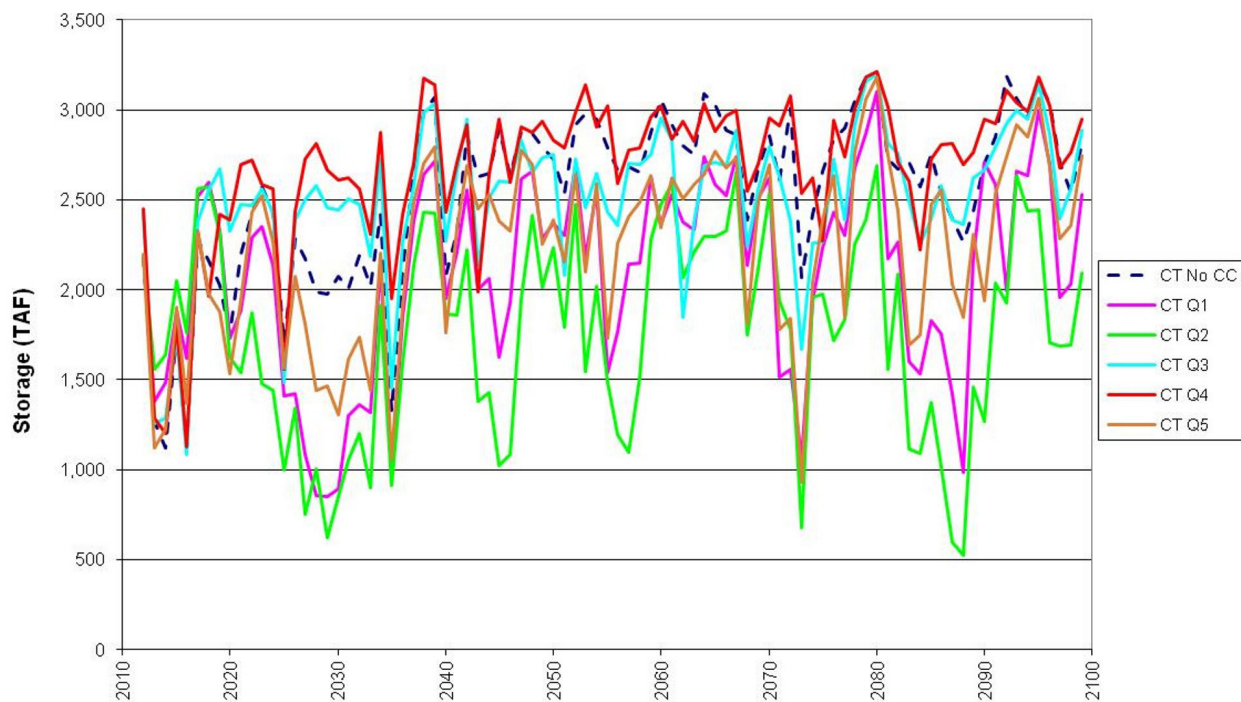


Figure 5-53. Time Series of Average Storage in Each Year in Lake Oroville in the Baseline

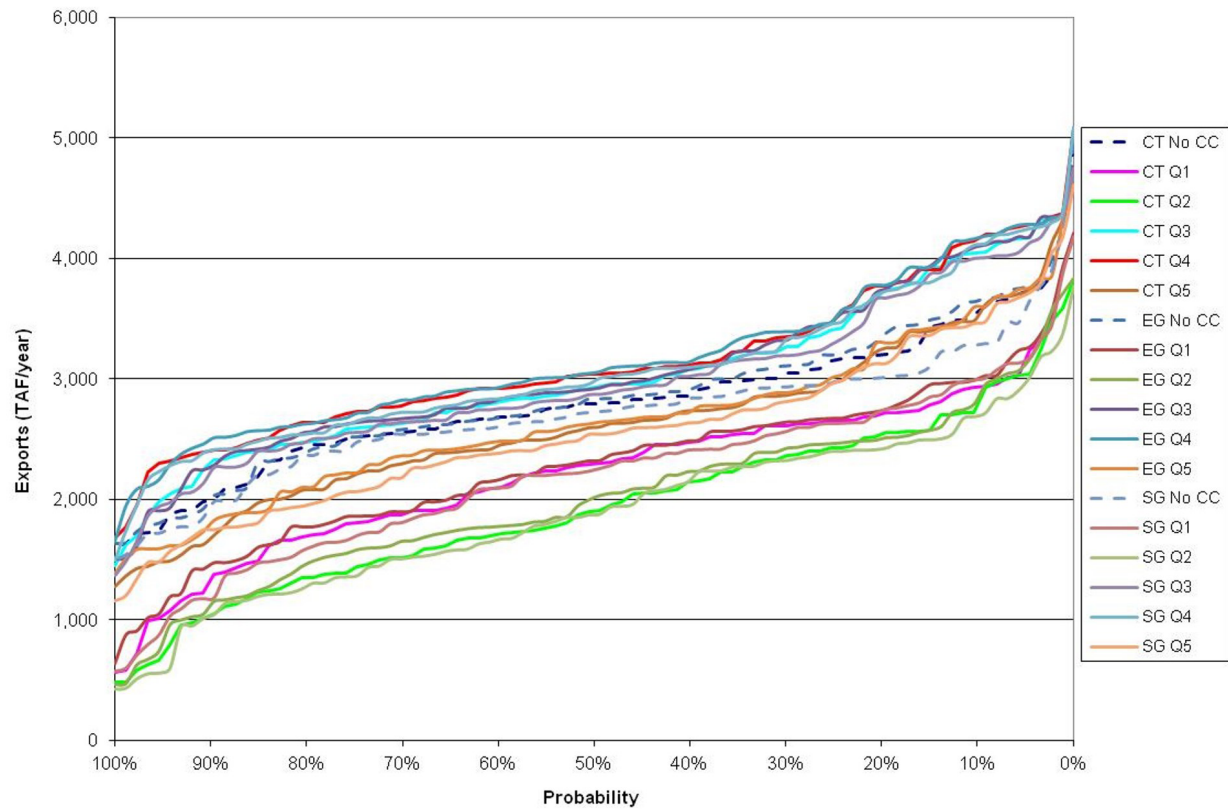


Figure 5-54. Annual Exceedance of Banks Pumping in the Baseline in Each Scenario

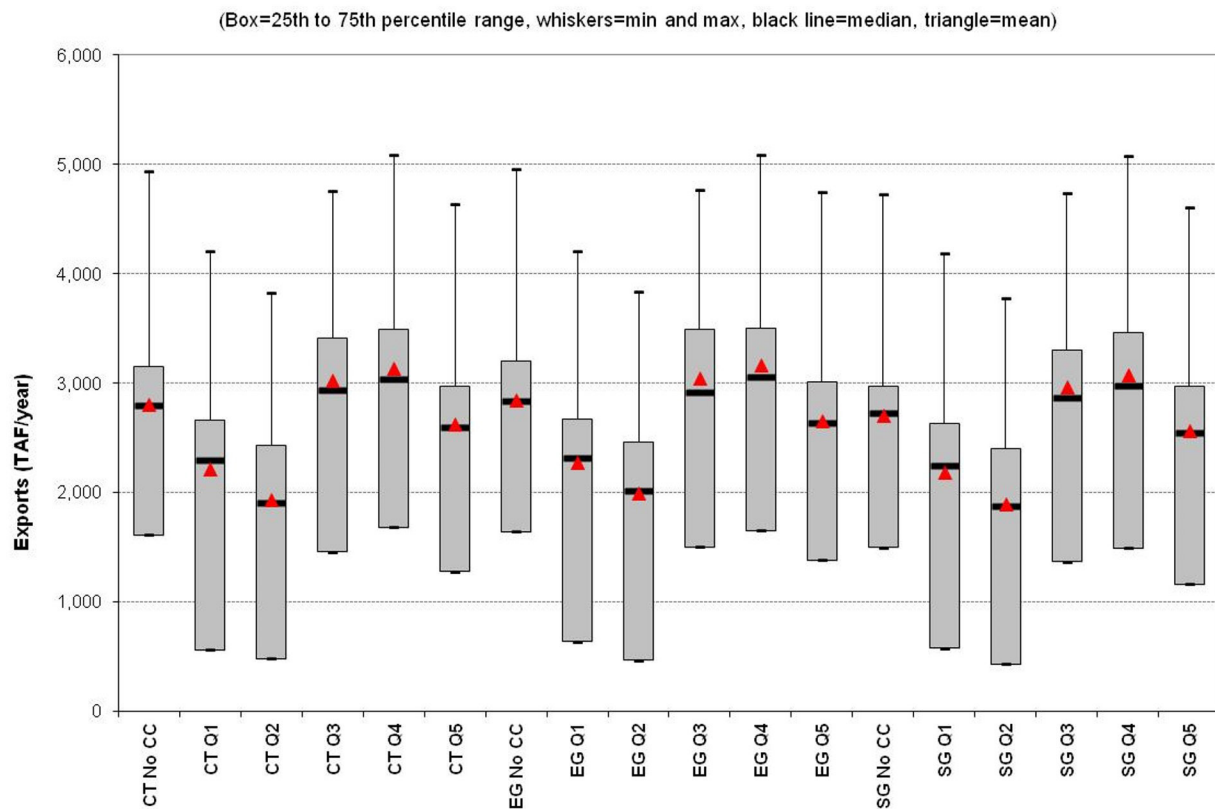


Figure 5-55. Box Plot of Banks Pumping in the Baseline in Each Scenario

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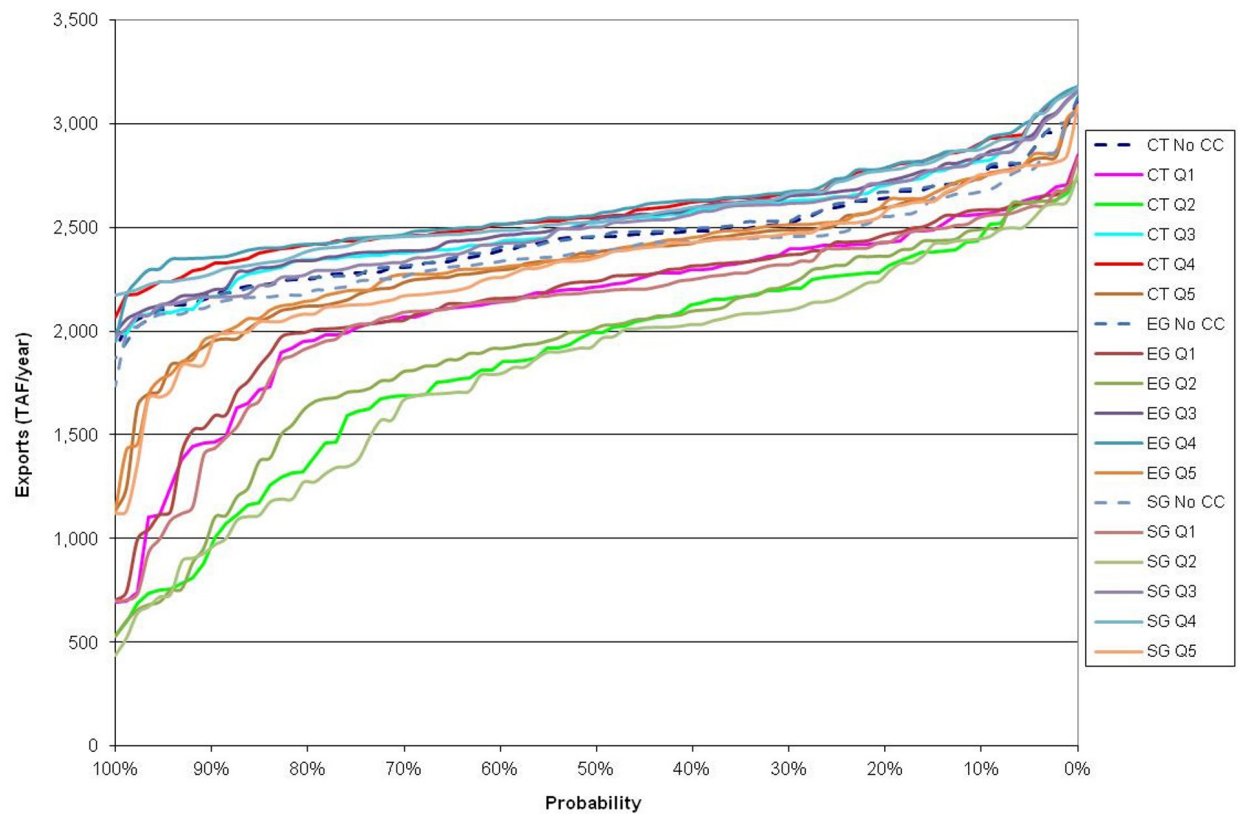


Figure 5-56. Annual Exceedance of Jones Pumping in the Baseline in Each Scenario

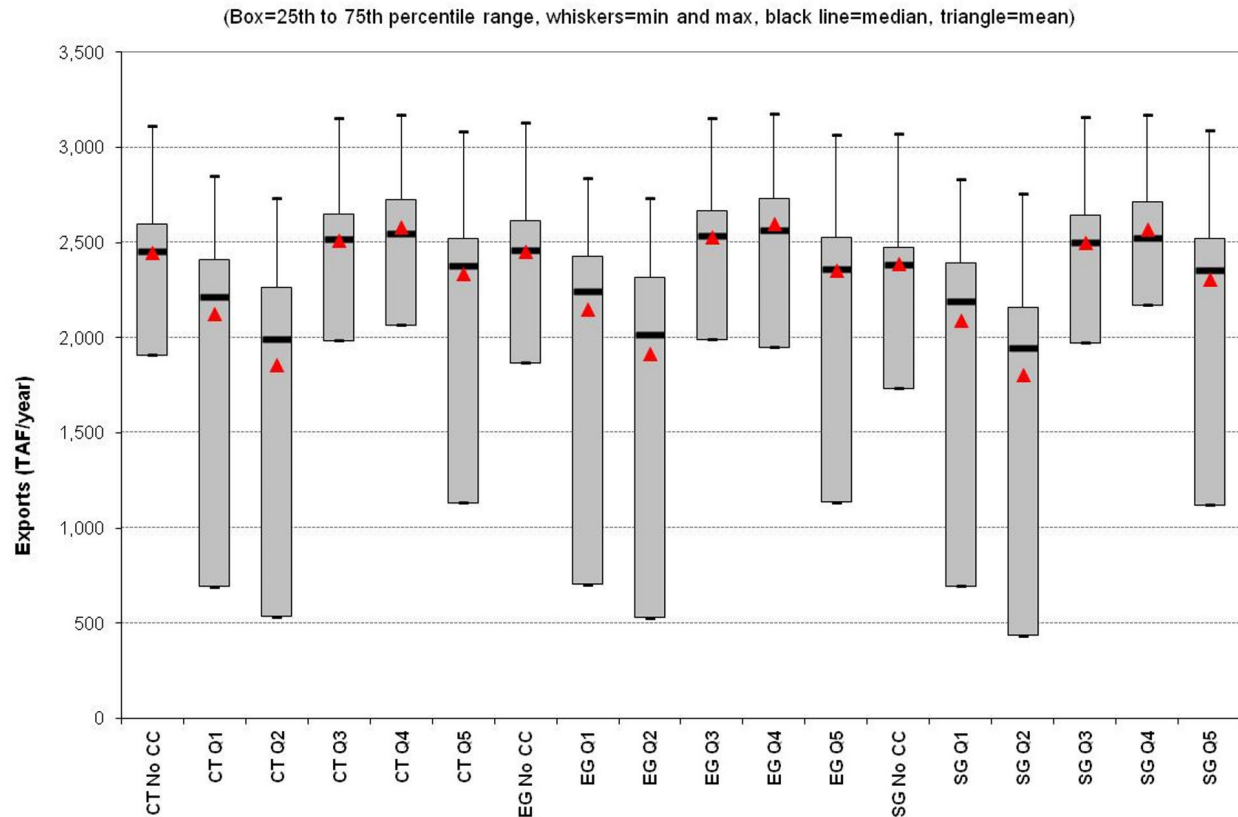


Figure 5-57. Box Plot of Jones Pumping in the Baseline in Each Scenario

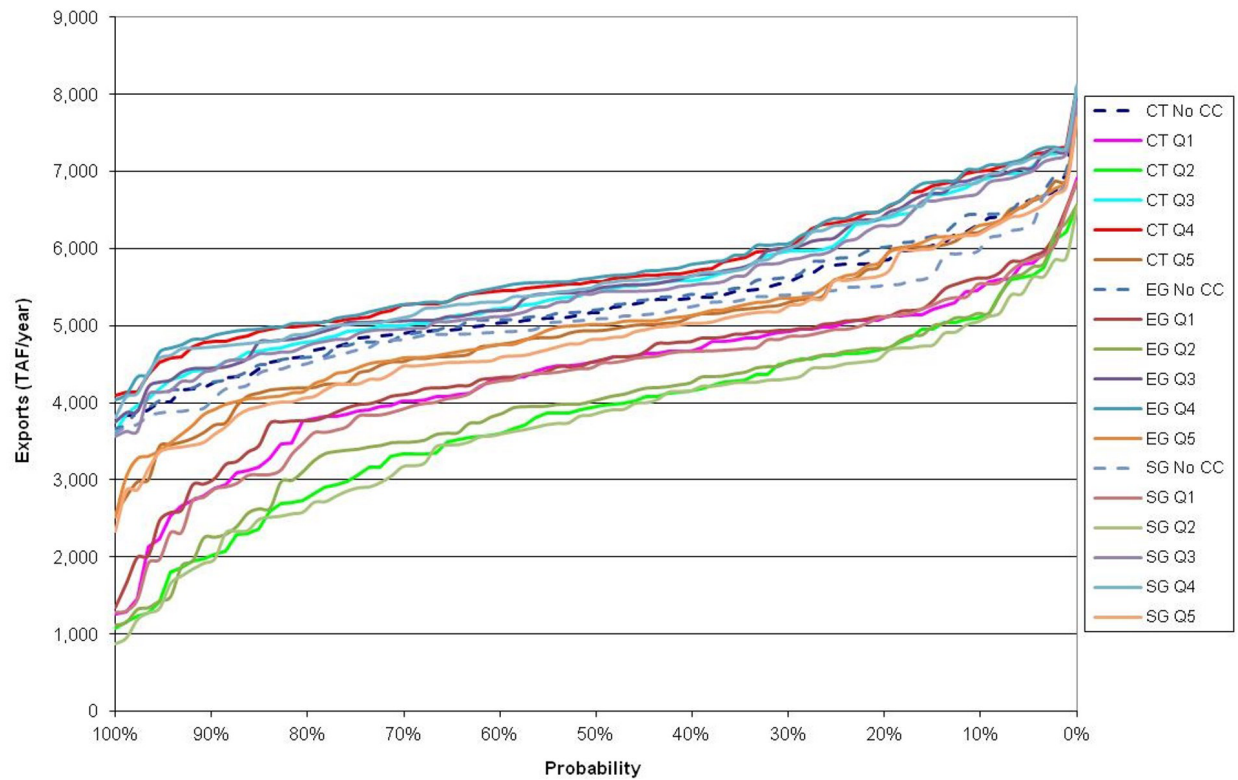


Figure 5-58. Annual Exceedance of Total Delta Exports in the Baseline in Each Scenario

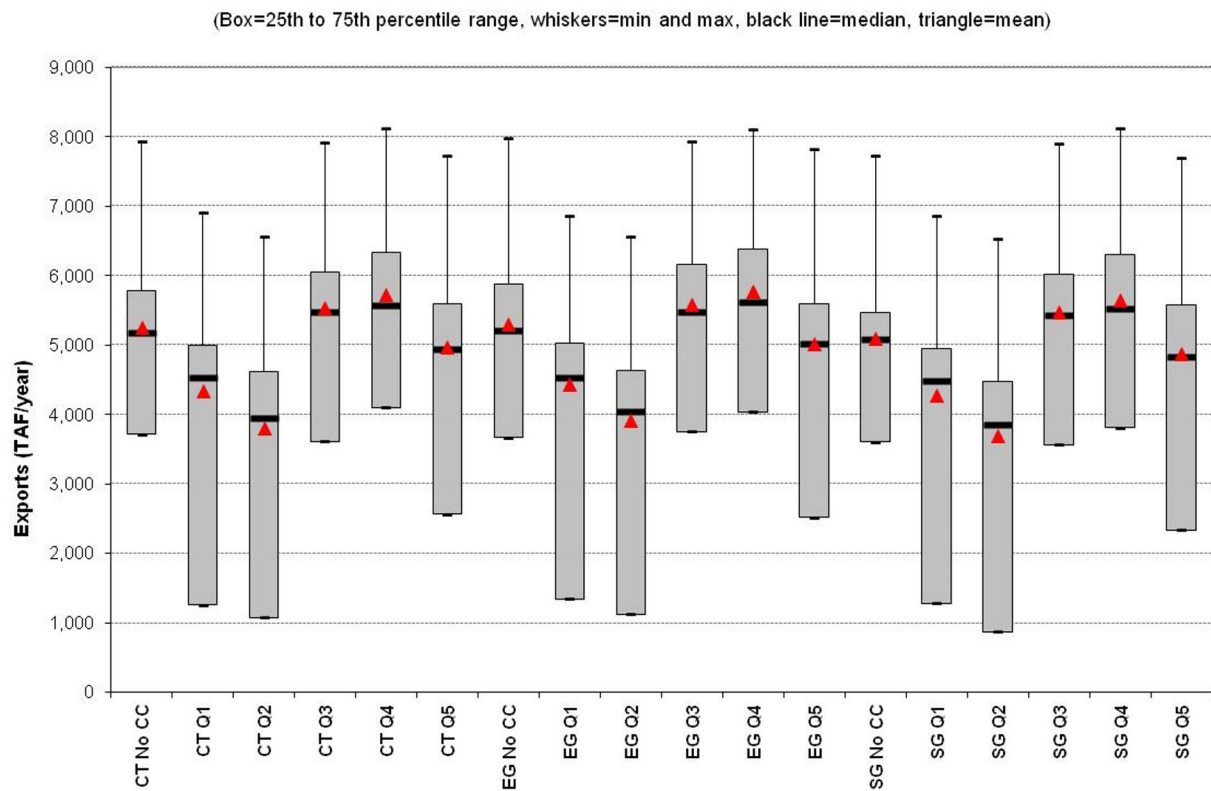


Figure 5-59. Box Plot of Total Delta Exports in the Baseline in Each Scenario

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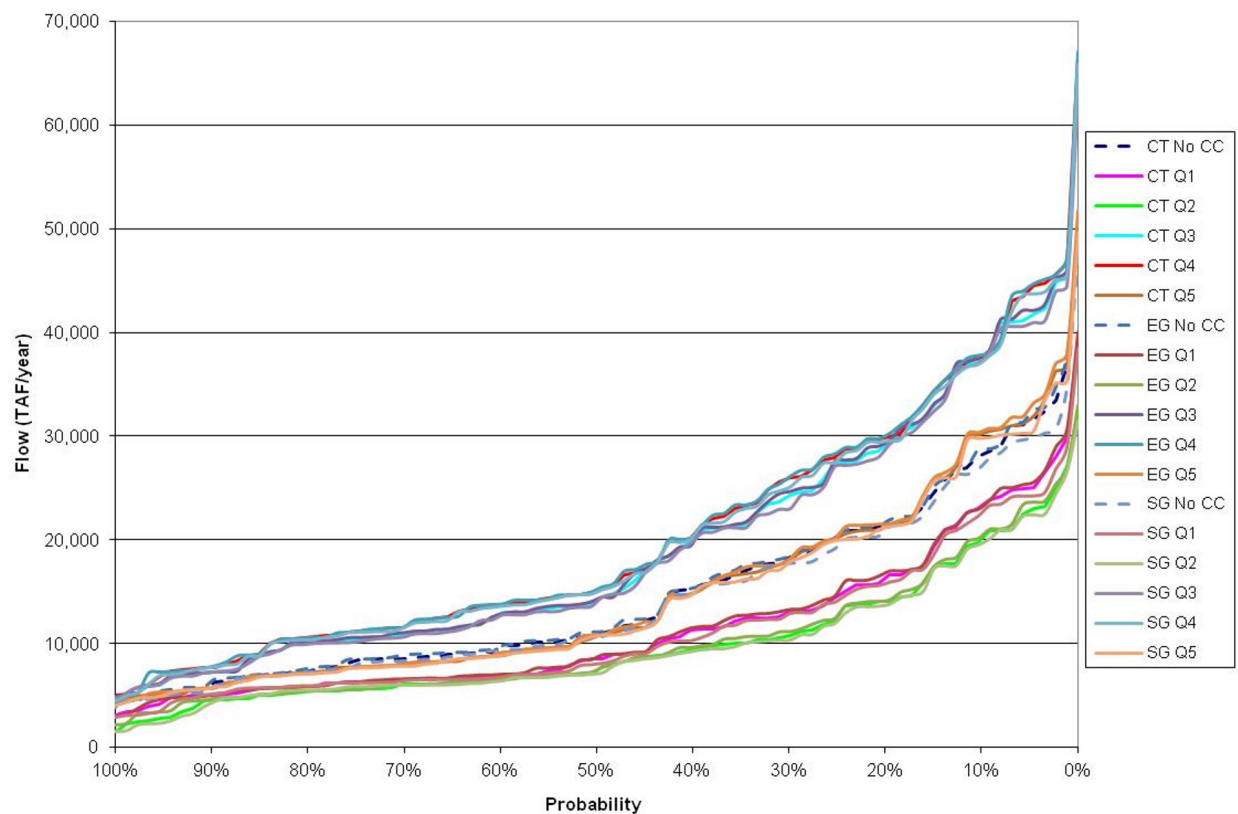


Figure 5-60. Annual Exceedance of Delta Outflow in the Baseline in Each Scenario

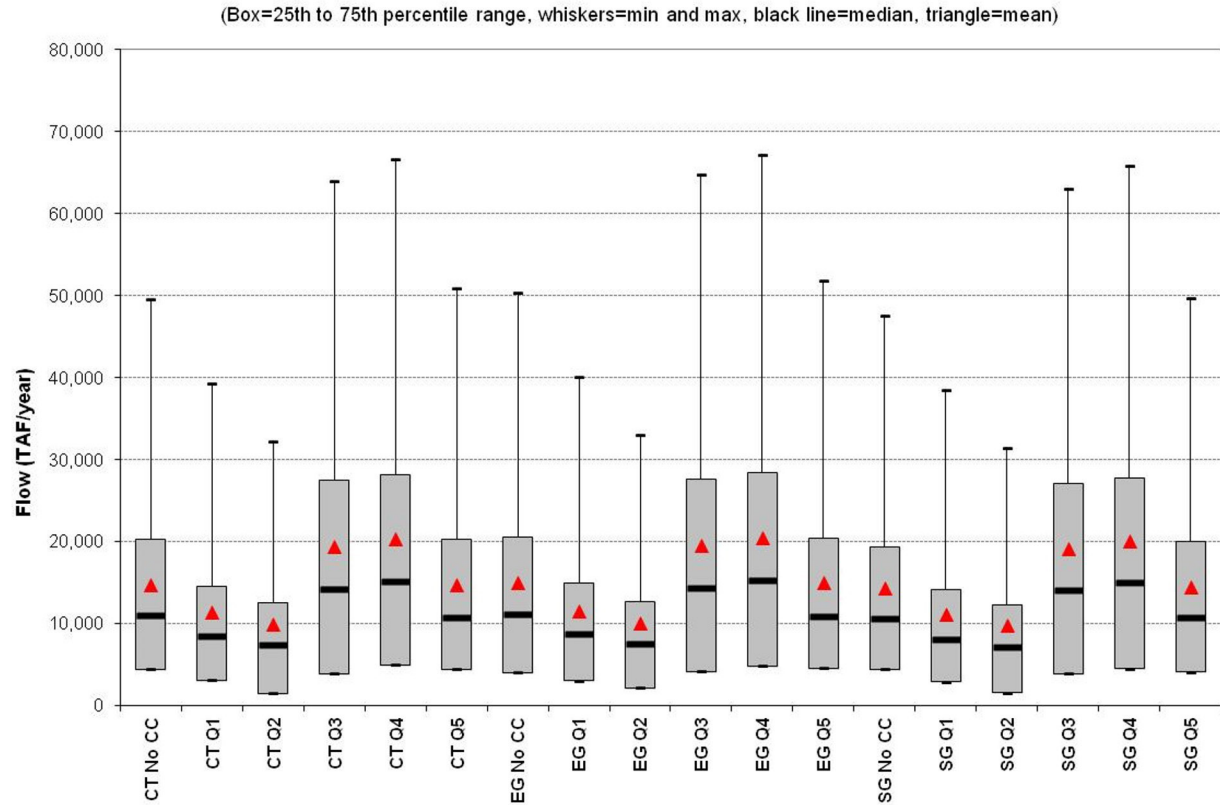


Figure 5-61. Box Plot of Delta Outflow in the Baseline in Each Scenario

the no climate change scenario. Conversely, total exports were about 0.5 to 0.6 MAF/year higher and Delta outflow was about 5.5 to 6.0 MAF/year higher under Q4 than under the no climate change scenario.

As with the storage results, the effects of climate change caused the differences in Delta exports and Delta outflow among the socioeconomic-climate scenarios to become greater as the simulation moved through the twenty-first century. As examples, Figures 5-62 and 5-63 show time series of average annual Delta exports and Delta outflow in each year in the six Current Trends scenarios. Although the trends for the six scenarios were very similar in the first few years of the simulation, the variability among scenarios grew greater as the transient simulation moved toward the latter part of the century.

5.3.3 Delta Salinity

Figures 5-64 and 5-65 show exceedance and box plots of the average distance measured from the Golden Gate Bridge of the X2 (2 parts per thousand salinity concentration) position from February through June for each of the socioeconomic-climate scenarios. Greater X2 positions indicate that salinity has moved farther eastward into the Delta. The period from February through June was when CVP and SWP reservoirs were operated to maintain State Water Resource Control Board Decision 1641 regulatory requirements concerning the location of X2 within the Delta. As with the other system metrics, the X2 results were very similar among the different socioeconomic scenarios but differed significantly relative to the different climate scenarios. The X2 position results under the wetter climate scenarios (Q3 and Q4) were similar to those of their corresponding no climate change scenarios because the increased flows into the Delta in those wetter scenarios compensated for the increased sea level rise. However, the X2 position was greater under the central tendency Q5 and the drier Q1 and Q2 scenarios where sea level rise combined with reduced Delta inflows relative to the no climate change scenarios resulted in greater X2 positions. The largest values occurred under the warmer-drier Q2 scenario, which also had the highest rate of sea level rise. The average X2 position from February through June under Q2 was about 9–10 kilometers (km) farther east than under the no climate change scenario.

5.4 Supplies and Demands in CVP Divisions

Figure 5-66 shows the average annual total CVP Service Area water supplies from various sources during the twenty-first century including surface water, groundwater, and local projects. Also shown on the figure is the average annual unmet demand (defined as total demands minus the sum of surface water deliveries, groundwater pumping, and the effects of any local actions) for the entire CVP Service Area under each of the socioeconomic-climate scenarios. As shown, the effects of differences in climate were more significant than the socioeconomic scenarios. Local project supplies were relatively small compared to other sources in all the scenarios. Overall groundwater pumping ranged from 1.5 to 2.3 MAF/year. The greatest usage occurred in the wetter Q3 and Q4 scenarios because under these conditions increased aquifer recharge maintained groundwater levels sufficiently high so that pumping was not as constrained as in the drier Q1 and Q2 scenarios. Surface water deliveries ranged from 3.7–5.1 MAF/year across the range of scenarios. In general, the central tendency Q5 scenarios were similar to their corresponding no climate change scenarios. The relationship among deliveries and the climate scenarios was similar to groundwater, but the differences between the drier (Q1 and Q2) and wetter (Q3 and Q4) scenarios were more significant. In the central tendency Q5 scenario, deliveries were slightly reduced relative to their corresponding no climate change scenarios.

Over the twenty-first century, the unmet demands ranged from 2.7–8.2 MAF/year across the range of socioeconomic-climate scenarios. The largest unmet demands occurred in the warmer-drier scenarios (Q2) and the least in less warm-wetter climate scenarios (Q4). Overall, the central tendency (Q5) unmet demands tended to be slightly greater than their corresponding no climate change scenarios. Because the Slow Growth socioeconomic scenarios assumed more agricultural land remains in production, they had the higher unmet demands, and Expansive Growth scenarios had the least.

Figures 5-67 through 5-75 present similar information for each of the CVP Divisions. Significant unmet demands existed in all CVP

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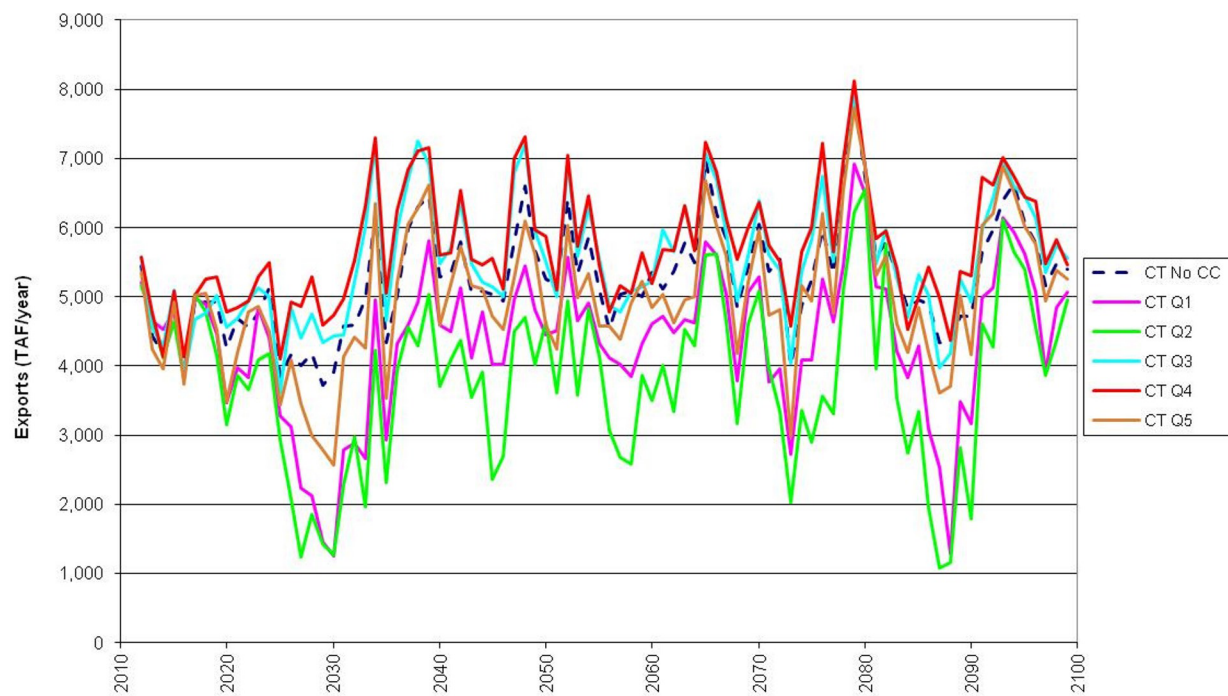


Figure 5-62. Annual Time Series of Total Delta Exports in the Baseline in Each Scenario

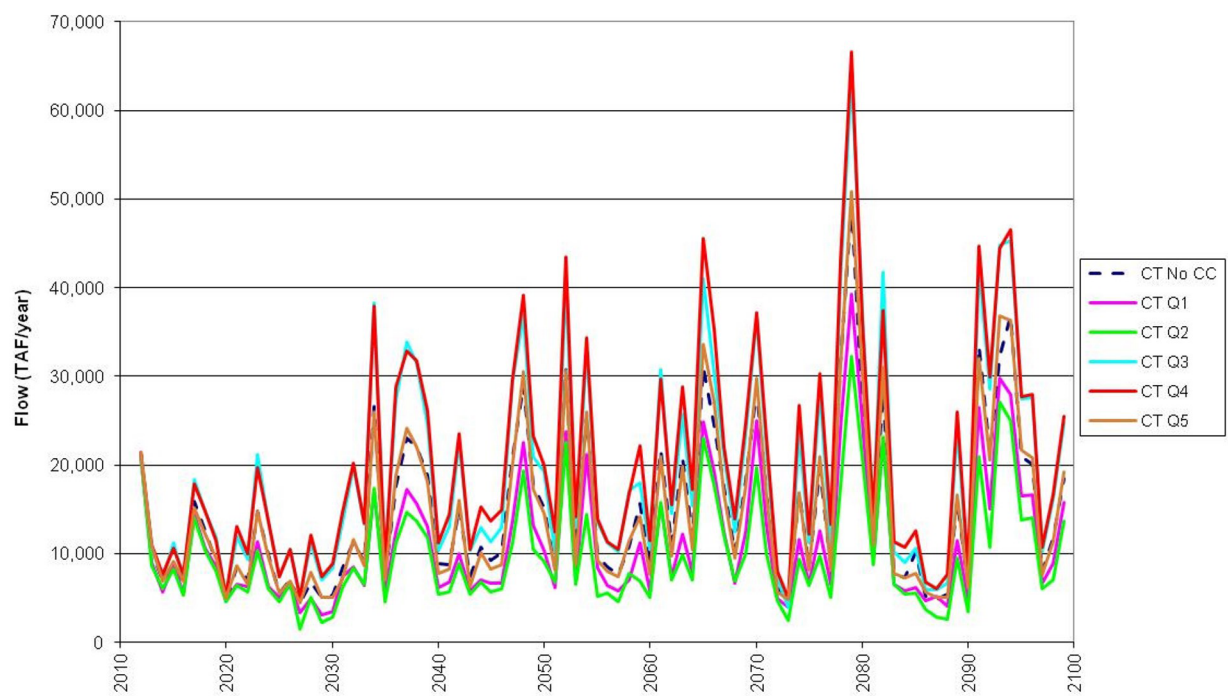


Figure 5-63. Annual Time Series of Delta Outflow in the Baseline in Each Scenario

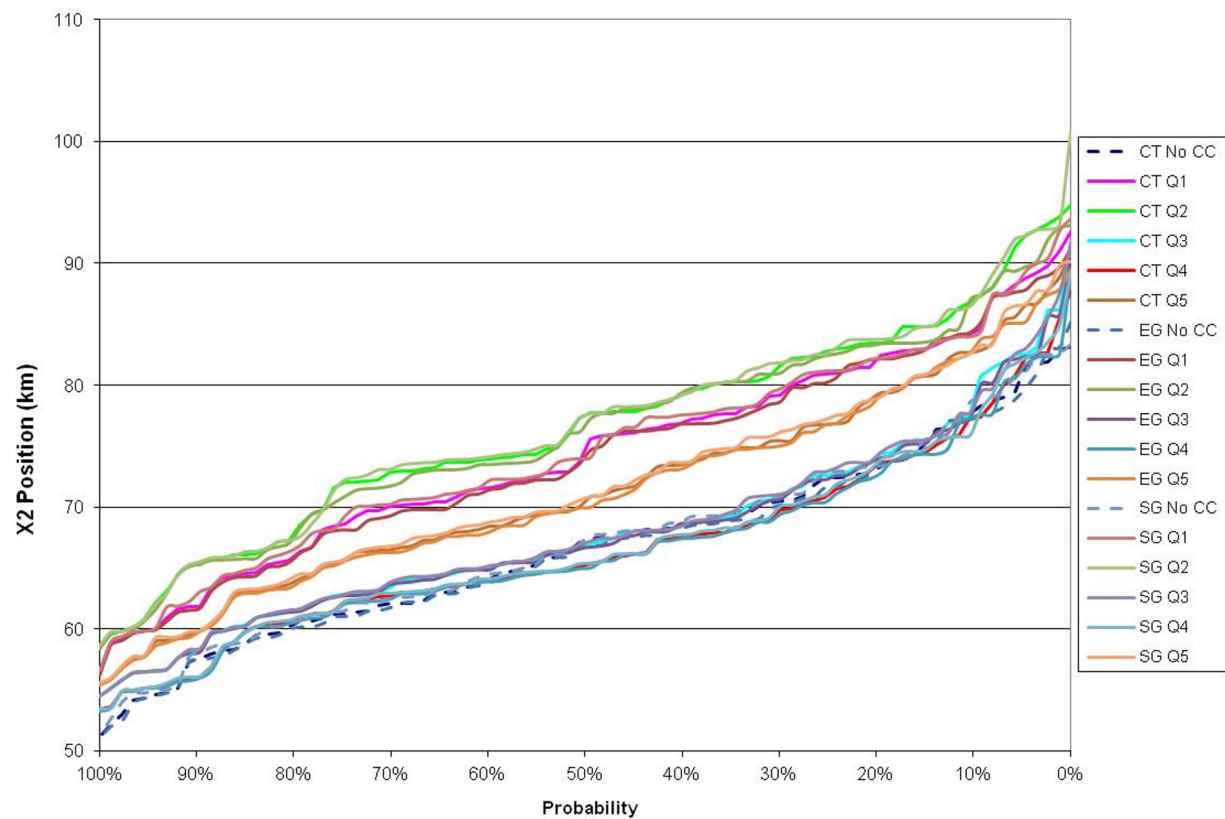


Figure 5-64. Exceedance of Average February-to-June X2 Position in the Baseline in Each Scenario

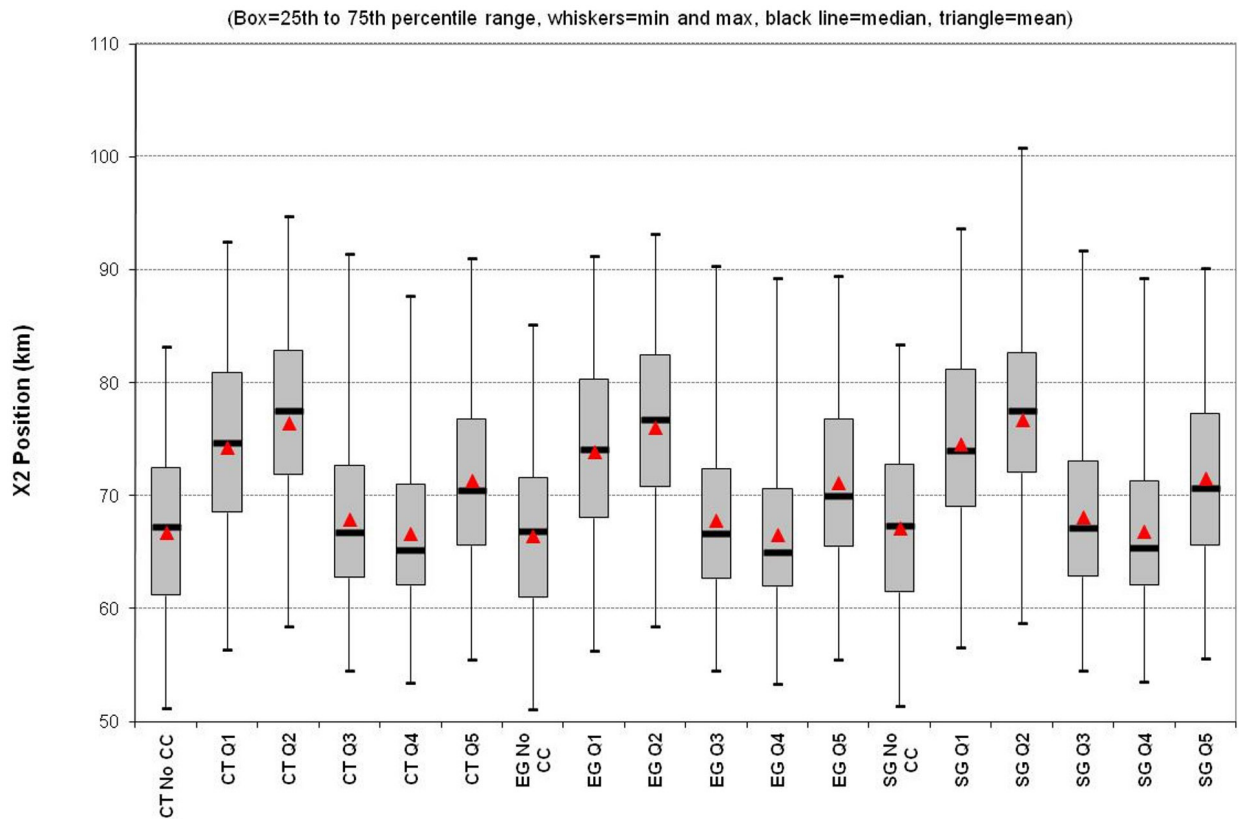


Figure 5-65. Box Plot of Average February-to-June X2 Position in the Baseline in Each Scenario

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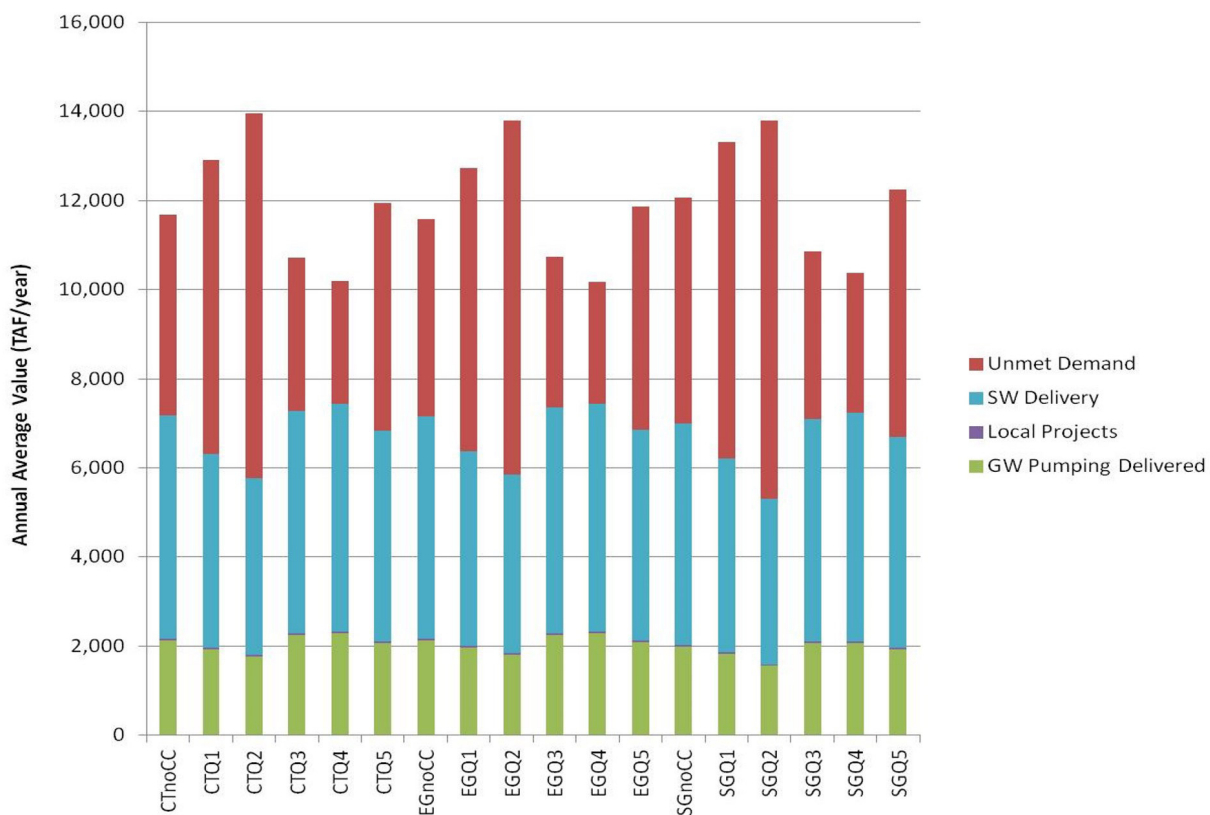


Figure 5-66. Average Annual Supplies and Unmet Demand in the CVP Service Area in the Baseline in Each Scenario

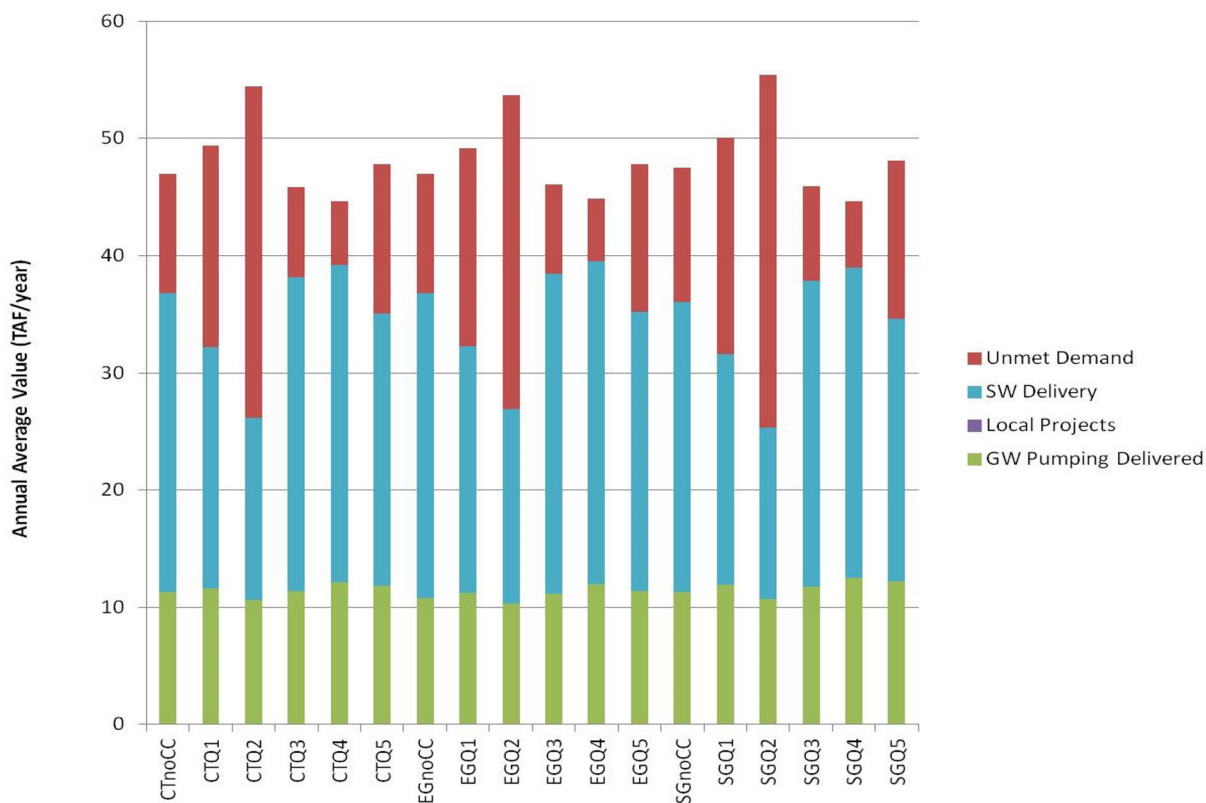


Figure 5-67. Average Annual Supplies and Unmet Demand in the Trinity River Division in the Baseline in Each Scenario

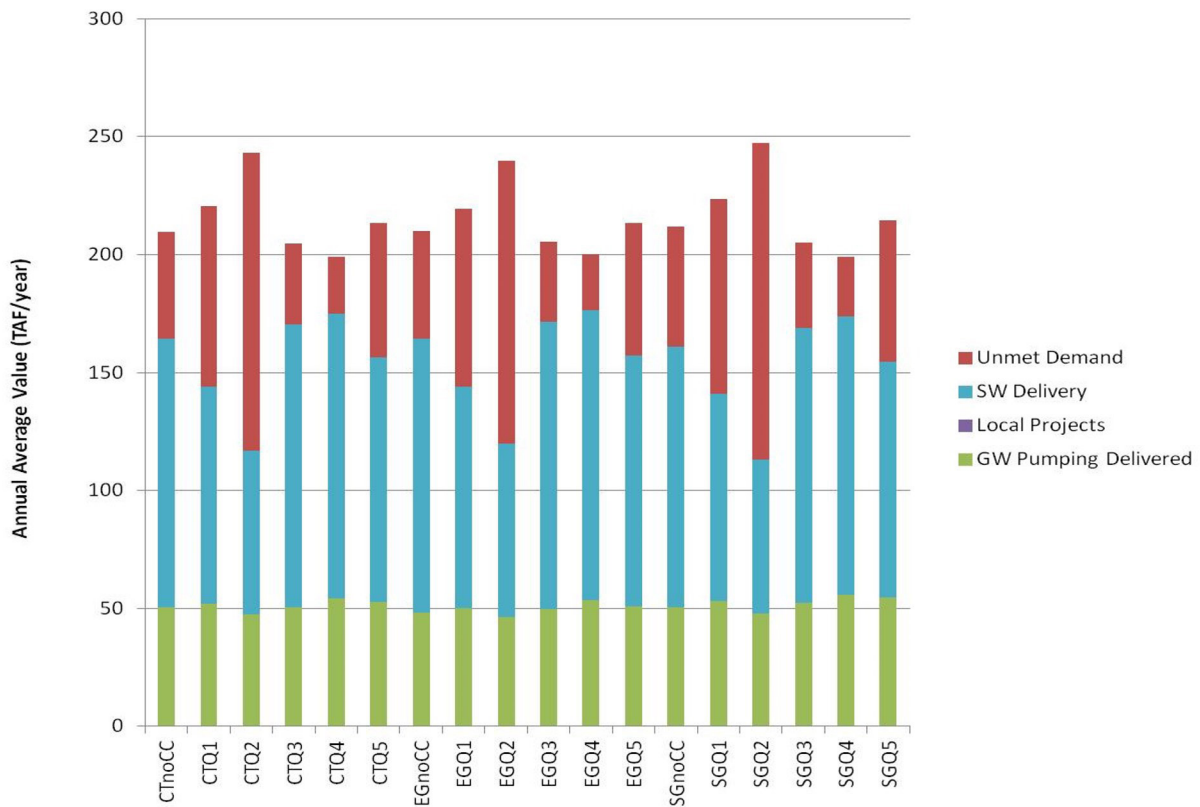


Figure 5-68. Average Annual Supplies and Unmet Demand in the Shasta Division in the Baseline in Each Scenario



Figure 5-69. Average Annual Supplies and Unmet Demand in the Sacramento River Division in the Baseline in Each Scenario

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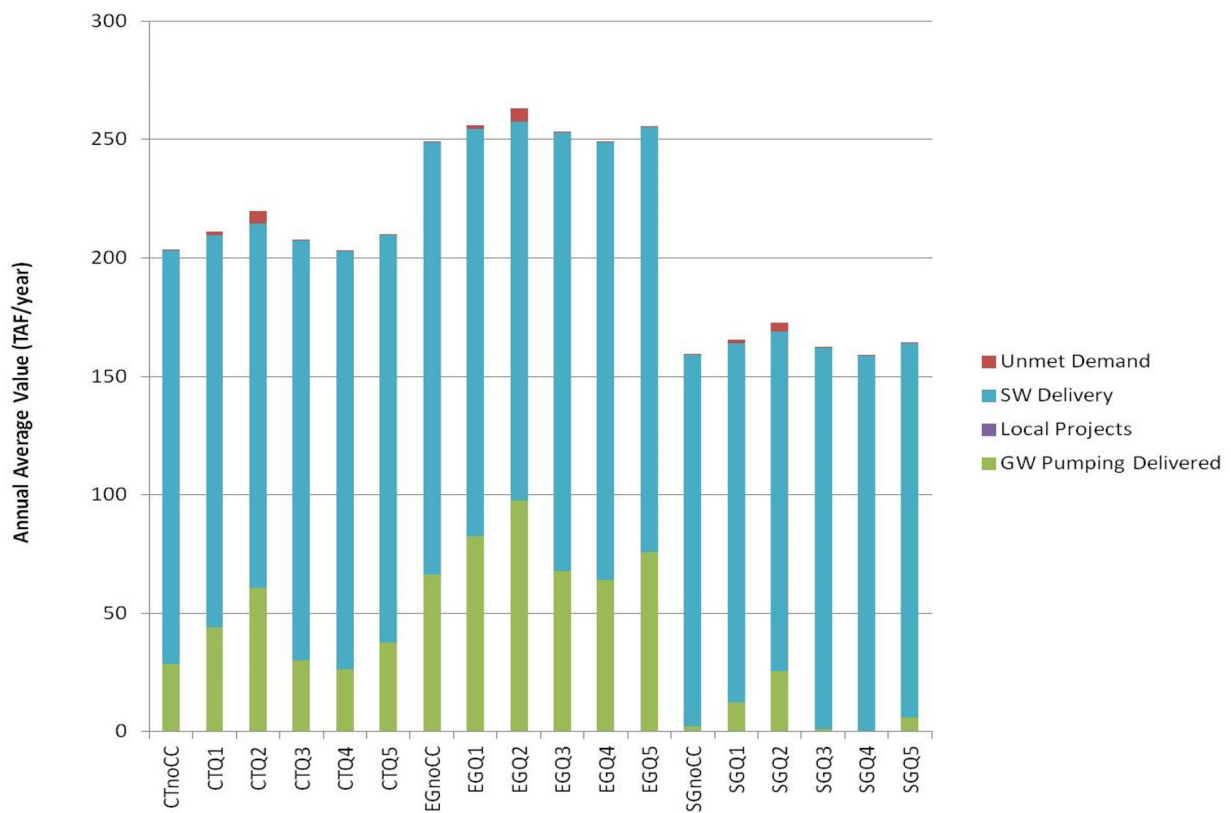


Figure 5-70. Average Annual Supplies and Unmet Demand in the American River Division in the Baseline in Each Scenario

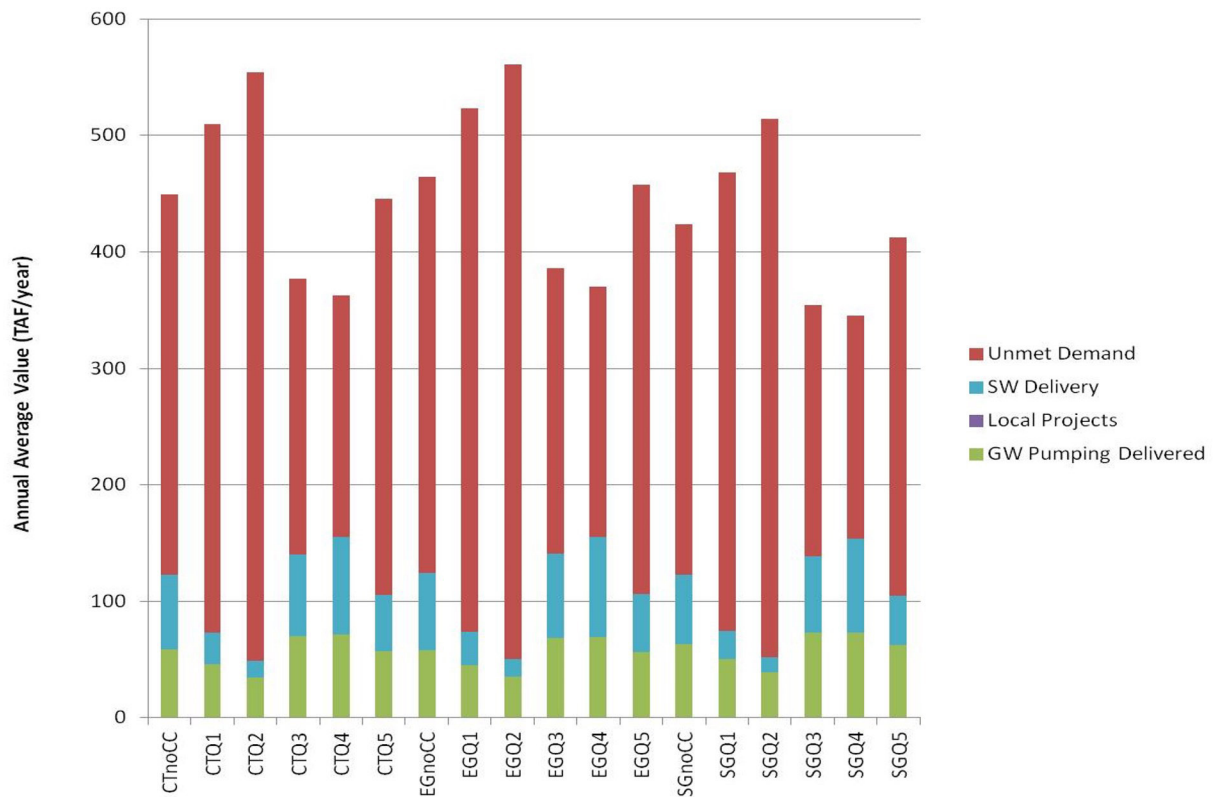


Figure 5-71. Average Annual Supplies and Unmet Demand in the East Side Division in the Baseline in Each Scenario

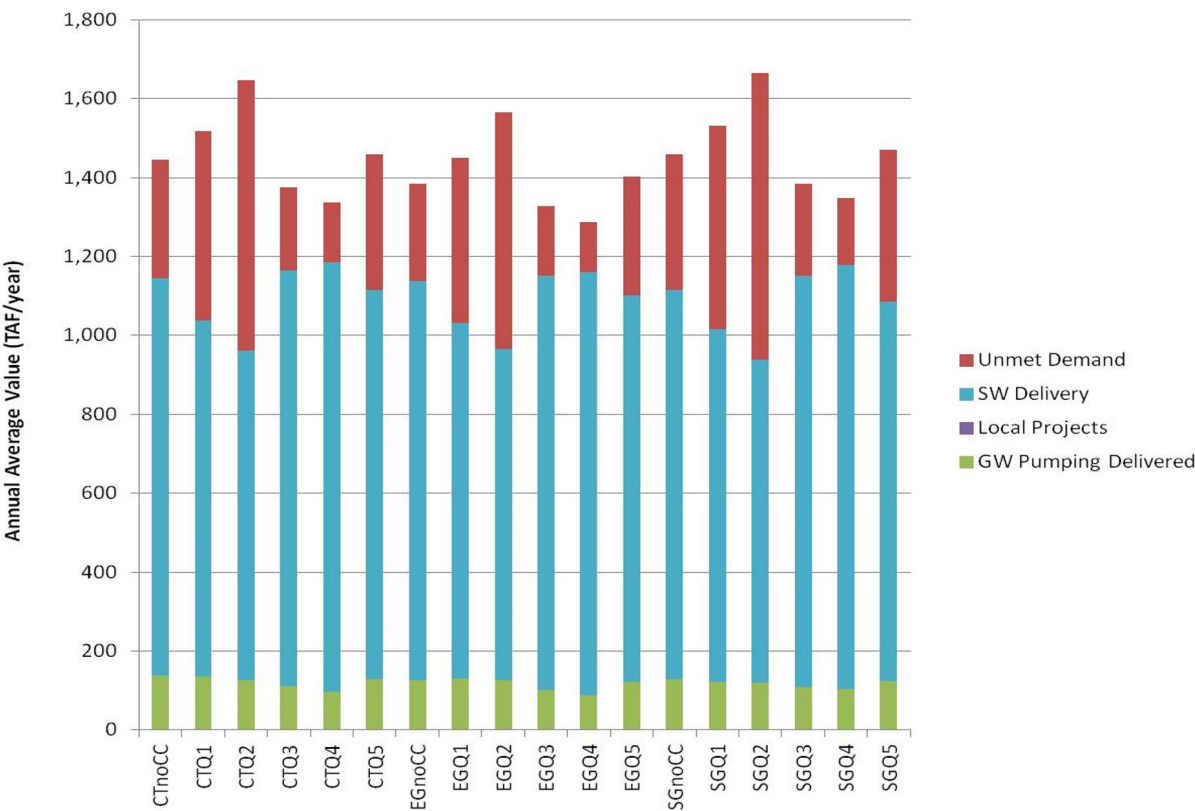


Figure 5-72. Average Annual Supplies and Unmet Demand in the Delta Division in the Baseline in Each Scenario



Figure 5-73. Average Annual Supplies and Unmet Demand in the San Felipe Division in the Baseline in Each Scenario

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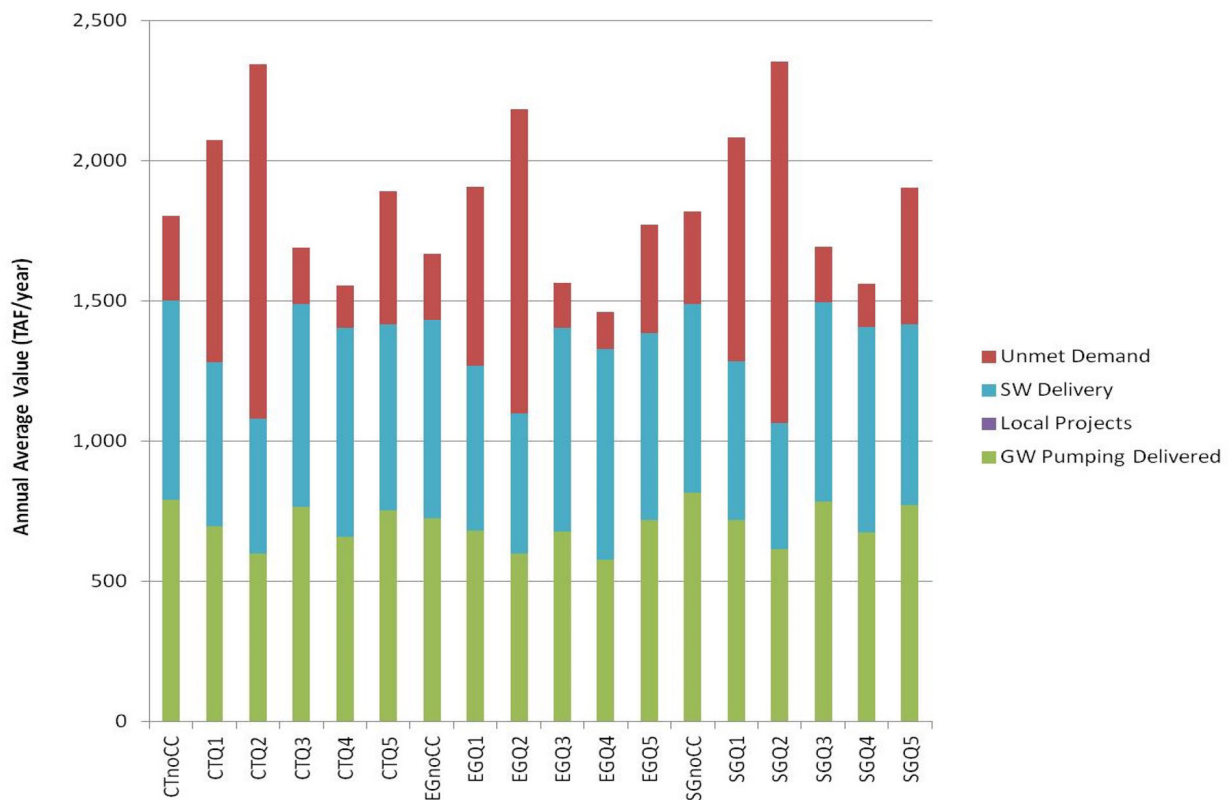


Figure 5-74. Average Annual Supplies and Unmet Demand in the West San Joaquin Division in the Baseline in Each Scenario

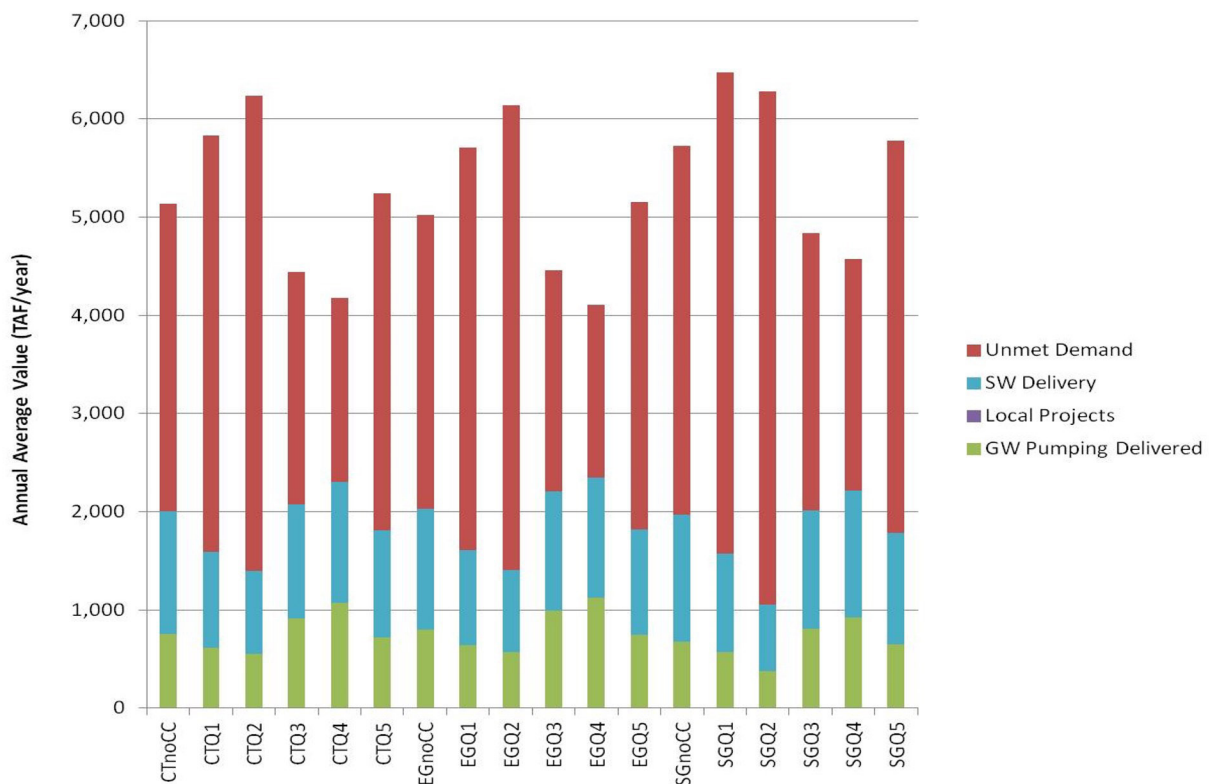


Figure 5-75. Average Annual Supplies and Unmet Demand in the Friant Division in the Baseline in Each Scenario

Divisions with the exception of the American River Division. The largest unmet demands occurred in the Friant Division. In general, the magnitude of unmet demands primarily reflects the amount of agricultural demand in the Service Area. In most of the Divisions, the differences among socioeconomic-climate scenarios exhibited the same relationships as described above for the overall CVP Service Area. In the San Felipe Division there was more differentiation in total demand among the socioeconomic scenarios as compared to the other Divisions because increases in urban demands were not offset by reductions in agricultural demand. In addition, the San Felipe Division demands did not differ among different climate scenarios because they were not simulated in WEAP-CV. Because of this, in the Slow Growth scenario, the San Felipe Division did not fully use all of its potential groundwater supplies because demands were low enough that not all potential groundwater pumping was required to fully meet projected demands in most years.

Figures 5-76 through 5-79 present annual time series of groundwater, surface water, local project supplies, and unmet demand for the entire CVP Service Area. All four scenarios showed similar year-to-year variability, with demands increasing and surface water supplies decreasing during dry periods, and the opposite occurring in wetter years. In the Current Trends no climate change (CT noCC) scenario, unmet demands ranged from a low of about 800 thousand acre-feet per year (TAF/year) to a high of about 10,400 TAF/year over the course of the simulation period. The Current Trends – central tendency (CT Q5) scenario showed only modest increases in demand and reductions in supply relative to the CT-noCC, with unmet demands ranging from 800–11,900 TAF/year. The Expansive Growth – warmer and drier (EG-Q2) scenario had much greater increases in demand and reductions in supply as compared to the CT-noCC scenario, with unmet demands ranging from 900–15,700 TAF/year. Conversely, the Slow Growth – less warming and wetter (SG Q4) scenario had lower demands, higher supplies, and, consequently, lower unmet demands than the CT-noCC scenario, with unmet demands ranging from 800–7,600 TAF/year.

5.5 Other Performance Assessments

The following sections describe the results of the other performance assessment tools for the Baseline condition. The socioeconomic-climate scenarios analyzed under Baseline conditions included the Current Trends – central tendency projection (CT-Q5), to represent a midrange projection of climate effects; the Expansive Growth – warmer-drier projection (EG-Q2) to represent the upper range of effects and the Slow Growth – less warming-wetter projection (SG-Q4) to represent the lower range of climate effects. Because of the sensitivity of the economic and temperature models to climate inputs, additional scenarios without climate change were simulated for the economic and temperature models in order to better understand the effects of climate changes. The results of these simulations are described below.

5.5.1 Economics

The results from four economically based water management models are presented in this section: These models provided the following capabilities:

- LCPSIM provided economic results for the South San Francisco Bay Region.
- OMWEM provided economic results for urban regions in Central Valley.
- SBWQM estimated salinity costs for deliveries to the South San Francisco Bay Region.
- SWAP provided economic results for agricultural regions in the Central Valley.

Because these economics models were designed to analyze differences among scenarios rather than the absolute values for a single scenario, the results were summarized in terms of differences in average annual net benefits among the different socioeconomic-climate scenarios described above. In addition, the results from these economic models were presented at three future levels of development (LOD). Three LODs were selected to represent early (2025), mid (2055), and late (2085) twenty-first century socioeconomic and climate conditions. This approach allowed for

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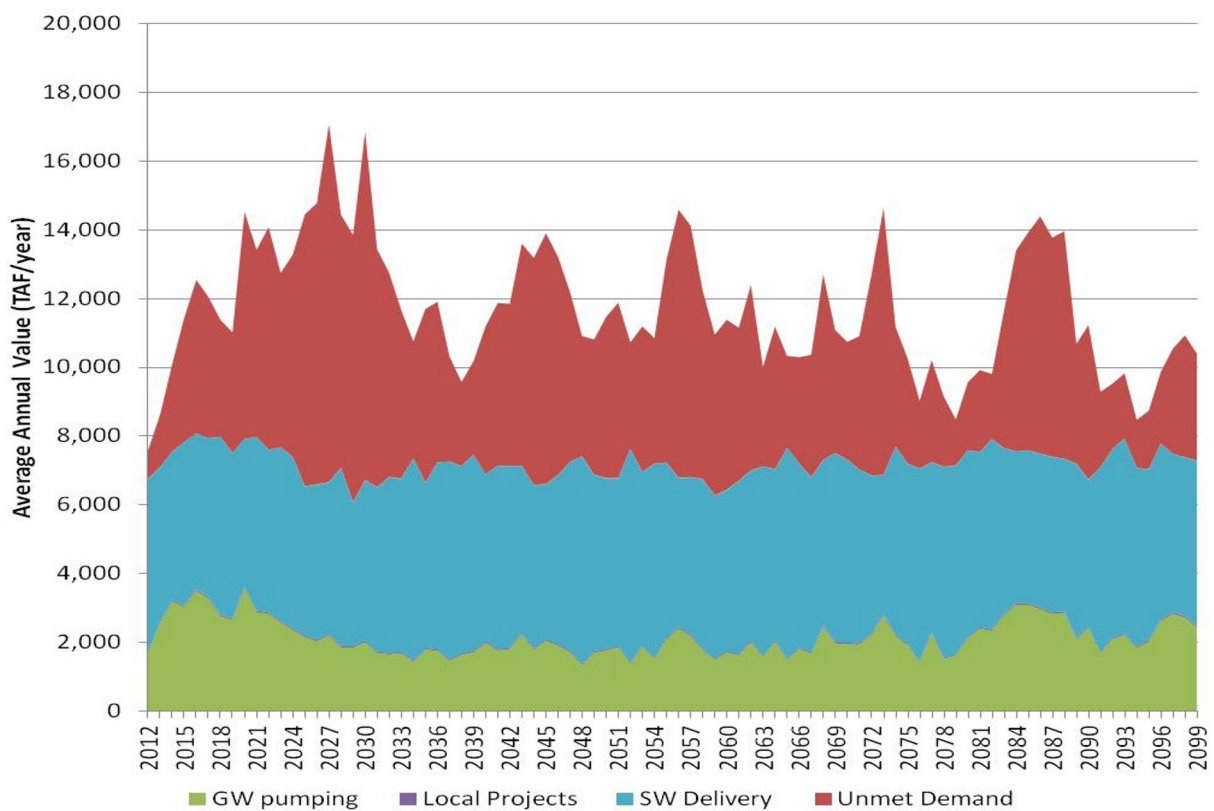


Figure 5-76. Annual Time Series of Supplies and Unmet Demand in the CVP Service Area in the CT noCC Scenario

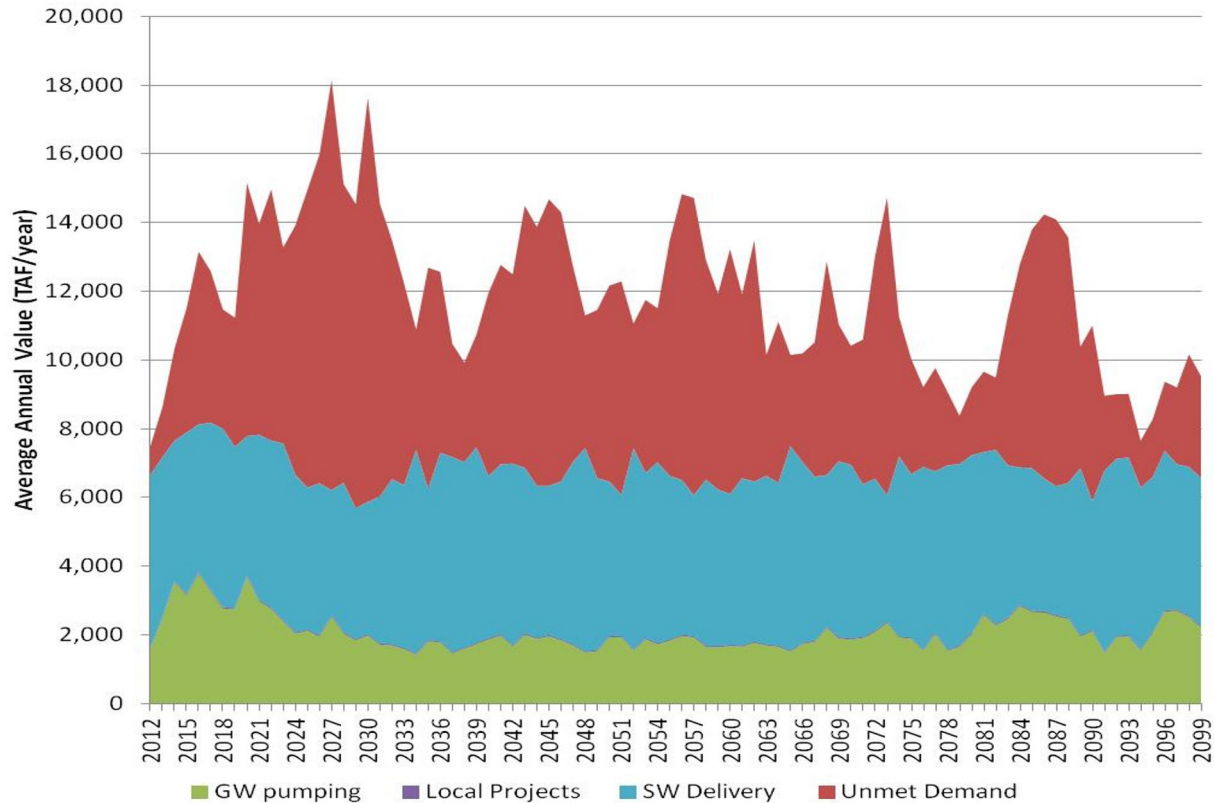


Figure 5-77. Annual Time Series of Supplies and Unmet Demand in the CVP Service Area in the CT-Q5 Scenario

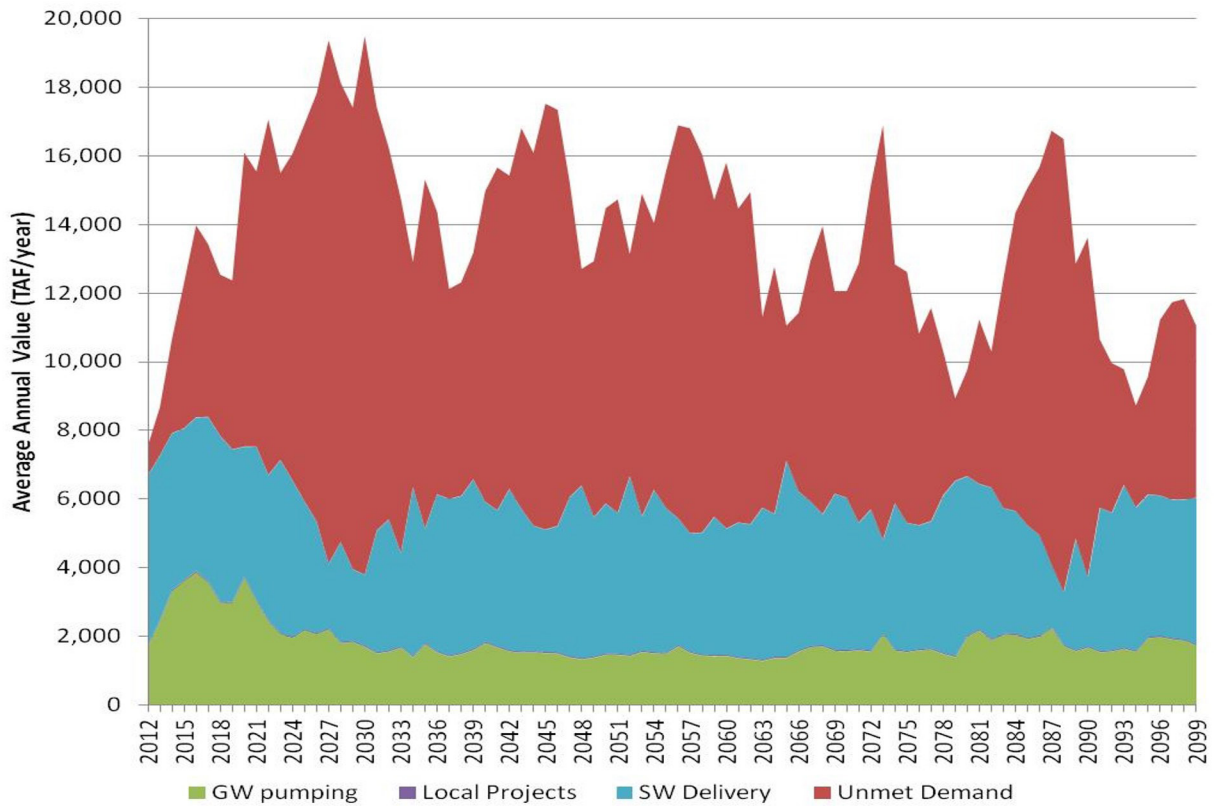


Figure 5-78. Annual Time Series of Supplies and Unmet Demand in the CVP Service Area in the EG-Q2 Scenario

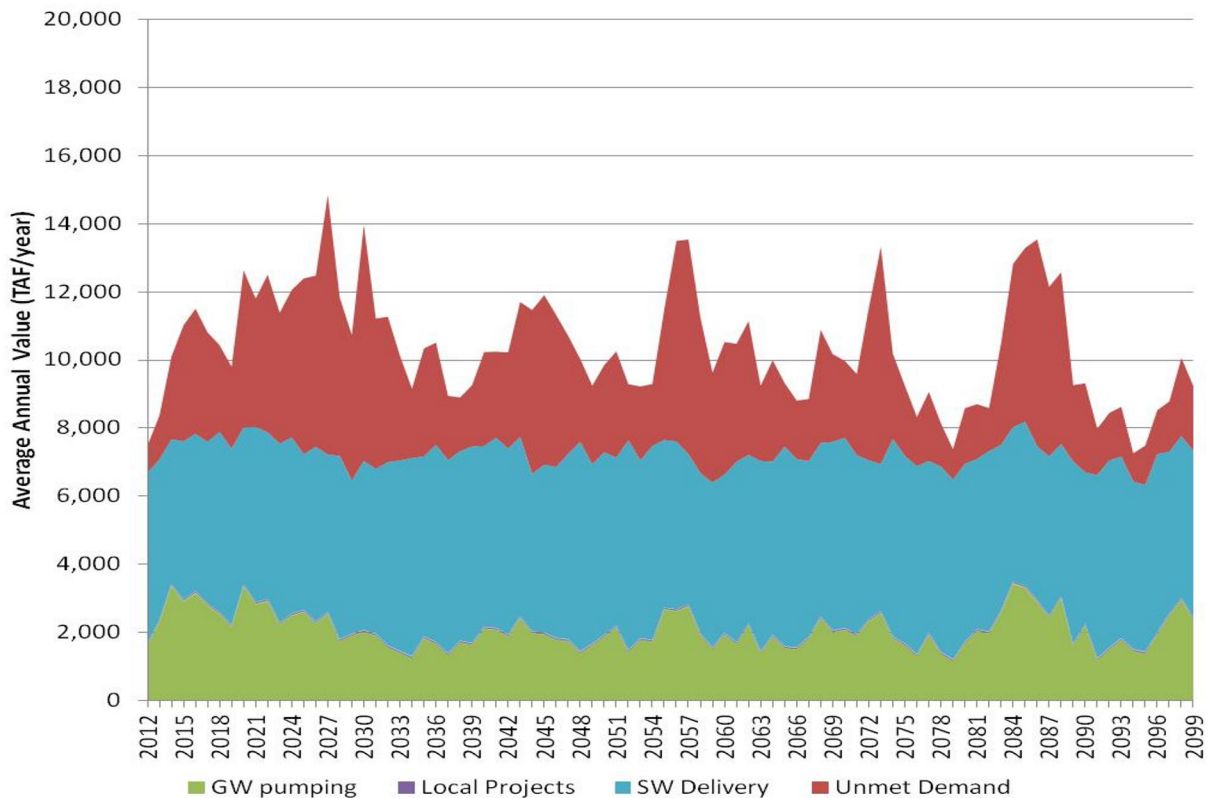


Figure 5-79. Annual Time Series of Supplies and Unmet Demand in the CVP Service Area in the SG-Q4 Scenario

a clearer understanding of how the changes in socioeconomic and climate factors affected the net economic benefits in the CVP Service Area over different timeframes during the twenty-first century.

The following discussion presents the results in two steps because the model inputs differed significantly both among different socioeconomic scenarios and different climate scenarios.

1. Comparisons of the three socioeconomic scenarios without climate change to understand the effect of socioeconomic changes
2. Comparisons of CT-Q5, EG-Q2, and SG-Q4 scenarios with their corresponding no climate change scenarios to understand the effects of climate changes

To evaluate the effects of changes in socioeconomic conditions, simulations of all three growth scenarios without climate change were compared. Figures 5-80 through 5-82 show the changes in net water supply system costs in urban regions based on LCPSIM and OMWEM results, and in net revenue for agricultural regions based on SWAP results for the Expansive Growth and Slow Growth scenarios relative to the Current Trends at the three LODs. (The SBWQM is not capable of producing comparisons among simulations and, therefore, was not included in this comparison.) All three models indicated that there are significantly less net water supply system costs and significantly more net revenue in the Slow Growth scenario than in the Current Trends scenario, and significantly more net water supply system costs and significantly less net revenue in Expansive Growth than in the Current Trends scenario. Furthermore, these differences continued to increase during the twenty-first century. The primary factors accounting for these differences were the changes in population and corresponding changes in land use from agricultural to urban use that occur in each socioeconomic scenario. The Expansive Growth scenario represented the greatest increase in population and in conversion of agricultural to urban land uses, and, consequently, it had more water supply system costs in the urban models and the lowest net agricultural revenue when compared

to the Current Trends scenario. Conversely, Slow Growth had the lowest increase in population and the smallest conversion of agricultural land to urban, which resulted in lower urban water supply system costs and greater net agricultural revenue relative to Current Trends.

Figures 5-83 through 5-86 show the net improvement in net economic benefits for scenarios CT-Q5 relative to CT-noCC, EG-Q2 relative to EG-noCC, and SG-Q4 relative to SG-noCC, at the three future LODs based on results from LCPSIM, OMWEM, SWAP, and SBWQM. The urban economic models (LCPSIM and OMWEM) showed decreases in net economic benefits in CT-Q5 and EG-Q2 due to decreased Delta exports and increased salinity at the Delta pumping plants. OMWEM showed increases in net benefits in SG-Q4 due to increased surface water deliveries in the Central Valley, but LCPSIM had almost no change in benefits because Delta exports in the SG-Q4 scenario were almost the same as in the SG-noCC scenario.

The SWAP model results had similar changes in deliveries as OMWEM but indicated increases in net benefits in all three scenarios because improvements in agricultural production due to climate changes such as increasing CO₂ offset the negative effects of reduced SWP and CVP deliveries projected in CT-Q5 and EG Q2 scenarios.

Changes in SBWQM salinity management costs are a function of the amount of water being diverted and the salinity of the water at the diversion locations for CCWD and on the SBA. The changes in diversions at these locations were consistent with the changes in exports discussed above. The changes in salinity at each division location in CT Q5 relative to CT-noCC, EG-Q2 relative to EG noCC, and SG-Q4 relative to SG-noCC are shown on Figure 5-87. South Bay salinity management costs were greater in SG-Q4 and in CT-Q5 because of increases in salinity in those scenarios as compared to the corresponding scenarios without climate change. However, there was a net benefit in avoided salinity costs in SG-Q4 relative to SG-noCC because of improved salinity conditions at the export locations.

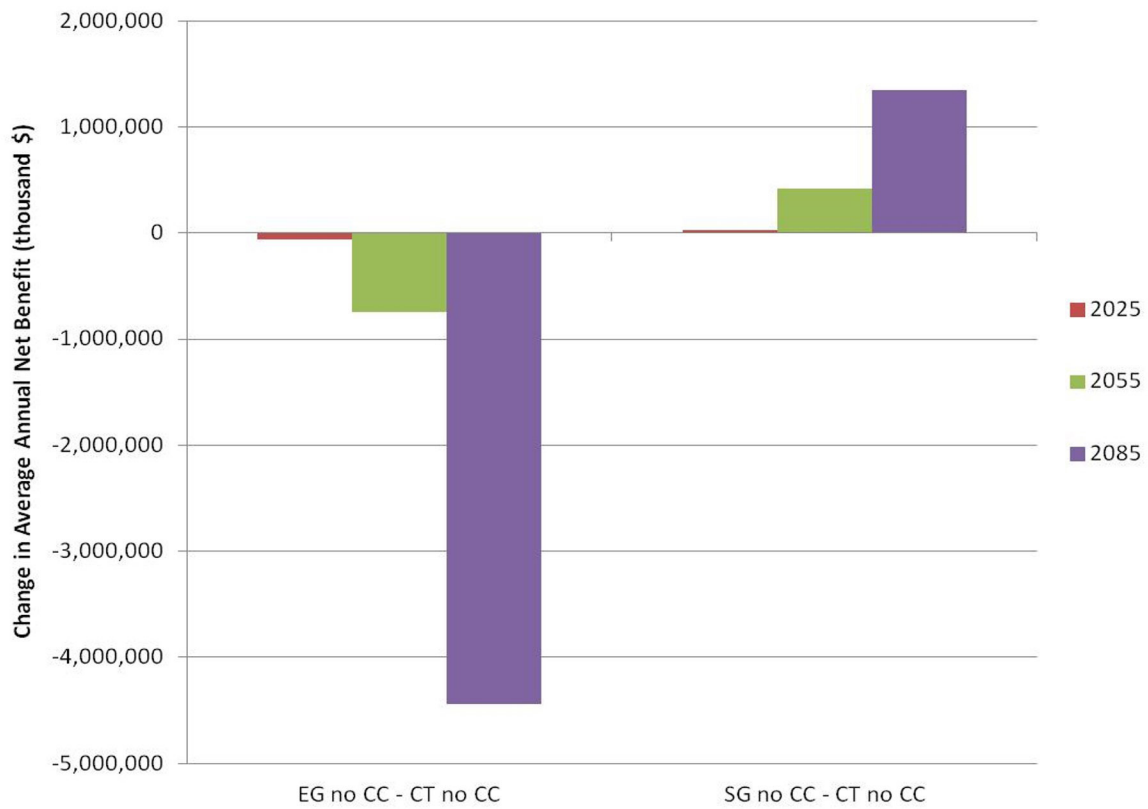


Figure 5-80. Change in Average Annual Net Benefit in South San Francisco Bay Region from LCPSIM in the Baseline



Figure 5-81. Change in Average Annual Net Benefit in Central Valley Urban Areas from OMWEM in the Baseline

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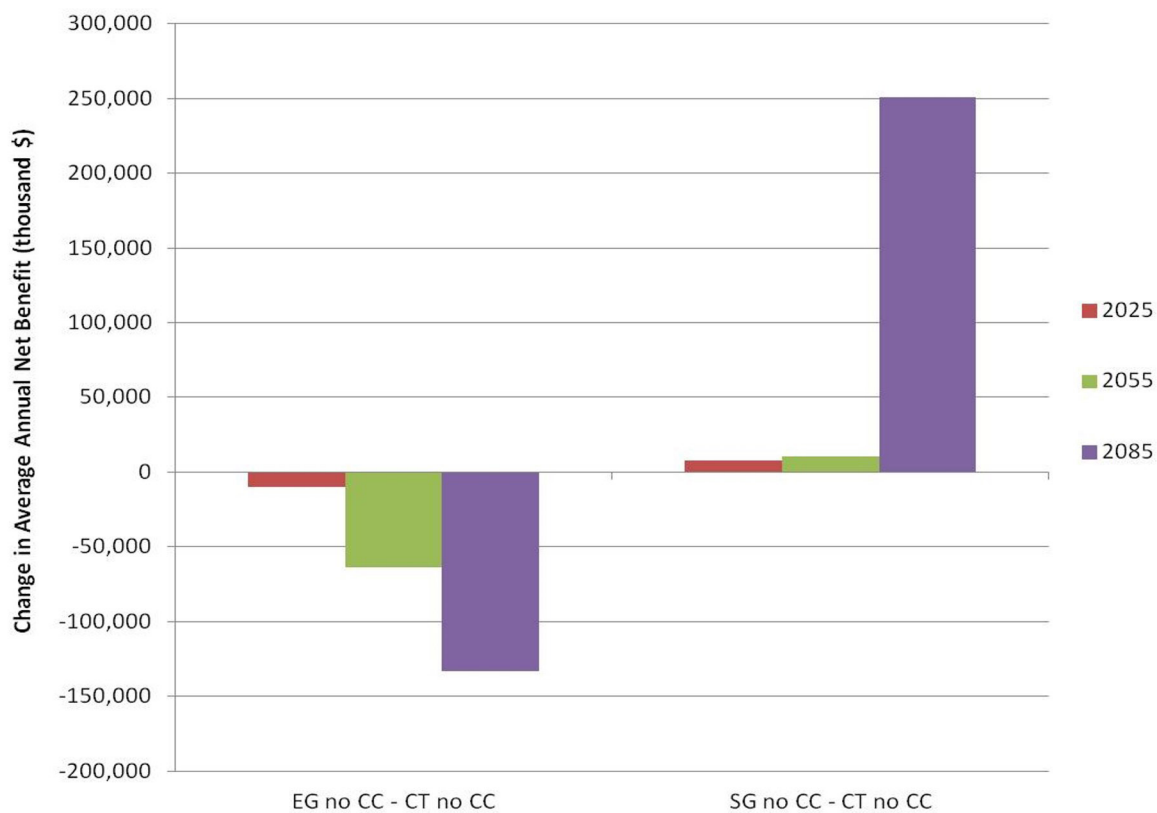


Figure 5-82. Change in Average Annual Net Benefit in Central Valley Agricultural Areas from SWAP in the Baseline

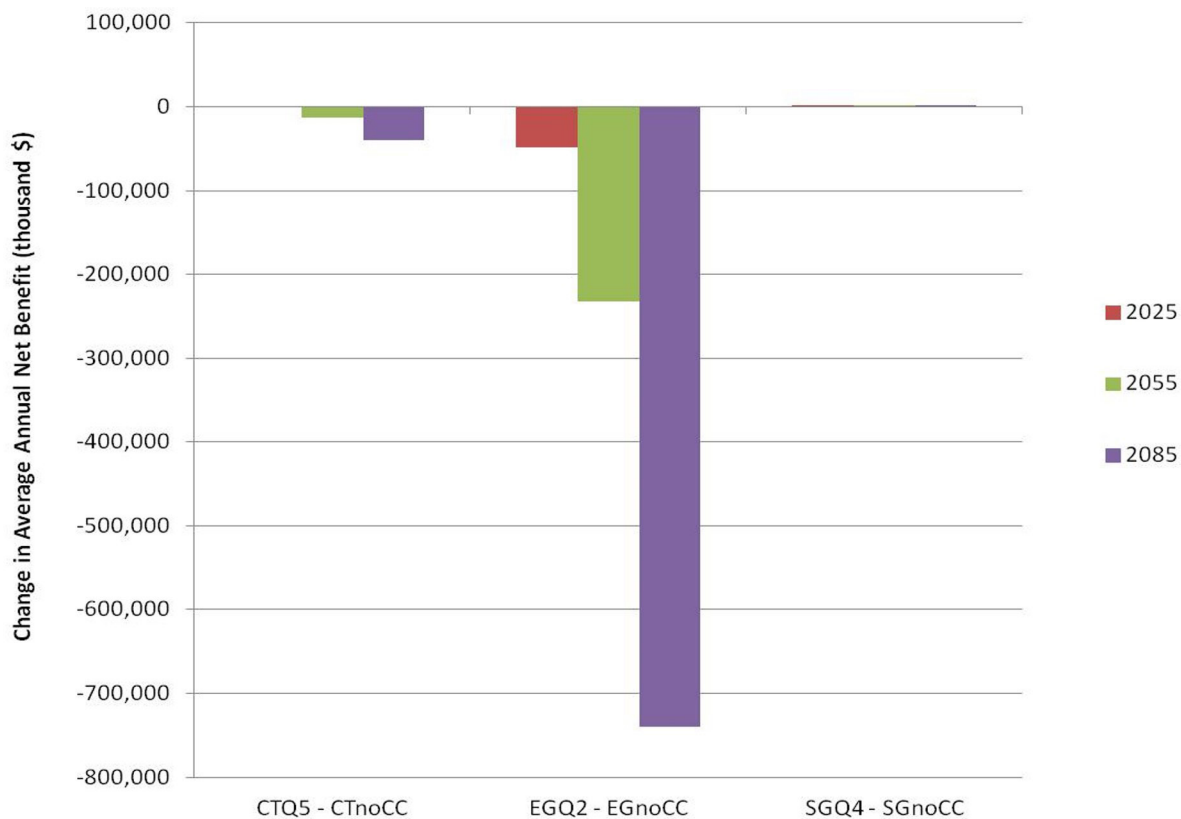


Figure 5-83. Change in Average Annual Net Benefit in South San Francisco Bay Region from LCPSIM in the Baseline

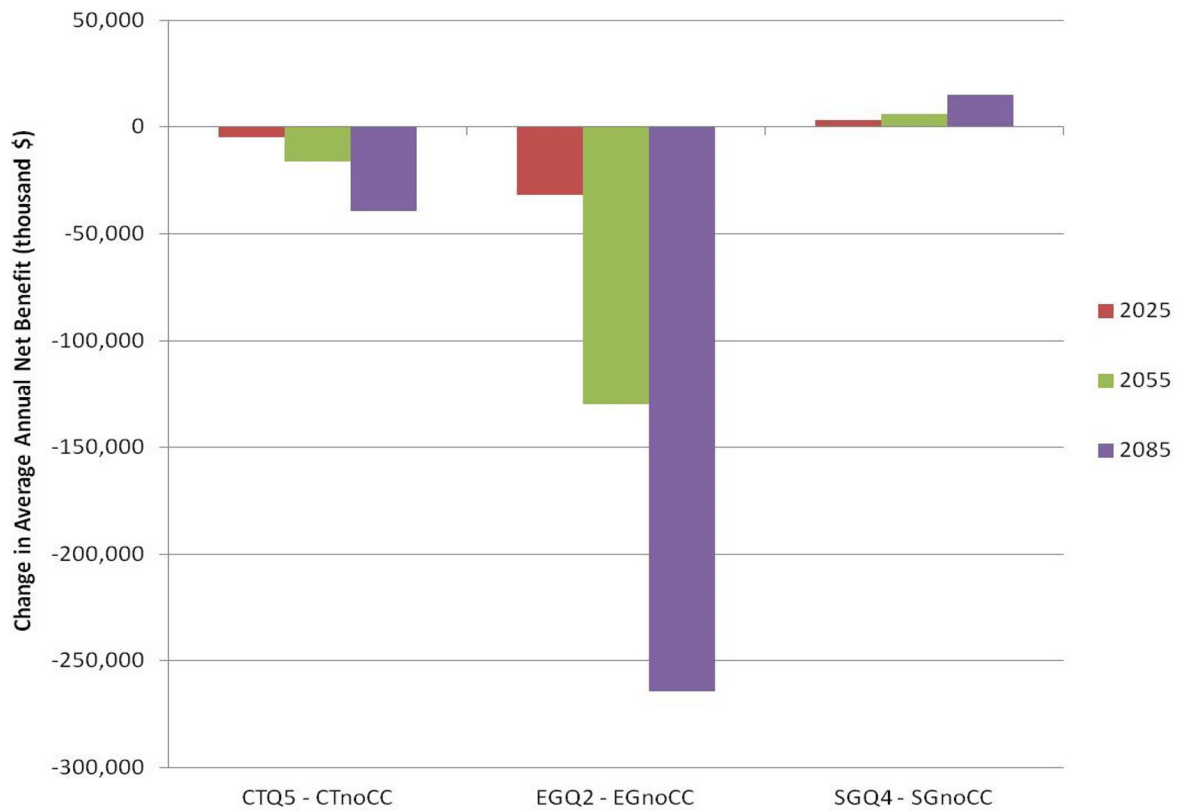


Figure 5-84. Change in Average Annual Net Benefit in Central Valley Urban Areas from OMWEM in the Baseline

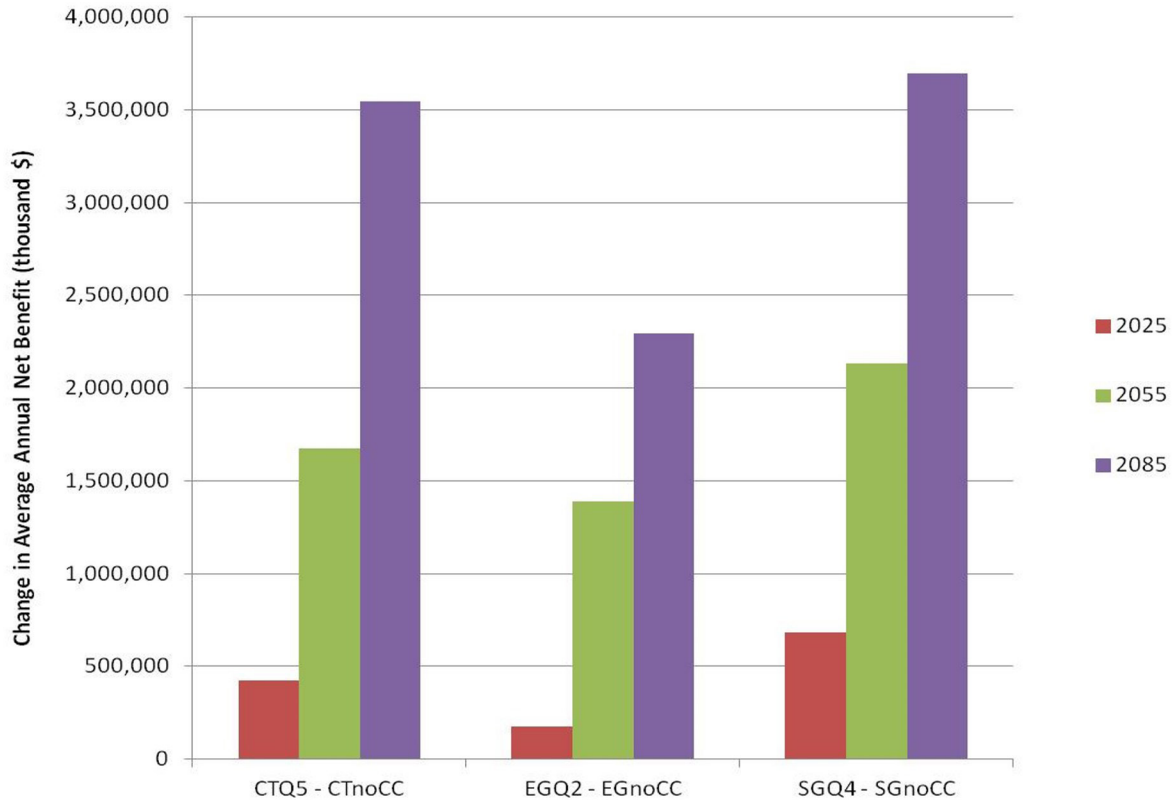


Figure 5-85. Change in Average Annual Net Benefit in Central Valley Agricultural Areas from SWAP in the Baseline

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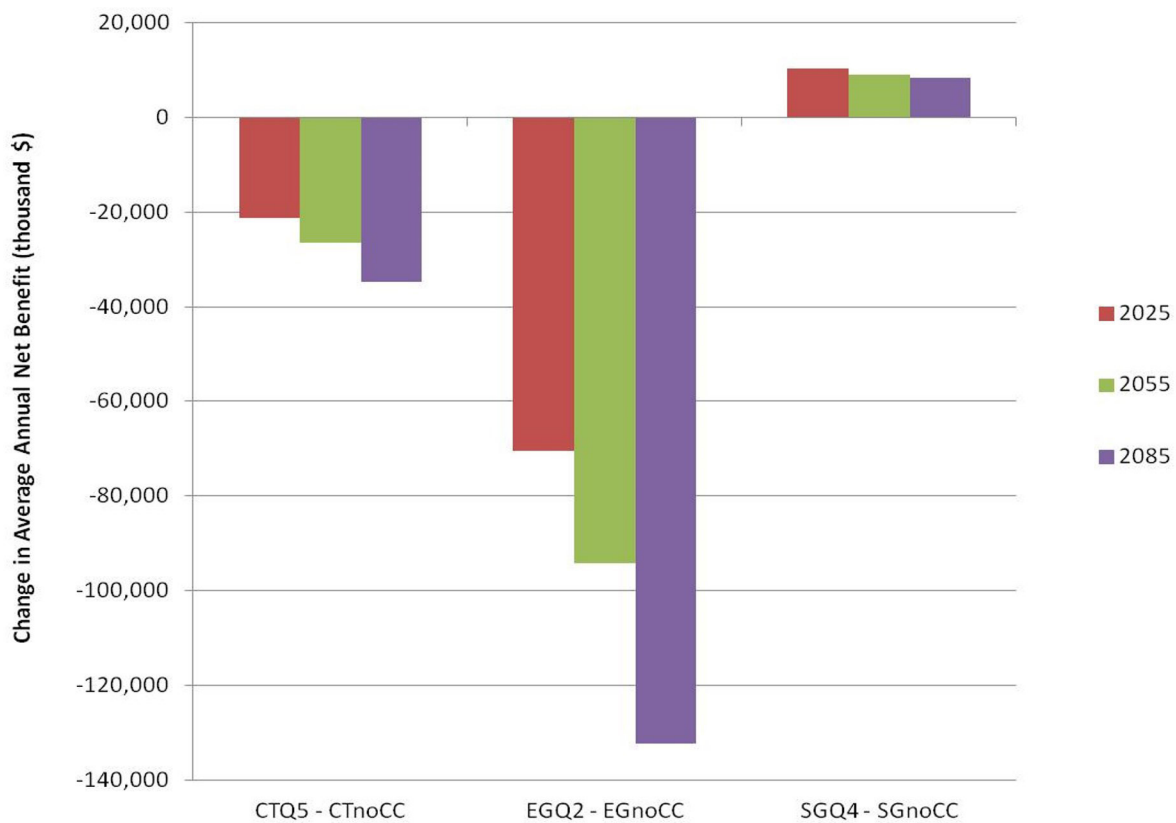


Figure 5-86. Change in Average Annual Net Benefit in South San Francisco Bay Region Salinity Costs from SBWQM in the Baseline

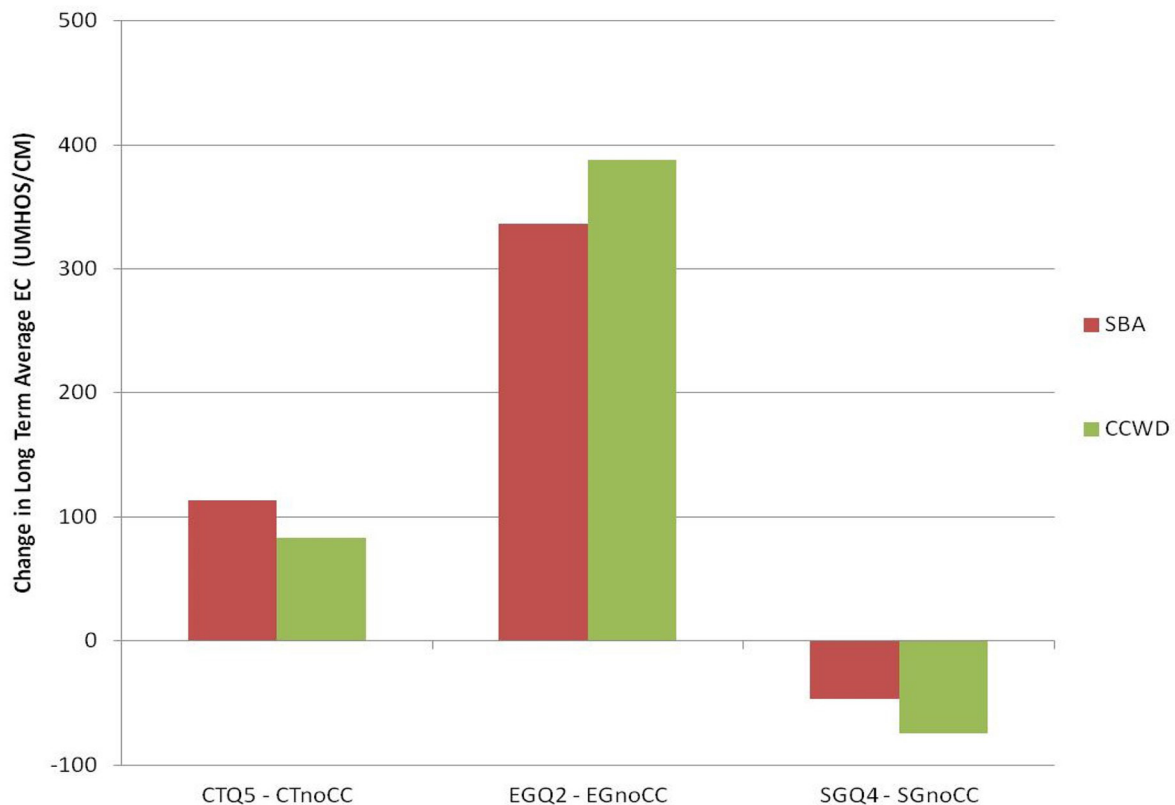


Figure 5-87. Change in Long-Term Average EC at CCWD and SBA Diversion Locations in the Baseline

5.5.2 Water Temperature

To understand the effects of climate change on river water temperatures, the Sacramento and San Joaquin water temperature models were simulated for the CT-noCC scenario as well as the CT-Q5, EG-Q2, and SG-Q4 scenarios.

Figures 5-88 through 5-91 show exceedance plots and box plots of daily water temperatures from July through September for these four scenarios in the Sacramento River at Keswick and at Jelly's Ferry. At both locations the water temperatures in SG-Q4 were slightly lower than those in CT-noCC, reflecting the effects of increased Shasta coldwater pool, and greater flows in the river. Conversely, the water temperatures in CT-Q5 were slightly higher and the water temperatures in EG-Q2 were significantly higher than those in CT-noCC at both locations, reflecting the changes in the storage and flow at both locations. The mean July–September water temperatures in EG-Q2 were 53.3 degrees Fahrenheit (°F) at Keswick and 56.7°F at Jelly's Ferry, as compared to 50.7°F at Keswick and 53.7°F at Jelly's Ferry in SG-Q4. These differences reflect a range of about 3 degrees on average between the two most extreme climate conditions and also a difference of about 3 degrees between the two locations indicative of the majority of the spawning and rearing habitat in the upper Sacramento River.

Figures 5-92 through 5-97 show exceedance plots and box plots of daily water temperatures for the same four scenarios in the San Joaquin River at Lost Lake, Gravelly Ford, and Vernalis from August through November. The mean daily water temperatures at Lost Lake (just downstream of Millerton Lake) during these months ranged from 53.5 to 54.9°F across the four scenarios. With respect to CT noCC scenario, scenarios CT-Q5 and EG-Q2 showed reduced water temperatures at this location, and SG-Q4 showed a small increase. The lowest water temperatures were in the EG-Q2 scenario, with the largest water temperatures occurring in the SG Q4 scenario. The warming under SG-Q4 occurred because Millerton Lake has limited capacity to hold high flows, so when there were higher inflows to Millerton (as occurred frequently in climate scenario Q4), the thermocline in the lake was disturbed as the high flows flushed out any cold water sitting in the lake. This

caused warm flows to be passed down the river, resulting in warmer water temperatures at Lost Lake. Conversely, when there were lower inflows into Millerton (as occurred frequently in climate scenario Q2), the thermocline in the lake was retained; and the water released from Millerton was colder, resulting in cooler water temperatures at Lost Lake, as observed in the EG-Q2 scenario.

Farther downstream on the San Joaquin River at Gravelly Ford, the mean daily water temperatures increased significantly under all climate scenarios due to the effects of diversions in this reach of the San Joaquin River and increasing distance downstream. In contrast to the Lost Lake results, warming was greatest in Q2 and smallest in Q4 at Gravelly Ford. At Gravelly Ford, the mean daily water temperature for these scenarios ranged from a low of 72.2°F in SG-Q4 to a high of 73.4°F in EG-Q2, with CT-noCC being at 71.9°F.

At Vernalis, the water temperature results showed warming under all climate scenarios, reflecting the effects of all operations in the San Joaquin River system including the tributaries. The mean daily average water temperature at Vernalis in the CT-noCC scenario was 66.7°F. For the three climate scenarios, the mean daily water temperatures at Vernalis ranged from 67 to 68°F, with lowest in the SG Q4 scenario and highest in the EG-Q2 scenario.

5.5.3 Hydropower and Greenhouse Gas Emissions

Figures 5-98 and 5-99 show the average annual energy generation and use for the CVP and SWP systems under the CT-noCC, CT-Q5, EG-Q2, and SG-Q4 scenarios. Figure 5-100 shows the average annual net energy generation for the CVP and SWP systems under these same four scenarios. In all four socio-economic-climate scenarios, the CVP system had more hydropower generation than energy use, and the SWP system had more energy use than hydropower generation. The relative levels of net generation among the four scenarios were consistent with the CVP storage and the Banks pumping results for each scenario. SG-Q4 had the highest storage levels in CVP reservoirs and the greatest amount of Banks pumping and, therefore, had the most CVP net generation and SWP net energy use. Conversely, EG-Q2 had the

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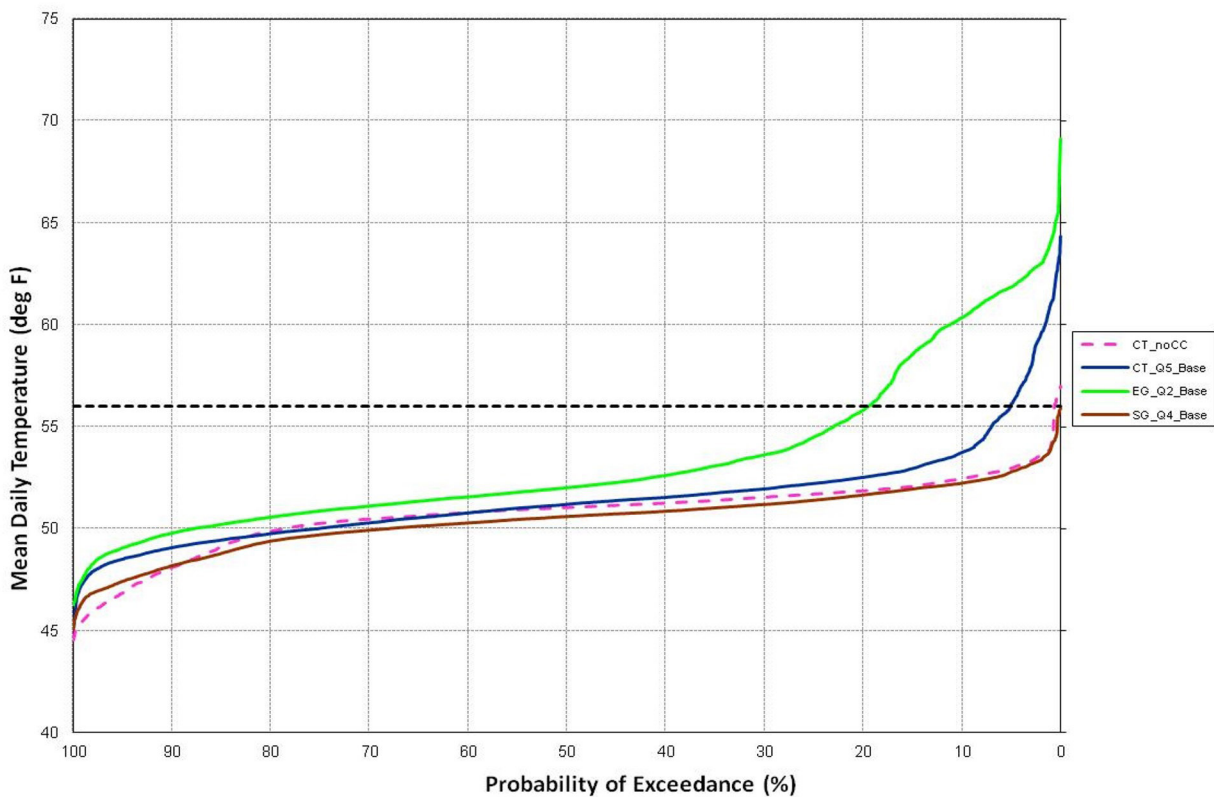


Figure 5-88. Exceedance of Average Temperature on Sacramento River at Keswick from July to September in the Baseline

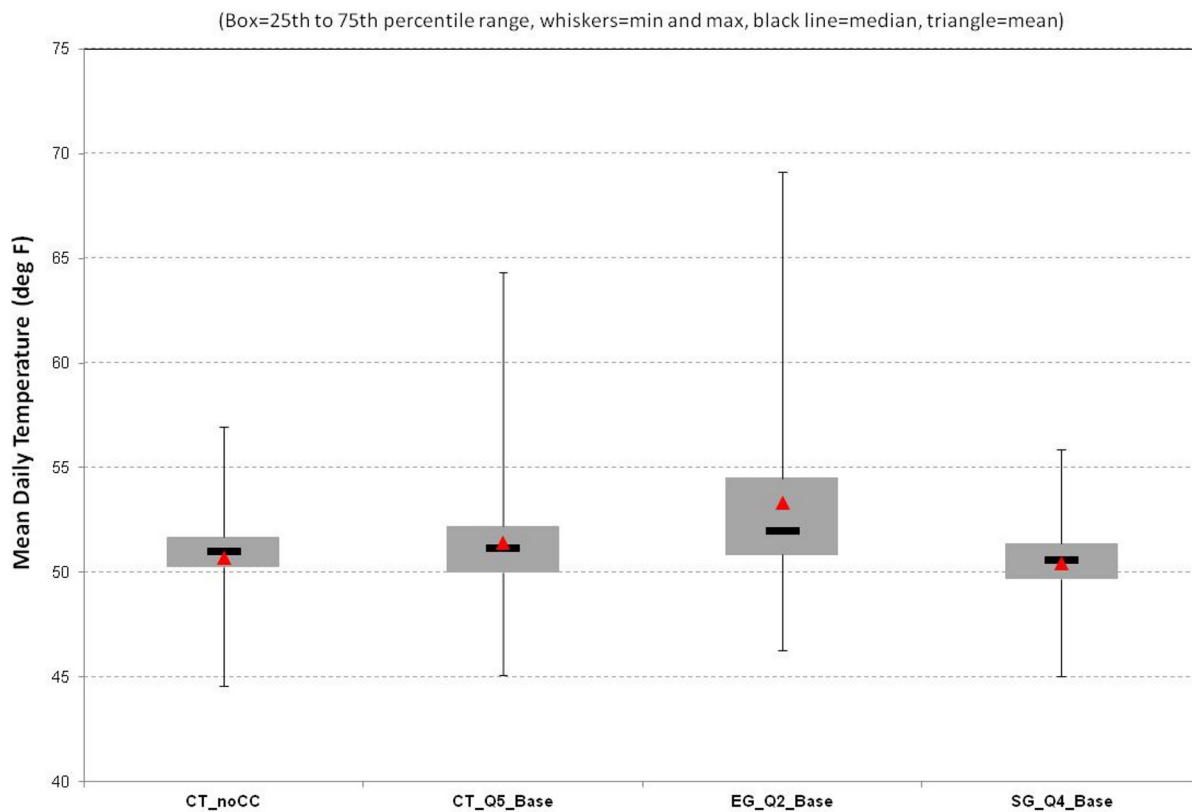


Figure 5-89. Box Plot of Average Temperature on Sacramento River at Keswick from July to September in the Baseline

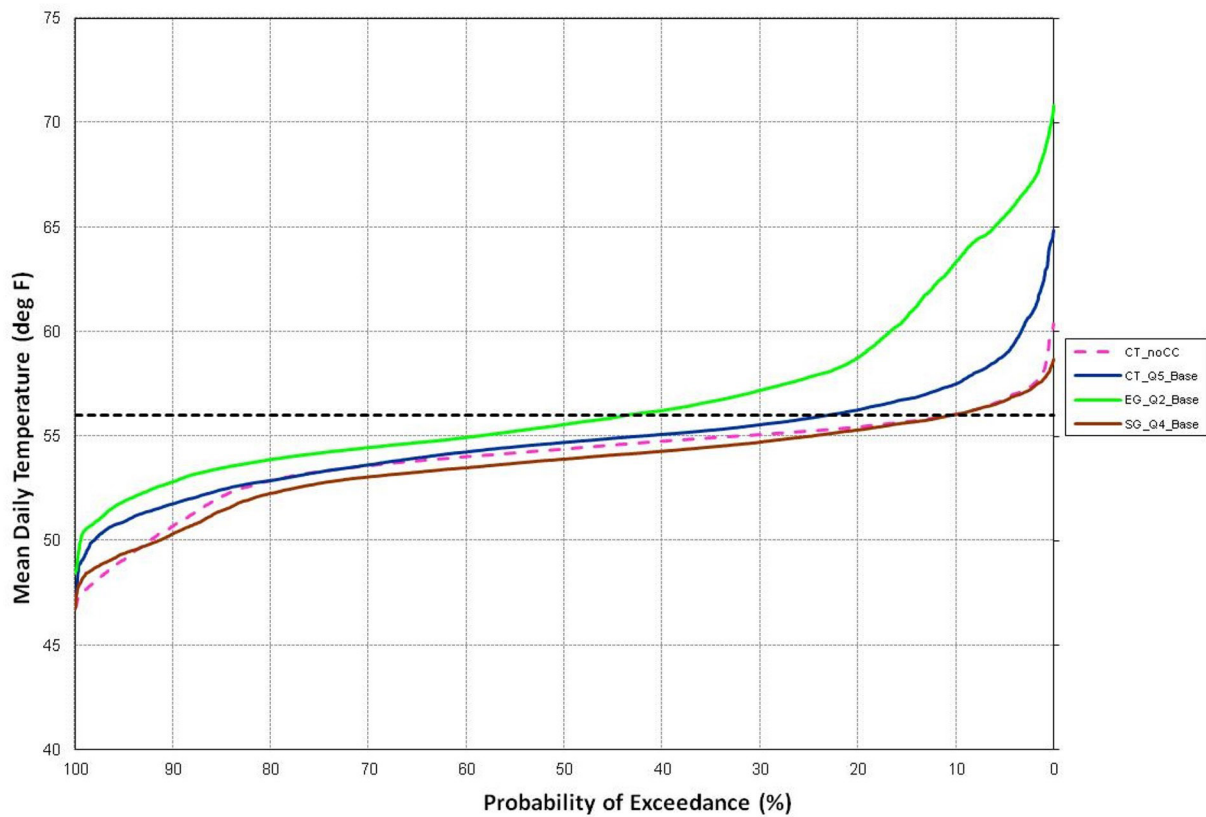


Figure 5-90. Exceedance of Average Temperature on Sacramento River at Jelly's Ferry from July to September in the Baseline

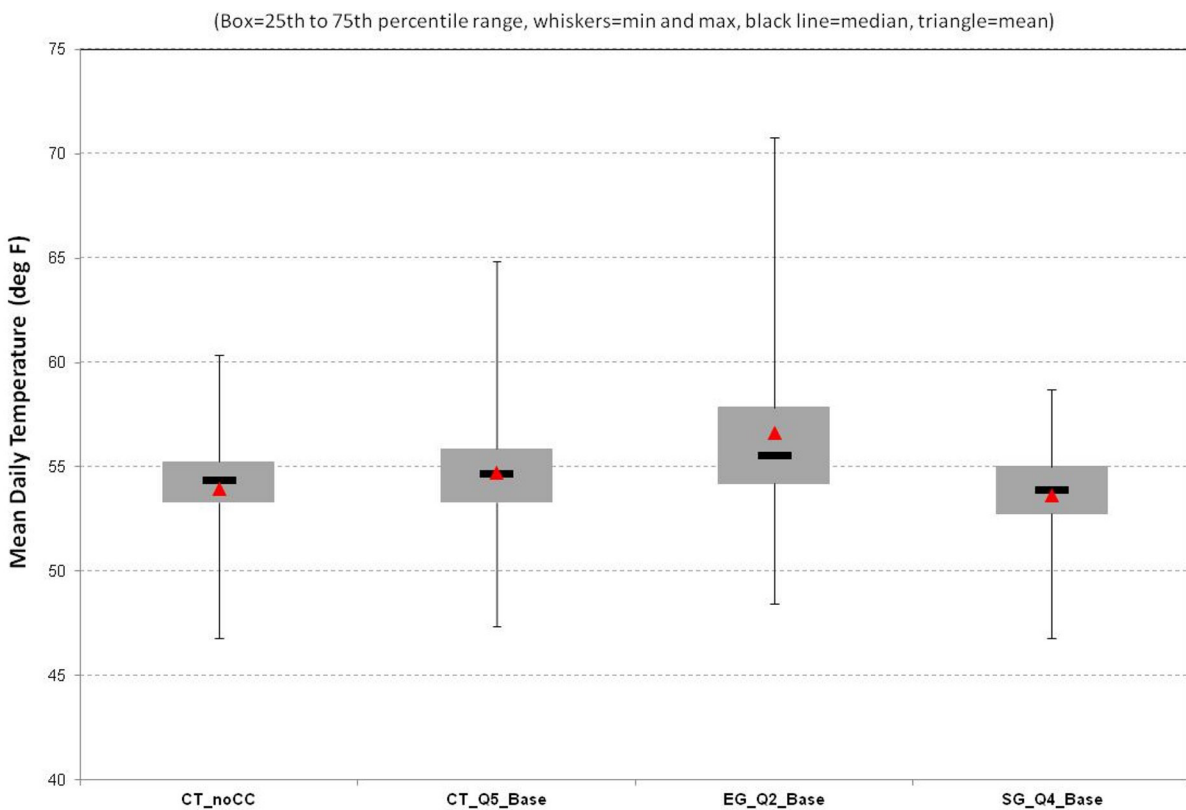


Figure 5-91. Box Plot of Average Temperature on Sacramento River at Jelly's Ferry from July to September in the Baseline

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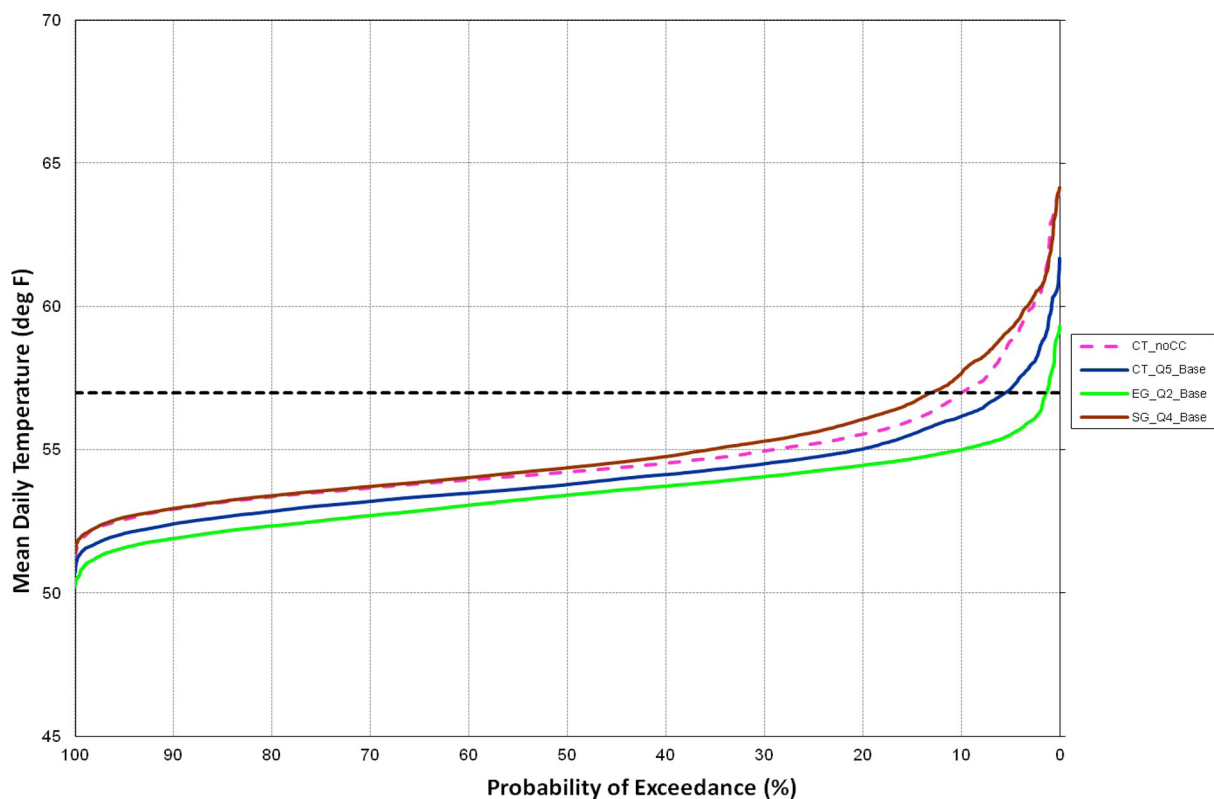


Figure 5-92. Exceedance of Average Temperature on San Joaquin River at Lost Lake from August to November in the Baseline

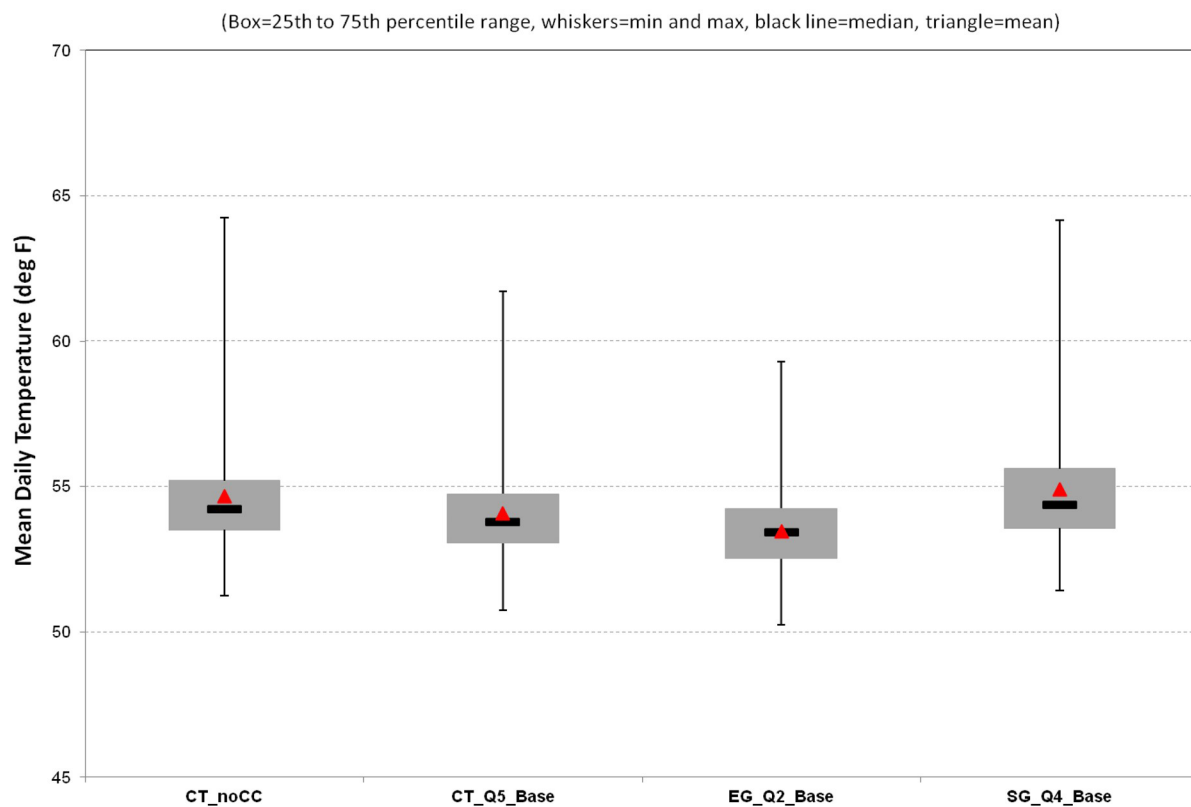


Figure 5-93. Box Plot of Average Temperature on San Joaquin River at Lost Lake from August to November in the Baseline

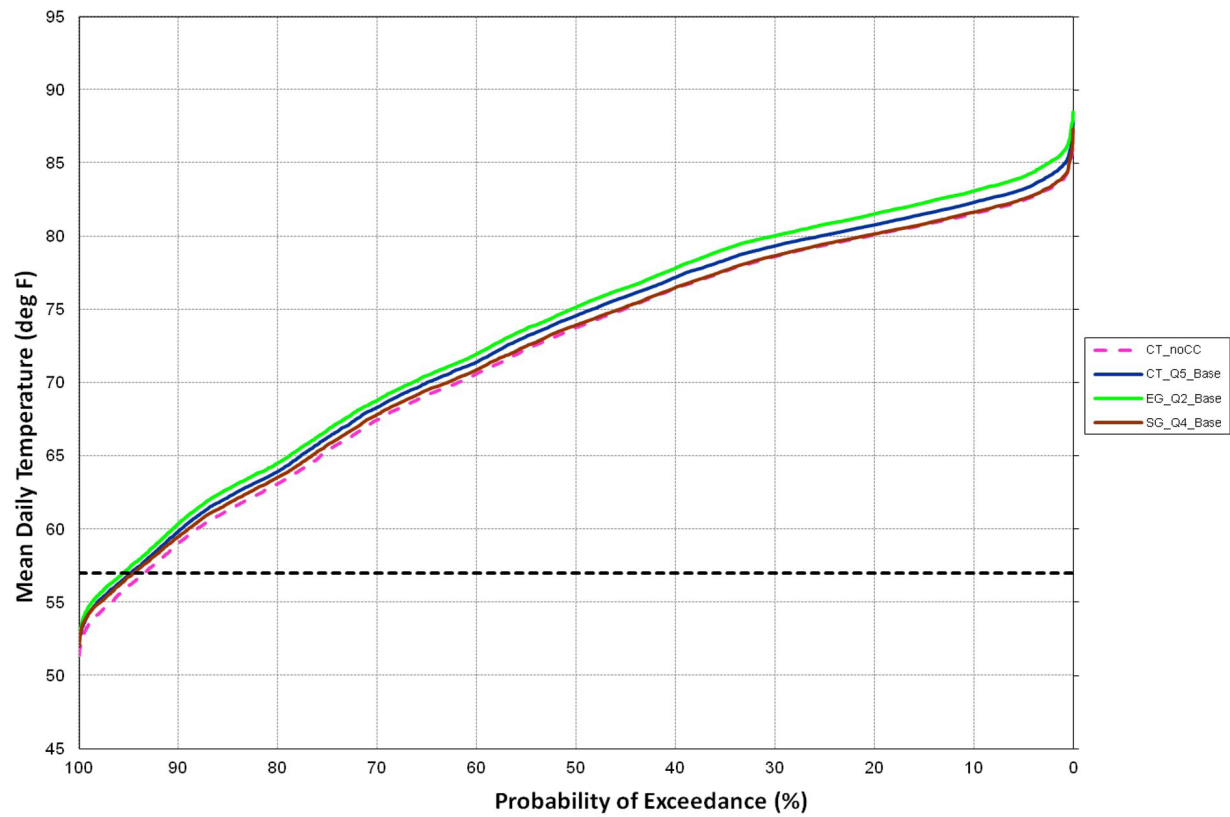


Figure 5-94. Exceedance of Average Temperature on San Joaquin River at Gravelly Ford from August to November in the Baseline

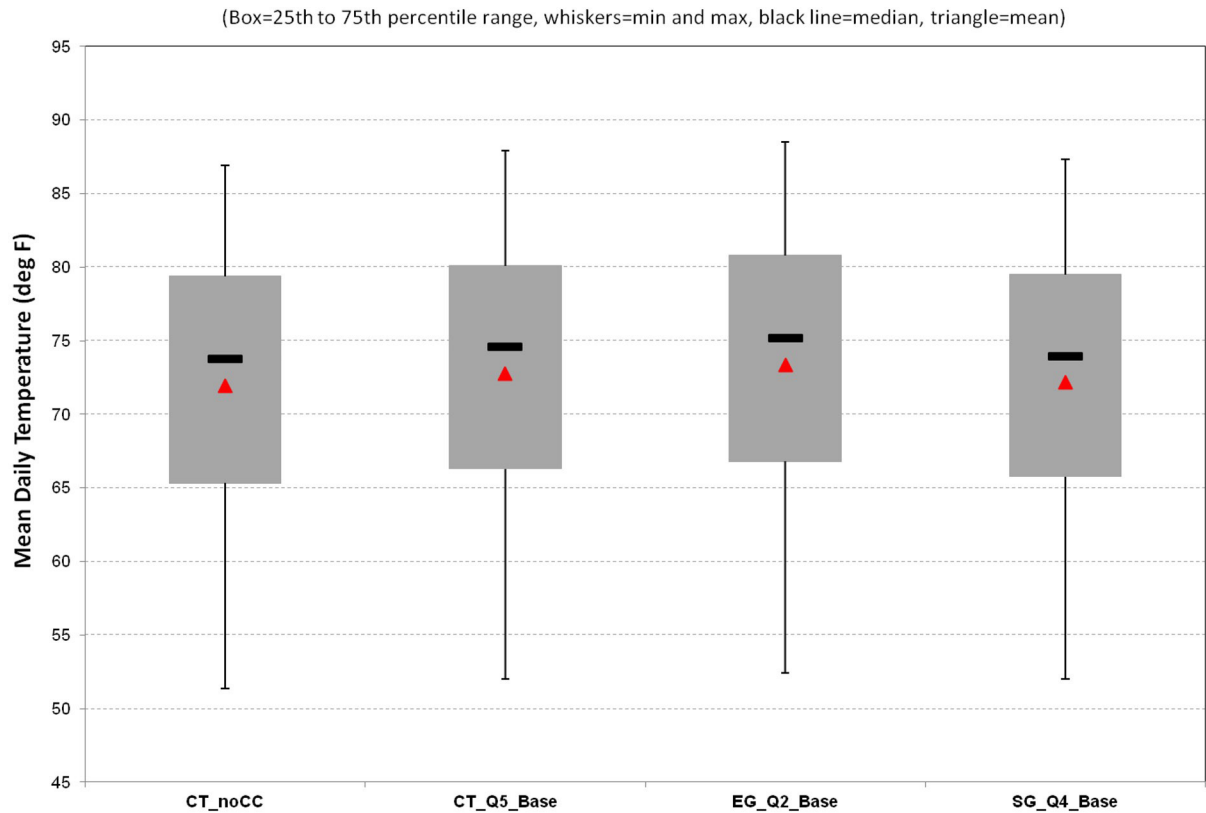


Figure 5-95. Exceedance of Average Temperature on San Joaquin River at Gravelly Ford from August to November in the Baseline

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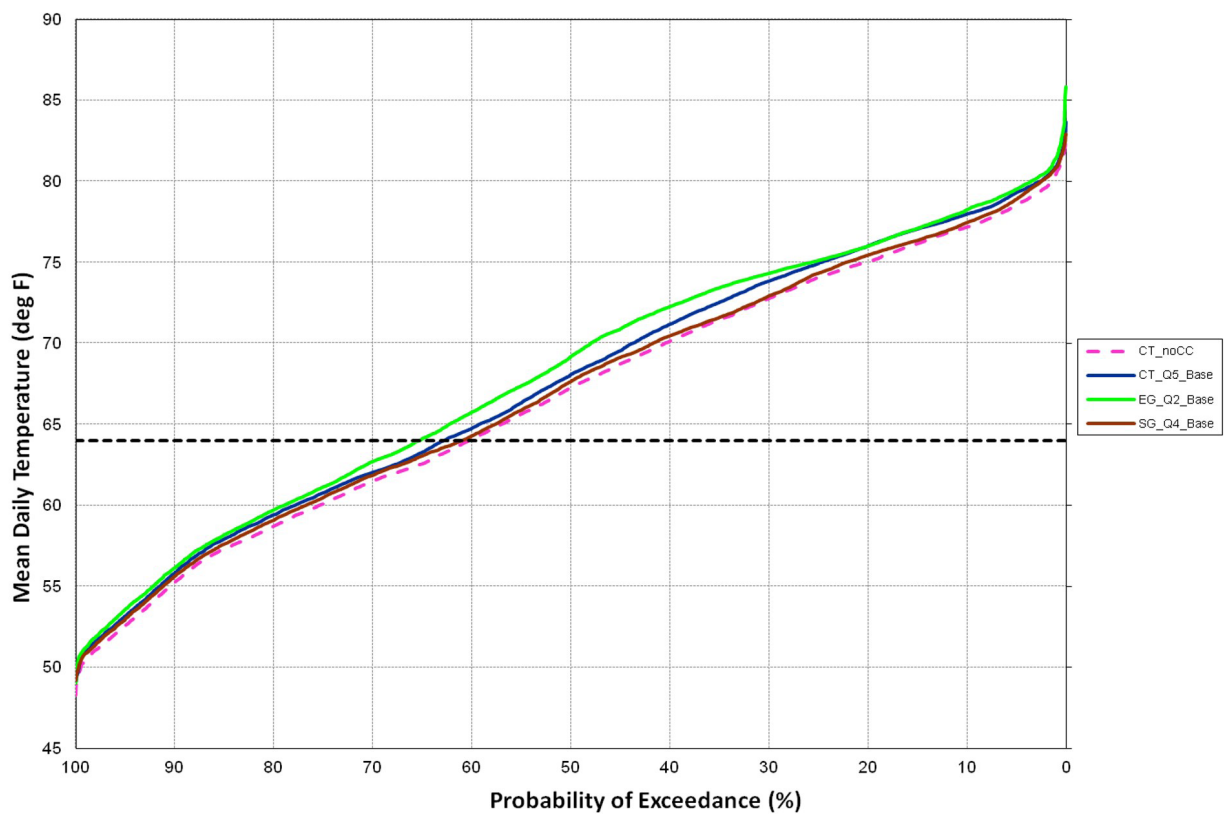


Figure 5-96. Exceedance of Average Temperature on San Joaquin River at Vernalis from August to November in the Baseline

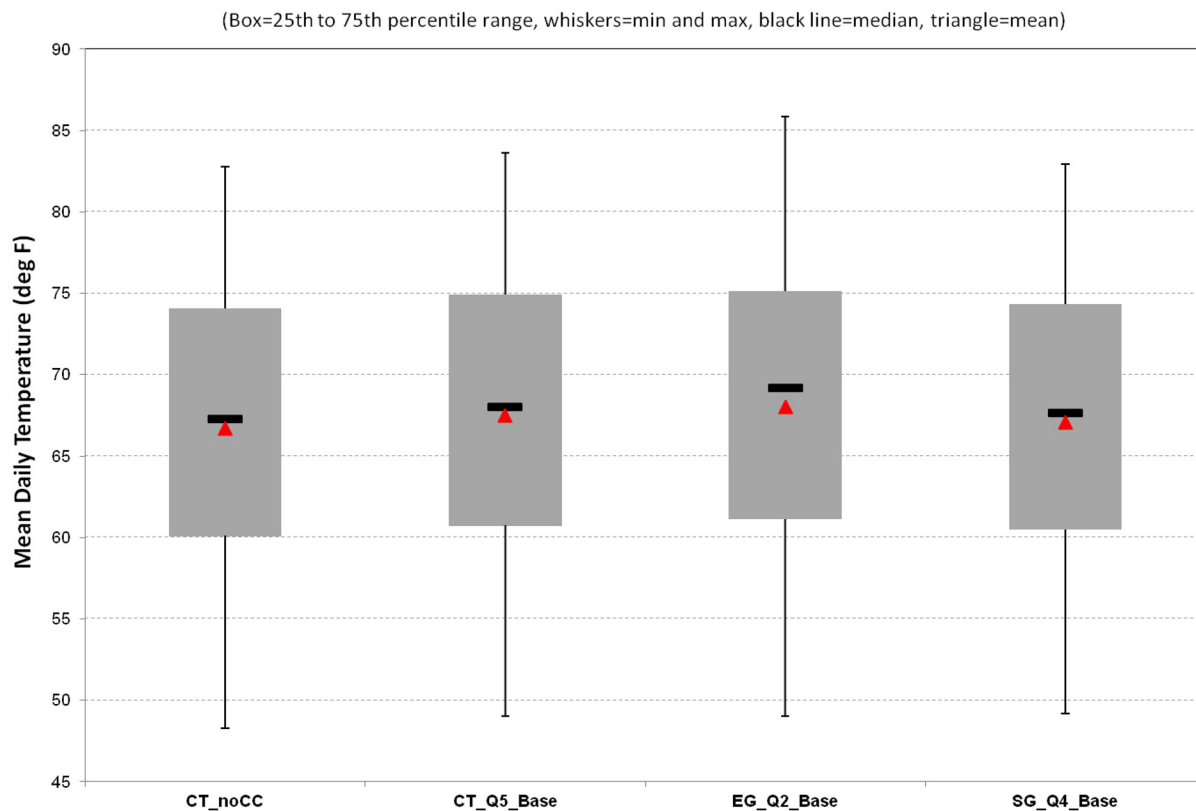


Figure 5-97. Box Plot of Average Temperature on San Joaquin River at Vernalis from August to November in the Baseline

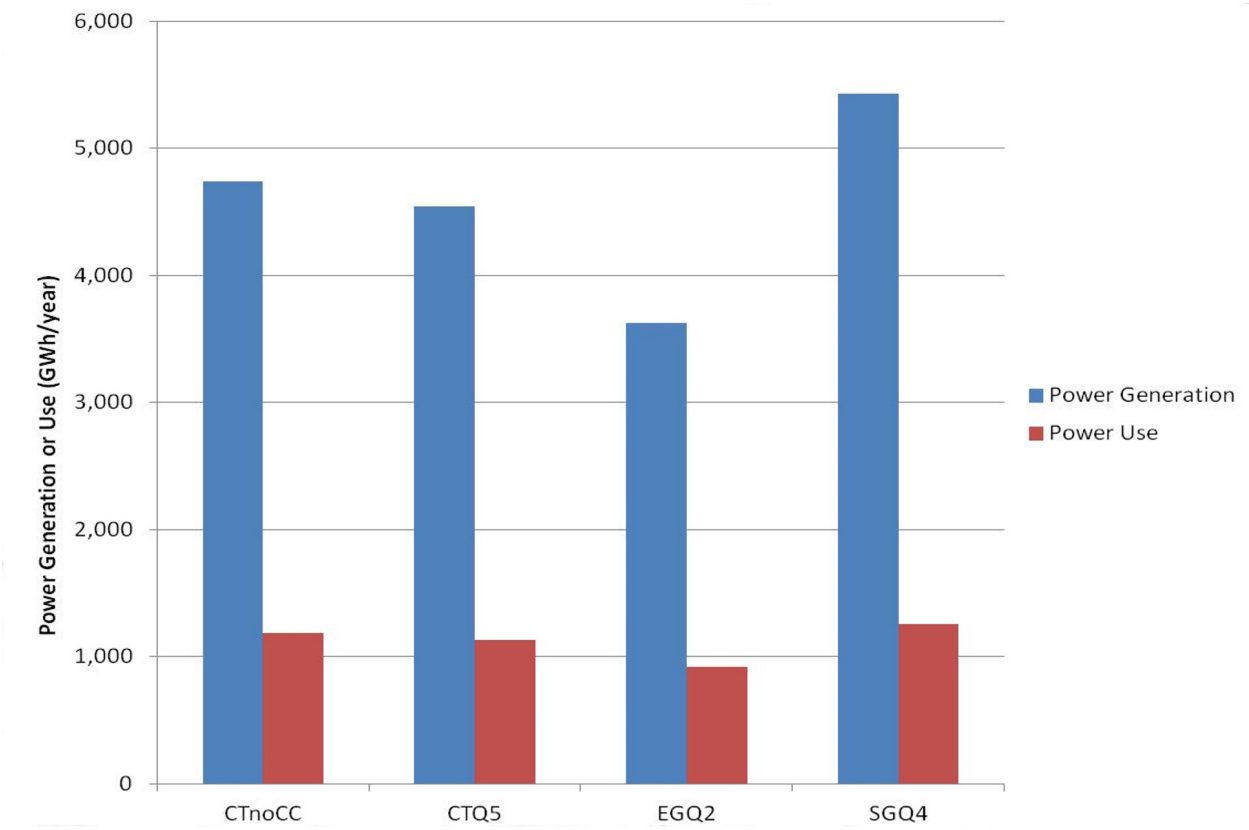


Figure 5-98. Average Annual Energy Generation and Use for the CVP System in the Baseline

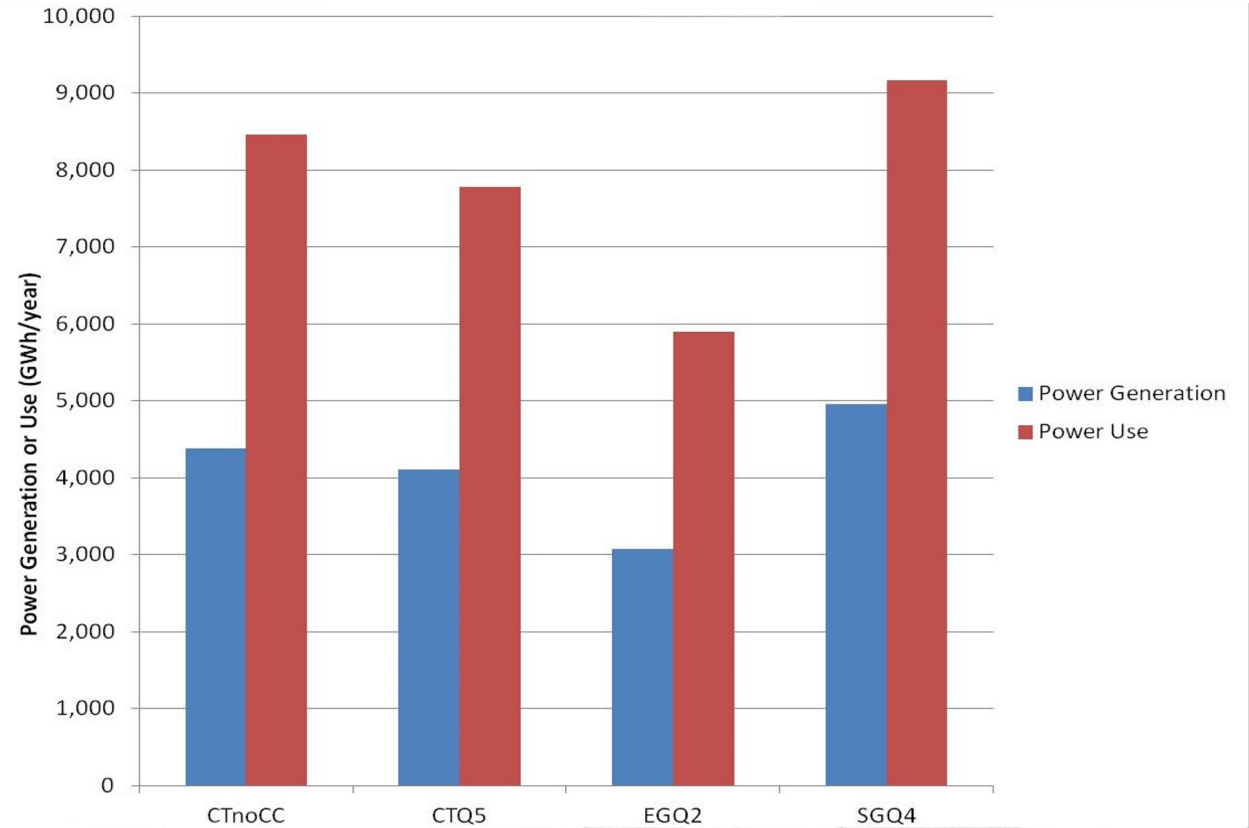


Figure 5-99. Average Annual Energy Generation and Use for the SWP System in the Baseline

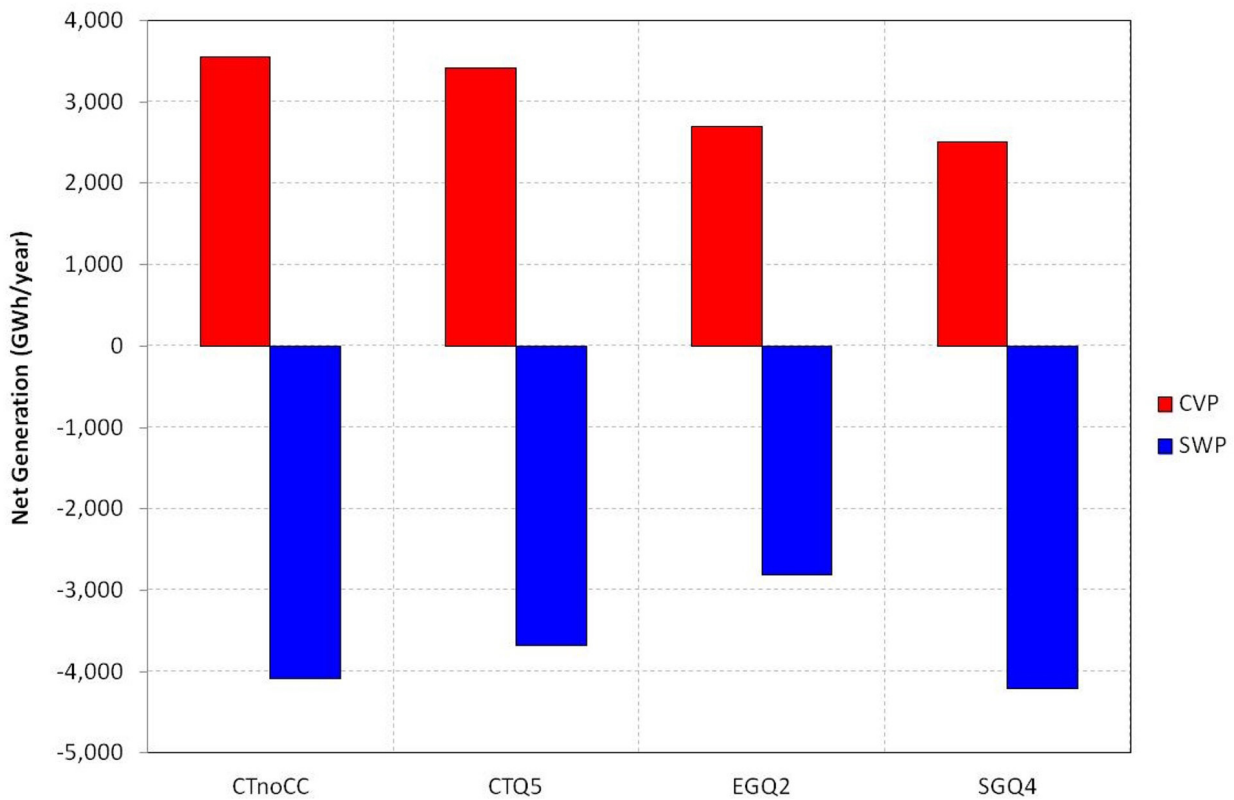


Figure 5-100. Average Annual Net Energy Generation for the CVP and SWP Systems in the Baseline

lowest storage levels in CVP reservoirs and the lowest amount of Banks pumping and, therefore, had the least CVP net generation and SWP net energy use.

Figure 5-101 presents the average annual GHG emissions in the SWP system and potential GHG offsets in the CVP system for the CVP and SWP systems under the CT-noCC, CT-Q5, EG-Q2, and SG-Q4 scenarios. These results are consistent

with the net generation results for the CVP and SWP system in each scenario. The CVP system had potential GHG offsets because it had positive net hydropower generation, and the SWP system had GHG emissions because it had negative net hydropower generation. In addition, the GHG emission results were greatest in SG-Q4 where the net generation results were greatest, and lowest in EG-Q2 where the net generation results were lowest.

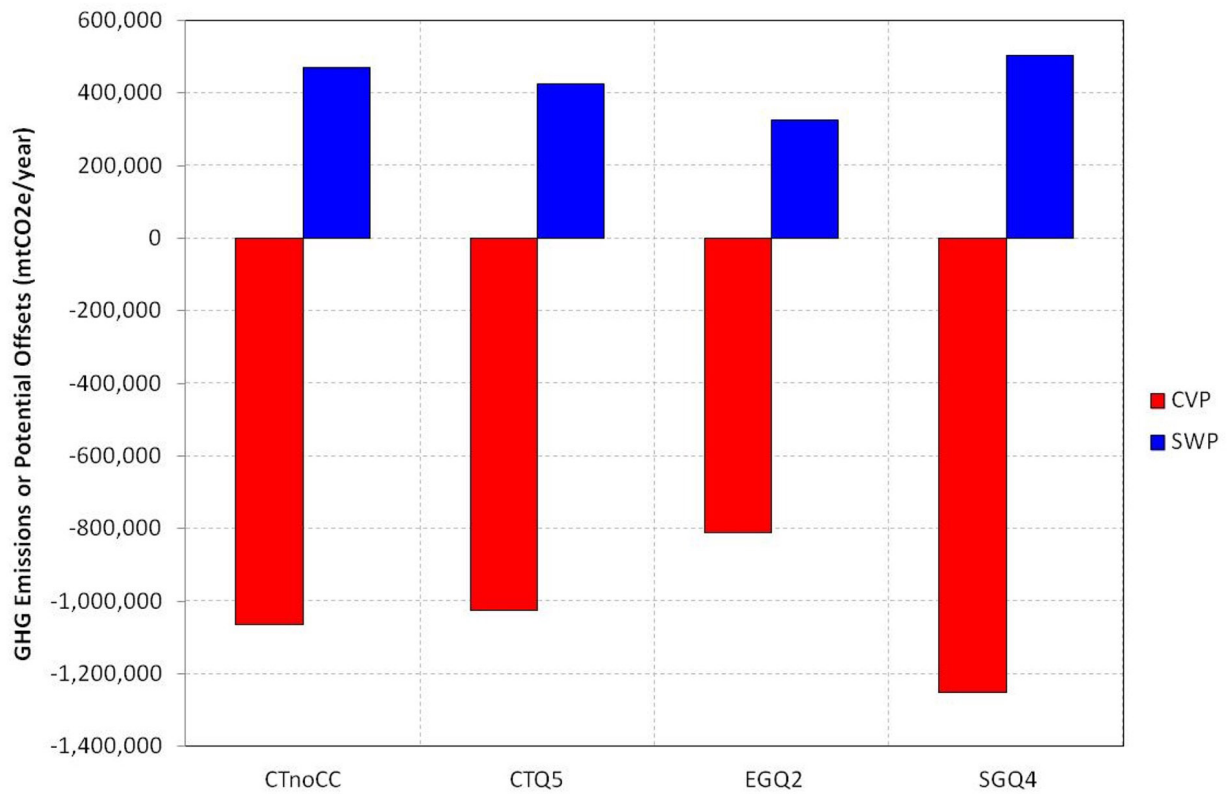


Figure 5-101. Average Annual Greenhouse Gas Emissions in the SWP System and Potential Greenhouse Gas Offsets in the CVP System in the Baseline

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