Appendix R Sensitivity of Future Central Valley Project and State Water Project Operations to Potential Climate Change and Associated Sea Level Rise

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Executive Summary

Numerous studies have been conducted on the potential implications of climate change for water resources management in California's Central Valley. Such studies have suggested that climate change resulting in future warming would lead to more rain and less snow, less spring-summer runoff, increased crop water needs, and rising sea levels. The uncertainty of coincidental precipitation change confounds these messages, as precipitation increases or decreases would generally offset or reinforce warming-related impacts, respectively.

This report offers an analysis of potential climate change implications for Central Valley Project (CVP) and State Water Project (SWP) operations, consistent with the analytical framework featured in this CVP Operations Criteria and Plan Biological Assessment (OCAP BA). The analysis was scoped to illustrate how the OCAP BA's future depictions of CVP/SWP operations and system conditions are sensitive to a range of future climate and sea level possibilities that may occur during the consultation horizon of this BA (i.e. 2030). Regional climate change could affect CVP/SWP surface water supplies originating in mountain headwater basins. Sea level rise stemming from global climate change could affect Delta conditions that constrain CVP/SWP operations.

Study scoping focused in three areas: definition of regional climate change scenarios, definition of sea level rise assumptions, and selection of methods for conducting "scenario-impacts" analyses.

- Four regional climate change scenarios were defined to represent a range of ~2030 possibilities from available climate projection information. Four climate projections were selected for how their paired precipitation-temperature changes spanned these climate possibilities, given four selection factors: (1) historical and future climate periods, (2) climate change metrics, (3) location of climate change, and (4) change-range of interest. OCAP BA considerations influenced each factor decision. The resultant projection selections collectively span regional climate changes that vary from: less warming to more warming from historical; and, drier to wetter than historical.

- One sea level rise assumption was defined for joint consideration with the four regional climate changes. The assumption was based on contemporary projections of sea level rise by 2030, and availability of Delta model-applications developed by the California Department of Water Resources to represent a chosen increment of sea level rise. The latter consideration constrained the assumption in this study. Given available Delta model-applications, the assumption featured in this study is a 1-foot sea level rise coupled with a 10% increase in tidal range. Relative to the anticipated sea level rise assumptions to be featured in the Second Biennial Science Report to the California Climate Action Team (due later in 2008), this assumed amount of sea level rise by 2030 would seem to represent the high end of the rate of rise.

- Given scenarios for both regional climate change and sea level rise, scenario-impacts assessment followed. Regional climate changes were translated into monthly changes in surface water runoff and CVP/SWP reservoir inflows. Two runoff model-applications were used (a set of SacSMA/Snow17 basin-applications supporting Central Valley flood-forecasting operations; and a Central Valley VIC application supporting past research studies). Sea level rise was then combined with water supply changes to determine changes for CVP/SWP operations and dependent conditions (i.e. Delta flows and velocities, reservoir and river water temperatures). The "scenario-impacts" assessments followed methodologies demonstrated in peer-review literature. CVP/SWP operations studies also featured other adjustments dependent on changes to reservoir inflows: year-type classifications, water supply forecasts, and allocation rules based on foresight of reservoir inflows. CVP/SWP water demands were not modified based on the assumption that district-level demand-management flexibility existed for both CVP and SWP water contractors (e.g., shifts in cropping choices, irrigation technology, etc.), enough so that district-level water demands wouldn't necessarily change even though crop-specific water needs would be expected to increase with warming.

Results from this climate change study are consistent with previous literature studies, suggesting that a range of possible impacts could occur for water supply, CVP/SWP operations and dependent conditions.

- <u>Monthly natural runoff and water supply</u>: Results show that climate change leading to future warming would be expected to cause greater *fraction of annual* runoff to occur during winter and early spring and reduced fraction of annual runoff to occur during late spring and summer. This relates to how warming leads to more rain and less snow, more rainfall-runoff during winter and early spring, and less snowmelt volume during late spring and summer. However, magnitude changes depend significantly on precipitation changes. Increased monthly precipitation would reinforce warming-related influences during winter and early spring runoff (presuming storms are still warmer, but involve more precipitation), and perhaps offset warming-related influences in late spring and summer runoff. In contrast, precipitation decreases would interact with warming to produce generally opposite seasonal effects.

- <u>Annual natural runoff and water supply</u>: Results show that climate change leading to either more or less mean-annual precipitation would have a more influential effect on annual runoff than changes in mean-annual temperature. Results also showed that for each headwater basin evaluated, the range of annual impacts was not significantly sensitive to choice of runoff model tool (SacSMA/Snow17 versus VIC). Only SacSMA/Snow17 results were carried forward to CVP/SWP operations analysis.

- CVP/SWP operations: Results were examined for how climate change and sea level rise might affect long-term mean-annual water deliveries, carryover storage in major system reservoirs, and Delta outflow conditions. The first two metrics relate to the tradeoff objectives of allocating CVP/SWP water supplies to satisfy current-year water demands versus reserving supplies to provide insurance against drought possibility in subsequent years. In general, changes in both mean-annual deliveries and carryover storage were found to be more sensitive to scenario changes in mean-annual precipitation. Relative to precipitation changes, the influence of scenario changes in mean-annual air temperature on either metric was minor. Sea level rise impacts on salt water intrusions result in a significant decrease in both CVP and SWP deliveries, ignoring the effects of regional climate change. Sea level rise also leads to greater salinity intrusion into the Delta, indicated by simulated X2 results. However, the wetter regional climate change scenarios showed that such sea level rise effects on salinity intrusion were offset by increased upstream runoff and delta outflow.

- Delta Flows and Velocities: Results showed that Spring flows at the head of Old River are most affected by the wetter/warmer climate change scenarios which lead to increased flows during wetter years and decreased flows during drier years. Velocity changes at the “head of Old River” were relatively minor. Negative Old and Middle River flows typically increased under climate change, especially during the winter; velocity changes were minor. Both the magnitude and direction of QWEST flows was affected by climate change, and the impacts varied by scenario and season; velocity changes were minor. Cross Delta flows were the least sensitive to climate change, and velocity changes were minor.

- Reservoir and River Water Temperatures: Changes in mean-annual air temperature have more relatively influence on changes in reservoir and river water temperature changes than they had with changes in CVP/SWP storage and delivery operations (i.e. water “quantity” operations). Changes in mean-annual precipitation toward wetter or drier conditions act to partially offset or reinforce air temperature warming effects on reservoir and river water temperatures.

These results quantify how CVP/SWP water supply, operations, and operations-dependent conditions might vary relative to a range of 2030 climate possibilities and associated sea level rise conditions. While using the best available scientific information, the results do not fully represent uncertainties associated with a number of key analytical assumptions, including those related to:

- climate forcing (e.g., greenhouse gas emission pathways, translation into perturbed biogeochemical cycles, atmospheric accumulation of greenhouse gases, and altered atmospheric forcing on climate)

- climate simulation (e.g., physical paradigms that underlie climate models, and computational limitations)

- climate projection bias-correction (i.e. whether climate model tendencies to be wet/cool or warm/dry should be accounted for and imposed on the analysis, as they were in this study given the projection information used)

- climate projection downscaling (e.g., how monthly timestep, large-scale climate projections produced by global climate models should translate into "basin-relevant" local scales and with what sub-monthly time-characteristics)

- watershed response (e.g., how long-term groundwater and/or land cover responses would interact with the hydrologic cycle to affect surface water runoff assessed in this analysis)

- social response (e.g., how district-level water and energy demands might evolve with climate change and reservoir operating objectives; or, how societal values concerning flood protection, environmental management, recreation, etc., might evolve and lead to changed constraints on reservoir operations)

- discretionary operational response (i.e. how this analysis, except for adjustments made to CVP/SWP allocation rules related to foresight of reservoir inflows, reflects a "static" operator that is unresponsive to climate change, when realistically some degree of operators' learning and change in discretionary operation might be anticipated).

Consequently the results from this study should be viewed as conditional on analytical assumptions and with potentially significant uncertainties not quantified or represented.

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A2	One of the relatively faster-accumulating trajectories for atmospheric greenhouse gas accumulation in the 21st century, as reported in the IPCC Special Report on Emissions Scenarios (IPCC 2000).
ANN	Artificial Neural Network, the empirical modeling technique used to develop a simplified emulator of DSM2 simulated relationships between Delta outflow and salinity conditions at Delta regulatory compliance locations.
AR3	IPCC Third Assessment Report, issued in 2001, predecessor to the Fourth Assessment (see AR4).
AR4	IPCC Assessment Report 4, issued in 2007 (http://www.ipcc.ch/ipccreports/ar4-syr.htm), summarizing science and understanding as reported by three Working Groups (I. “The Physical Science Basis,” II. “Impacts, Adaptation and Vulnerability,” and III. “Mitigation of Climate Change”)
B1	One of the relatively slower-accumulating trajectories for atmospheric greenhouse gas accumulation in the 21st century, as reported in the IPCC Special Report on Emissions Scenarios (IPCC 2000).
BCSD	A statistical method for climate projection spatial downscaling labeled “Bias-Correction Spatial Disaggregation”
BSR	Biennial Science Report produced by the California Climate Change Center
CalSim II	Simulation model of monthly CVP/SWP operations, forced by time-series scenarios of water supply, water demand, and operational constraints
CEGC1	California-Nevada River Forecast Center’s label for the basin “Trinity River basin above Claire Engle Reservoir”
cfs	cubic feet per second, a unit-measure of volumetric flow rate
CMIP	Coupled Model Intercomparison Project, focused on comparing performances of coupled ocean-atmosphere general circulation models, and coordinated by the WCRP Working Group on Coupled Modeling and U.S. CLIVAR program (http://www.clivar.org/organization/wgcm/cmip.php). CMIP began in 1995; phase 3 activities (CMIP3) produced climate projection information for the IPCC AR4.
CVP	Central Valley Project
D1641	California State Water Resources Control Board Decision 1641

DCP	downscaled climate projections
Delta	confluence region where the Sacramento, San Joaquin, Mokelumne, and Calaveras Rivers enter the San Francisco Bay estuary
DLTC1	California-Nevada River Forecast Center’s label for the basin “Sacramento River above the town of Delta”
DSM2	Simulation model of Delta hydrodynamics and water quality, forced by time-series scenarios of Delta inflows, outflow, exports, and operational constraints
DWR	California Department of Water Resources
ET	Evapotranspiration
FRAC1	California-Nevada River Forecast Center’s label for the basin “San Joaquin River above Friant Dam”
GHG	greenhouse gas
HETC1	California-Nevada River Forecast Center’s label for the basin “Tuolumne River above Hetch Hetchy Dam”
IPCC	Intergovernmental Panel on Climate Change
MRMC1	California-Nevada River Forecast Center’s label for the basin “Middle Fork Feather River above Merrimac” (additive to runoff from upstream basin labeled MFTC1)
NBBC1	California-Nevada River Forecast Center’s label for the basin “North Yuba River above New Bullards Bar Dam” (additive to runoff from upstream basin labeled GYRC1)
NFDC1	California-Nevada River Forecast Center’s label for the basin “North Fork American River above North Fork Dam” (additive to runoff from upstream basin labeled GYRC1)
NMSC1	California-Nevada River Forecast Center’s label for the basin “Stanislaus River above New Melones Dam”
NOD	North-of-Delta
OCAP BA	Operations Criteria and Plan – Biological Assessment
P	precipitation
POHC1	California-Nevada River Forecast Center’s label for the basin “Merced River above Pohono Bridge”
QWEST	the average daily flow traveling past Jersey Point in the Delta
SacSMA/Snow17	“Sacramento Soil Moisture Accounting” surface water runoff model coupled to “Snow17” snowpack development and melt

	model, applied by the National Weather Service River Forecast Centers to support operational hydrologic forecasting
SLR	sea level rise
SOD	South-of-Delta
SRES	IPCC Special Report on Emissions Scenarios
SRWQM	Sacramento River Water Quality Model
SWP	State Water Project
T	temperature
TAF	1000 acre-feet, a unit-measure of volume
USBR	Reclamation
VIC	“Variable Infiltration Capacity” hydrologic model simulating both surface water and surface energy balances, applied to the Central Valley and other western U.S. basins by various research groups, including University of Washington and Santa Clara University
WCRP	World Climate Research Programme (http://wcrp.wmo.int/Special_IPCC.html), coordinating climate modeling activities fundamental to the completion of IPCC AR4
WSI-DI	water supply index – delivery index
X2	location of the 2 parts-per-thousand “bottom salinity” concentration (or 2000 mg/L total dissolved solids concentration) upstream of the Golden Gate Bridge in the San Francisco Bay-Delta estuary

Chapter 9 1.0 INTRODUCTION

1.1 Climate Change and its Relation to OCAP

The Central Valley Project Operations Criteria and Plan Biological Assessment (OCAP BA) illustrates system operations and habitat conditions under various existing and future operational baselines. Each operational baseline includes assumptions about water supplies for the Central Valley Project and State Water Project (CVP/SWP) systems, water demands for each system, and constraints on system operations (e.g., institutional, regulatory, social, environment). Supply and demand assumptions, as well as many operations constraint, are linked to expectation about the climate associated with a given baseline, which reflects expected weather throughout the Central Valley over different time scales (e.g., annual weather statistics, seasonal statistics, and daily statistics). Some examples:

- CVP/SWP water supply assumptions reflect expected monthly weather patterns that translate into monthly runoff patterns in the Sierra Nevada and Southern Cascades, and ultimately CVP/SWP reservoir inflow patterns.

- CVP/SWP flood control rules reflect expected storm or runoff possibilities in upstream watersheds and associated reservoir-fill potential. These rules combined with downstream flood protection capacity determine CVP/SWP reservoir space requirements during the calendar year and constrains water supply operations.

- CVP/SWP drought management strategies reflect expected cycles of year-to-year and decade-to-decade climate variability (e.g., cycling between wetter and drier multi-year episodes), which influence CVP/SWP operations to satisfy competing objectives of maximizing water deliveries in any given year versus reserving stored water supply for use in subsequent years on the chance that drought could occur or continue.

- CVP strategies for managing the release of “cold water” required for support of Sacramento and American River fisheries during summer and autumn reflects expected weather during winter, which determines type of precipitation (rain versus snow), snowpack development, and ultimately the snowmelt contributing to cold water “pool” development in Lake Shasta and Folsom Lake during spring.

These are examples of how operational baseline depictions in this BA contain implicit *regional* climate assumptions. These baselines also contain an implicit *global* climate assumption with respect to how sea level is represented in the depiction of the Sacramento-San Joaquin River Delta (Delta) and its effect on water conveyance from CVP and SWP reservoirs in the Sacramento Valley to export service areas served from the south Delta. Specifically, sea level determines the Delta’s downstream sea level and salinity conditions, in-Delta distribution of salinity and water levels, and ultimately the Delta and export water quality and flow constraints that constrain opportunity to convey of upstream reservoir releases to export service areas.

As described above, climate is a relative and encompassing term describing aggregate expected weather aspects and statistics, and defined over some period of time. The World Meteorological Organization traditionally uses a climate definition period of 30 years (IPCC 2007). Climate is also defined within a geographic context. Climate *change* is defined as any statistical change in expected weather conditions and is typically assessed over a span of multiple decades (IPCC 2007). It is possible that climate change could translate into changes in CVP/SWP water supplies, water demands, and operational constraints. The significance of such changes depends on the increment of climate change and operational outcome of concern. Evidence from instrumental and paleoclimate records indicates that California's climate has gone through cycles over time, for example varying between wetter and drier periods (Meko et al. 2001). Such climate oscillations, or natural climate cycles, remain difficult to predict (IPCC 2007). However, recent evidence suggests that a human-affected warming trend is occurring and interacting with such natural climate variations (IPCC 2007). This warming trend is also expected to continue into the 21st century (IPCC 2007).

Given the relevance of both global and regional climate conditions in the OCAP baseline depiction, and the prospects of future climate change impacting OCAP *future* baseline depiction, it is relevant to consider the implications of projected climate change for the future OCAP operational baselines. In particular, it is of interest to understand how future assessments CVP/SWP storage, water deliveries, river flows, delta conditions, and water temperatures are sensitive to a range of future climate change possibilities occurring during the consultation horizon for the OCAP BA.

1.2 Current Understanding on Global to Regional Climate Change

Assessments on climate change science and summaries of contemporary climate projections have been periodically updated by the Intergovernmental Panel on Climate Change (IPCC) since 1988. The IPCC was established by the World Meteorological Organization and the United Nations Environment Programme and charged with coordinating the assessments of "*…climate change, its potential impacts and options for adaptation and mitigation.*" (http://www.ipcc.ch).

The IPCC recently released its Fourth Assessment Report, AR4 (IPCC 2007). AR4 offers statements and uncertainty estimates on recent trends, apparent human influence on those trends, and projections for various climate conditions. AR4 offers relatively more certain statements about warming-related events. For example, Table SPM.2 of AR4's report from Working Group I, Summary for Policy Makers (http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf), states that it is "*very likely*" that global trends of "*warmer and fewer cold days*" and "*warmer and more frequent hot days*" occurred during the 20th century and that it is "*virtually certain*" that these trends will continue based on 21st century climate projections in response to future scenarios for global greenhouse gas emissions (IPCC 2000). The AR4 synthesis report noted the major projected impacts on water resources to be "effects on water resources relying on snowmelt; effects on some water supplies," and goes on to state that "Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources." Relatively less certain statements are offered about future precipitation-related events (e.g., phenomena like the areal extent of droughts, frequency of heavy precipitation events).

In addition to the findings reported in the IPCC AR4, several U.S. science groups have recently issued statements on climate change. The American Meteorological Society issued a statement in February 2007 that they label as "*consistent with the vast weight of current scientific understanding as expressed in assessments and reports from the Intergovernmental Panel on Climate Change, the U. S. National Academy of Sciences, and the U. S. Climate Change Science Program.*" The American Geophysical Union adopted a revised climate change policy in December 2007, asserting that the Earth's climate is "*now clearly out of balance and is warming. Many components of the climate system—including the temperatures of the atmosphere, land and ocean, the extent of sea ice and mountain glaciers, the sea level, the distribution of precipitation, and the length of seasons—are now changing at rates and in patterns that are not natural and are best explained by the increased atmospheric abundances of greenhouse gases and aerosols generated by human activity during the 20th century.*" Additionally, the U.S. Climate Change Science Program (http://www.climatescience.gov/) continues to work on a series of Synthesis and Assessment Product reports addressing various climate research elements, including those related to atmospheric composition, climate variability and change (including climate modeling), global water cycle, land-use and land-cover change, global carbon cycle, ecosystems, decision-support systems, climate monitoring systems, and communication.

Information on historical climate change in the California region, as observed during the period of instrumental record, can be obtained from the Western Regional Climate Center (http://www.cefa.dri.edu/Westmap/). Figure 1 and Figure 2 show historical temperature and precipitation time series, respectively, for California's Sacramento Valley. Figure 3 and Figure 4 show similar information, but for California's San Joaquin Valley. Results on these figures show that the Central Valley region temperatures appear to be following a warming trend. Comparatively, annual precipitation has been more variable relative to its long-term mean, which doesn't appear to be following a clear positive or negative trend during the full period of record.

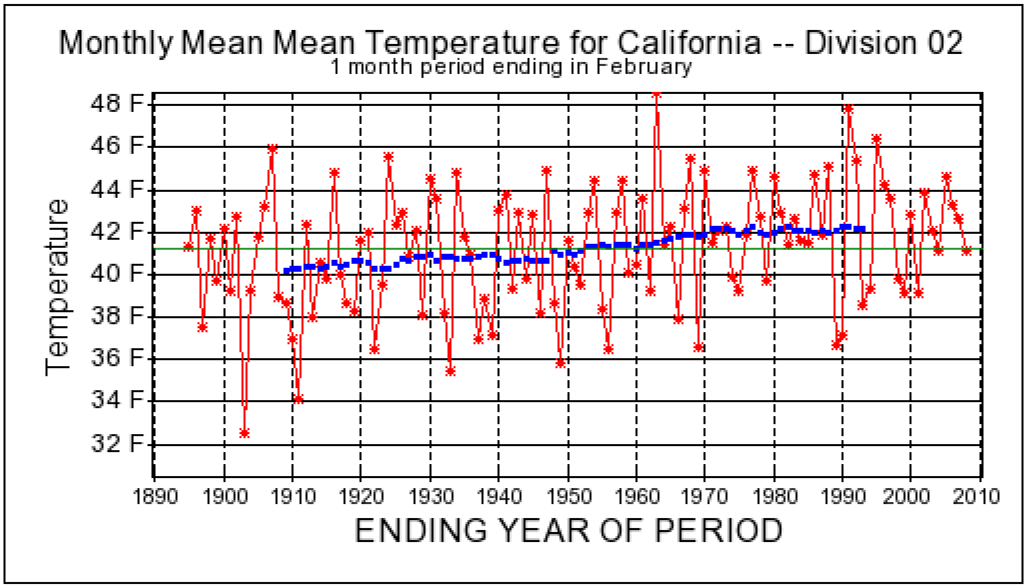


Figure 1. Observed Temperature in California Climate Division 02 "Sacramento Drainage". Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean. Data are from the Western Regional Climate Center (http://www.cefa.dri.edu/Westmap/).

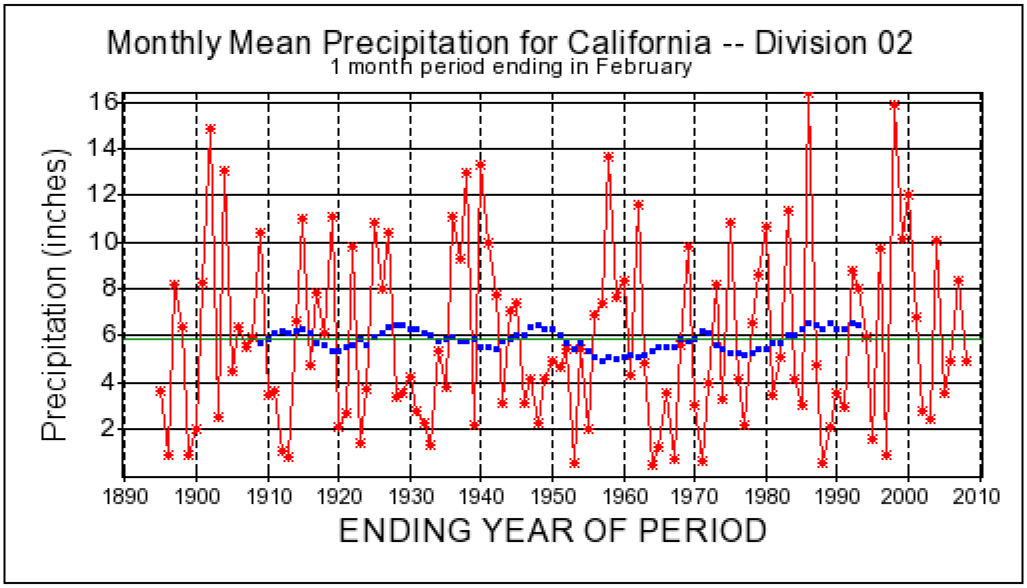


Figure 2. Observed Precipitation in California Climate Division 02 "Sacramento Drainage". Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean. Data are from the Western Regional Climate Center (http://www.cefa.dri.edu/Westmap/).

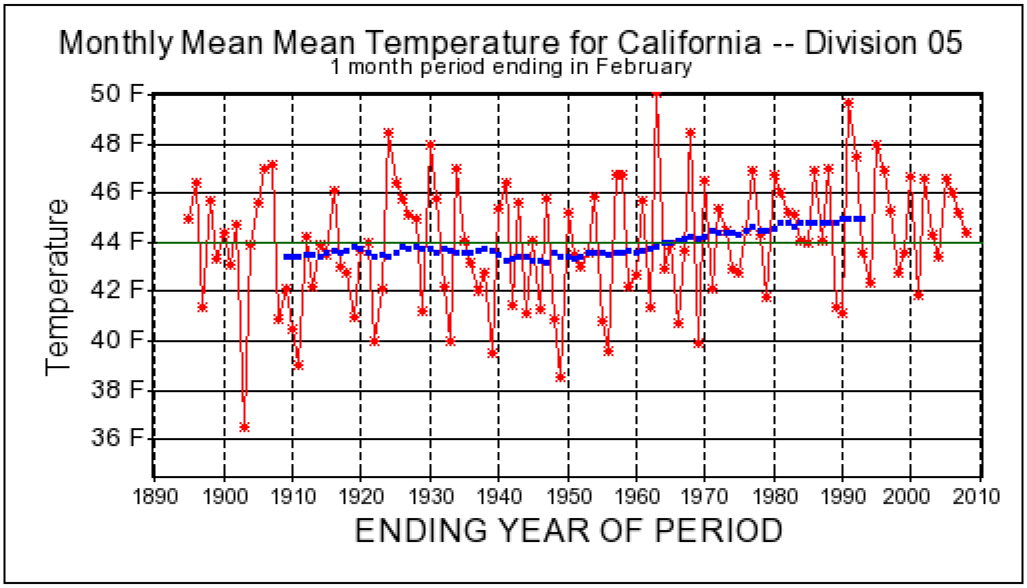


Figure 3. Observed Temperature in California Climate Division 05 "San Joaquin Drainage". Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean. Data are from the Western Regional Climate Center (http://www.cefa.dri.edu/Westmap/).

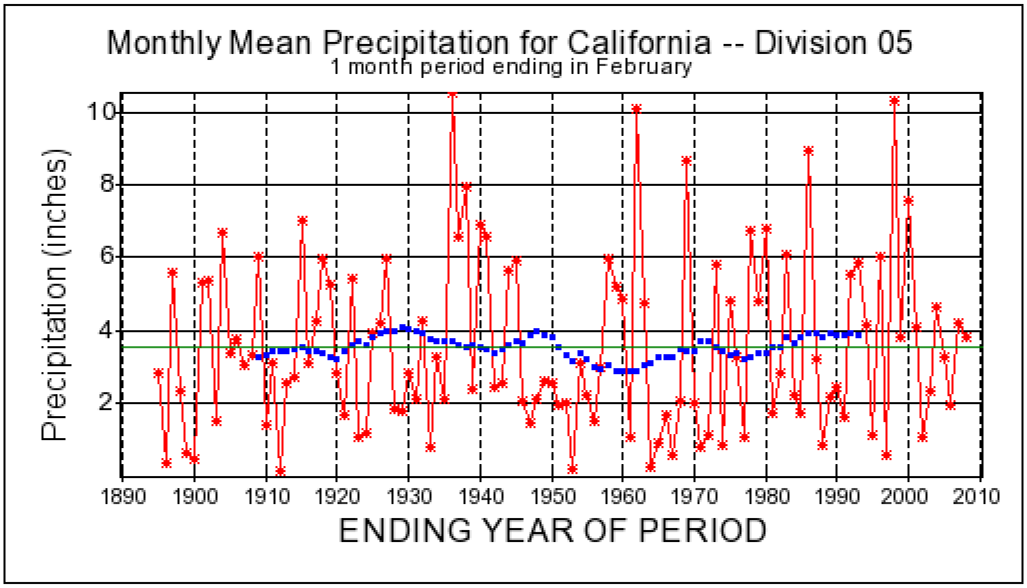


Figure 4. Observed Precipitation in California Climate Division 05 "San Joaquin Drainage". Plot shows time series of (red line) mean annual, (blue line) running 30-year mean annual, and (green line) full-period mean. Data are from the Western Regional Climate Center (http://www.cefa.dri.edu/Westmap/).

1.3 Central Valley Region Studies on Climate Change Impacts for Water Resources

Numerous studies have been conducted to explore the potential implications of climate change for water resources management in California's Central Valley. In fact, the regional literature on this topic is expanding rapidly and the purpose of this section is to note its breadth, cite some notable studies, and summarize common themes among recent findings.

A comprehensive review of past studies, roughly through 2005, is offered by Vicuna and Dracup 2007. Several notable studies have explored implications for Central Valley hydrology (Miller et al. 2003, Van Rheenan et al. 2004, Maurer and Duffy 2005, and Maurer 2007) while others have explored extended these hydrologic implications into studies on impacts for CVP, SWP, and other regional reservoir operations (Brekke et al. 2004, Zhu et al. 2005, DWR 2006, Anderson et al. 2008, Purkey et al. 2007).

Several general themes are found when comparing the findings from these various impacts studies. These themes support the qualitative discussion on potential regional implications offered by California Department of Water Resource's report "Progress on Incorporating Climate Change into Management of California's Water Resources" (DWR 2006):

> *Climate change may seriously affect the State's water resources. Temperature increases could affect water demand and aquatic ecosystems. Changes in the timing and amount of precipitation and runoff could occur. Sea level rise could adversely affect the Sacramento-San Joaquin River Delta and coastal areas of the State.*

DWR 2006 additionally provides discussion on potential impacts by water resource type and related consequences for water and environmental management, generally supported by the report's quantitative analyses on the potential implications of mid-21st century climate change for Central Valley water resources (Table 1)

Table 1. Potential Effects of Climate Change on California's Water Resources and Expected Consequences (DWR 2006)

Potential Water Resource Impact	Related Consequence (DWR 2006, Table 2-1)
Reduction of the California's average annual snowpack	• Potential loss of 5 million acre-feet or more of average annual water storage in the State's snowpack • Increased challenges for reservoir management (e.g., balancing the competing concerns of flood protection and water supply)
Changes in the timing, intensity, location, amount, and variability of precipitation	• Potential increased storm intensity and increased potential for flooding • Possible increased potential for droughts
Long-term changes in watershed vegetation and increased incidence of wildfires	• Changes in the intensity and timing of runoff • Possible increased incidence of flooding and increased sedimentation
Sea level rise	• Inundation of coastal marshes and estuaries • Increased salinity intrusion into the Sacramento-San Joaquin River Delta • Increased potential for Delta levee failure • Increased potential for salinity intrusion into coastal aquifers (groundwater) • Increased potential for flooding near the mouths of rivers due to backwater effects
Increased water temperatures	• Possible critical effects on listed and endangered species • Increased water demand for water temperature control • Possible increased problems with invasive species in aquatic ecosystems • Potential adverse changes in water quality, including the reduction of dissolved oxygen levels
Changes in urban and agricultural water demand	• Changes in evapotranspiration rates and water use decisions

1.4 Contemporary Climate Projection Information

The studies discussed in Section 1.3 describe Central Valley hydrology and CVP/SWP water management implications associated with assumed future climate scenarios based on reasonable climate projection information available at the time of those studies. The studies do not provide a “probability” for the climate scenarios represented, which reflects our current inability to assign a probability to future climate conditions given our limited ability to predict future human influence on climate at relevant temporal and spatial scales and our limited ability to simulate climate response to these influences (Section 5.0). The key point from these studies is that available climate projection information informed assumptions about future climate possibilities framing the studies.

During the past decade, climate projections have been made available through the efforts of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project (CMIP), which has advanced in three phases (CMIP1 (Meehl et al. 2000), CMIP2 (Covey et al. 2003), and CMIP3 (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php)). The

WCRP CMIP3 efforts were fundamental to the completion of the IPCC AR4. The CMIP3 dataset was produced using climate models that include coupled atmosphere and ocean general circulation models, each applied to simulate global climate response to various future greenhouse gas (GHG) emissions paths (IPCC 2000) from various end-of-20th century climate conditions. The emissions paths vary from lower to higher emissions rates, depending on global technological and economic developments during the 21st century.

One issue with the CMIP3 dataset and climate models projections in general, is that the spatial scale of climate model output is too coarse for regional studies on water resources response (Maurer et al. 2007). Addressing this issue, spatially downscaled translations of 112 CMIP3 projections have been made available ("Statistically Downscaled WCRP CMIP3 Climate Projections" served at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/), where the projections were collectively produced by 16 different CMIP3 models simulating 3 different emissions paths (e.g., B1 (low), A1b (middle), A2 (high)) from different end-of-20th century climate conditions. Section 3.1 provides discussion on various downscaling approaches that are commonly used, and the considerations that drove selection of the approach supporting development of the downscaled climate projections (DCP) archive mentioned above.

The DCP archive permits survey of projection information at various locations within the OCAP study region. For example, Figure 5 shows the distribution of projected changes in mean-annual precipitation and temperature conditions during 2011-2040 relative to 1971-2000 at four Central Valley locations. Figure 6 provides similar information, but with the future period shifted to 2041-2070. Both figures show projection consensus that some increment of warming is expected to occur by the early period, with more warming by the later period. Also the range of incremental warming among the 112 projections does not vary significantly among the mountain headwater and lower-elevation locations considered. In contrast, precipitation range of change is broader in magnitude for mountain headwater locations than for lower-elevation locations. And perhaps more importantly, there is little consensus among the projections toward drier or wetter conditions.

The location-specific analyses from Figure 5 and Figure 6 can be repeated at all downscaled the California region using DCP archive data, which was developed on a 1/8º, or roughly 12km by 12km, spatial grid. Doing this and sampling ranked-changes at each location (e.g., ranked value that is exceeded by 10% of the other values, or "10%Exc"; and similar to determine 50%Exc and 90%Exc) permits display of ranked changes as shown on Figure 7 and Figure 8, corresponding to 2011-2040 and 2041-2070, respectively. Focusing on centrally expected temperature change (50%Exc), the expected change does not vary much with location for either future period. Focusing a broad range of projected temperature changes (e.g., comparing changes on 10%Exc and 90%Exc maps, by location), it appears that the range of projected change does not depend a lot on location. Switching focus to precipitation, the centrally expected change (50%Exc) varies with location to some degree, with a more pronounced geographic tendency toward less precipitation over Southern California and more over Northern California by

2041-2070 (Figure 8). However, the range of projected precipitation changes (i.e. comparing 10%Exc and 90%Exc maps) is typically much greater at any given location than the centrally expected change (50%Exc value).

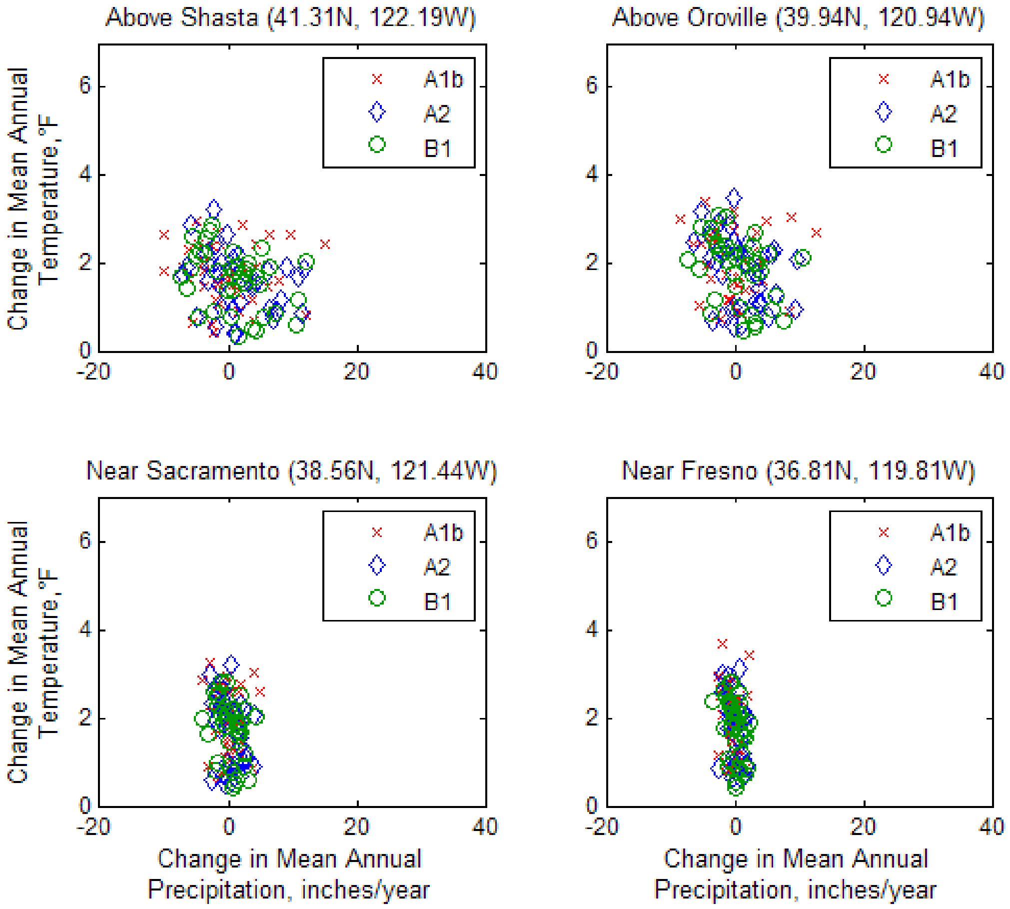


Figure 5. Projected climate change at several Central Valley Locations, 2011-2040 from 1971-2000. Each panel represents a location-specific survey of projections listed in Table 2. Symbols correspond to projection-specific change, which was assessed as the 2011-2040 Mean Annual condition minus the 1971-2000 Mean Annual condition. Legend indicates projection subsets corresponding to climate simulations forced by one of three greenhouse gas emissions pathways (A2 (“higher” path), A1b (“middle” path), or B1 (“lower “path) (IPCC 2000)

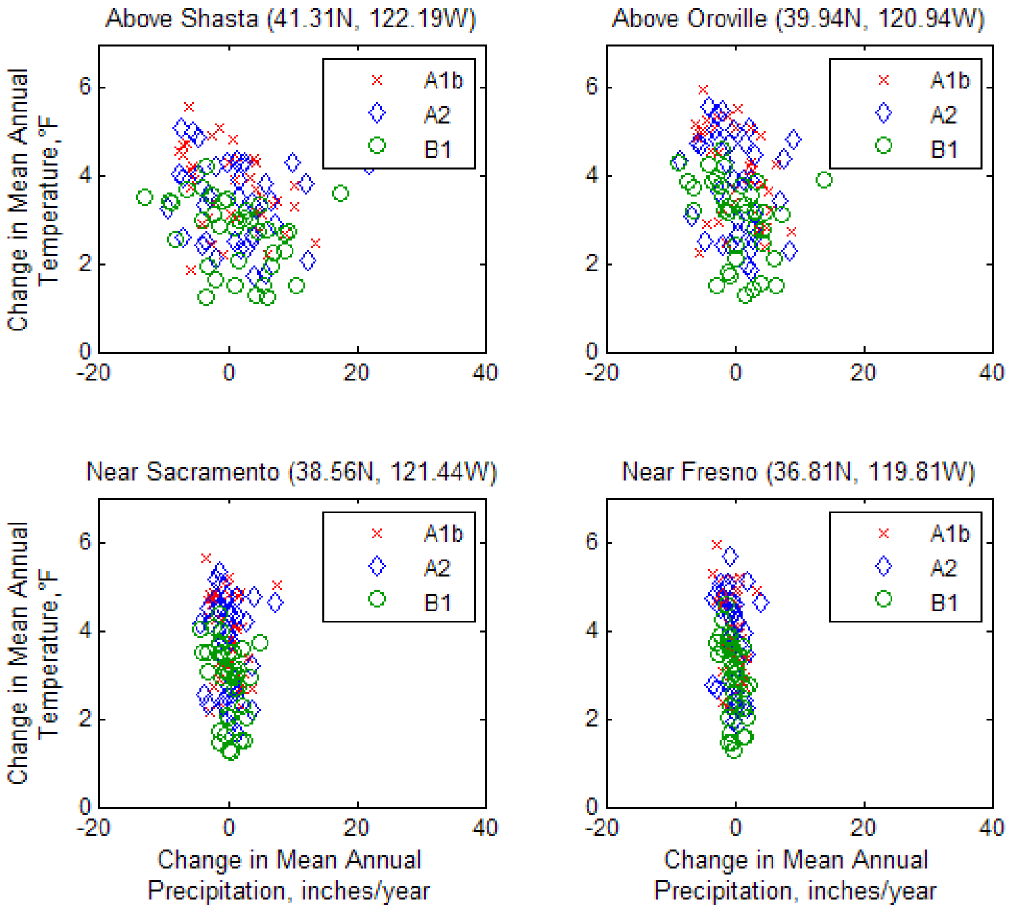


Figure 6. Projected climate change at several Central Valley Locations, 2041-2070 from 1971-2000. This figure is the same as Figure 5, but with climate change assessed as the 2041-2070 Mean Annual condition minus the 1971-2000 Mean Annual condition.

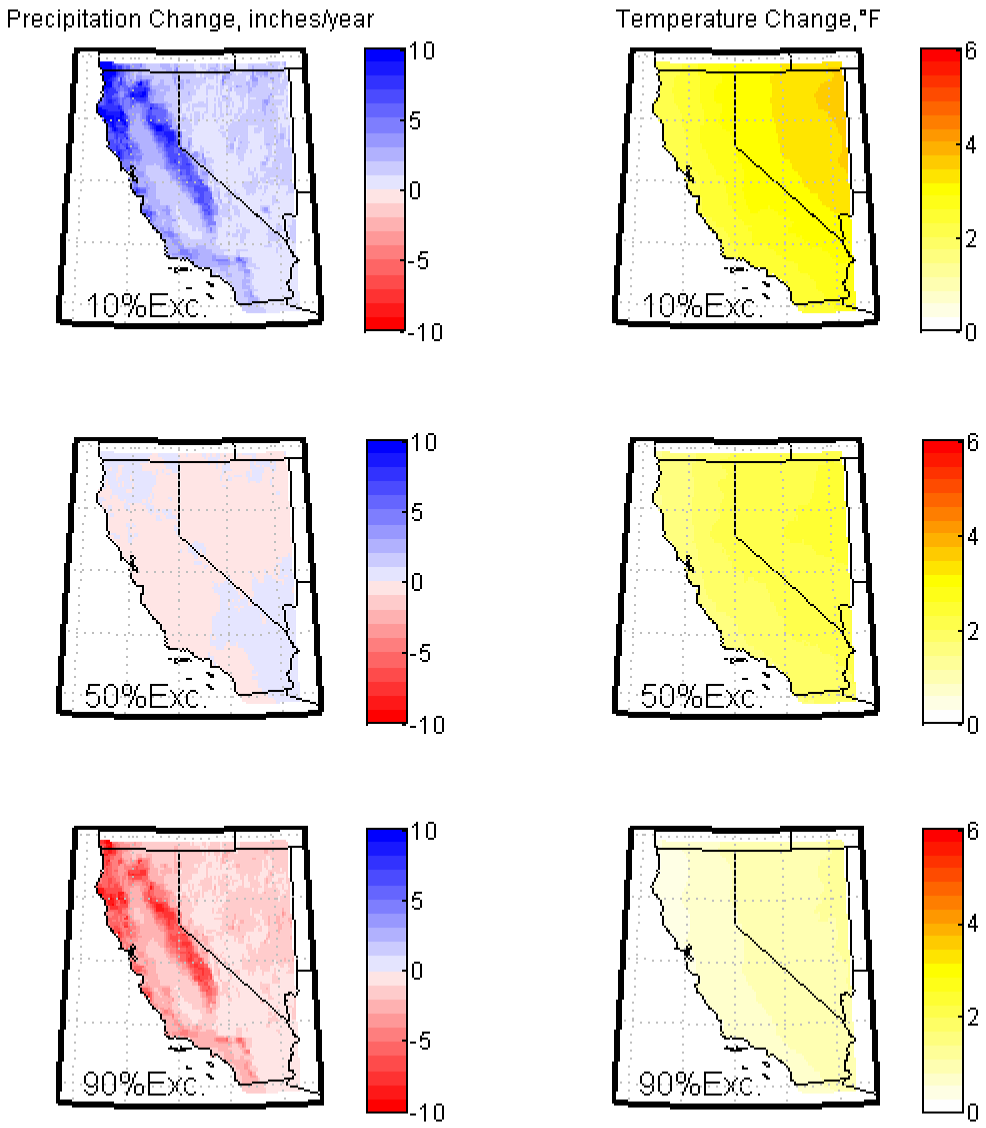


Figure 7. Rank-Projected climate change over California, 2011-2040 from 1971-2000. The 112 projected changes from Figure 5 were evaluated at each downscaling location (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/) within the CA/NV domain, corresponding to grid of locations at roughly 12km, or 1/8° latitude-longitude, resolution. Ranked-projections are shown for the 10%-, 50%, and 90% exceedence levels within each location's set of 112 projected values. Change was assessed as the 2011-2040 Mean Annual condition minus the 1971-2000 Mean Annual condition.

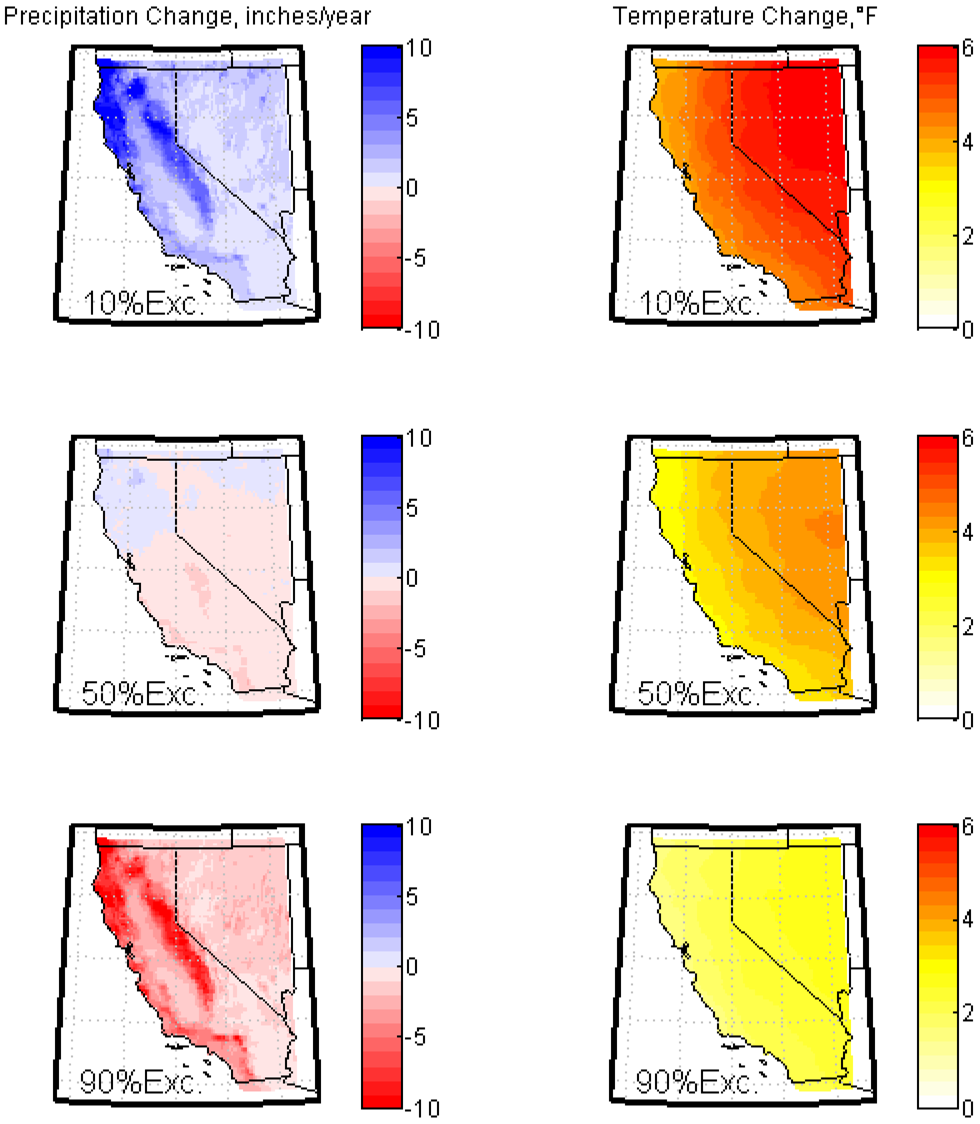


Figure 8. Rank-Projected climate change over California, 2041-2070 from 1971-2000. This figure is the same as Figure 7, but with climate change assessed as the 2041-2070 Mean Annual condition minus the 1971-2000 Mean Annual condition.

1.5 Incorporating Climate Change Information into the OCAP BA

Several approaches might be considered for incorporating climate change information into the OCAP BA. Several candidate approaches are listed below:

- *qualitative* discussion of implications for future CVP and SWP operations

- *quantitative* analysis of implications for future CVP and SWP operations under a range of potential climates in order to illustrate the how the OCAP future operational baseline is sensitive to the future climate assumption

- *quantitative* depiction of the OCAP future operational baseline with the complete probability distribution expected for future climate change and associated changes in water supply, demand, and operational constraint assumptions.

The second approach was chosen for this OCAP BA, hereafter referred to as a “sensitivity analysis”. Several considerations contributed to this approach decision:

- computationally, the availability of the DCP archive (Section 1.4) and analytical methodologies (Section 1.3) support implementation of either quantitative approach, which would help to better illustrate potential climate change implications for CVP/SWP operations than a qualitative discussion

- the OCAP consultation horizon extends to 2030, meaning that consultation extends multiple decades into the future, which is long enough to permit “detectable” climate change according to IPCC AR4 definitions (Section 1.1), thereby supporting the relevancy of a quantitative approach using DCP archive information.

- defining an expected increment of future climate change (i.e. joint consideration of temperature and precipitation change) is confounded by the considerable range of projected precipitation changes over the OCAP study region (Figure 5 to Figure 8); the sensitivity analysis approach can more easily incorporate this uncertainty by showing CVP/SWP operations response to a range of future climate possibilities that not only include various levels of warming, but also the drier to wetter possibilities supported by contemporary projections.

In the chosen approach (sensitivity analysis), the OCAP future operations baseline is re-evaluated multiple times. The first evaluation involves using water supply, demand, and constraint assumptions that reflect recent climate. Subsequent and “parallel” evaluations are then conducted, using scenario-specific sets of assumptions corresponding to climate change scenarios defined in Section 2.0. Each set of scenario-specific results are then to be compared against the “recent-climate” set of results to reveal CVP/SWP operational response to the given scenario's assumed climate change. Collective consideration of results across scenarios illustrates the sensitivity of CVP/SWP operations to a range of future climate possibilities.

1.6 Report Outline

The remaining sections of this report are outlined as follows:

- (Section 2.0) Development of Climate Change Scenarios for the sensitivity analysis, including OCAP-specific considerations, rationale for developing regional climate assumptions and its implementation, and rationale for sea level rise assumptions.

- (Section 3.0) Methodology for translating climate change scenario information into adjusted inputs and adjusted depiction of the CVP/SWP future operations baseline.

- (Section 4.0) Scenario-specific results for various natural and operational responses, including natural runoff in headwater basins; CVP/SWP operational outcomes for storage, delivery, and managed environmental conditions; Delta channel flow and velocity conditions associated with CVP/SWP operations; and tributary reservoir and river water temperature conditions associated with CVP/SWP operations.

- (Section 5.0) Uncertainties associated with relating climate change scenarios to CVP/SWP operational responses, focusing on sources of uncertainty that were not quantified in the analysis.

- (Section 6.0) References.

Chapter 10 2.0 CLIMATE CHANGE SCENARIOS FOR THIS ANALYSIS

This section describes considerations, assumptions and rationale for defining the mix of regional climate change and sea level rise assumptions framing this sensitivity analysis on CVP/SWP operational response to potential climate change. After discussing OCAP-specific considerations, a discussion is provided on available climate projection information and rationale for establishing regional climate change assumptions. Finally, available information is presented on projected sea level rise, along with rationale for assumptions on sea level rise for this study.

2.1 OCAP-Specific Concerns

This sensitivity analysis is focused on exploring how climate change might affect:

- CVP/SWP operational conditions of interest (e.g., reservoir storage, water deliveries, river flows, water temperature in reservoirs and downstream river reaches, delta water levels and salinity),

- conditions described statistically during long-term periods, year-groups classified by hydrologic year-type, or notable drought periods,

- conditions estimated for 2030, consistent with the consultation horizon.

2.2 Developing Regional Climate Change Assumptions

2.2.1 Available Climate Projections Data and Culling Considerations: The OCAP BA is required to be based on the use of best *available* data. In this case, the best available dataset defining future *global* climate possibilities is the WCRP CMIP3 climate projections dataset introduced in Section 1.4. Given the computational requirements and marginal differences described previously, the best available dataset of downscaled climate projections necessary for regional water resources evaluation is the DCP archive also introduced in Section 1.4. The DCP archive features data developed using a peer-reviewed downscaling technique that has been applied in support of numerous hydrologic impacts investigations (Maurer 2007). Among efforts that have applied this technique to CMIP3 projections, it offers the most comprehensive subset of available CMIP3 projections (Table 2), surveyed as of April 2008 when this sensitivity analysis was completed.

The DCP archive features CMIP3 data that have been processed in two ways. First, they have been “bias-corrected”, which means that they have been adjusted to account for climate model tendencies to simulate past conditions that statistically differ from observations (e.g., too warm, cool, wet, or dry). Second, they have been “spatially downscaled", which essentially involves mapping the bias-corrected CMIP3 data to a finer-scale spatial grid while also factoring in historical spatial climate patterns at the finer-scale grid. Techniques for accomplishing both steps are described at the DCP archive website (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections) and were initially introduced by Wood et al 2002 and Wood et al. 2004.

Table 2 lists the complete menu of CMIP3 climate projections represented in the DCP archive, as well as two notable projection subsets:

- the four CMIP3 projections produced by 2 CMIP3 models and their respective simulations of GHG emissions paths A2 and B1, subsequently used to frame the first biennial science report (BSR) to the California Climate Action Team summarized in CCAT 2006, which included DWR 2006 as an attachment.

- 11 of the 12 CMIP3 projections that will be framing the 2008 update to the BSR (http://meteora.ucsd.edu/cap/scen08.html) produced by 6 CMIP3 models and respective simulations of GHG emissions paths A2 and B1.

For discussion purposes, the two subsets are referred to as "CA Scenarios 2006" and "CA Scenarios 2008," respectively. These two subsets and the rationale behind assembling them is potentially relevant to climate change assumptions made in the OCAP BA, given the overlapping geographic interests between the OCAP BA and BSR efforts.

Review of "CA Scenarios 2006" shows that projection selection was influenced by a desire to focus on projections produced by climate models that produce a realistic simulation of aspects of California's recent climate, notably distribution of monthly temperatures and the strong seasonal cycle of precipitation that exists in the region (Cayan et al. 2008). Also, selected models were required to contain realistic representations of some regional features, such as the spatial structure of precipitation (e.g., annual cycle of precipitation, interannual-interdecadal variability) and represent differing levels of global temperature "sensitivity" to greenhouse gas forcing (Cayan et al. 2008). Selection of "CA Scenarios 2008" will again be influenced by these considerations. However, new and significant criteria are being imposed to represent: (1) a larger selection of models, and (2) models having readily available *daily* and, to some extent, *hourly* projection data. At the time of assembling "CA Scenarios 2008," not all climate models had readily available data at the daily, and particularly, the hourly time step (see http://meteora.ucsd.edu/cap/scen08.html, link to *"Slideshow used for 21 Nov 2007 WebEx conf call"*). This latter criterion was imposed given that the 2008 BSR update is scoped to explore hydrologic and resource management implications on three time-scales (monthly, daily, hourly). Given that the OCAP BA is primarily concerned on monthly aspects of climate change and associated CVP/SWP operational responses, the second criterion framing "CA Scenarios 2008" is not applied here. Thus, for defining a starting point for available projections consideration, this OCAP BA begins with consideration given to all projections in the DCP archive rather than the "CA Scenarios 2008" subset (Table 2).

Table 2. Available Downscaled and Bias-Corrected Climate Projections Data

Climate Modeling Group, Country	Climate Model (WCRP CMIP3 I.D.)	SRES runs [1, 2, 3]			Primary Reference
		A2	A1b	B1	
Bjerknes Centre for Climate Research	BCCR-BCM2.0	1	1	1	Furevik et al., 2003
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	Flato and Boer, 2001
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3	**1**	1	**1**	Salas-Melia et al., 2005
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0	1	1	1	Gordon et al., 2002
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0	1	1	1	Delworth et al., 2005
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1	**1**	1	**1**	Delworth et al., 2005
NASA / Goddard Institute for Space Studies, USA	GISS-ER	1	2, 4	1	Russell et al., 2000
Institute for Numerical Mathematics, Russia	INM-CM3.0	1	1	1	Diansky and Volodin, 2002
Institut Pierre Simon Laplace, France	IPSL-CM4	1	1	1	IPSL, 2005
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	MIROC3.2 (medres)	**1**, 2, 3	1, 2, 3	**1**, 2, 3	K-1 model developers, 2004
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G	1, 2, 3	1, 2, 3	1, 2, 3	Legutke and Voss, 1999
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM	**1**, 2, 3	1, 2, 3	**1**, 2, 3	Jungclaus et al., 2006
Meteorological Research Institute, Japan	MRI-CGCM2.3.2	1, 2, 3, 4, 5	1, 2, 3, 4, 5	1, 2, 3, 4, 5	Yukimoto et al., 2001
National Center for Atmospheric Research, USA	CCSM3	1, 2, 3, 4	1, 2, 3, 5, 6, 7	1, 2, 3, 4, **5**, 6, 7	Collins et al., 2006
National Center for Atmospheric Research, USA	PCM	**1**, 2, 3, 4	1, 2, 3, 4	**2**, 3	Washington et al., 2000
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3	1	1	1	Gordon et al., 2000

Notes:

1. These downscaled climate projections are from LLNL-Reclamation-SCU downscaled climate projections dataset, derived from World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, stored and served at the LLNL Green Data Oasis (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/).
2. **Bold**-styling indicates 11 of the 12 projections framing the Second Biennial Science Report to the California Climate Action Team, due in 2008 (http://meteora.ucsd.edu/cap/scen08.html). The 12th projection is produced by CCSM3, run 5 of SRES A2.
3. Underline-styling indicates the 4 projections framing the First Biennial Science Report to the California Climate Action Team, produced in 2006 (http://www.climatechange.ca.gov/biennial_reports/2006report/index.html)

Before moving towards selecting a few available projections to define a range of future climate possibilities, it might be questioned whether a reduced, or culled, set of "preferred" projections should be first be assembled. Such culling rationale would have to be supported by the notion that there are relatively more likely emissions paths among those represented in projections and/or relatively more credible climate models producing projections.

On determining relative likelihood for emissions paths, there is limited guidance on which path is more probable (IPCC 2007). However, this question may not be significant in the time-scale applicable to this OCAP BA, where consultation extends to 2030. This is because the distribution of CMIP3 climate projections presented in AR4 show that expected range of climate possibilities does not become seemingly dependent on IPCC Special Report on Emissions Scenarios (SRES) paths (IPCC 2000) until about the middle 21st century (IPCC 2007). Consequently, for defining regional climate change scenarios in this OCAP BA, a decision was made to consider all of the IPCC AR4 projections in the DCP archive rather than to not limit consideration based on emissions path.

On determining relative credibility of climate models, there has been more research activity (e.g., Dettinger 2005, Tebaldi et al. 2005, Brekke et al. 2008a, Reichler and Kim 2008). The general approach has been to evaluate climate models' simulations of the past and compare those simulation outputs to observations. The models found to have a closer match to observations (for the variables and statistical metrics considered) are regarded as having relatively better "skill." A philosophical bridge is then made, saying that the relatively more credible models based on past skill assessment offer more reliable climate projection information, although there is currently no evidence to support such a philosophical statement (Reichler and Kim 2008). It has been shown that when such skill assessments are extended to consider multiple aspects of climate, the clarity of "better" versus "worse" climate models becomes less obvious and depends on how many simulation aspects are considered (Brekke et al. 2008a, Reichler and Kim 2008). Further, when climate models are rank based on past simulation skill, and when that ranking information is used to affect evaluation of future climate projections (e.g., considering projections produced only by the "better half" of models rather than projections from "all models", as in Brekke et al. 2008a), the assessed range and central tendency of projected climate change doesn't necessarily adjust significantly. This is because the collective of CMIP3 projected climate changes are not found to stratify according to climate model skill, where "better" models (classified based on past simulation skill) produce middle changes and "worse" models produce higher or lower extreme changes (Brekke et al. 2008a). Consequently, a decision was made in this OCAP BA follow the precedent of the IPCC AR4 and to consider all projections in the DCP archive rather than to attempt to assess relative climate model credibility and apply those results to cull projections from consideration when selecting a representative suite of projected "change range" of interest.

2.2.2 Rationale for Selecting Projections to define Assumed Range of Future Climates: To define a range of future climate possibilities, it was decided that four climate projections would be selected to encapsulate a reasonable range of projected temperature and precipitation changes over the study region. The four projections would be selected based on how they collectively represent:

- "lesser" to "greater" temperature changes, which correspond to "*less warming*" to "*more warming*" over the OCAP study region based on Figure 5 to Figure 8,

- "lesser" to "greater" precipitation changes, which correspond to "*drier*" to "*wetter*" conditions over the OCAP study region based on Figure 5 to Figure 8.

Projections selection was guided by four factors (Figure 9) that characterized consistently with OCAP-specific study considerations (Section 2.1):

- *Factor 1 – Look-ahead horizon* and future climate period relevant to this study

- *Factor 2 – Climate metric* relevant to the study's operational conditions of interest

- *Factor 3 – Location* representative of the study region

- *Factor 4 – Projected "Change Range" of Interest,* a subjective choice on how much projections spread to represent.

2.2.3 Implementing the Projection Selection Rationale: Decisions must be made for each factor to guide the selections that are relevant to a given study. Decisions made for this sensitivity analysis are shown on Figure 9. *For other studies in the Central Valley, having potentially different study objectives, these decisions could be rationally changed, resulting in a set of different projection selections framing a similar sensitivity analysis.* Considerations that led to selection factor decisions are summarized as follows:

- *Factor 1 - Look-ahead horizo*n: For the OCAP consultation, the look-ahead horizon is 2030. A traditional period for climate definition is 30 years (Section 1.1). Decisions were made to define climate change from a base (historical) to future period, were climate is defined for a future period of 2011-2040 and a base period of 1971-2000. Climate change would then be assessed as statistical change in temperature (T) and precipitation (P) from base to future period.

- *Factor 2 - Climate Metric*: For the assessment of projections spread, it is convenient to be able to summarize each projection using a single climate metric, in contrast with the scenario-specific evaluations that would follow where multiple climate projection aspects would be translated into hydrologic and CVP/SWP operational responses (Section 3.0). A decision was made to use "period mean-annual" as a measure of either T or P climate in base or future periods. Given the decision for Factor 1, this means that "30-year mean annual" T and P were computed for both 2011-2040 and 1971-2000 periods, for each projection considered. Other single-value climate metrics might have been considered (e.g., season-specific mean T and P, or range and variability of T and P during annual or season periods, etc.). For this study, “period mean-annual” T and P conditions broadly relate to long-term statistics on water supplies managed by CVP/SWP reservoir operations, and were therefore viewed to be suitable metrics for use in assessing projections spread and selecting projections to represent a desired range of future climate changes (Factor 4).

- *Factor 3 - Location*: Figure 5 shows how projected climate change varies by location within the Central Valley region. The assessment of projections spread should be performed at a location that represents the climatic influences targeted in the sensitivity study. As will be discussed in Section 3.0, this sensitivity analysis targets projected climate change implications for Central Valley surface water supplies, and its effects on CVP/SWP operations. CVP surface water supplies span headwaters tributary to the Sacramento/San Joaquin Valley. Given this focus, a location of “Above Folsom” was chosen for its central proximity to headwater supply origins for multiple CVP/SWP tributary basins.

- *Factor 4 – Projected “Change Range” of Interest*: As mentioned, it is of interest to represent a range of future T and P possibilities in this sensitivity analysis. This can be done by choosing a set of projections to span the range of possibilities, based on spread among available projections. In this study, both projected T and P conditions are considered. So it is necessary to consider “change range” of interest for both variables. *Subjectively*, decisions were made to identify projections that come closest to matching the following threshold pairs of projections (given decisions for Selection Factors 1-3):

    - 10th percentile T change paired with 10th percentile P change.
    - 10th percentile T change paired with 90th percentile P change.
    - 90th percentile T change paired with 10th percentile P change.
    - 90th percentile T change paired with 90th percentile P change.

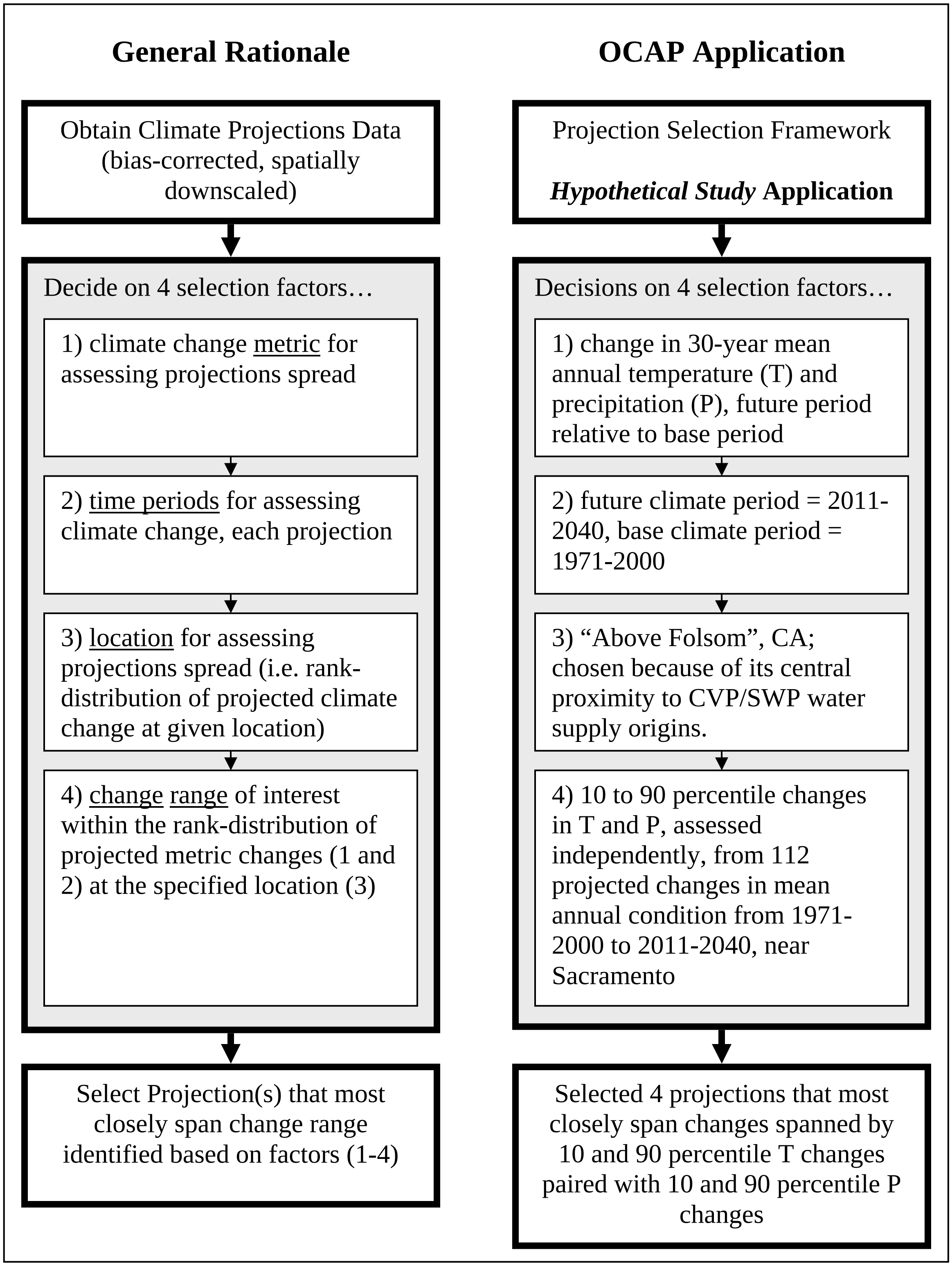


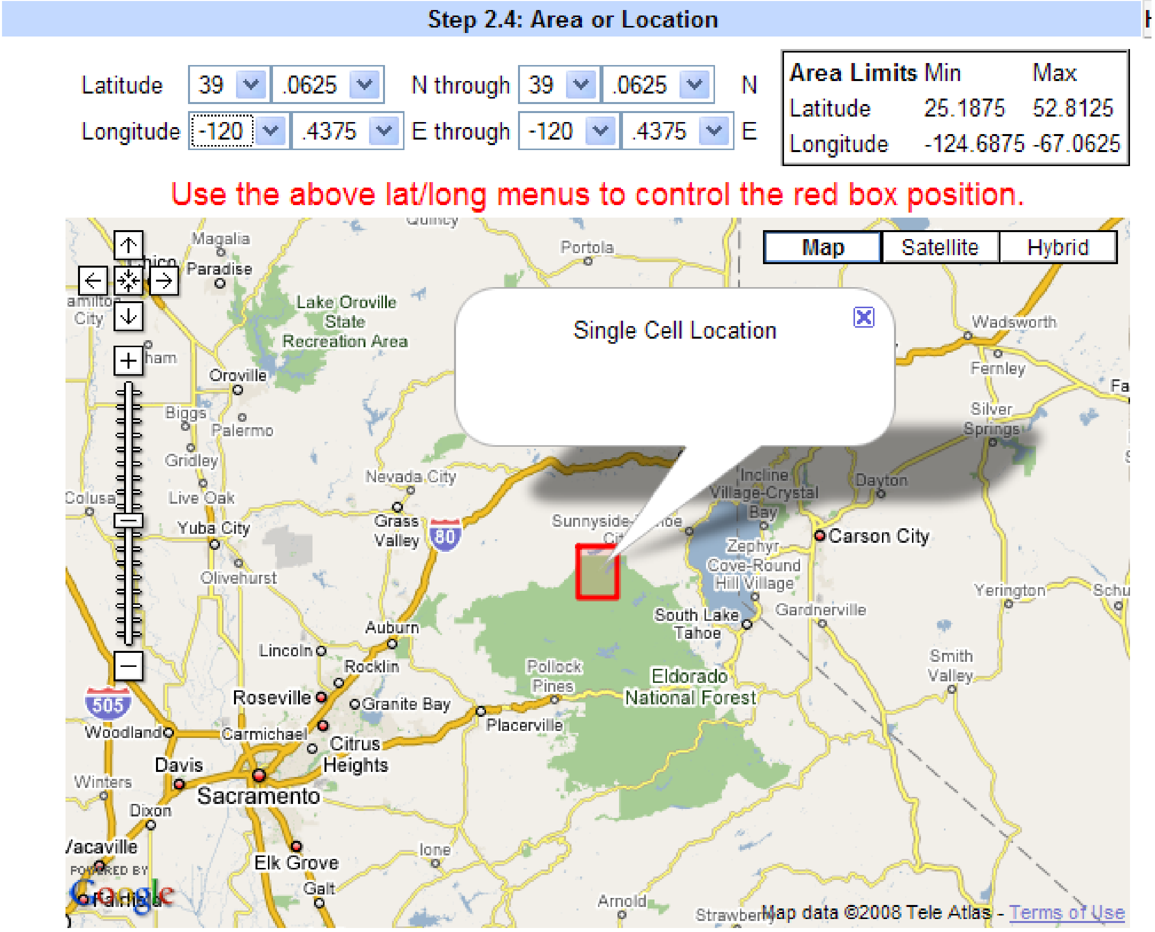
Figure 9. Projection Selections Rationale
Climate projection selection for the OCAP sensitivity analysis then proceeded with a four-step implementation process based on the four selection factor decisions from the preceding section.

- *Step 1*: Survey all DCP archive data at the location selected (Factor 3) for monthly time series T and P during a period spanning the base and future period decisions (Factor 1), noting that DCP "historical" T and P data reflect simulated historical time series T and P (by climate model) and not observed (Figure 10).

- *Step 2*: Compute 30-year-mean-annual (Factor 2) T and P for both base and future periods for each of the 112 projections surveyed in Step 1, and then the change in mean annual T and P (ΔT and ΔP, respectively) from base to future period, by projection. Next, assemble rank-distributions of each variable's 112 projected changes (Figure 11, upper left and lower right panels). Finally, identify rank-percentile changes for each variable corresponding to thresholds selected in Factor 4 (i.e. 10th and 90th percentile changes for both ΔT and ΔP).

- *Step 3*: Begin assessment of projections spread by plotting ΔT versus ΔP. Overlay rank-percentile changes identified for each variable in Step 2 (Figure 11, upper left and lower right panels). The intersection of the $\Delta T_{10\%\text{-tile}}$ and $\Delta T_{90\%\text{-tile}}$ with $\Delta P_{10\%\text{-tile}}$ and $\Delta P_{90\%\text{-tile}}$ formulates a two-variable "change range of interest" (i.e. yellow region on Figure 11, upper left and lower right panels).

- *Step 4*: Choose the four projections having paired projected changes (i.e. $\{\Delta T, \Delta P\}$) that most closely match each of the four vertices of the two-variable "change range of interest," respectively. In this case, the selected projections are shown on Figure 12 for how they most closely match the vertices of the yellow rectangle region. The chosen projections happen to not match the vertices exactly in this case because no single projection produced a pair of $\{\Delta T, \Delta P\}$ that coincide with any combination of the paired rank-percentiles of interest (i.e. $\{\Delta T_{10\%\text{tile}}, \Delta P_{10\%\text{tile}}\}$, $\{\Delta T_{10\%\text{tile}}, \Delta P_{90\%\text{tile}}\}$, etc.).



Step 2.4: Area or Location

Latitude 39 .0625 N through 39 .0625 N

Longitude -120 .4375 E through -120 .4375 E

Area Limits	Min	Max
Latitude	25.1875	52.8125
Longitude	-124.6875	-67.0625

Use the above lat/long menus to control the red box position.

Single Cell Location

Figure 10. "Above Folsom Lake" Location for Assessing Climate Projections Spread. Map illustrates decision on Selection Factor #3 in the OCAP Application of the Projection Selections Rationale (Figure 9).

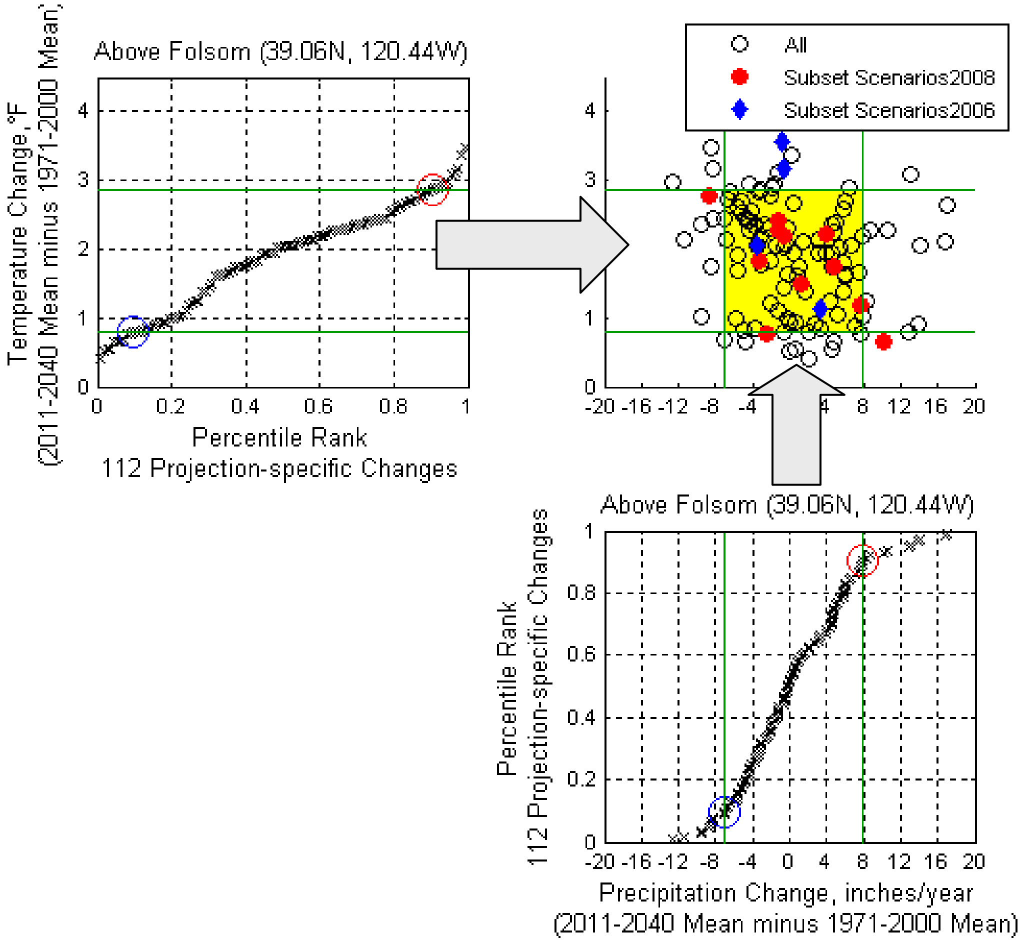


Figure 11. Climate Projections Spread given Decisions on Projection Selection Factors. Given decisions on Selection Factors #1-4 (Figure 9), distributions of variable-specific and paired-variable changes are shown. Top left panel shows rank-distribution of change in mean annual T. Lower right panel shows rank-distribution of change in mean annual P. Change range spanned by 10 and 90 percentile values (Selection Factor #4) are shown on both plots as separation between green lines. Upper right panel shows scatter of paired changes in mean annual T and P (black circles), with intersected change range of interest highlighted (Selection Factor #4, "yellow" region). Two projection subset "overlays" are shown: (a) 11 of the 12 projections from "California Scenarios 2008" (red circles; Table 2, note 2), and (b) the 4 projections from "California Scenarios 2006" (blue diamonds, assessed at 2035-2064 consistent with DWR 2006; Table 2, note 3).

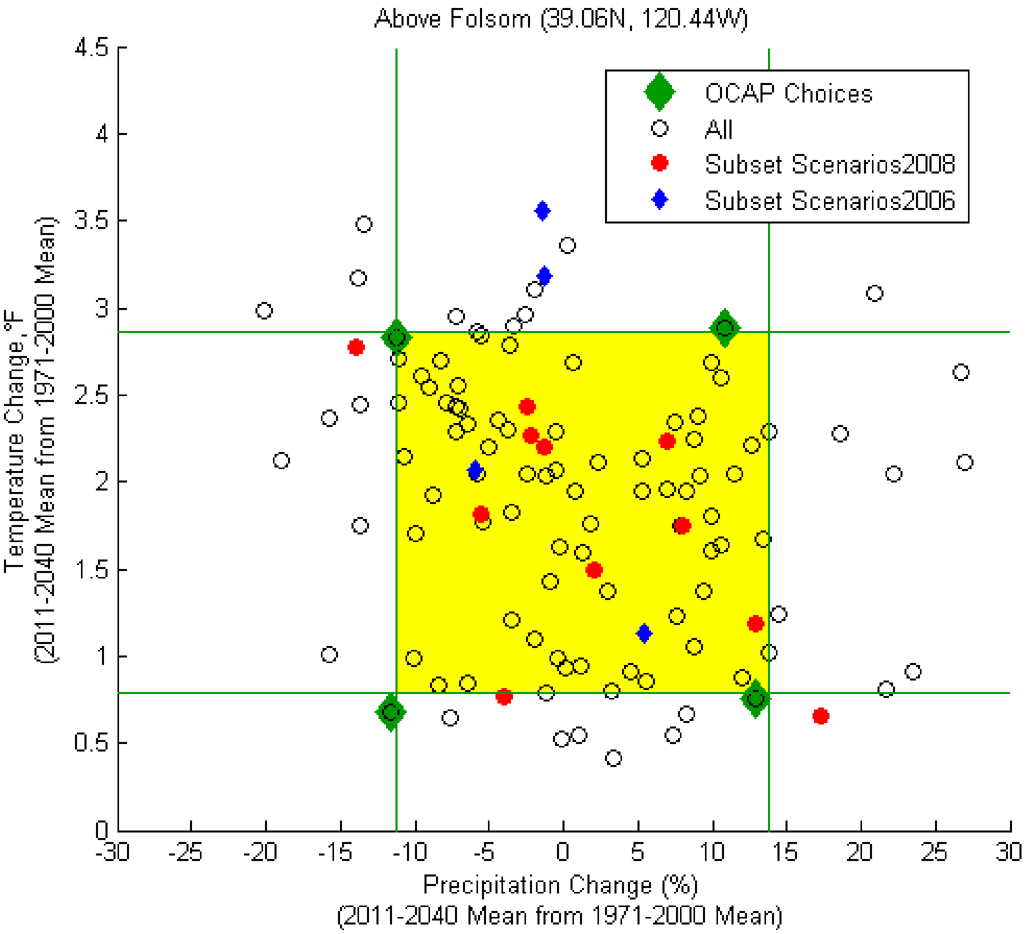


Figure 12. Projections Spread with chosen OCAP Projections highlighted ("OCAP Choices") defining Range of Climates framing this Sensitivity Analysis.

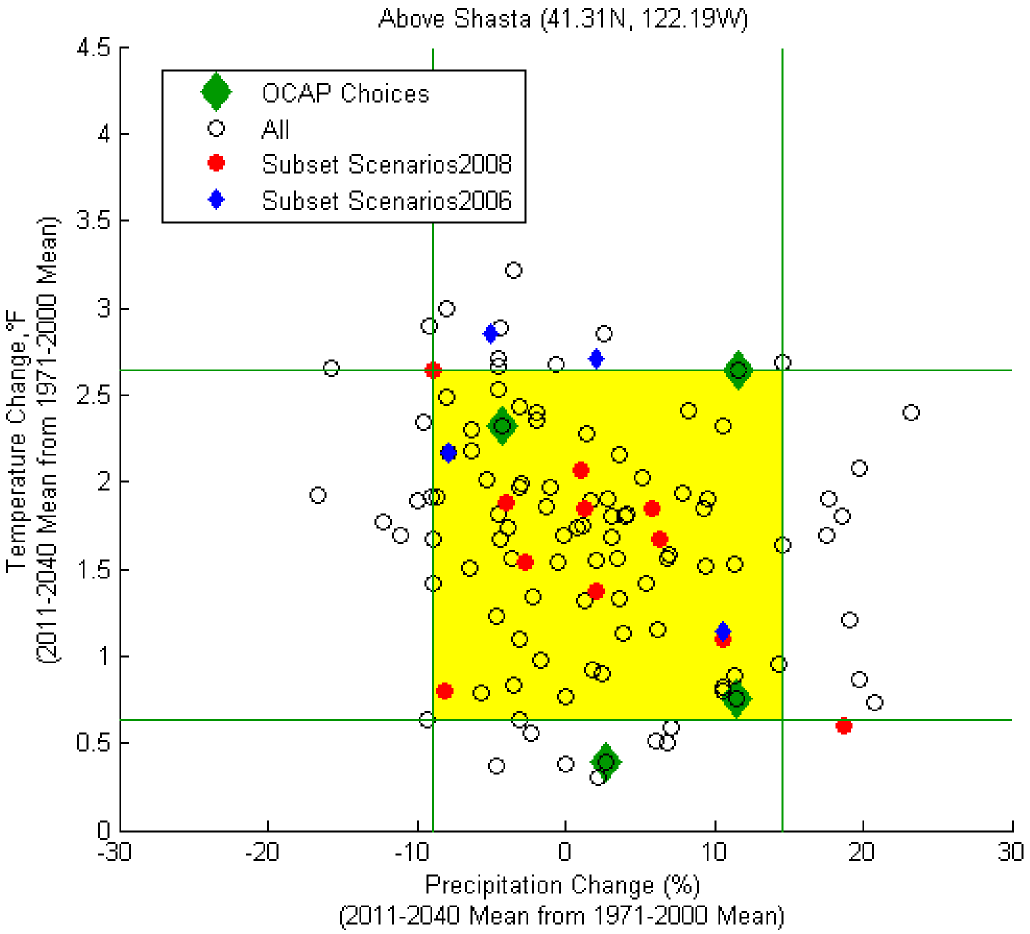


Figure 13. Comparison of OCAP Projections relative to Climate Projections Spread assessed at location "Above Shasta."

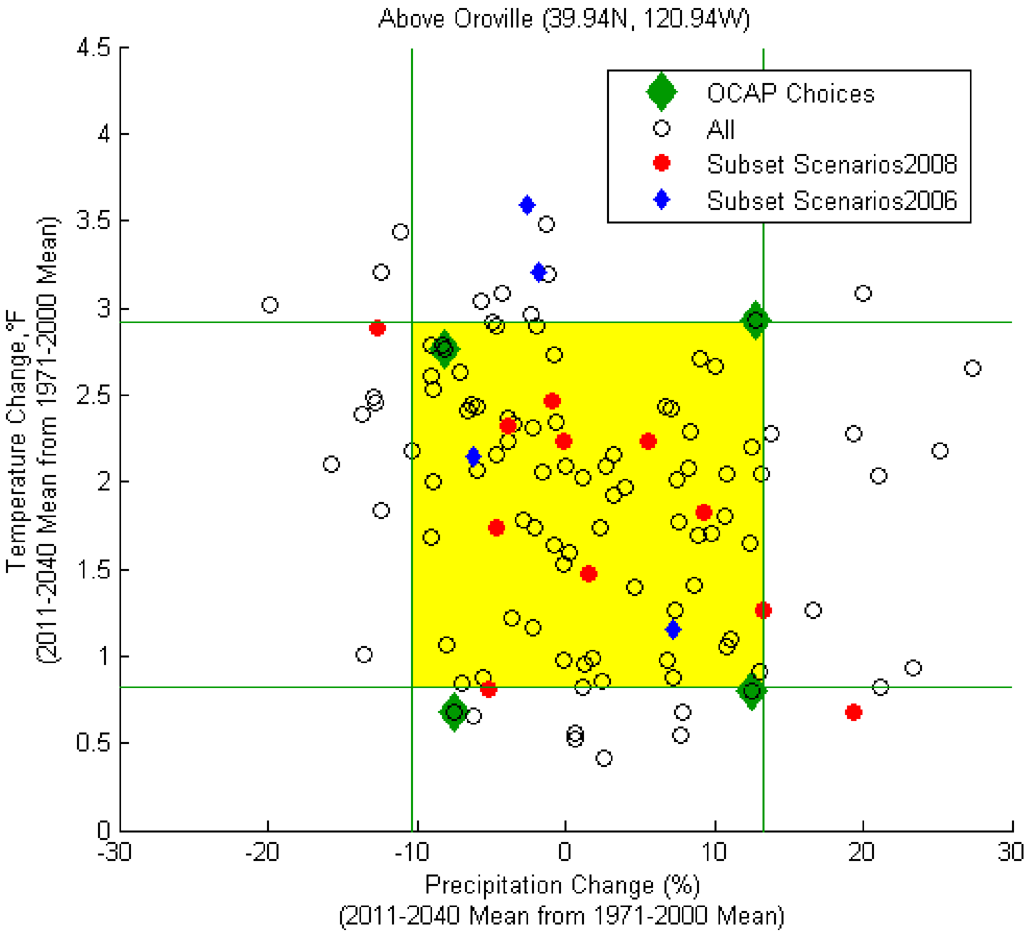


Figure 14. Comparison of OCAP Projections relative to Climate Projections Spread assessed at location "Above Oroville."

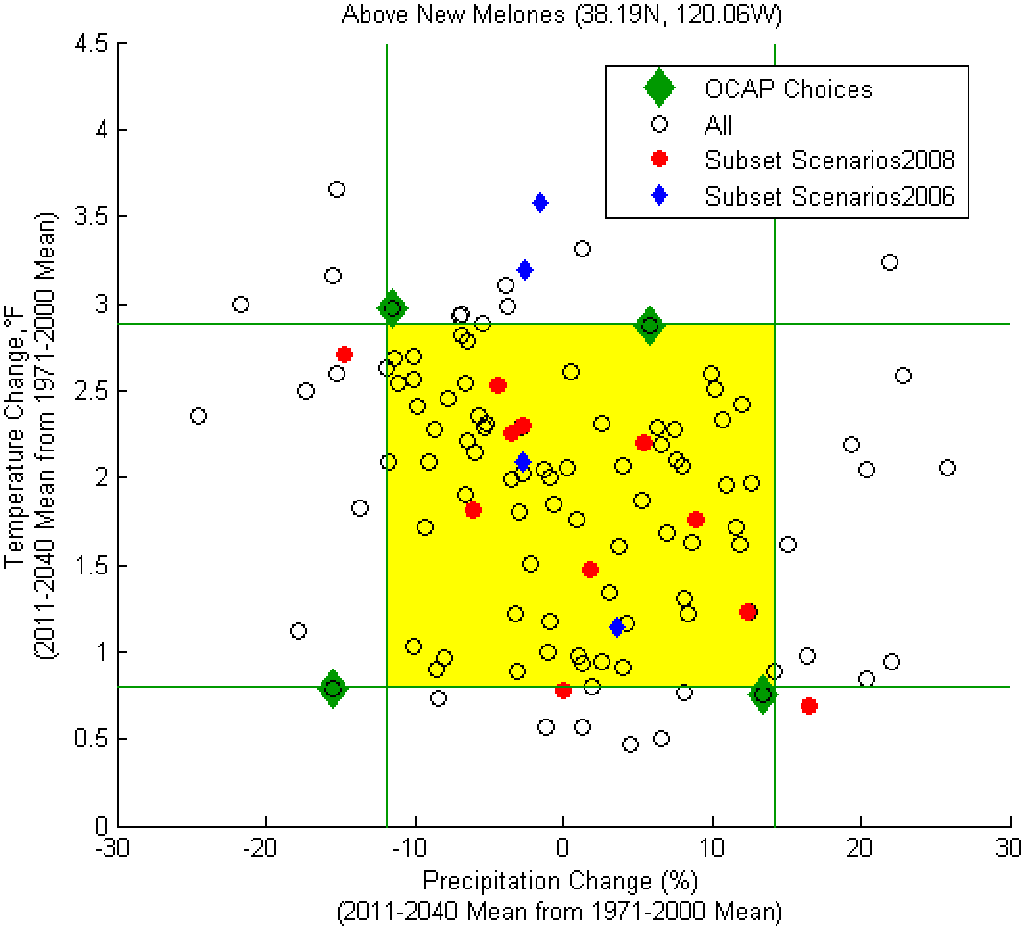


Figure 15. Comparison of OCAP Projections relative to Climate Projections Spread assessed at location "Above New Melones."

If the location decision is changed (Factor 3), the projections selections framing a change-range of interest may also shift. To illustrate, projections selection was re-assessed given different decisions for Factor 3, representing three headwater locations besides the "Above Folsom" location discussed above, and without changing Factors 1, 2, or 4. Figure 13 to Figure 15 show change-range of interest assessed at the three other headwaters locations labeled "Above Lake Shasta," "Above Lake Oroville," and "Above New Melones", while still highlighting the selected projections based on change-range of interest at location "Above Folsom" (Figure 12). (Note: The precipitation-change axis on Figure 12 to Figure 15 shows *percentage* change in 30-year mean annual precipitation change, whereas the precipitation-change axes on Figure 11 shows *incremental* change. This is done to provide a frame of reference for precipitation change at the various locations.) Figure 13 to Figure 15 show that the four projections chosen at location "Above Folsom" (Figure 12) come close to spanning the change-range of interest at the two more proximate locations, "Above Lake Oroville" and "Above New Melones". By comparison, the four projections do less well at spanning the change-range of interest at the more distant location, "Above Lake Shasta". These results indicate that *for the sake of assessing projections spread and choosing projections to span a change-range of* *interest within that spread*, no location is ideal for an entire study region. However, this finding doesn't undermine the basic purpose of the sensitivity analysis, which is to assess CVP/SWP operations sensitivity to range of future climate possibilities. The four selected projections define those possibilities, and their regionally distributed projection features will be represented in the subsequent scenarios-impacts analysis (Section 3.0). Following the projection selection rationale introduced in this section, it is inevitable that the selected projections will more closely match a change-range of interest in some portions of the study area better than in others.

<u>2.2.4 Summary of Selected Climate Projections for this Analysis</u>: The four selected climate projections from Figure 12 are listed below, with *labels* describing general type of climate change from recent historical conditions:

- Projection 1: "*Wetter, Less Warming*" ($\Delta T_{10\%\text{-tile}}$, $\Delta P_{90\%\text{-tile}}$)
  - Climate Model: mri cgcm2.3.2a
  - Emissions Pathway: A2
  - Simulation Run Number: 5
- Projection 2: "*Wetter, More Warming*" ($\Delta T_{90\%\text{-tile}}$, $\Delta P_{90\%\text{-tile}}$)
  - Climate Model: ncar ccsm3.0
  - Emissions Pathway: A1b
  - Simulation Run Number: 3
- Projection 3: "*Drier, Less Warming*" ($\Delta T_{10\%\text{-tile}}$, $\Delta P_{10\%\text{-tile}}$)
  - Climate Model: mri cgcm2.3.2a
  - Emissions Pathway: A2
  - Simulation Run Number: 2
- Projection 4: "*Drier, More Warming*" ($\Delta T_{90\%\text{-tile}}$, $\Delta P_{10\%\text{-tile}}$)
  - Climate Model: ukmo hadcm3
  - Emissions Pathway: A2
  - Simulation Run Number: 1

Figure 16 and Figure 17 show changes in mean-monthly P and T, respectively, for each projection at the four headwater locations considered in Figure 12 through Figure 15.

Note that Projections 3 and 4 reflect drier conditions for the Central and Southern Sierra, and were selected as "Drier" projections based on its values over the location "Above Folsom". However, over the northern limits over the study region, Projection 3 happens to exhibit relatively little precipitation change relative to the other projections represented on Figure 12, while Projection 4 is still a "drier" projection relative to the others but to a lesser extent. In contrast, in the southern Sierra, Projection 3 is relatively drier than Projection 4 (e.g., location "Above New Melones" shown on Figure 15). These geographic aspects of the projections are relevant for interpreting tributary-specific runoff responses associated effects on CVP operations.

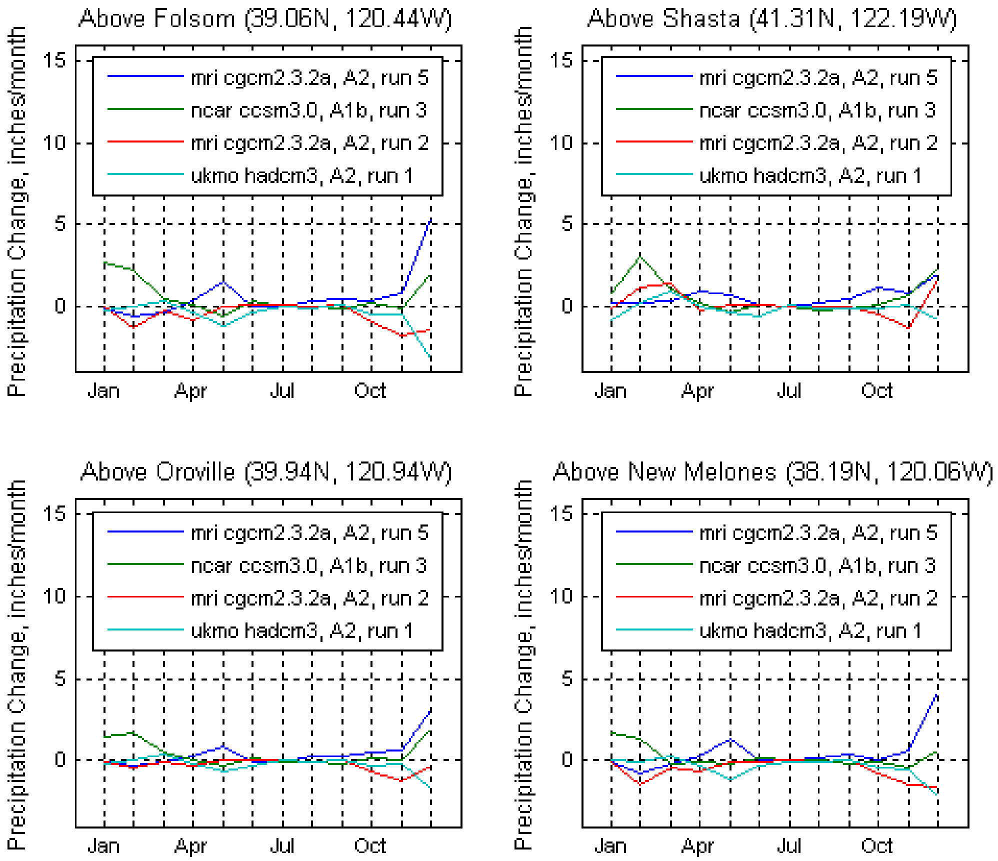


Figure 16. **Change in mean monthly precipitation, from 1971-2000 to 2011-2040, for each of the OCAP climate projections, at 4 Central Valley locations: near Sacramento, Above Lake Shasta, Above Lake Oroville, and Above New Melones reservoir.**
Note: legend labels list {climate model, emissions path, and run #} corresponding to OCAP climate projections 1 through 4, respectively.

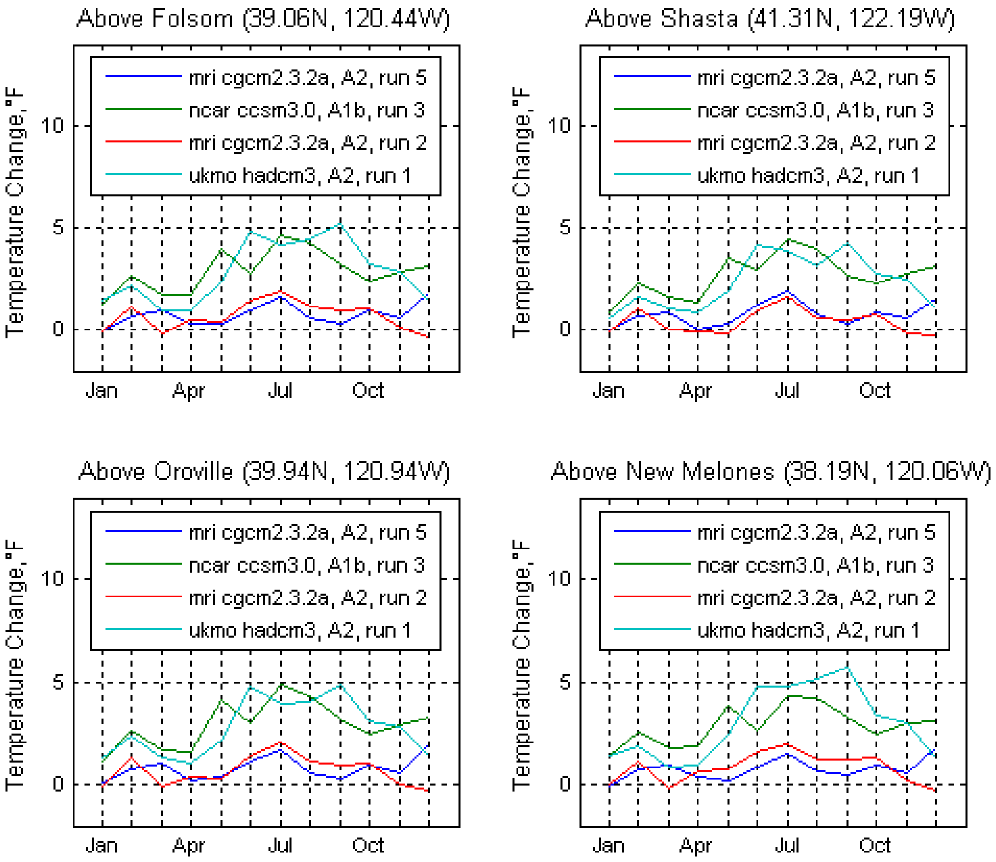


Figure 17. **Same as Figure 13, but showing changes in mean monthly temperature.**
Note: legend labels list {climate model, emissions path, and run #} corresponding to OCAP climate projections 1 through 4, respectively.

2.3 Developing Sea Level Rise Assumptions

2.3.1 Available Sea Level Projection Information: Sea level conditions at the Golden Gate determine water level and salinity conditions in the San Francisco Bay and upstream Sacramento-San Joaquin Delta. The IPCC AR4 report from Working Group I (Chapter 10, "Sea Level Change in the 21st Century" (IPCC 2007)) provides projections of global average sea level rise that primarily represent thermal expansion associated with CMIP3 global air temperature projections, and not the full potential of ice melting effects on sea level rise (e.g., glaciers, polar ice caps). Given this context, inspection of Figure 10.31 in IPCC 2007 suggests a global average sea level rise of approximately 3 to 10 cm (or 1 to 4 inches) by roughly 2035 relative to 1980-1999 conditions. These projections are based on CMIP3 models' simulation of ocean response to atmospheric warming under a collection of GHG emissions paths. The report goes on to discuss local deviations from global average sea level rise due to effects of ocean density and circulation change. Inspection of Figure 10.32 in IPCC 2007 suggests that sea level rise near California's Golden Gate should be close to the global average rise, based on CMIP3 climate projections associated with the A1b emissions path.

As noted, the CMIP3 models do not fully account for potential ice melt in their sea level rise calculations, and therefore miss a major source of sea level rise. Meehl et al. (2007) note that further accelerations in ice flow of the kind recently observed in some Greenland outlet glaciers and West Antarctic ice streams could substantially increase the contribution from the ice sheets, a possibility not reflected in the CMIP3 projections. Further, the sea level data associated with direct CMIP3 output on sea level rise are potentially unreliable due to elevation datum issues (*M. Tyree, personal communication, 4/21/2008*). A separate approach for estimating global sea level rise (Rahmstorf et al. 2007a) uses the observed linear relation between rates of change of global surface air temperature and sea level, along with projected changes in global surface air temperature, to predict future sea-level rise. This approach is being used to estimate global sea level rise for the 2008 BSR update, associated with the "CA Scenarios 2008" global temperature projections (*D. Cayan, personal communication, 2/6/2008*). Figure 2 in Rahmstorf et al. 2007a illustrates application of the approach, translating air temperature projections from the IPCC Third Assessment Report, or AR3 (IPCC 2001) into predicted global sea level rise ranges between 20 and 30 cm by roughly 2030 (i.e. about 8 to 12 inches). The range of predicted sea level rise from AR3 temperature projections may still be relevant using AR4 air temperature projections, given that the latter's range is still comparable to the ~2030 range in AR3 (i.e. Figure SPM-5 in IPCC 2001 (AR3) suggests a range of projected global temperature increases by 2030 of roughly 0.6 to 1.9 ºC; Figure SPM-5 in IPCC 2007 (AR4) suggests an increase by 2030 of roughly 0.7 to 1.6 ºC). To the extent that the ice melting mechanism is present in the historical record, Rahmstorf et al. 2007a, accounts for it, albeit imperfectly and with a very simplified model (*D. Cayan, personal communication, 4/21/2008*). In response to questions about approach and significance of findings (Schmith et al. 2007 and Holgate et al. 2007), Rahmstorf et al.

2007b showed that the semiempirical method for projecting future sea-level rise supports conclusions that are robust with respect to choices of data binning, smoothing, and detrending. Rahmstorf et al. 2007b also addressed the concern that Rahmstorf et al. 2007a showed "nonsense correlations" without causal basis, saying that the starting point of the original analysis was not a correlation found between sea level and global surface air temperature data, but rather a physical reasoning that there should be a proportional relationship between global temperature change and sea-level change, to first order approximation, which is supported by Rahmstorf et al. 2007a.

2.3.2 Scenario Sea Level Rise affecting Delta Conditions: For this OCAP BA, assumptions are made about sea level conditions at the Golden Gate by 2030. Assumptions are meant to represent a reasonable increment of rise that might be anticipated, and translated into upstream Delta water level and salinity conditions. The information summarized in Section 2.3.1 informs these assumptions. The *availability* of model-applications representing sea level effects on the Delta, necessary CVP/SWP operations and Delta hydrodynamic analyses (Section 3.0), *limits* what assumptions can be made.

On the latter, DWR had developed (as of April 2008) draft sets of Delta model applications adjusted for sea level rise, with each set representing a scenario increment of potential sea level rise. The applications also featured a 10% increase in tidal range, similar to assumptions made in supporting analyses for DWR's development of Delta Risk Management Strategy (URS-Benjamin 2007). For this study, based on information provided in Section 2.3.1, it was decided that DWR's model-applications representing a 1-foot sea level rise increment were most appropriate for representing potential 2030 sea level rise (emphasizing information from Rahmstorf et al. 2007a). The associated model-applications included: (1) an adjusted version of the Delta hydrodynamic simulation model (DSM2, described in Appendix F), and (2) a developed version of the computationally efficient DSM2-emulator of Delta outflow and salinity conditions at various Delta regulatory compliance points, necessary for CVP/SWP operations modeling (Section 3.4.2).

Note that it would be ideal to apply Rahmstorf et al. 2007a individually to the four climate projections associated with selections in 2.2.4, and to thereby develop unique sea level rise assumptions associated with each projection. However, lack of available Delta model-applications capable of reflecting these assumptions prevented consideration of such an approach for this study. Therefore, a common sea level rise assumption is paired with each of the climate projections listed in Section 2.2.4.

Chapter 11 3.0 METHODOLOGY FOR SCENARIO-SPECIFIC ANALYSIS OF RUNOFF, OPERATIONS, AND OPERATIONS-DEPENDENT RESPONSES

Using the climate projection and sea level rise assumptions defined in Section 2, this study follows a scenario-specific analytical method similar to Maurer 2007 and Anderson et al. 2008. Figure 18 offers a generalized view of that analytical method, which involves four steps:

- (Step 1) Obtain downscaled climate projections data and decide on which aspects of the climate projection to relate to natural systems, social systems, and operational responses (step 1b).

- (Step 2) Translate climate projection information into responses for the targeted natural systems, social systems, and constraints on operations.

- (Step 3) Simulate operations and operations-dependent responses to adjusted natural systems, social systems, and constraints on operations.

- (Step 4) Summarize results, uncertainties, and limitations of interpretation.

For this study, the generalized method of Figure 18 was tailored in several ways:

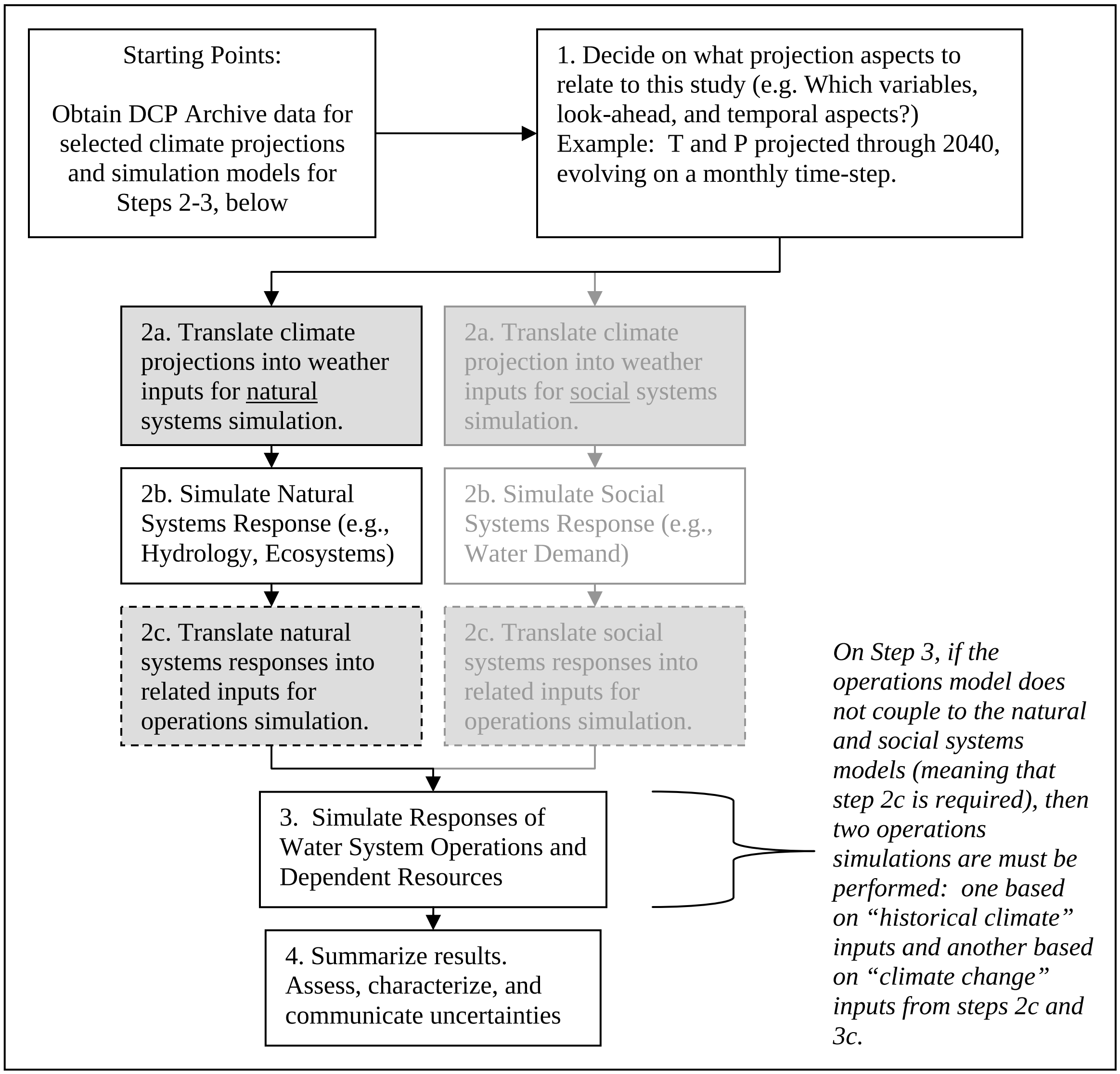
- (Step 1) Obtain downscaled climate projections data and *decision to relate monthly evolving climate (T and P conditions) to monthly evolving runoff response*.

- (Step 2) Relate climate projection information from Step 1 to *responses in natural runoff in headwater basins tributary to major CVP/SWP reservoirs, highlighting climate change impacts on CVP/SWP water supply*.

- (Step 3) Simulate *CVP/SWP operations, Delta water flows and velocities relevant to the OCAP BA, and water temperatures of CVP/SWP reservoirs and downstream river reaches relevant to the OCAP BA.*

- (Step 4) Summarize results, uncertainties, and limitations of interpretation.

Table 3 provides references for method decisions at each analytical step, and a summary of how these decisions compare to those featured in DWR 2006. The following sections provide additional discussion on methods decisions. A summary of all simulations conducted in this sensitivity analysis, for each analytical step, is provided in Section 3.7.



On Step 3, if the operations model does not couple to the natural and social systems models (meaning that step 2c is required), then two operations simulations are must be performed: one based on "historical climate" inputs and another based on "climate change" inputs from steps 2c and 3c.

Figure 18. Generalized Analytical Sequence for Scenario-Specific Impact Analysis
The sequence is tailored for a given study analysis (e.g., this sensitivity analysis for the OCAP BA). The sequence may include analyses of natural systems, social systems, operations, and operations-dependent responses to climate change. *This* sensitivity analysis focuses on responses for natural runoff (i.e. surface water supply), reservoir operations, and several operations-dependent responses (delta channel flows and velocities, and tributary reservoir and river water temperatures).

Table 3. Method Decisions for Projection-Specific Analysis

Analytical Step	Consistency with DWR 2006	Reference
Step 1a) Obtain Climate Projections Data, Bias-Corrected and Downscaled		
Method: Bias-Correction Spatial Disaggregation method (BCSD)	Same	Wood et al. 2002; Wood et al. 2004
Step 2) Headwater Runoff Analysis		
Natural Runoff Model Choice(s): (1) Central Valley application of the Variable Infiltration Capacity (VIC) model; and (2) NOAA-NWS CA-NV River Forecast Center applications of the Sacramento-Soil Moisture Accounting Model coupled to Snow17 (SacSMA/Snow17) for nine headwater basins listed in Table 4.	Inclusive. DWR 2006 was supported by VIC.	VIC: Liang et al. 1994; Maurer 2007 SacSMA/Snow17: Burnash et al. 1973; Anderson et al. 1973
Translating Climate Projections into Weather Inputs for Headwater Runoff Simulation: Temporal disaggregation technique (Maurer 2007) that involves randomly selecting and scaling historical weather months to match the projected month's mean T and total P condition. Historical data is model specific (i.e. observed meteorology structured for either the VIC or SacSMA/Snow17).	Same	Maurer 2007
Step 3) CVP/SWP Operations and Dependent Resources Analyses		
CVP/SWP Operations - Model Choice: CalSim II "future" level of development study with one regulatory condition (D1641), defined in Chapter 9**.**	Same, except for model refinements and assumption updates that have occurred since preparation of DWR 2006, and modifications to account for sea level rise.	CalSim II: Draper et al. 2004, Appendix D
Translating Headwater Runoff Response into "Runoff-related" Inputs for Operations Simulation: Streamflow Perturbation Method.	Same, except for one refinement to account for how monthly "natural" runoff response information is being used to adjusted monthly "impaired inflows" for CalSim II [4].	Perterbation Method: Anderson et al. 2007
Delta Channel Flows and Velocities - Model Choice: DSM2	Same, except for model refinements that have occurred since development of DWR 2006 and changes in downstream boundary condition to reflect one-foot sea level rise [5].	Appendix F
Reservoir and River Water Temperature - Model Choice: Reclamation Temperature SRWQM and USBR Models	Same [6].	Appendix H

3.1 Climate Projections Downscaling Methodology

Table 3 references the Bias-Correction Spatial Disaggregation (BCSD) as the downscaling methodology used to produce DCP archive data and regional climate projections selected for this study (Section 2.2.4). By definition, downscaling is the process of taking global climate model output on simulated climate, and translating that to a finer spatial scale that is more meaningful for analyzing local and regional climate conditions. Many downscaling methods have been developed, all of which have strengths and weaknesses. Several reports offer discussion on the various methodologies, notably the IPCC Fourth Assessment (IPCC 2007, Chapter 11, Regional Climate Projections) and Wigley, 2004. The various methodologies might be classified into two classes: dynamical, where a fine scale regional climate model (RCM) with a better representation of local terrain simulates climate processes over the region of interest; and, statistical, where large scale climate features are statistically related to fine scale climate for the region.

To date, there has not been a demonstration of using dynamical downscaling to produce a dataset as comprehensive as the DCP archive (in terms of geography, variables, projections and projected years represented). While there are new efforts to downscale multiple climate projections using multiple RCMs, such as the North American Regional Climate Change Assessment Program (NARCCAP, http://www.narccap.ucar.edu/), the computational requirements of RCM implementation for more than a few years of simulation have limited the feasibility of using dynamical downscaling to produce a dataset like the DCP archive.

Among the various statistical methods that might be considered to produce such an archive, certain characteristics are desirable:

- well tested and documented, especially in applications in the U.S.
- automated and efficient enough to feasibly permit downscaling of many 21st century climate projections, thereby permitting more comprehensive assessments of downscaled climate projection uncertainty.
- able to produce output that statistically matches observations for a historical period.
- capable of producing spatially continuous, fine-scale gridded output of precipitation and temperature suitable for water resources and other watershed-scale impacts analysis.

While there are many statistical techniques available (IPCC 2007, Wigley 2004), only the Bias-Correction and Spatial Disaggregation (BCSD) approach of Wood et al. (2004) met all of these criteria, which led to its selection as downscaling methodology for DCP development (http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/#Limitations).

Compared to dynamical downscaling approaches, the BCSD method has been shown to provide downscaling capabilities comparable to other statistical and dynamical methods in the context of hydrologic impacts (Wood et al., 2004). However, dynamical downscaling has also been shown to identify some local climate effects and land-surface feedbacks that BCSD cannot readily identify (Salathé et al. 2007). Another potential limitation of BCSD, like any statistical downscaling method, is the assumption of some stationarity. In the case of BCSD, the assumption is made that the relationship between large-scale precipitation and temperature and fine-scale precipitation and temperature in the future will be the same as in the past. For example, the processes determining how precipitation and temperature anomalies for any 2 degree grid box are distributed within that grid box are assumed to govern in the future as well. A second assumption included in the bias-correction step of the BCSD method is that any biases exhibited by a GCM for the historical period will also be exhibited in future simulations. Tests of these assumptions, using historic data, show that they appear to be reasonable, inasmuch as the BCSD method compares favorably to other downscaling methods (Wood et al, 2004).

Several of the impacts assessments listed in Section 1.3 involved the use of BCSD to downscale climate projection information prior to runoff analysis (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, and Maurer 2007). DWR 2006 also relied on downscaled climate projections information produced using the BCSD methodology. It's noted that the 2008 BSR update is producing such information using two techniques (http://meteora.ucsd.edu/cap/scen08_data.html): BCSD and "Constructed Analogues" (CA) (Hidalgo et al., 2008). A recent comparison of the methods (Maurer and Hidalgo, 2008) showed that results are not significantly different when the methods are used to develop monthly time series T and P projections. Given that this study is focused on monthly climate projection aspects and monthly runoff and operational responses, it was decided that the BCSD-derived downscaled data is sufficient for OCAP purposes.

3.2 Decisions on which Natural and Social System Responses to Analyze

Quantitative assessment of natural runoff and surface water supply response to each climate projection was supported by the availability of runoff models and well documented methodologies for translating downscaled climate projection into runoff responses (Section 1.3). Other than the Delta model-applications developed to represent sea level rise increments (Section 2.3.2), no other quantitative analyses were performed for other natural systems. This was due to data limitations and/or uncertainties about methodology. For example, watershed ecosystem and land cover response to climate change, and the related affect on hydrologic processes like infiltration and evapotranspiration (ET) might have been considered given well-established tools and methods.

For social system response, several changes might be anticipated, including shifts in societal values on flood protection (related to CVP/SWP flood control rules), environmental management (related to CVP/SWP operational objectives to support river and Delta environmental conditions), and district-level water and power demands (related to CVP/SWP monthly release patterns as discretion permits). Consideration was given to adjusting water demand assumptions for the operations analysis, given that a warming climate might be expected to increase crop water needs through increased ET potential (e.g., Hidalgo et al. 2005). However, such an analysis performed at district-level depends on understanding future cropping choices and expected trends in demand management. It is recognized that at the district-level, flexibility exists that could offset field- and crop-specific increases in water needs associated with warmer temperatures, enough so that district-level demand doesn't necessarily change. Given that the CVP/SWP operations analyses in this study are preformed with district-level water demands used as inputs, a decision was made to hold demands constant for this sensitivity analysis.

3.3 Natural Runoff Analysis – Basins, Models, and Weather Generation

3.3.1 Basins and Runoff Model Choices: As indicated in Table 3, two available runoff model-applications are used in this study to relate climate projections to natural runoff response in the nine Sierra Nevada headwater basins listed in Table 4. The nine basins in Table 4 were chosen to represent natural runoff responses in basins tributary to lower CVP/SWP reservoirs because they contain relatively less impairments than other Sierra Nevada headwater basins, and are therefore more desirable for providing a natural runoff response signal to a changing climate.

Table 4. Headwater Basins evaluated for Natural Runoff Response

Basin I.D.[1]	**Basin Outflow Description**[1]	**Elevation**[2] **(m)**	**Area (km^2)**	**Outflow Latitude**	**Outflow Longitude**
CEGC1	Trinity at Claire Engle Reservoir	1510	1750	40.80	-122.76
DLTC1	Sacramento at Delta	1248	1080	40.94	-122.42
FRAC1	San Joaquin at Friant Dam	2168	4140	37.00	-119.69
HETC1	Tuolumne at Hetch Hetchy Dam	1852	1210	37.95	-119.79
MRMC1[3]	Middle Fork Feather at Merrimac	1581	2770	39.71	-121.27
NBBC1[3]	North Yuba at New Bullards Bar Dam	1485	1260	39.39	-121.14
NFDC1	North Fork American at North Fork Dam	1307	890	38.94	-121.01
NMSC1	Stanislaus at New Melones Dam	1714	2370	37.96	-120.52
POHC1[3]	Merced at Pohono Bridge	2581	830	37.72	-119.67

Notes:

1. I.D. and Description from National Weather Service California-Nevada River Forecast Center.
2. Elevation represents basin area-average above mean sea level.
3. Runoff from upstream MFTC1 is routed through MRMC1, runoff from upstream GYRC1 is routed through NBBC1, and runoff from HPIC1 is routed through POHC1.

In this case, model-application *availability* was defined as (1) having chosen a runoff model type (e.g., VIC, SacSMA/Snow17), (2) having applied the model type to the regional setting (i.e. to the Central Valley watershed or just headwater subbasins of interest, and (3) having verified the application through model calibration. The two chosen available applications have been applied recently to support studies on climate change implications for Central Valley water resources (i.e. VIC used in support of DWR 2006 and Maurer 2007; SacSMA/Snow17 support of Miller et al. 2003, Brekke et al. 2004, Zhu et al. 2005, and Brekke et al. 2008b). Given that preference between these two tools has not been demonstrated, it was decided to conduct parallel runoff analyses using both, and to judge how crucial runoff model choice is in the analytical design based on comparison of results. This comparison determined the decision on whether subsequent analyses would be based on one or both runoff models' sets of results (Section 4.1).

Excluding application considerations, the two runoff models are structurally consistent in that they depict an evolving water balance through time, where accumulated precipitation eventually leaves the watershed as either runoff or ET (assuming that the model is applied such that deep percolation losses are not simulated). There are some "structural" differences. The VIC model is "forced" by four weather inputs (assuming daily time step of simulation): daily minimum air temperature, daily maximum air temperature, precipitation, and wind speed. In comparison, a SacSMA/Snow17 model is forced by two weather inputs: temperature and precipitation. Treatment of potential ET also differs between the two models. VIC computes potential ET based on weather inputs while the SacSMA/Snow17 is designed to be forced by pre-computed ET that are consistent with the temperature and precipitation inputs. Finally, the models also simulate distributed soil moisture conditions using different spatial resolution of the subsurface (SacSMA/Snow17 disaggregates soil moisture between more "buckets").

Focusing on the model applications, there are some additional differences to note. The VIC application simulates runoff on a daily time-step, and was developed as described in Van Rheenan et al. 2004 and Maurer 2007, based on historical stream gage data and station weather observations aggregated to a *1/8º spatial grid*. The SacSMA/Snow17 basin-specific applications simulate runoff on a 6-hourly time-step, and were developed by the National Weather Service California-Nevada River Forecast Center, based on historical stream gage data and station weather observations aggregated to *topographically-defined basin subareas* (e.g. elevation-dependent lower, middle, and upper areas of a given basin). Consequently, the Central Valley VIC application and SacSMA/Snow17 applications compute water balances over time for *different spatial elements* (Figure 19) and require weather inputs to be developed consistent with these spatial elements. Given the different spatial disaggregation of the Central Valley watershed, the runoff results from the two models for a common sub-basin assessed at a desired stream location would be expected to differ slightly.

3.3.2 Generating Input Weather Sequences: Both of the chosen runoff models simulate watershed processes at daily timesteps or shorter, which contrasts with the monthly timestep of the chosen climate projections. This sets up the need to generate weather sequences consistent with the runoff model input timestep and also, in monthly aggregate, consistent with the monthly climate projections. As an alternative, it might be reasoned that daily weather sequences provided by GCMs might be used to provide this sequencing because GCMs simulate atmospheric conditions on sub-hourly timesteps. However, such GCM "weather sequences" are not appropriate for this application because they are only consistent with the GCM's view of the land surface, which is spatially very coarse, homogeneous within GCM spatial elements (i.e. grid cells being ~100 x 100 miles square), and does not include important topographic controls on local-scale weather.

To represent the monthly evolving T and P conditions associated with the selected climate projections, sequences of daily weather and 6-hourly weather were developed for the VIC and SacSMA/Snow17 model applications, consistent with the simulation timestep of each application, respectively. The 1971-2040 period is of interest because it contains both the base and future periods used for climate projection selection (Section 2.2.2), and because period-to-period changes in simulated natural runoff are used to adjust reservoir inflow inputs for the CVP/SWP operations analysis (Section 3.4.1).

The method for generating weather sequences (Maurer 2007) involves:

- progressing through the simulated monthly climate time series, month by month from January 1971 through December 2040, and associating a randomly selected historical observed month with a given projection month,

- adjusting temperature and precipitation data from the randomly selected historical observed month (spatially reconciled with the given runoff model) to match the month-aggregate temperature and precipitation from the simulated climate month.

To illustrate, consider generating weather for the VIC model for a given climate projection’s January 2031. This involves developing daily weather for four inputs (daily minimum air temperature, daily maximum air temperature, precipitation and wind speed). Assume that January 1979 was randomly selected as the historical observed month to associate with January 2031, simply to provide a sequence of weather variability. The weather *sequence* of January 2031 is assumed to be the same as the sequence from January 1979 aggregated to VIC’s spatial structure, but with the two air temperature variables uniformly *shifted* in the month so that they’re combined monthly average matches that of January 2031, and with the precipitation sequence uniformly *scaled* so that it sums to the monthly total of January 2031. The sequence of associated wind speed would be the unchanged. Similarly, consider generating weather for the SacSMA/Snow17 for the same projection’s January 2031. This involves developing 6-hourly weather for two inputs (temperature and precipitation). The weather sequence of January 2031 is assumed to be the same as the sequence from January 1979 aggregated to SacSMA/Snow17’s spatial structure, but with the same temperature-shifting and precipitation-scaling performed, as described above.

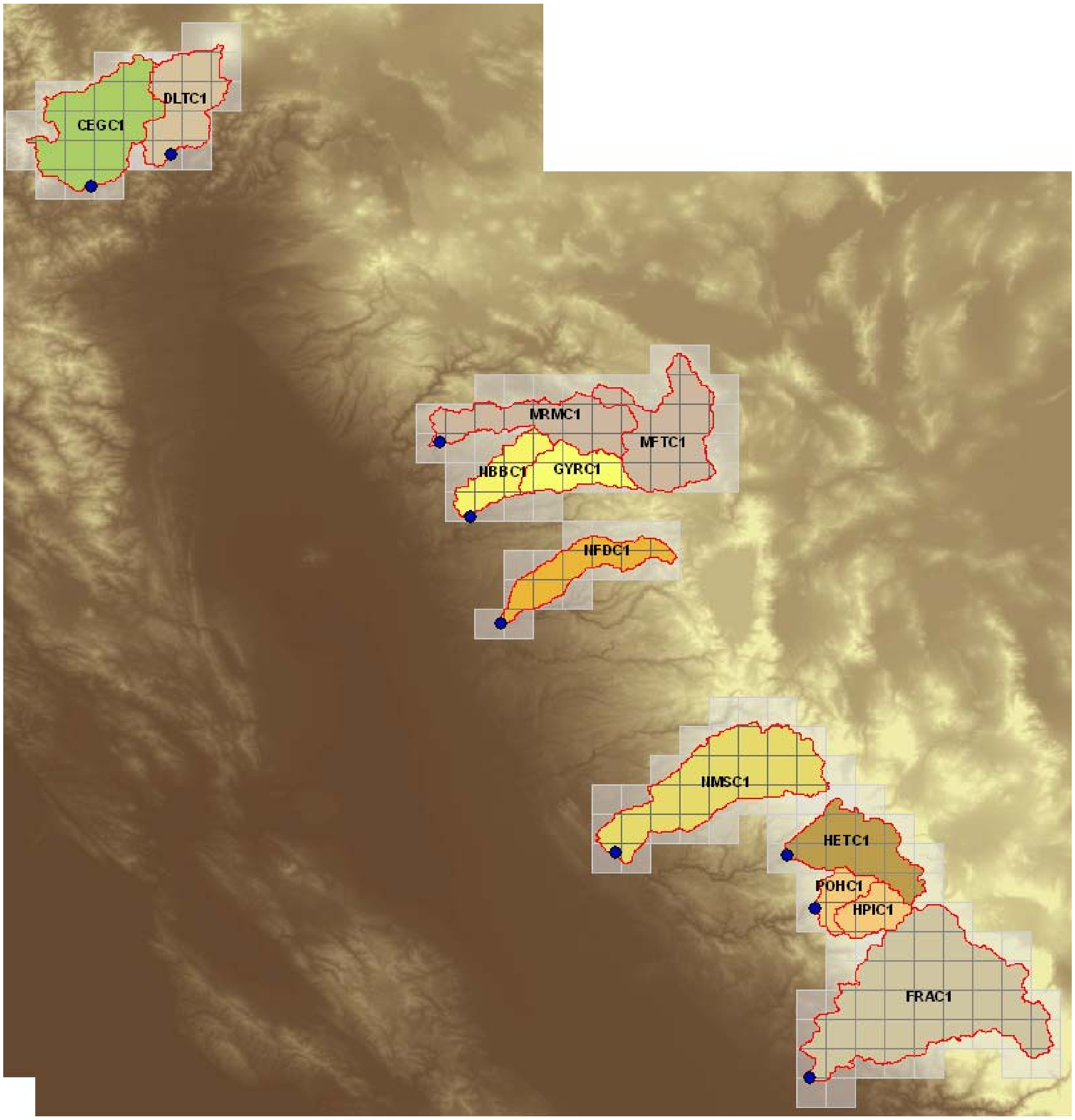


Figure 19. Basins analyzed in Natural Runoff Response Analysis.
Red basin outlines correspond to SacSMA/Snow17 basin-specific model applications (with basin identifier labels shown (Table 4)). Gridded overlay indicates the Central Valley VIC applications grid cells, and show the intersection of spatial structures between the two model-applications.

One final note on the weather sequence generation methodology: the sequence of generated weather from 1971-2040 will always aggregate to the same monthly time series for T and P. However, the sub-monthly characteristics will differ and depend on the random-sequencing of associated historically observed months. This sequence changes if the exercise is repeated. Preliminary runoff simulations showed that consideration of multiple weather sequences consistent with a given monthly climate projection can introduce some uncertainty in the assessed runoff response. Consequently, a decision was made to repeat weather generation 30 times for each climate projection and runoff-model combination to reveal central tendency in runoff response in relation to the uncertainty introduced by this weather generation methodology.

3.4 CVP/SWP Operations Analysis – Water Supply and Delta Adjustments

CVP/SWP operations are simulated using a version of CalSim II derived from OCAP BA as “Study 8” (Chapter 9), but set up to simulate only the D1641 regulatory constraints on CVP/SWP operations and not other regulatory overlays. Following the OCAP BA naming convention for CalSim II studies, this “D1641 Standalone” study is labeled “Study 9.0.” Study variants reflecting sea level rise and regional climate change are listed as follows:

- Study 9.0 – Base climate, and no sea level rise
- Study 9.1 – Base climate, with sea level rise
- Study 9.2 – Projection #1 “Wetter, Less Warming” climate with sea level rise
- Study 9.3 – Projection #2 “Wetter, More Warming” climate with sea level rise
- Study 9.4 – Projection #3 “Drier, Less Warming” climate with sea level rise
- Study 9.5 – Projection #4 “Drier, More Warming” climate with sea level rise

The purpose of Study 9.1 is to offer information on the impact of sea level rise on the OCAP future operational baseline depiction before overlaying the additional impact of regional climate change. Also, as will be discussed in Section 4.1, only natural runoff response information produced using the SacSMA/Snow17 runoff model was used to prepare CalSim II Studies 9.2-9.5. The remainder of this section explains how water supply adjustments related to regional climate change and Delta adjustments related to sea level rise were represented in the CalSim II studies.

3.4.1 Adjusting Surface Water Supply inputs in CalSim II based on results from the Natural Runoff Analysis: Adjustments are made to three types of inputs related to CVP/SWP surface water supply in CalSim II: (1) monthly reservoir inflows, (2) hydrologic year-type classifications that constrain operations, and (3) seasonal water supply forecast data that constrain annual delivery allocations in a given simulation year. All three types of inputs have “base” sequences consistent with the 1922-2003 hydroclimate represented in Study 9.0. These sequences were preserved for study comparison purposes, and scaled to reflect mean-monthly effects of regional climate change on water supply.

Reservoir inflows were addressed first. They were adjusted so that they are consistent with period-mean changes in natural runoff in associated tributary basins. Subsequently, hydrologic year-types are reclassified for the climate-adjusted inflow sequence, using the context of historical relations between year-types and inflows. Likewise, seasonal water supply forecast data are adjusted consistent with historical relations between forecasts and inflows.

The method for adjusting reservoir inflows is influenced by the fact that *natural* runoff responses to climate change in headwater basins are being used to adjust *impaired* CalSim II inflow variables at lower elevations. The latter inflow variables are situated at a lower elevation reservoir and reflect upstream impairments that are significant at the monthly time scale for some CVP/SWP tributaries. These impairments are introduced by the upstream reservoir operations of water utilities and hydropower generation entities. The system storage capacities of these entities are generally small enough such that these impairments primarily influence monthly runoff patterns and with generally minor influence on annual runoff amount. Preferably, the response of upstream impairments to climate change would be simulated as part of the preparation of CalSim II inflows. However, information on how those impairments would adjust under climate change was not available for this study. Given this limitation, the following approach is taken:

- Establish consistency between period-mean *annual* changes in CalSim II “impaired reservoir inflow” and tributary “natural runoff” based on subjective headwater response assignment to the lower elevation inflow variables (Table 5).

- To the extent possible, preserve consistency between the period-mean *monthly* changes in “impaired reservoir inflow” and tributary “natural runoff.”

The mechanics of the approach start on a monthly basis. For a given reservoir inflow variables, the sequence of monthly impaired inflows is considered one month at a time. For a given month, all of the inflows for that month during the simulation sequence (e.g., all Januarys) are scaled by the month’s corresponding period mean *ratio* change in natural runoff within an assigned headwater tributary basin (Table 5). Table 5 shows how headwater tributary basins were assigned to CalSim II inflow variables. Sometimes multiple headwater basins were used to adjust a given CalSim II inflow variable, in which case a subjectively weighted average change-ratio was computed from the change-ratios of each assigned multiple headwater basin (e.g., adjustment to CalSim II inflow variable I200 “Kelly Ridge” is based on the monthly change-ratios computed as the weighted average of MRMC1 “Middle Fork Feather River” (50% weighted) and NBBC1 “North Yuba at New Bullards Dam” (50% weighted)). The subjective weights are generally based on geographic proximity. When multiple basins are assigned, the weights sum to 100% (i.e. sum across rows in Table 5 equals 100%). This month-specific scaling is then repeated for all calendar months, producing an adjusted reservoir inflow sequence that represents mean-monthly changes in natural runoff. To this point in the methodology, the approach is consistent with that used for adjusting CalSim II reservoir inflows in Brekke et al. 2004, DWR 2006, and Anderson et al. 2008. The approach then changes by introducing a second and final scaling, this time using period mean ratio changes in *annual* natural runoff from the assigned headwater basin(s). These ratios are used to rescale the entire reservoir inflow sequence so that the ratio of its full-period mean, climate change versus unadjusted, equals the ratio change in annual natural runoff.

The second scaling is necessary to preserve consistency between long-term mean annual changes in “impaired reservoir inflow” and tributary “natural runoff.” If adjustments stop after just the month-specific scaling, then mean annual changes in the CalSim II reservoir inflow variable won’t be consistent because the mean annual natural runoff change in tributary basins because monthly natural flow changes were applied to monthly impaired inflow patterns.

After preparing monthly reservoir inflow time series for all inflow variables, consistent with a given climate projection and natural runoff response, subsequent adjustments are made to CalSim II inputs for hydrologic year-types under the various classification systems used in CalSim II. Adjustments were made so that relations between historical year-type classifications and historical inflows were preserved. The result is that the proportional split of classified drier to wetter year-types will change as the climate changes. Likewise, adjustments are made to CalSim II inputs on “seasonal water supply forecast data” which represent water supply forecasts informing the CalSim II simulation during January through May months, and used for establishing annual water delivery targets for the CVP and SWP systems each year of simulation. Adjustments were made so that relations between historical forecast data and historical inflows were preserved.

Table 5. Assignment of Headwater Basin Responses to CalSim II Inflow Variables for making Climate Change Scenario Inflow Adjustments

Assignment (%)	**Basins listed in Table 4**								
CalSim II Inflow Variable	**CEGC1 (Trin.)**	**DLTC1 (Sac.)**	**FRAC1 (San J.)**	**HETC1 (Tuol.)**	**MRMC1 (M Fea.)**	**NBBC1 (N Yub)**	**NFDC1 (N Am.)**	**NMSC1 (Stan.)**	**POHC1 (Merc.)**
I1 (Trinity)	100%								
I10 (New Melones)								100%	
I18 (Millerton)			100%						
I20 (Exchequer)									100%
I200 (Kelly Ridge)					50%	50%			
I230 (Yuba)						100%			
I285 (Bear)						40%	60%		
I3 (Clear Creek)	100%								
I300 (Folsom)							100%		
I4 (Shasta)		100%							
I501 (Cosumnes)							70%	30%	
I52 (Fresno)			80%						20%
I53 (Chowchilla)			75%						25%
I6 (Oroville)					100%				
I8 (Folsom Local)							100%		
I81 (Tuolumne)				100%					
I90 (Mokelumne)							40%	60%	
I92 (Calaveras)							25%	75%	

3.4.2 CalSim II Delta Representation of Sea Level Rise assumptions: Sea level rise (SLR) assumptions were outlined in Section 2.3.2 (i.e. 1-foot SLR and 10% increase in tidal range, representing potential conditions by 2030). CalSim II represents sea level in how it represents Delta conditions and their constraints on CVP/SWP operations. The complexity of Delta hydrodynamics and salinity distribution are represented in CalSim II using a computationally efficient DSM2-emulator (Section 2.3.2, and Appendix D). Development of this emulator is described in OCAP Section and is labeled here as the Delta-ANN (Artificial Neural Network) module.

CalSim II Study 9.0 features a Delta-ANN module representing "current" sea level constraints on the Delta. Studies 9.1-9.5 feature the draft Delta-ANN developed by DWR, representing SLR assumptions listed above. Use of the Delta-ANN with SLR necessitated adjustment to CalSim II logic linking X2 assessment and constraint on upstream operations (i.e. how the location of the X2-defined salinity isohaline upstream of the Golden Gate changes and triggers different upstream operating decisions). Given SLR affecting X2 position and assessment, the Delta-ANN with SLR was used in Studies 9.1-9.5 to assess X2 during simulation in place of the X2 logic in the Study 9.0.

3.5 Delta Flows and Velocities Analysis – Setup Considerations

Delta simulations of channel flows and velocities are simulated using DSM2 (Appendix F) and constrained by delta inflows and exports as simulated in CalSim II. The procedure used in the other OCAP studies to transfer CalSim II simulation output into DSM2 input were preserved in this sensitivity analysis. Five DSM2 simulations were considered in this sensitivity analysis: a base simulation reflecting no SLR or upstream climate change, and four additional simulations corresponding to four different upstream climate projections combined with a one-foot SLR and 10% increase in tidal range (Sections 2.2.4 and 2.3.2, respectively). DSM2 boundary conditions were adjusted to reflect the same SLR assumption represented in development of the Delta-ANN with SLR used for CalSim II Studies 9.1-9.5.

3.6 Reservoir and River Water Temperatures Analyses – Input Adjustments

The Reclamation water temperature and salmon mortality models for the Trinity, Sacramento, Feather, American, and Stanislaus Rivers and water temperature models for upstream reservoirs (Trinity Reservoir, Lake Shasta, Lake Oroville, Folsom Lake, and New Melones) are described in Appendix H. The procedure used in the other OCAP studies to transfer CalSim II simulation output into water temperature models input was preserved in this sensitivity analysis. However, two types of water temperature modeling inputs related to air temperature were adjusted to be consistent with projected changes in air temperature:

- air temperature time series applied to downstream river reaches, determining river water-surface heating and demand for upstream release of reservoir “cold water”.

- reservoir inflow water temperature, estimated monthly. (Note: The two hydrologic models used in this study do not calculate water temperature, therefore necessitating the assumed changes in reservoir inflow.)

The river and reservoir water temperature models are packaged with a time series sequence of air temperatures at various Central Valley locations, where the sequence is consistent with hydroclimate sequence in CalSim II Study 9.0. To reflect air temperature adjustments consistent with the manner of water supply adjustments for CalSim II, mean-monthly temperature changes are imposed on the “base” sequence. This was done by identifying incremental mean-monthly changes in air temperature from 1971-2000 to 2011-2040. on a location-basis using air temperature (T_{air}) data obtained from the DCP archive for the four climate projections considered (Section 2.2.4), and shifting the base air temperature sequence by these increments, by location, on a month-specific basis. For example, Red Bluff is one of the location-based air temperatures constraining Sacramento River water temperature simulation. Consider DCP archive data at Red Bluff for simulated T_{air} in Projection 1 (i.e. the “Wetter, More Warming” projection produced by climate model “ncar ccsm3.0” simulating emissions path A1b, run 5). The change in mean-July T from 1971-2000 to 2011-2040 is 1.0 ºC (1.8 ºF). The increment of 1.0 ºC (1.8 ºF) was then added to all July time-step Red Bluff air temperatures in the base sequence to create a sequence consistent with the July temperature change associated with Projection 1.

Reservoir inflow water temperatures are expected to reflect several influences of air temperature change: (1) different blend of rain and snow affecting the mix and time-average temperature of rainfall-runoff and snowmelt-runoff, and (2) different temperature of groundwater affecting the temperature contribution from baseflow. For (1), it was assumed that the blended water temperature of surface runoff from both rainfall and snowmelt origins would change by an increment equal to period-mean annual air temperature change from 1971-2000 to 2011-2040. For (2), it was assumed that all baseflow water temperature would also change by this increment. Both assumptions would seem to reflect upper-limit possibilities of inflow temperature change. For (1), snowmelt-runoff temperature is not likely to change significantly, so the change in air temperature would only affect the portion originating from rainfall-runoff. For (2), there would seem to be a time-lag in groundwater temperature response to surface air temperature increase, which is not reflected in the assumption. Following these assumptions and rationale, T_{air} data were obtained from the DCP archive at locations upstream of the five reservoirs modeled (Trinity Reservoir, Lake Shasta, Lake Oroville, Folsom Lake, and New Melones). Inflow water temperature inputs of the unadjusted water temperature models were then uniformly adjusted, on a projection-specific basis, by the period-mean annual change in T_{air} from 1971-2000 to 2011-2040.

3.7 Summary of Studies

Table 6 provides a list of analytical steps and studies conducted in this sensitivity analysis. A set of “base” studies (CalSim II, DSM2, and water temperature models) are listed and provide a point of reference for interpreting climate change and sea level rise effects on CVP/SWP operations and dependent resources. For headwater runoff analyses, parallel sets of studies are conducted for each runoff model-application option, however VIC-based results were not carried forward to subsequent analyses based on interpretation of runoff results (Section 4.1.3).

Table 6. List of Studies included in this Sensitivity Analysis

Tool: Headwater Runoff Studies	*Assumption: Climate Projection (Section 2.2.4)*	**Studies: Headwater Runoff [(1)]**	*With Sea Level Rise (SLR)? (Section 2.3.2)*	**Studies: CVP/SWP Operations (CalSim II [(2)])**	**Studies: Delta Water Level and Quality (DSM2 [(3)])**	**Studies: Reservoir and River Temperatures (Reclamation models [(4)])**
No Climate and Runoff Adjustments			*No*	**X (Study 9.0)**	**X**	**X**
			Yes	**X (Study 9.1)**		
SacSMA-Snow17	*Proj. 1*	**X**	*Yes*	**X (Study 9.2)**	**X**	**X**
	Proj. 2	**X**	*Yes*	**X (Study 9.3)**	**X**	**X**
	Proj. 3	**X**	*Yes*	**X (Study 9.4)**	**X**	**X**
	Proj. 4	**X**	*Yes*	**X (Study 9.5)**	**X**	**X**
VIC	*Proj. 1*	**X**	*Yes*			
	Proj. 2	**X**	*Yes*			
	Proj. 3	**X**	*Yes*			
	Proj. 4	**X**	*Yes*			

Notes:

1. Models and target-basins described in Table 3 and Table 4. For each "X", ensembles of 30 simulations were conducted having different weather sequences, as described in Section 3.3.2.
2. Model described in Appendix D with study-specific adjustments described in Section 3.4.
3. Model described in Appendix F with study-specific adjustments described in Section 3.5.
4. Models described in Appendix H with study-specific adjustments described in Section 3.6.

4.0 RESULTS

This section illustrates and summarizes key results on climate change implications for natural runoff, CVP/SWP water supply, CVP/SWP operations, and several operation-dependent effects: delta channel flows and velocities and reservoir water temperatures. Qualitative discussion is also provided on how reservoir water temperature effects translate into associated managed river water temperatures given current management paradigm.

4.1 Natural Runoff

Expected results from the natural runoff analysis include the following:

- increased monthly runoff during winter and early spring and decreased runoff during late spring and summer as air temperature increase cause more rainfall precipitation rather than snow fall (typically during winter and spring), more rainfall-runoff during winter and early-spring, reduced development of snowpack during this period, and reduced snowmelt volume during the subsequent late spring and summer.

- Increased or decreased annual runoff consistent to changes in mean-annual precipitation

The following sections first summarize results from natural runoff analyses using the SacSMA/Snow17 runoff models, then results from analyses using the VIC runoff model, and finally a comparison of how CalSim II inflow and water supply adjustments are affected by runoff model choice.

4.1.1 Results based on using SacSMA/Snow17 model applications: Before summarizing runoff results for all basins and projections, an example set of inputs and results are presented in more detail, for one basin and one climate projection. The example basin is the Trinity River above Trinity Reservoir (CEGC1, Table 4), and the example projection is Projection #3 (Section 2.2.4).

Using the methodology described in Section 3.3.2, 30 sequences of 6-hourly T and P (i.e. weather “realizations”) were generated, consistent with the input requirements of the CEGC1 SacSMA/Snow17 model. Projection #3 monthly time series of T and P, averaged over the basin, is shown on the top panels of Figure 20. Daily time-series aggregates of those 6-hourly sequences consistent with the monthly time series (i.e. in terms of month-by-month mean air temperature and total precipitation) are plotted on the bottom panels of Figure 20.

For each weather sequence, a runoff simulation is completed from 1971-2040. This results in 30 sequences of 6-hourly runoff from 1971-2040. Each output sequence was then surveyed for period mean-monthly runoff conditions during 1971-2000 and 2011-

2040. Mean-monthly results for all weather sequences, by period, are shown in the first and second panels on Figure 21 (light-blue lines), respectively. Historical-to-future period changes in mean-monthly runoff are illustrated on the third and fourth panels. The third panel shows *incremental* change in mean-monthly runoff (panel 2 results minus panel 1 results, by sequence). The fourth panel shows *ratio* change in mean-monthly runoff (panel 2 results divided by panel 1 results, by sequence). Incremental change results suggest that for Projection #3, a decrease in autumn and early-winter runoff would be expected in basin CEGC1, as well as an increase in late-winter through early-summer runoff.

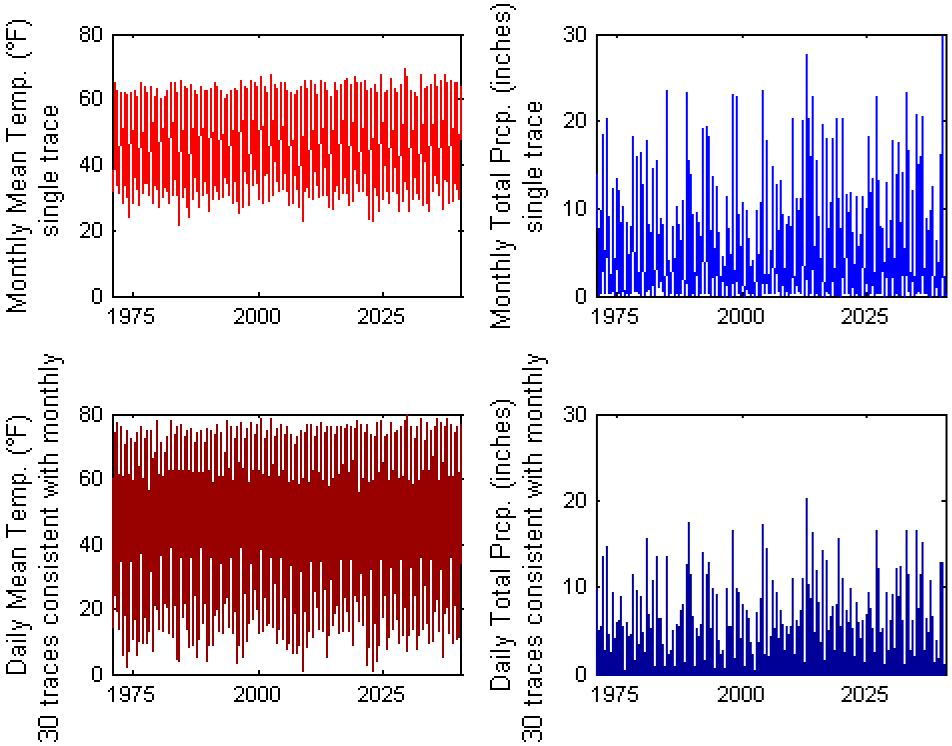


Figure 20. Runoff Simulation Setup Example – Monthly and Daily Climate and Weather Inputs for the SacSMA/Snow17 application in the Trinity Basin (CEGC1, Table 4)
(*top row*) Climate-model "Projected" Monthly T and P, basin-area averaged, 1971-2040, from Projection #3 (Section 2.2.4); (*bottom row*): Daily weather traces re-generated 30 times (Section 3.4.1) to make 30 daily traces, or realizations, all consistent with the monthly times series in the top row.

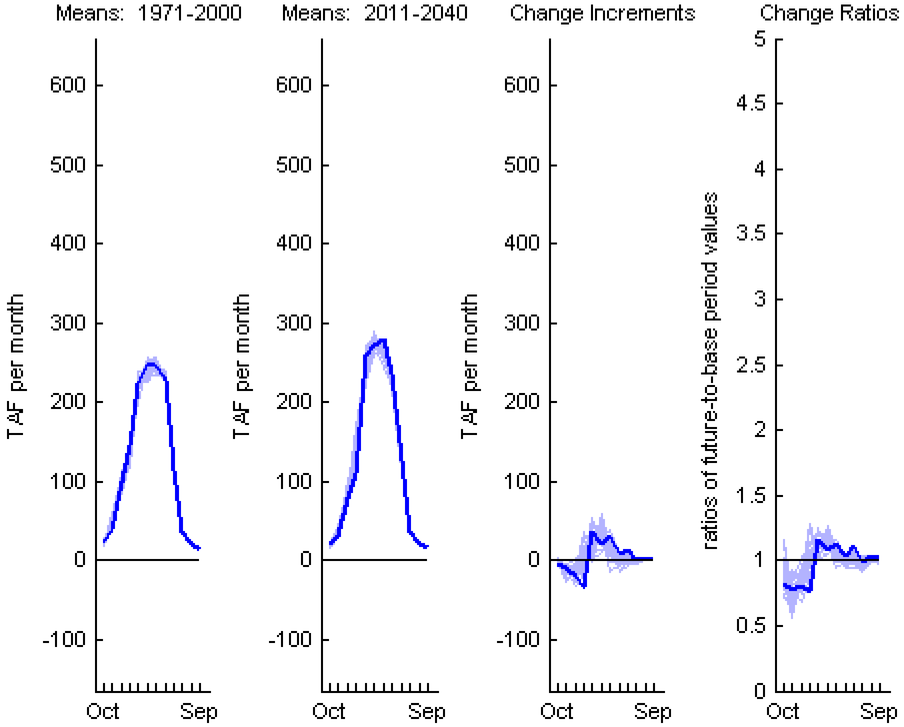


Figure 21. Runoff Simulation Results Example – Monthly Runoff, using SacSMA/Snow17 application in the Trinity Basin (CEGC1, Table 4)
(*1st panel*) simulated mean-monthly runoff, 1971-2000, from each of the 30 realizations (Figure 20); (*2nd panel*) simulated mean-monthly runoff, 2011-2040, from each of the 30 realizations; (*3rd panel*) incremental change in mean-monthly runoff by realization, for 30 realizations; (*4th panel*) ratio change of future period to base period mean-monthly runoff by realization, for 30 realizations. Thicker line on each panel indicates results from the realization having the median ratio change (among 30) in future-to-base period *annual* runoff (not shown).

Figure 21 shows thick-line overlays on each panel. These lines highlight the results from the weather sequence chosen to provide natural runoff results for subsequent CVP/SWP operations analysis. The decision to choose results from one weather sequence (among the 30 sequence-specific sets of results) was motivated by the fact that only one CalSim II study was scoped to be completed per climate projection. This was because the runoff uncertainty introduced by the different weather sequences appeared to be minor, based on simulation results, compared to the runoff uncertainty associated with the four climate projections (Figure 22 to Figure 30). Subjectively, a choice was made to choose the results from the weather sequence that produced the *median* ratio-change in mean-annual runoff among the 30 weather-specific ratios (
Figure 31).

Results illustrated on Figure 21 are for one basin and one projection. In a similar fashion, basin-specific results for all four projections are illustrated, respectively, on Figure 22 to Figure 30, using different line color to indicate projection-specific results (i.e. Projections #1 through #4 are indicated by line colors red, green, blue, and black, respectively). To review, Projections #1 and #2 (the red and green line groups) feature annual precipitation increase across the region, while Projections #3 and #4 (the blue and black line groups) feature annual precipitation decrease across most of the region. Projection #3 is an exception featuring unchanged to slightly wetter conditions in the northern portions of the study region. Review of results across basins (Figure 22 to Figure 30) and across climate projections (line colors) shows that monthly runoff responses to climate change were generally similar in all basins (i.e. panels 1-3). Air temperature increase causes a shift towards an increased fraction of annual runoff occurring during winter and early-spring and a decreased fraction occurring during late-spring and summer. That annual runoff response is also affected by change in mean-annual precipitation. Review of ratio-changes in mean-monthly runoff (i.e. panel 4) shows that some basins have relatively large ratio changes during some months (e.g., September, HETC1 results shown on fourth panel of Figure 25). This does not mean that the incremental runoff change is large (see corresponding September results in the third panel of Figure 25). The large ratio changes usually occur when there's a small denominator in the ratio (i.e. in this example, the September mean HETC1 runoff during 1971-2000).

Switching to uncertainty in the mean-annual response,
Figure **31** shows how the ratio-change in mean-annual runoff varies by both climate projection (i.e. red, green, blue, and black boxplots corresponding to Projections #1 through #4) and among weather sequences for a given projection (i.e. a given boxplot's "box" that indicates range from 25th percentile to 75th percentile ratio values from 30 weather sequences).
Figure 31 shows that the uncertainty introduced by weather-sequencing has very little effect on the ratio change in mean-annual runoff. For example, basin CEGC1 had *median {range of}* ratio changes in mean-annual runoff of 1.16 {1.16-1.17}, 1.14 {1.13-1.14}, 1.03 {1.03-1.04}, and 0.91 {0.91-0.92} for Projections #1 through #4, respectively (Section 2.2.4).

<u>4.1.2 Results based on using VIC model applications:</u> Switching focus to results produced using the VIC hydrologic model, a summary of ratio changes in mean-annual runoff is shown on

Figure 32, and is comparable to
Figure 31 showing ratios produced using SacSMA/Snow17. Considering variation of ratios among the four climate projections, the trends in VIC-based results are similar to those based on use of SacSMA/Snow17. For example, basin CEGC1 had a median ratio change in mean-annual runoff of 1.21, 1.16, 1.02, and 0.89 for Projections #1 through #4, respectively, compared to 1.16, 1.14, 1.03 and 0.92 using SacSMA/Snow17. Considering variation in ratios for a given projection, but introduced by 30 different weather sequences, the range of VIC-based ratios was about the range produced using SacSMA/Snow17.

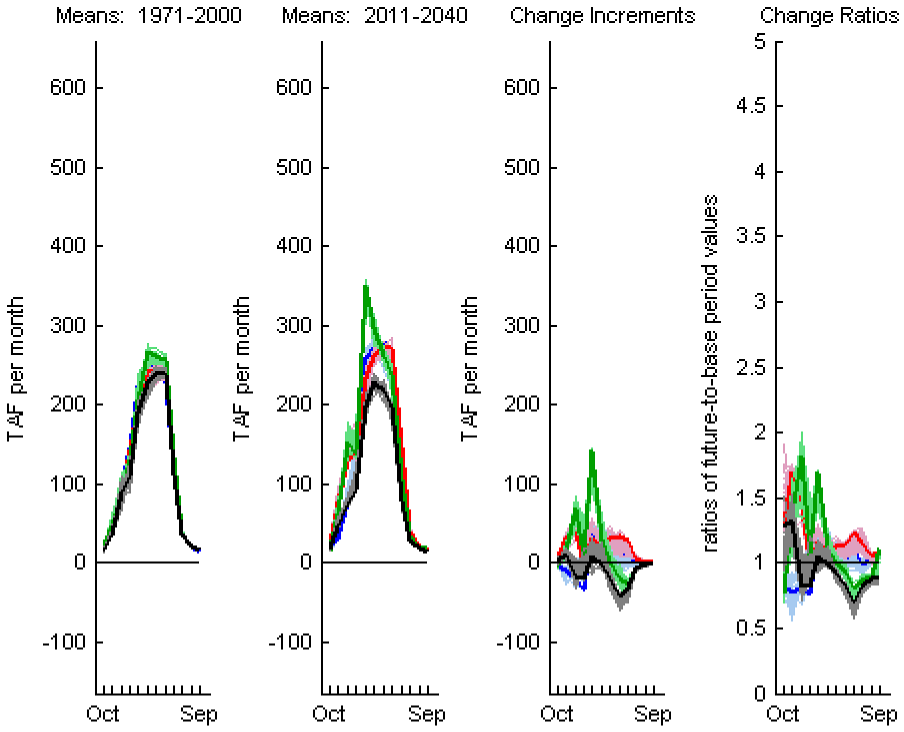


Figure 22. Simulated Monthly Runoff Response, Trinity at Trinity Reservoir (CECG1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

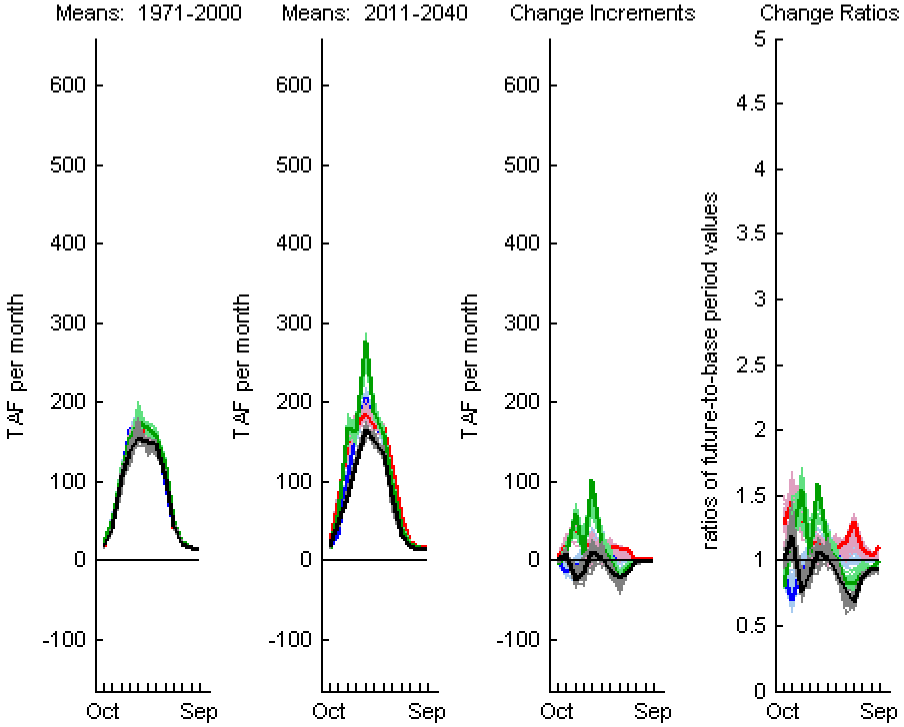


Figure 23. Simulated Monthly Runoff Response, Sacramento at town of Delta (DLTC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

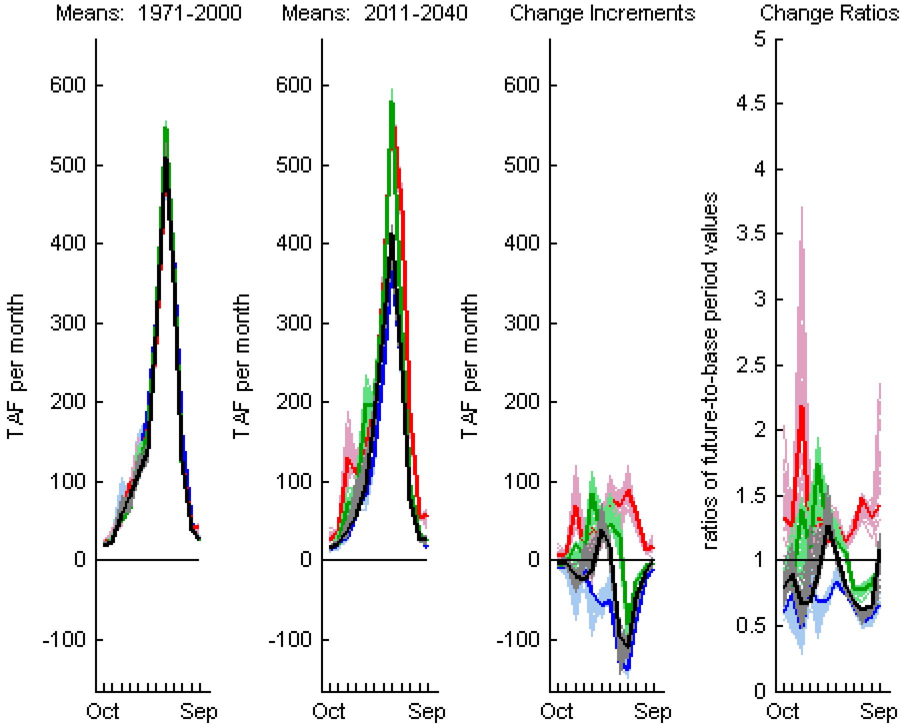


Figure 24. Simulated Monthly Runoff Response, San Joaquin at Millerton Lake (FRAC1, Table 4), using the SacSMA/Snow17 tool.

Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

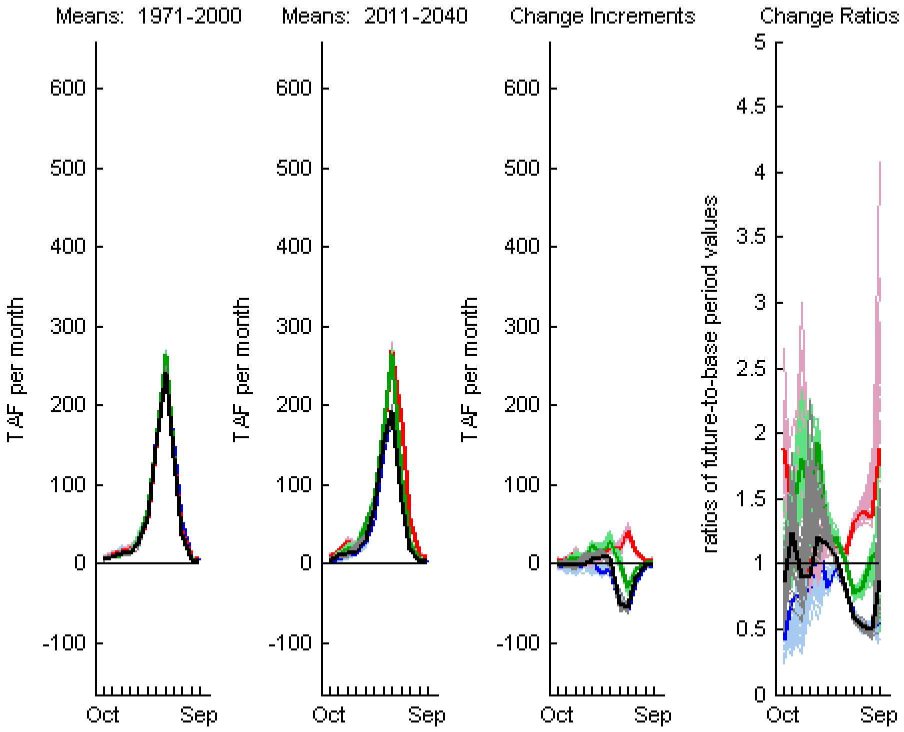


Figure 25. Simulated Monthly Runoff Response, Tuolumne at Hetch Hetchy Dam (HETC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

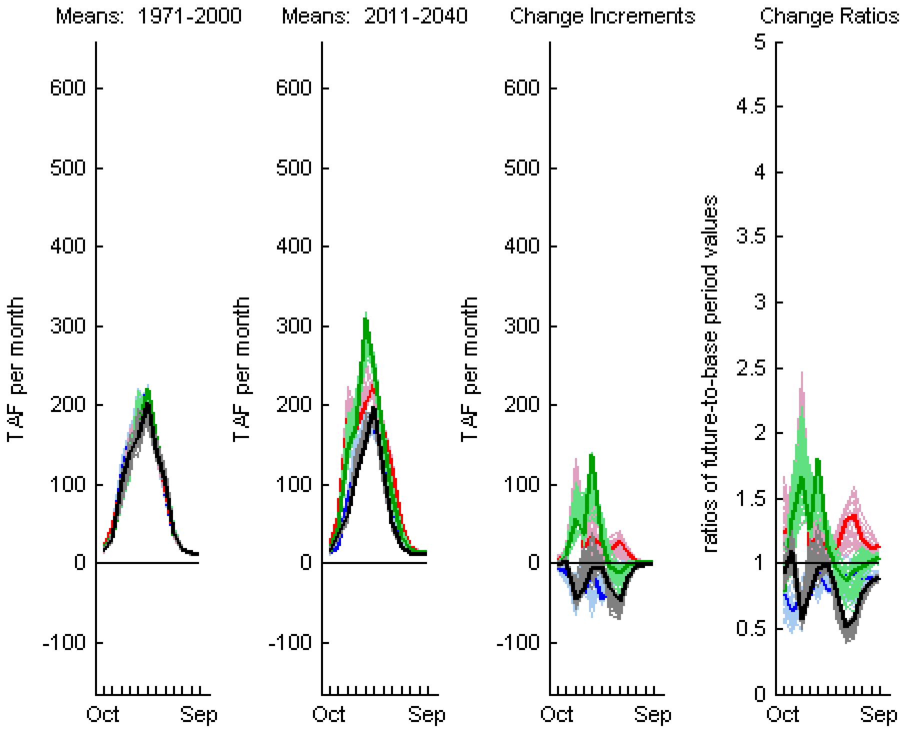


Figure 26. Simulated Monthly Runoff Response, Feather, Middle Fork, at Merrimac (MRMC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

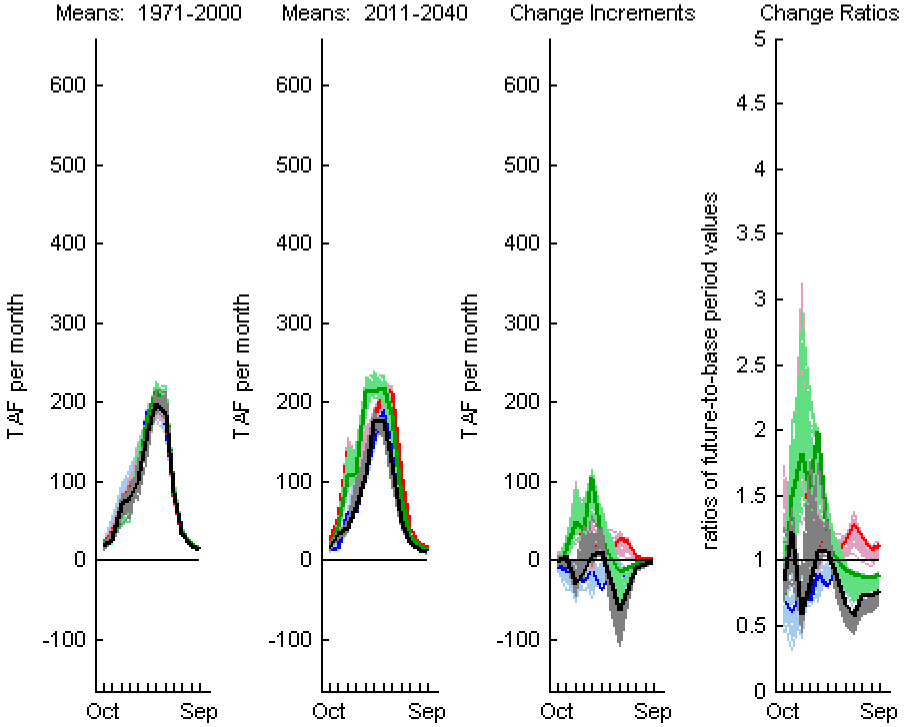


Figure 27. Simulated Monthly Runoff Response, North Yuba at New Bullards Bar Reservoir (NBBC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

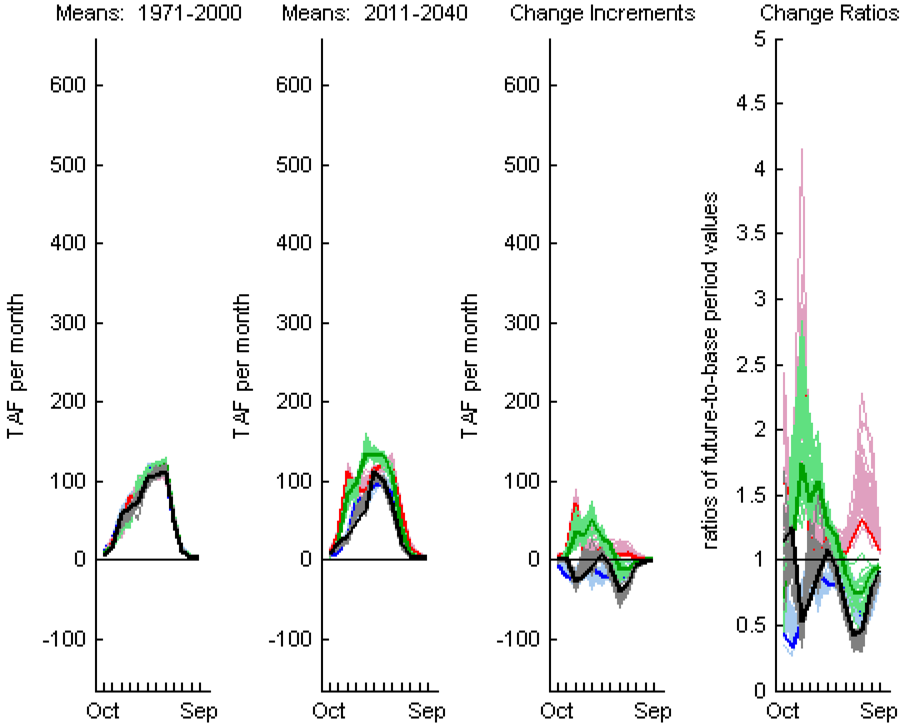


Figure 28. Simulated Monthly Runoff Response, American, North Fork, at North Fork Dam (NFDC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

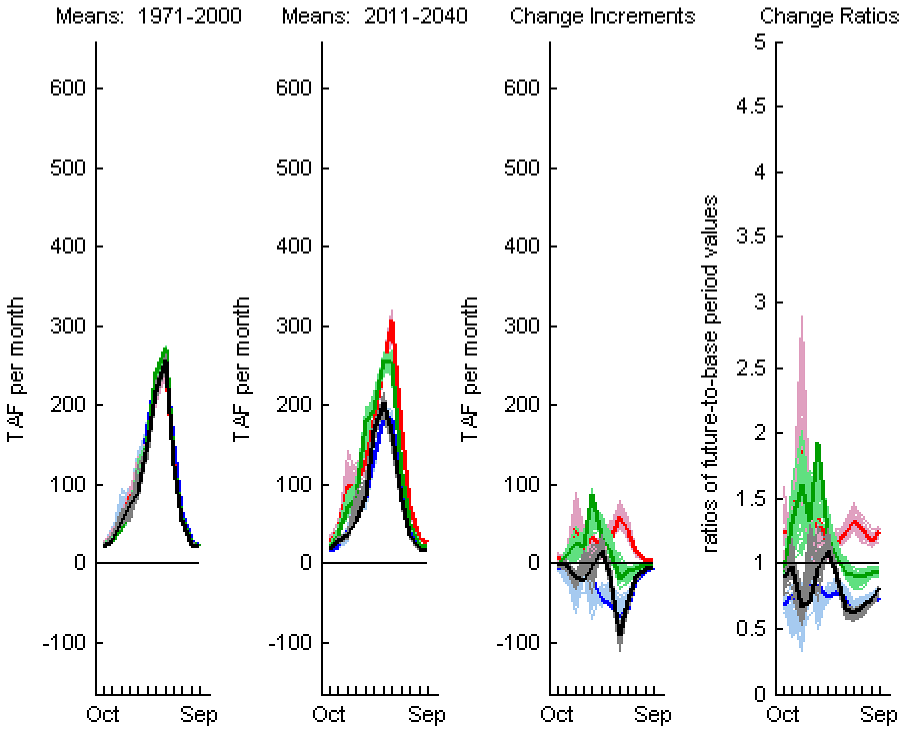


Figure 29. Simulated Monthly Runoff Response, Stanislaus at New Melones Reservoir (NFDC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

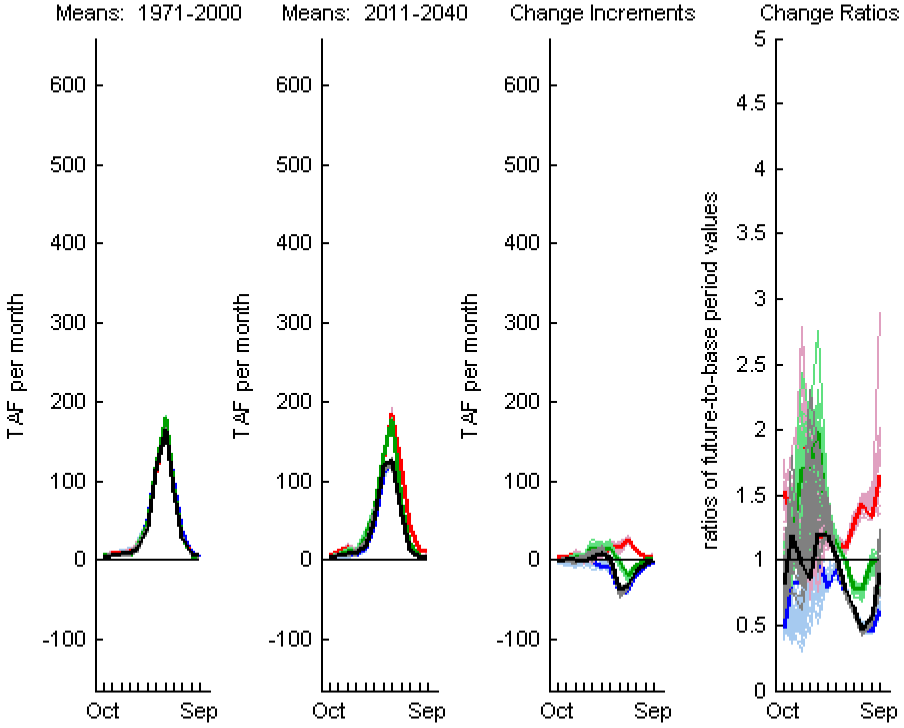


Figure 30. Simulated Monthly Runoff Response, Merced at Pohono Bridge (POHC1, Table 4), using the SacSMA/Snow17 tool.
Similar to Figure 21, but with results shown for all four projections (Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively).

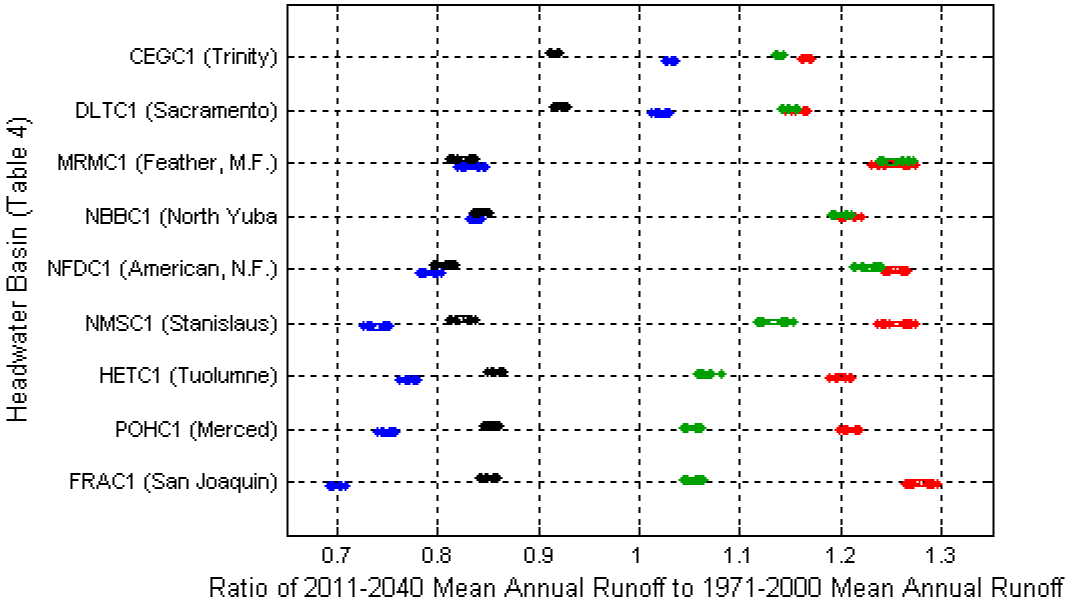


Figure 31. Simulated Annual Runoff Response, All Basins, using the SacSMA/Snow17 tool. Results are shown for all four projections, where Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively. For each basin-projection pair, results include 30 ratio values corresponding to the 30 different weather sequences simulated (each consistent with the given projection); values are arranged in a boxplot, although the features are difficult to distinguish relative to this x-axis scale, which was chosen to highlight results variation relative to projections choice.

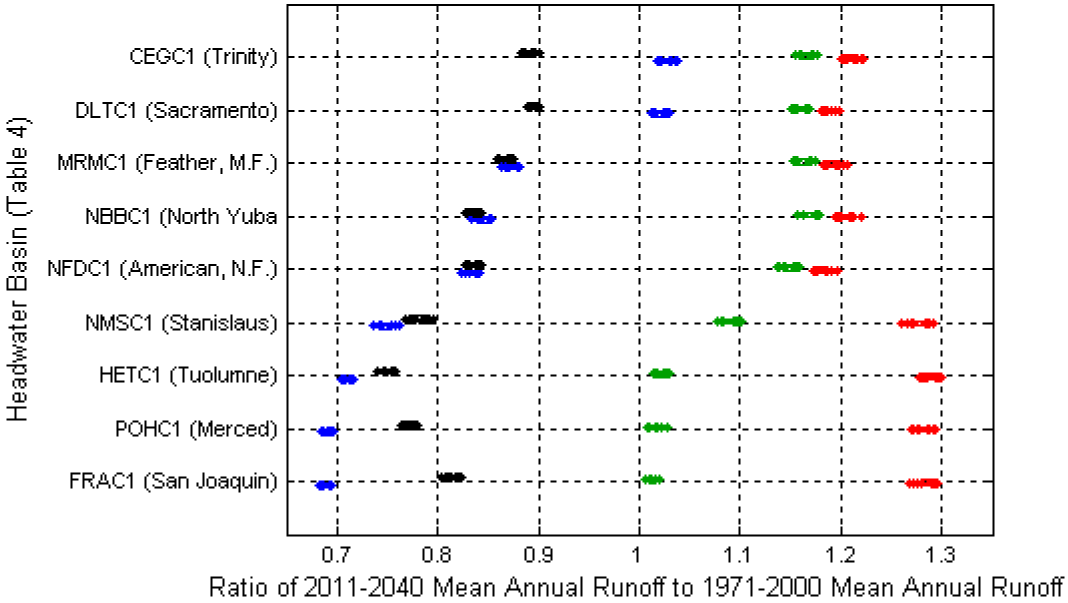


Figure 32. Simulated Annual Runoff Response, All Basins, using the VIC tool . Similar to

Figure 31, as results are shown for all four projections, where Projections 1 – 4 indicated by line colors red, green, blue, and black, respectively.

4.1.3 Effect of Runoff Model Choice on CalSim II Inflows and Related Inputs: Following the approach described in Section 3.4.1, CalSim II inflows were scaled on a monthly basis according to ratio-changes in mean-monthly and mean-annual runoff (i.e. ratios indicated by "thick lines" on the fourth panels of Figure 22 through Figure 30; and boxplot medians from
Figure 31, respectively, when using results from the SacSMA/Snow17 model). Projection-specific mean-monthly and mean-annual inflows, adjusted using runoff results from *both* runoff models, are summarized in Table 7 through Table 10 for 5 CVP reservoirs (Trinity Reservoir, Lake Shasta, Folsom Lake, New Melones, and Millerton Lake) and also for the SWP's Lake Oroville. Adjusted inflows and incremental differences from base inflows, based on using SacSMA/Snow17 runoffs results, are summarized in Table 7; percentage differences from base are listed in Table 8. Similar inflow summaries based on VIC results are listed in Table 9 and Table 10, respectively.

Comparing results in Table 8 and Table 10 shows that the runoff-model choice (i.e. the SacSMA/Snow17 models versus the VIC model) had some influence on the percentage change in mean-annual inflow simulated for CalSim II, assessed for a given reservoir and for a given projection. However, when the range of inflow adjustments across projections is considered (Figure 33), the runoff-model choice is considerably less significant. This means that the long-term mean-annual water supply changes represented by the range of climate projections in this sensitivity analysis were largely the same when assessed using either SacSMA/Snow17 or VIC model-applications. Given this finding, a decision was made to continue this study using only the natural runoff results based on using the SacSMA/Snow17 model-applications.

Finally, as stated in Section 3.4.1, other inflow-related CalSim II inputs were adjusted consistent with changes made to reservoirs inflows (summarized in Table 7), specifically water supply forecast and hydrologic year-type data associated with the various year-type classification systems. Figure 34 provides an example of how distribution of hydrologic year-types under one classification system (i.e. the Sacramento 40-30-30 (SWRCB 2000)) changed for each climate projection relative to the "Base" distribution of year-types in the base CalSim II study (Study 9.0). The distributional shifts in classification counts across year-types seemed more influenced by change in mean-annual precipitation (where Projections #1 and #2 were "wetter" and Projections #3 and #4 were "drier") than by change in mean-annual temperature (where Projections #1 and #3 were "less warm" and Projections #2 and #4 were "more warm").

Table 7. Average CalSim II Inflows(1) and Incremental Differences by Climate Projection, based on natural runoff responses simulated using SacSMA/Snow17

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSim II inflow variable I1)													
Base	18	53	99	128	149	176	205	239	126	39	13	9	1253
Projection 1	23	86	138	127	172	188	228	270	155	45	13	9	1454
Projection 2	13	71	173	136	249	196	206	223	102	34	12	10	1423
Projection 3	15	42	82	100	173	191	231	249	142	39	13	9	1286
Projection 4	23	69	82	107	157	176	189	199	90	33	11	8	1143

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Proj. 1 – Base	5	33	39	-2	23	12	23	31	29	6	0	1	201
Proj. 2 – Base	-4	18	74	7	100	20	1	-16	-24	-5	-1	1	170
Proj. 3 – Base	-3	-11	-17	-29	24	16	27	10	15	0	0	0	33
Proj. 4 – Base	5	16	-17	-21	7	0	-15	-40	-36	-6	-1	-1	-109
(CVP) Lake Shasta (CalSim II inflow variable I4)													
Base	245	338	545	720	801	835	688	509	323	238	214	211	5667
Projection 1	314	484	718	804	903	868	754	581	416	259	220	233	6554
Projection 2	199	408	848	765	1276	947	712	429	273	219	206	216	6497
Projection 3	221	240	519	701	916	886	680	561	376	254	217	213	5783
Projection 4	246	398	416	639	842	838	624	395	221	206	199	193	5217
Proj. 1 – Base	69	147	173	84	102	33	66	72	93	20	5	22	887
Proj. 2 – Base	-46	70	303	45	475	112	24	-80	-50	-20	-9	5	830
Proj. 3 – Base	-24	-98	-26	-19	115	52	-8	52	52	16	3	2	116
Proj. 4 – Base	0	61	-128	-81	41	3	-64	-114	-102	-32	-15	-17	-450
(SWP) Lake Oroville (CalSim II inflow variable I6)													
Base	124	185	343	477	511	567	562	506	280	159	137	119	3967
Projection 1	151	237	623	536	617	631	617	665	382	188	152	135	4934
Projection 2	100	257	578	618	943	665	570	463	277	163	145	130	4908
Projection 3	94	117	249	359	481	442	439	448	257	138	118	106	3249
Projection 4	115	207	203	378	497	564	462	272	165	125	121	109	3219
Proj. 1 – Base	28	52	280	60	106	65	55	159	102	29	15	16	967
Proj. 2 – Base	-24	72	235	141	432	98	8	-42	-3	4	8	11	941
Proj. 3 – Base	-30	-68	-93	-118	-30	-124	-122	-58	-23	-21	-18	-13	-718
Proj. 4 – Base	-8	22	-139	-99	-14	-2	-100	-234	-115	-34	-16	-10	-749
(CVP) Folsom Lake (sum of CalSim II inflow variables I8 and I300)													
Base	96	129	228	291	350	338	362	375	229	133	111	110	2751
Projection 1	148	178	562	328	341	399	389	385	267	169	128	113	3409
Projection 2	70	144	399	425	572	440	448	350	181	103	106	109	3345
Projection 3	44	45	121	320	315	283	298	299	171	78	82	100	2155
Projection 4	108	158	121	207	307	361	338	243	97	62	87	100	2189
Proj. 1 – Base	52	49	334	37	-8	61	28	10	38	36	18	3	658
Proj. 2 – Base	-26	15	170	134	222	102	86	-25	-48	-30	-5	-1	595
Proj. 3 – Base	-52	-84	-107	29	-35	-55	-64	-76	-58	-55	-28	-10	-596
Proj. 4 – Base	12	30	-107	-84	-43	22	-24	-132	-132	-71	-23	-10	-562
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Base	359	519	872	1139	1300	1349	1254	1123	678	410	338	329	9670
Projection 1	484	748	1418	1259	1417	1455	1371	1235	839	472	361	355	11416
Projection 2	282	622	1419	1326	2097	1583	1365	1001	556	356	323	335	11265
Projection 3	279	326	723	1120	1404	1361	1210	1109	688	371	313	322	9224
Projection 4	376	626	619	953	1306	1374	1151	837	408	300	298	301	8549
Proj. 1 – Base	125	229	547	120	117	107	117	112	161	62	23	26	1746
Proj. 2 – Base	-77	103	547	187	796	234	111	-122	-122	-54	-15	5	1595
Proj. 3 – Base	-80	-193	-149	-19	104	12	-45	-15	10	-39	-25	-7	-446
Proj. 4 – Base	17	107	-252	-186	6	26	-104	-286	-271	-110	-40	-28	-1121
(CVP) New Melones Reservoir (CalSim II inflow variable I10)													
Base	34	41	62	85	95	112	128	204	164	75	47	39	1087
Projection 1	41	49	112	99	126	126	143	249	215	93	54	48	1358
Projection 2	31	53	97	110	177	133	135	189	151	67	44	37	1224
Projection 3	24	31	44	70	80	84	100	150	104	49	33	30	798
Projection 4	31	41	43	62	93	125	123	137	107	51	36	33	881
Proj. 1 – Base	7	8	50	14	32	15	15	45	51	18	7	9	271

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Proj. 2 – Base	-3	12	34	25	83	22	7	-15	-13	-8	-3	-3	137
Proj. 3 – Base	-10	-10	-18	-15	-15	-28	-28	-54	-61	-25	-14	-10	-288
Proj. 4 – Base	-3	0	-20	-23	-2	14	-5	-68	-58	-23	-12	-7	-205
(CVP) Millerton Lake (CalSim II inflow variable I18)													
Base	65	63	78	101	119	146	198	254	291	187	124	105	1730
Projection 1	83	76	161	111	156	161	246	279	351	266	157	146	2192
Projection 2	49	52	110	114	209	177	232	274	235	149	104	104	1809
Projection 3	40	47	38	85	83	105	169	194	192	103	73	73	1202
Projection 4	51	56	52	71	106	186	211	209	204	118	81	114	1459
Proj. 1 – Base	18	14	84	9	37	15	48	25	60	79	33	40	462
Proj. 2 – Base	-16	-10	32	12	91	31	35	20	-56	-38	-19	-1	79
Proj. 3 – Base	-25	-15	-39	-16	-36	-41	-29	-60	-100	-84	-50	-33	-528
Proj. 4 – Base	-14	-7	-25	-31	-13	40	13	-45	-88	-69	-43	9	-271

Notes:

1. Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).

Table 8. Percentage Change in Average CalSim II Inflows (1) by Climate Projection, based on natural runoff responses simulated using SacSMA/Snow17

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSim II inflow variable I1)													
Proj. 1 – Base	27	64	40	-1	15	7	11	13	23	15	3	8	16
Proj. 2 – Base	-25	35	75	6	67	11	1	-7	-19	-13	-9	12	14
Proj. 3 – Base	-16	-21	-17	-22	16	9	13	4	12	0	4	2	3
Proj. 4 – Base	27	31	-17	-16	5	0	-8	-17	-29	-16	-11	-9	-9
(CVP) Lake Shasta (CalSim II inflow variable I4)													
Proj. 1 – Base	28	43	32	12	13	4	10	14	29	8	3	11	16
Proj. 2 – Base	-19	21	56	6	59	13	3	-16	-16	-8	-4	3	15
Proj. 3 – Base	-10	-29	-5	-3	14	6	-1	10	16	7	1	1	2
Proj. 4 – Base	0	18	-24	-11	5	0	-9	-22	-32	-14	-7	-8	-8
(CVP) Lake Oroville (CalSim II inflow variable I6)													
Proj. 1 – Base	22	28	82	12	21	11	10	31	37	18	11	14	24
Proj. 2 – Base	-19	39	69	30	85	17	1	-8	-1	2	6	9	24
Proj. 3 – Base	-24	-37	-27	-25	-6	-22	-22	-11	-8	-13	-13	-11	-18
Proj. 4 – Base	-7	12	-41	-21	-3	0	-18	-46	-41	-21	-12	-8	-19
(CVP) Folsom Lake (sum of CalSim II inflow variables I8 and I300)													
Proj. 1 – Base	54	38	146	13	-2	18	8	3	17	27	16	3	24
Proj. 2 – Base	-27	12	75	46	64	30	24	-7	-21	-22	-4	-1	22
Proj. 3 – Base	-54	-65	-47	10	-10	-16	-18	-20	-25	-42	-26	-9	-22
Proj. 4 – Base	13	23	-47	-29	-12	7	-7	-35	-58	-54	-21	-9	-20
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Proj. 1 – Base	35	44	63	11	9	8	9	10	24	15	7	8	18
Proj. 2 – Base	-21	20	63	16	61	17	9	-11	-18	-13	-4	2	16
Proj. 3 – Base	-22	-37	-17	-2	8	1	-4	-1	1	-10	-7	-2	-5
Proj. 4 – Base	5	21	-29	-16	0	2	-8	-26	-40	-27	-12	-9	-12
(CVP) New Melones Reservoir (CalSim II inflow variable I10)													
Proj. 1 – Base	22	20	80	17	34	13	12	22	31	24	15	23	25
Proj. 2 – Base	-9	29	55	29	87	19	6	-7	-8	-11	-7	-7	13
Proj. 3 – Base	-31	-24	-30	-18	-16	-25	-22	-26	-37	-34	-30	-24	-27
Proj. 4 – Base	-8	0	-32	-27	-2	12	-4	-33	-35	-31	-25	-17	-19

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Millerton Lake (CalSim II inflow variable I18)													
Proj. 1 – Base	28	22	108	9	31	10	24	10	21	42	27	38	27
Proj. 2 – Base	-25	-16	41	12	76	21	17	8	-19	-20	-16	-1	5
Proj. 3 – Base	-38	-24	-51	-16	-30	-28	-15	-23	-34	-45	-41	-31	-31
Proj. 4 – Base	-21	-11	-33	-31	-11	28	7	-18	-30	-37	-35	8	-16

Notes:

1. Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).

Table 9. Average CalSim II Inflows(1) and Differences by Climate Projection, based on natural runoff responses simulated using VIC

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSim II inflow variable I1)													
Base	18	53	99	128	149	176	205	239	126	39	13	9	1253
Projection 1	20	82	140	144	172	194	240	279	162	52	16	10	1512
Projection 2	14	72	148	149	252	214	221	235	103	25	11	10	1455
Projection 3	15	44	99	109	165	189	211	250	141	37	11	8	1280
Projection 4	19	89	67	106	138	173	189	201	87	22	11	8	1110
Proj. 1 – Base	3	30	42	16	23	19	36	40	36	13	3	1	260
Proj. 2 – Base	-3	20	49	20	103	38	16	-4	-23	-14	-1	2	202
Proj. 3 – Base	-3	-8	0	-19	15	13	6	11	14	-2	-1	0	27
Proj. 4 – Base	1	36	-32	-22	-11	-2	-16	-38	-40	-17	-2	0	-143
(CVP) Lake Shasta (CalSim II inflow variable I4)													
Base	245	338	545	720	801	835	688	509	323	238	214	211	5667
Projection 1	362	487	726	839	933	899	783	578	381	276	235	237	6735
Projection 2	205	460	793	828	1314	960	701	447	264	185	179	238	6575
Projection 3	220	279	567	628	927	899	705	545	364	240	196	200	5769
Projection 4	241	498	364	630	718	829	611	414	240	158	165	193	5060
Proj. 1 – Base	117	149	181	119	132	64	94	69	57	38	21	26	1068
Proj. 2 – Base	-40	122	248	109	513	125	13	-62	-59	-53	-35	27	908
Proj. 3 – Base	-25	-59	22	-91	126	64	17	36	41	2	-19	-11	102
Proj. 4 – Base	-5	160	-181	-90	-83	-5	-77	-95	-83	-81	-50	-18	-607
(SWP) Lake Oroville (CalSim II inflow variable I6)													
Base	124	185	343	477	511	567	562	506	280	159	137	119	3967
Projection 1	165	219	574	567	633	616	591	544	339	181	146	129	4705
Projection 2	110	231	469	581	839	672	597	486	222	135	127	112	4580
Projection 3	101	128	295	390	527	476	499	446	241	129	121	111	3462
Projection 4	122	191	247	423	511	580	484	353	171	110	114	104	3409
Proj. 1 – Base	41	34	231	91	123	50	30	38	59	22	10	10	738
Proj. 2 – Base	-13	45	126	104	328	106	35	-20	-58	-24	-10	-6	613
Proj. 3 – Base	-23	-57	-48	-87	16	-91	-63	-60	-39	-30	-16	-8	-505
Proj. 4 – Base	-2	5	-96	-53	0	13	-77	-152	-109	-49	-23	-15	-558
(CVP) Folsom Lake (sum of CalSim II inflow variables I8 and I300)													
Base	96	129	228	291	350	338	362	375	229	133	111	110	2751
Projection 1	121	140	409	354	431	348	372	398	275	152	114	112	3226
Projection 2	84	170	324	383	591	376	388	348	165	105	100	107	3142
Projection 3	72	77	192	240	320	259	303	323	188	100	98	102	2273
Projection 4	89	136	139	274	320	342	310	256	121	89	94	101	2272
Proj. 1 – Base	25	11	181	63	82	10	10	23	46	19	4	2	476
Proj. 2 – Base	-12	41	96	92	242	37	27	-27	-64	-28	-10	-3	391
Proj. 3 – Base	-24	-52	-36	-51	-29	-80	-59	-52	-41	-33	-13	-8	-477

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Proj. 4 – Base	-7	7	-89	-17	-30	3	-51	-119	-107	-44	-16	-9	-479
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Base	359	519	872	1139	1300	1349	1254	1123	678	410	338	329	9670
Projection 1	503	709	1276	1337	1537	1441	1395	1255	817	480	365	359	11474
Projection 2	304	702	1265	1360	2158	1550	1310	1030	532	315	291	356	11172
Projection 3	307	400	858	978	1412	1346	1218	1118	693	377	305	311	9322
Projection 4	349	723	570	1010	1176	1344	1110	871	449	269	270	302	8442
Proj. 1 – Base	144	190	404	199	237	93	141	131	139	70	28	29	1804
Proj. 2 – Base	-55	183	393	221	858	201	56	-93	-146	-95	-47	26	1502
Proj. 3 – Base	-52	-119	-14	-161	112	-2	-36	-5	14	-33	-33	-19	-349
Proj. 4 – Base	-10	204	-302	-129	-125	-5	-144	-253	-230	-141	-68	-28	-1229
(CVP) New Melones Reservoir (CalSim II inflow variable I10)													
Base	34	41	62	85	95	112	128	204	164	75	47	39	1087
Projection 1	38	44	121	100	136	128	145	243	211	103	55	49	1375
Projection 2	29	52	82	110	159	125	143	217	131	52	41	37	1177
Projection 3	25	26	46	84	82	76	94	158	116	46	31	33	817
Projection 4	32	40	44	80	78	109	118	141	96	39	34	37	848
Proj. 1 – Base	4	3	59	15	42	16	17	39	47	28	8	10	288
Proj. 2 – Base	-5	11	20	25	65	14	15	13	-33	-23	-7	-3	91
Proj. 3 – Base	-9	-15	-16	-2	-12	-35	-34	-46	-48	-28	-17	-7	-269
Proj. 4 – Base	-2	-1	-18	-5	-17	-2	-10	-63	-68	-36	-13	-2	-238
(CVP) Millerton Lake (CalSim II inflow variable I18)													
Base	65	63	78	101	119	146	198	254	291	187	124	105	1730
Projection 1	77	71	147	122	167	160	234	273	383	276	155	128	2194
Projection 2	59	58	87	112	204	166	241	293	207	110	108	103	1750
Projection 3	48	44	43	82	89	95	160	197	191	96	67	77	1189
Projection 4	56	54	58	85	104	163	210	203	187	91	84	115	1410
Proj. 1 – Base	12	9	70	20	48	14	36	19	92	90	32	23	464
Proj. 2 – Base	-5	-4	10	11	86	20	44	39	-84	-77	-15	-2	20
Proj. 3 – Base	-16	-18	-35	-19	-30	-51	-37	-57	-101	-90	-56	-29	-541
Proj. 4 – Base	-9	-9	-19	-17	-15	17	12	-51	-104	-95	-40	10	-320

Notes:

1. Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).

Table 10. Percent Change in Average CalSim II Inflows (1) by Climate Projection, based on natural runoff responses simulated using VIC

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
(CVP) Trinity Reservoir (CalSim II inflow variable I1)													
Proj. 1 – Base	14	56	42	12	15	11	18	17	28	34	23	10	21
Proj. 2 – Base	-19	38	50	16	69	22	8	-2	-18	-37	-11	20	16
Proj. 3 – Base	-15	-16	0	-15	10	8	3	5	11	-6	-11	-2	2
Proj. 4 – Base	5	69	-32	-17	-8	-1	-8	-16	-31	-43	-13	-5	-11
(CVP) Lake Shasta (CalSim II inflow variable I4)													
Proj. 1 – Base	48	44	33	17	17	8	14	14	18	16	10	12	19
Proj. 2 – Base	-16	36	45	15	64	15	2	-12	-18	-22	-16	13	16
Proj. 3 – Base	-10	-17	4	-13	16	8	2	7	13	1	-9	-5	2
Proj. 4 – Base	-2	48	-33	-12	-10	-1	-11	-19	-26	-34	-23	-9	-11
(CVP) Lake Oroville (CalSim II inflow variable I6)													
Proj. 1 – Base	33	18	67	19	24	9	5	8	21	14	7	9	19
Proj. 2 – Base	-11	25	37	22	64	19	6	-4	-21	-15	-7	-5	15

Units = TAF	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
Proj. 3 – Base	-18	-31	-14	-18	3	-16	-11	-12	-14	-19	-12	-7	-13
Proj. 4 – Base	-2	3	-28	-11	0	2	-14	-30	-39	-31	-17	-13	-14
(CVP) Folsom Lake (sum of CalSim II inflow variables I8 and I300)													
Proj. 1 – Base	26	9	79	22	23	3	3	6	20	14	4	2	17
Proj. 2 – Base	-12	32	42	32	69	11	7	-7	-28	-21	-9	-3	14
Proj. 3 – Base	-25	-40	-16	-18	-8	-24	-16	-14	-18	-25	-11	-7	-17
Proj. 4 – Base	-7	5	-39	-6	-9	1	-14	-32	-47	-33	-15	-8	-17
(CVP) Trinity Reservoir + Lake Shasta + Folsom Lake (main Sacramento Valley CVP reservoirs)													
Proj. 1 – Base	40	37	46	17	18	7	11	12	20	17	8	9	19
Proj. 2 – Base	-15	35	45	19	66	15	4	-8	-22	-23	-14	8	16
Proj. 3 – Base	-14	-23	-2	-14	9	0	-3	0	2	-8	-10	-6	-4
Proj. 4 – Base	-3	39	-35	-11	-10	0	-11	-22	-34	-34	-20	-8	-13
(CVP) New Melones Reservoir (CalSim II inflow variable I10)													
Proj. 1 – Base	10	8	95	18	44	15	14	19	29	38	16	25	27
Proj. 2 – Base	-15	26	31	29	69	12	12	6	-20	-31	-14	-7	8
Proj. 3 – Base	-27	-37	-26	-2	-13	-31	-26	-22	-29	-38	-35	-17	-25
Proj. 4 – Base	-6	-2	-29	-6	-18	-2	-8	-31	-41	-48	-28	-5	-22
(CVP) Millerton Lake (CalSim II inflow variable I18)													
Proj. 1 – Base	19	14	90	20	40	9	18	7	31	48	26	21	27
Proj. 2 – Base	-8	-7	12	11	72	13	22	15	-29	-41	-13	-2	1
Proj. 3 – Base	-25	-29	-45	-19	-25	-35	-19	-23	-35	-48	-46	-27	-31
Proj. 4 – Base	-14	-14	-25	-17	-13	12	6	-20	-36	-51	-32	9	-19

Notes:

1. Mean monthly or annual value during CalSim II simulation years, labeled 1922-2003 (82 years).

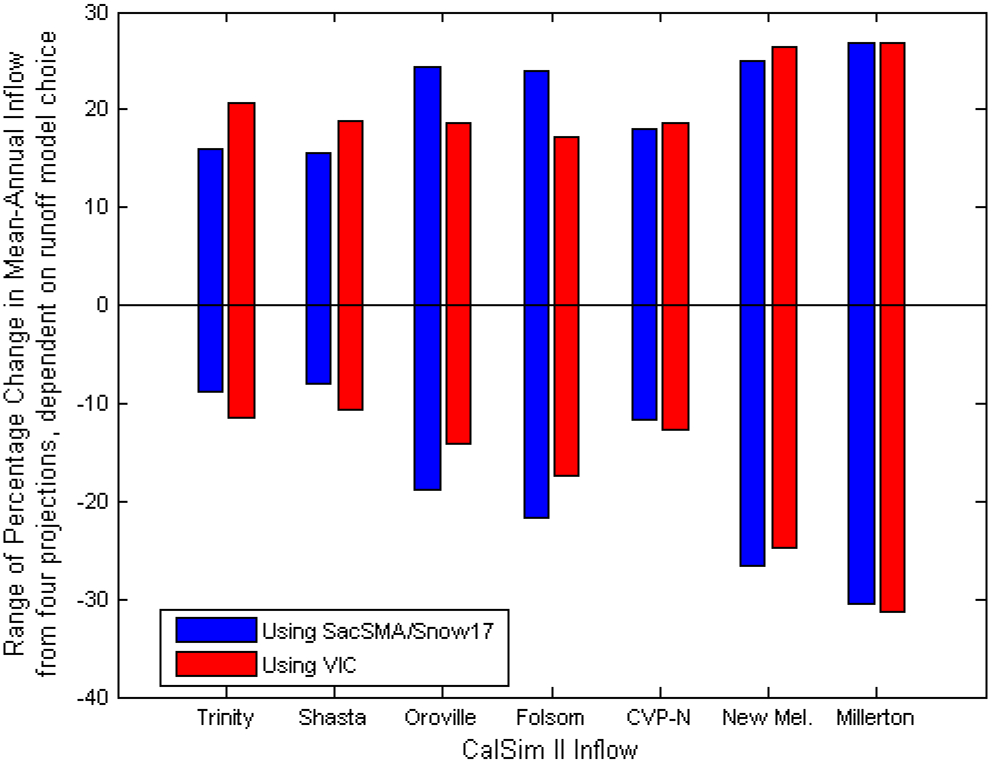


Figure 33. Dependence of CalSim II Inflow Changes on Runoff Model Choice
Graph shows the maximum to minimum change in mean annual inflow, among the four projections considered (Projections 1 – 4, Section 2.2.4), assessed twice: once using the SacSMA/Snow17 runoff model (blue bars) and again using the VIC runoff model (red bars).

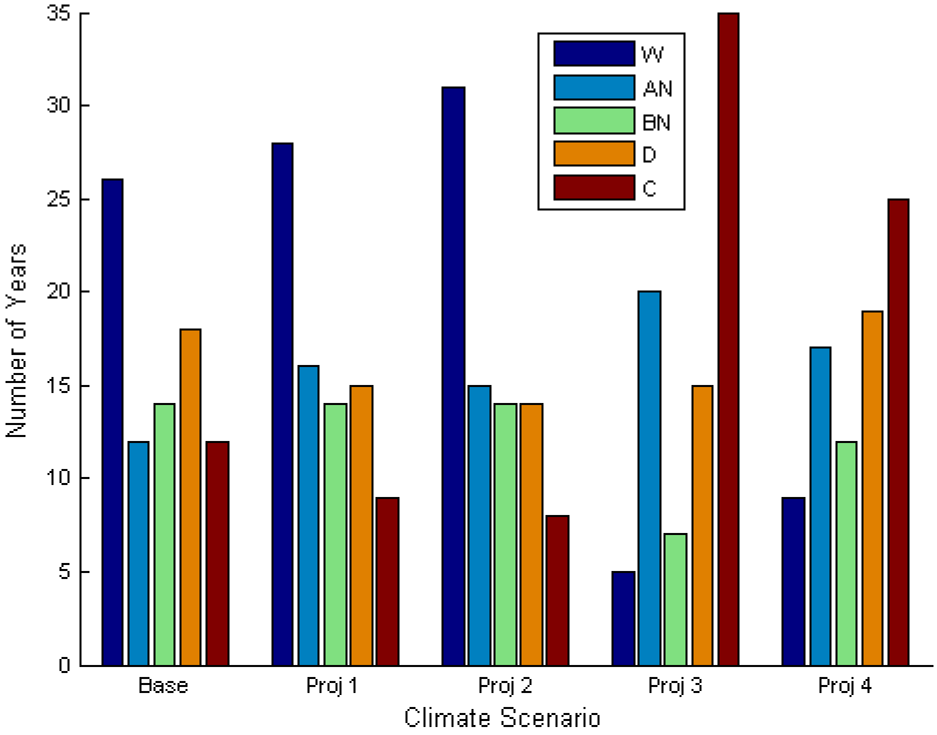


Figure 34. Distribution of Sacramento 40-30-30 Index Yeartype Counts, by Climate, based on natural runoff responses simulated using SacSMA/Snow17.
Results are shown for unadjusted CalSim II Study 9.0 (“Base”), and the four climate-adjusted versions of CalSim II Study 9.0 (i.e. 9.2, 9.3, 9.4, 9.5) corresponding to the four climate projection scenarios (Projections 1 – 4, from Section 2.2.4). Legend abbreviates classification labels, where W, AN, BN, D, and C abbreviations correspond to Wet, Above Normal, Below Normal, Dry and Critical hydrologic year-types, respectively.

4.2 CVP/SWP Operations

There were six D1641 modeling runs (OCAP Studies 9.0 to 9.5) developed to evaluate the potential effects of future climate change scenarios as discussed above. The basic difference in assumptions between the studies can be seen in Section 3.2 and the overall assumptions of the model and other OCAP BA CalSim II studies are summarized in Appendix D and Chapter 9, respectively. This section is divided into three subsections on upstream effects, delta effects, and effects to deliveries and San Luis Reservoir storage.

Expected results from the CVP/SWP operations analysis include the following:

- a 1-foot sea level rise should cause shifts in delta parameters and some noticeable changes in carryover storage potential.

- a 1-foot sea level rise combined with the *wetter* climate change scenarios would lead to a net increase in mean-annual water deliveries and end-of-September carryover storage due to how the second of two *counteracting* climate effects has a relatively greater influence in the wetter climate change scenarios considered:
    - (1) warming leading to proportionally less reservoir inflow during late spring and summer leading to increased water allocations, deliveries and end-of-September carryover storage; and
    - (2) increase in mean-annual inflow leading to increase in mean-annual water deliveries and end-of-September carryover storage.

- a 1-foot sea level rise combined with the *drier* climate change scenarios would lead to decreases in mean-annual water deliveries and end-of-September carryover storage because of two *reinforcing* climate effects:
    - (1) warming leading to proportionally less reservoir inflow during late spring and summer leading to increased water allocations, deliveries and end-of-September carryover storage; and
    - (2) decrease in mean-annual inflow leading to decrease in mean-annual water deliveries and end-of-September carryover storage.

- conservative and potentially exaggerated operational response to water supply changes given that analyses are conducted with no change to current institutions, regulations, and only very limited change to discretionary operations (i.e. the logic in CalSim II that relates forecast annual water supply to annual delivery volume-targets).

The following sub-sections will provide discussion on results relative to these expectations. As a summary preview of results, Table 11 lists long-term mean-annual values for simulated carryover storage, upstream river flows, Delta flows and exports, and project deliveries during water years 1922-2003. The results in Table 11 conform expected results, as described in the introduction of this section. For example, the effect of 1-foot sea level rise (SLR) without climate change (i.e. comparing results from Studies 9.1 to 9.0) led to a decrease in average annual carryover storage in each of the upstream reservoirs, with the exception of New Melones. This outcome is reasonable given that SLR would be expected to cause increased salinity concentrations in the Delta and force increased upstream release of stored water in order to maintain Delta water quality requirements while operating to meet Delta export objectives. The average carryover storage results for regional climate change with SLR (i.e. Studies 9.2 through 9.5, Table 11) also indicate either increased or decreased carryover storage relative to the condition of SLR without regional climate change (Study 9.1) depending on whether the scenario was wetter or drier. Likewise, the simulated average annual deliveries appear to be more sensitive to the regional climate change scenarios portrayed (i.e. comparing results across Studies 9.2 through 9.5) than to the amount of SLR portrayed (Study 9.1 relative to Study 9.0).

Before proceeding to the following more detailed discussions, it is mentioned that hydrologic sequences input to all studies (9.0 through 9.5) are all indexed 1922-2003 and have the same relative sequence of climate variability as that observed from 1922-2003. The climate change scenarios represented in Studies 9.2 through 9.5 represent a shift in hydroclimate norms (i.e. shift in mean-monthly headwater runoff) imposed on this sequence of climate variability.

Table 11. Mean Simulated CVP/SWP Conditions during full simulation period (1922-2003) for Studies 9.0-9.5

	Study 9.0: Base Without 1' Sea Level Change	Study 9.1: Base With 1' Sea Level Change	Study 9.2: Wetter, Less Warming	Study 9.3: Wetter, More Warming	Study 9.4: Drier, Less Warming	Study 9.5: Drier, More Warming
End of Sep Storages (TAF)						
Trinity	1394	1325	1524	1387	1313	1120
Shasta	2709	2591	2906	2686	2525	2286
Oroville	1973	1891	2290	1929	1538	1474
Folsom	492	476	518	472	428	402
New Melones	1533	1533	1695	1594	1022	1254
CVP San Luis	237	209	234	195	154	179
SWP San Luis	406	368	483	344	279	257
Total San Luis	643	576	716	539	433	436
River Flows (cfs)						
Trinity Release	974	958	1142	1131	978	874
Keswick Release	8674	8693	10049	9967	8907	8019
Nimbus Release	3321	3327	4221	4139	2518	2581
Flow Below Thermalito	4384	4396	5731	5734	3454	3431
Goodwin Release	654	654	976	826	389	451
Flow at Vernalis	4162	4161	5338	4626	3086	3437
Delta Parameters						
SWP Banks (cfs)	4669	4450	4940	4726	4029	3977
CVP Banks (cfs)	108	101	93	107	96	85
Jones (cfs)	3510	3334	3628	3479	3237	3030
Total Banks (cfs)	4777	4551	5034	4834	4124	4062
Cross Valley Pumping (cfs)	108	101	93	107	96	85
Sac Flow at Freeport (cfs)	22303	22488	25474	24685	20956	19900
Excess Outflow (cfs)	14175	15105	20331	19608	11876	11479
Required Outflow (cfs)	6193	5790	5300	5460	6220	6058
Total Inflow (cfs)	30190	30313	35833	34918	26980	26151
Old and Middle River (cfs)	-5151	-4785	-4812	-4906	-4931	-4481
QWEST (cfs)	1378	1843	2883	2381	815	1300
Deliveries (TAF)						
CVP						
North of Delta						
Agriculture	240	221	269	238	201	176
Settlement Contracts	1857	1857	1879	1879	1864	1825
M&I	201	196	207	200	188	181
Refuge	90	90	92	92	91	88
Total	2388	2364	2447	2409	2345	2270
South of Delta						
Agriculture	1210	1097	1322	1190	995	889
Exchange	852	852	867	867	856	834
M&I	129	123	132	126	119	115
Refuge	273	268	274	273	269	262
Total**	2647	2520	2776	2637	2419	2279

	Study 9.0: Base Without 1' Sea Level Change	Study 9.1: Base With 1' Sea Level Change	Study 9.2: Wetter, Less Warming	Study 9.3: Wetter, More Warming	Study 9.4: Drier, Less Warming	Study 9.5: Drier, More Warming
SWP						
Allocation	3209	3085	3332	3312	2772	2739
Table A	2959	2845	3072	3050	2563	2534
Article 56	110	112	106	120	111	107
Article 21	284	237	371	223	200	195
Table A + Art 56	3069	2957	3178	3170	2674	2641
Table A + Art 56 + Art 21	3353	3193	3550	3392	2874	2836
Anticipated Carryover	177	167	185	186	137	134
Allocations (%)						
CVP Allocation						
North of Delta						
Agriculture	68%	63%	76%	68%	57%	50%
M&I	88%	86%	92%	88%	83%	79%
South of Delta						
Agriculture	67%	61%	74%	67%	55%	49%
M&I	88%	86%	91%	88%	83%	79%
SWP						
All SWC	78%	73%	79%	78%	65%	65%

4.2.1 Upstream Effects: Upstream effects are evaluated for the major rivers systems in the CVP and SWP projects. The river systems discussed here include the Trinity River, Sacramento River, Feather River, American River, and the Stanislaus River. The effects of regional climate change and SLR on each of the river systems are evaluated in terms of (1) effect on carryover storage, and (2) effect on monthly reservoir releases.

Figure 35 summarizes the range and distribution of carryover storage conditions at Trinity Reservoir for water years 1922-2003 (where "probability of exceedence" for threshold storage values is indicated by the frequency that value was exceeded among the years evaluated). Figure 36 shows 5th, 50th, and 95th percentile values of monthly reservoir releases from Lewiston Reservoir below Trinity Reservoir. In Figure 35, the largest decreases in carryover storage was for the scenario of SLR with a "Drier, More Warming" climate (Study 9.5), where median carryover storage was roughly 1100 TAF compared to a median of about 1450 TAF without SLR or regional climate change (Study 9.0). SLR and regional climate change had little effect on the median releases at Lewiston (Figure 36) mainly due to how the simulated operation was constrained to maintain Trinity minimum instream flow requirements. However, the wetter regional climate change scenarios (Studies 9.2 and 9.3, Figure 36) suggest a potential for more flood releases out of Trinity Reservoir during winter-spring months.

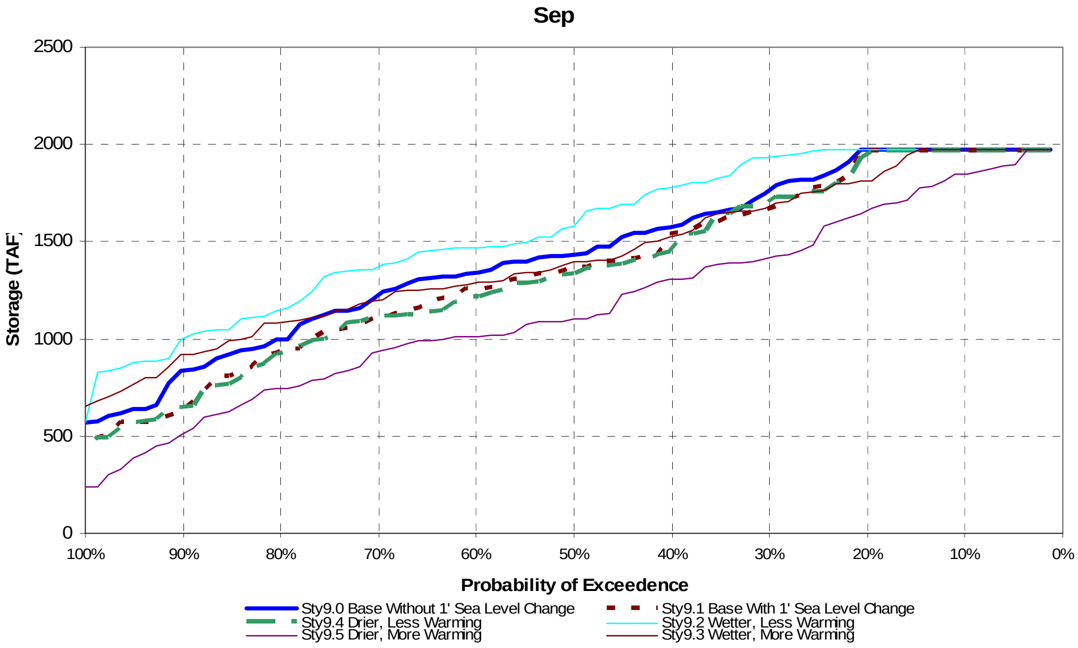


Figure 35. Trinity Reservoir End of September Exceedence

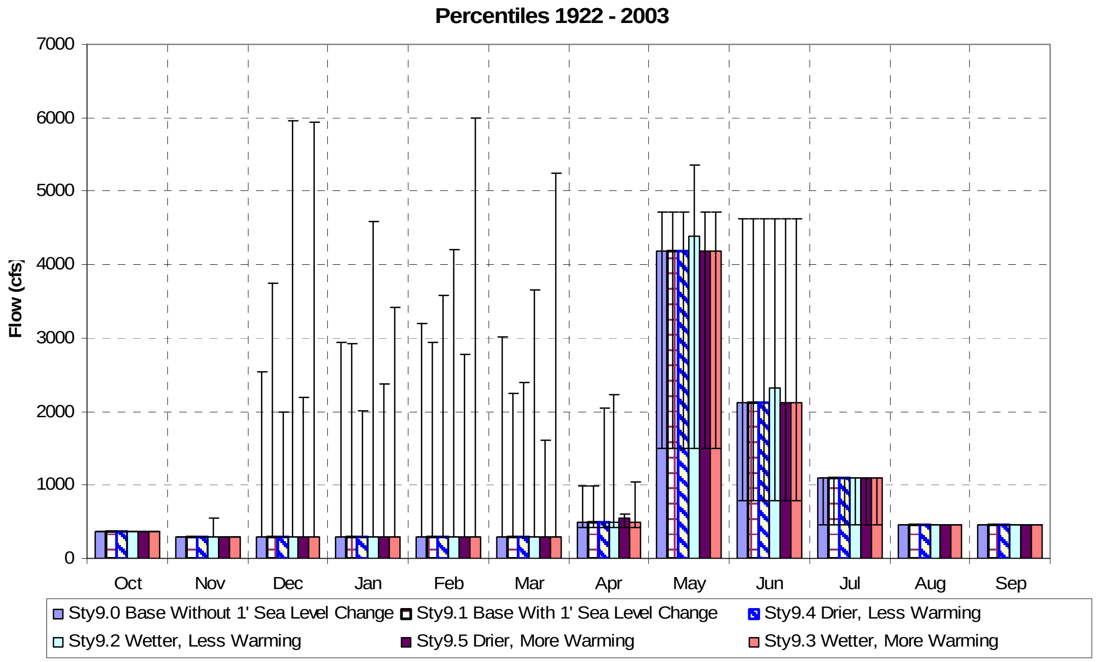


Figure 36. Lewiston 50th Percentile Releases with the 5th and 95th as the Whiskers

Figure 37 summarizes the range and distribution of carryover storage conditions at Shasta Reservoir for water years 1922-2003, while Figure 38 shows 5th, 50th, and 95th percentile values of monthly reservoir releases from Keswick Reservoir below Shasta Reservoir. Results on Figure 37 shows a 1-foot SLR without regional climate change would have some adverse effect carryover storage potential at Shasta, with median carryover storage decreasing by roughly 150 TAF (comparing Study 9.1 to 9.0, and not to be confused with the roughly 100TAF reduction in *mean* carryover storage listed in Table 11). However, results show that Shasta carryover storage is relative more sensitive to regional climate change possibilities, with median carryover varying by roughly 630 TAF across Studies 9.2 through 9.5. In particular, the “Drier, More Warming” aspects of Study 9.5 would seem to lead to a significant decrease in ability to operate Shasta to meet a 3400 TAF end-of-September storage target. In association, the Keswick release results shown on Figure 38 suggest that the wetter regional climate change possibilities (Studies 9.2 and 9.3) would lead to increased volume of flood releases during winter-spring.

Results also showed Shasta storage reduced to the deadpool constraint (550 TAF) near the end of the two key simulated drought sequences (simulation years 1928-1934 and 1987-1992) in the drier climate change scenarios (Studies 9.4 and 9.5). Given that simulated Shasta operations in those months involved passing reservoir inflow directly to reservoir release, the amount of water delivered to Settlement Contractors during those months and the amount of release contributing to instream flow requirements at Wilkins Slough (i.e. Navigation Control Point) were limited by available reservoir inflow. However, those results do not imply that Shasta storage would be managed during such climate conditions to reduce to dead pool. Rather, they suggest that some measure of drought response and adaptation would be required to operate past such conditions.

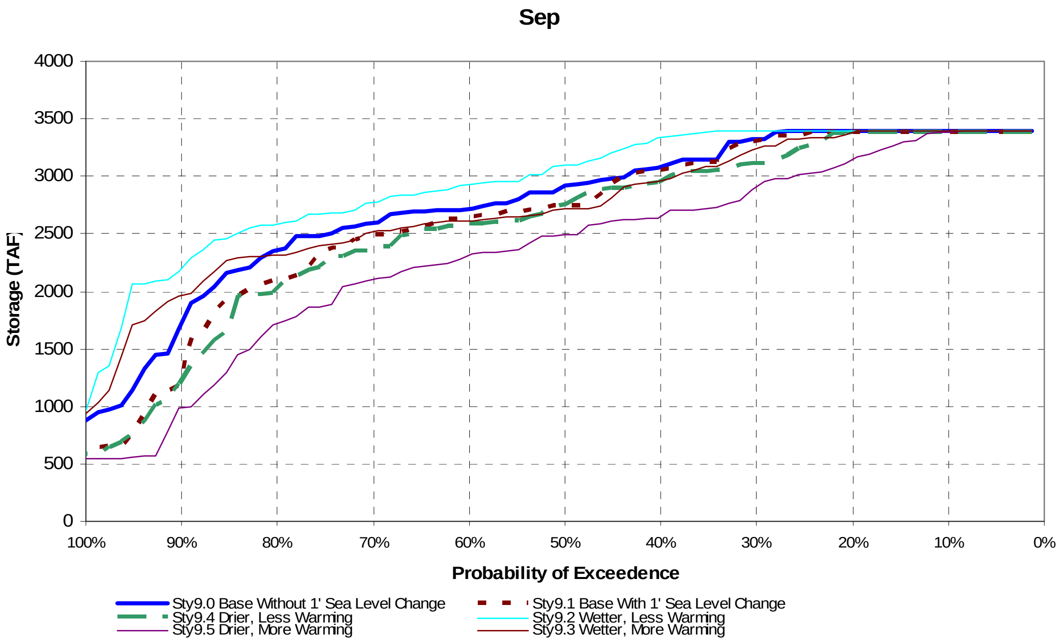


Figure 37. Shasta Reservoir End of September Exceedence

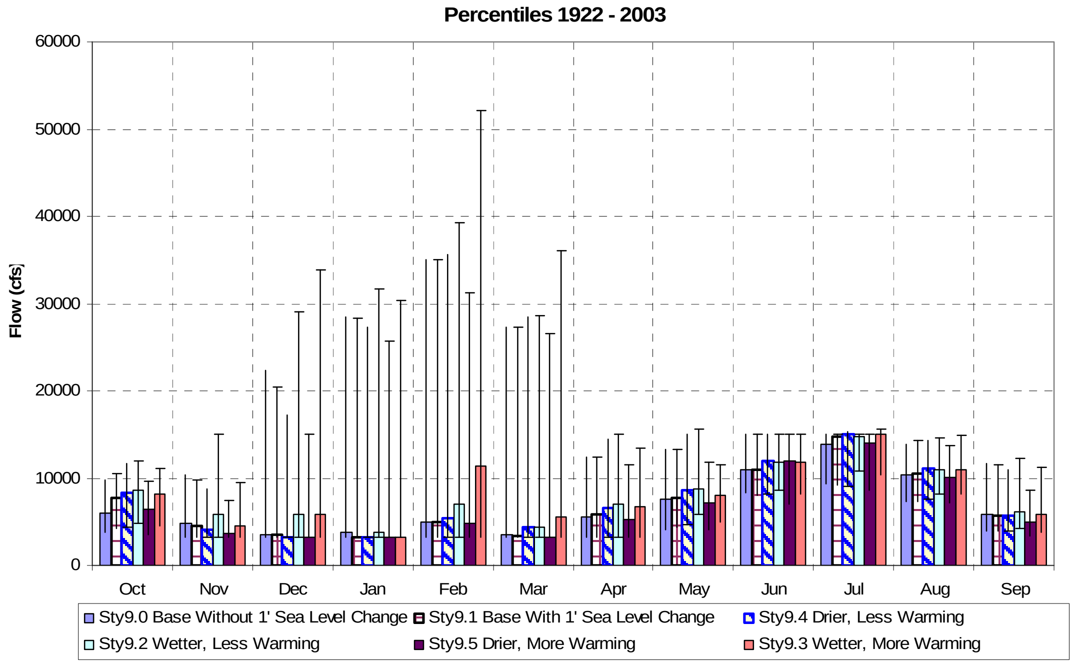


Figure 38. Keswick 50th Percentile Releases with the 5th and 95th as the Whiskers

The effects of SLR and regional climate change on Oroville Reservoir carryover storage are shown on Figure 39. The effect of 1-foot SLR on carryover storage, without climate change, is relative small compared to range of effects associated with the regional climate change scenarios. The wide range of end of September carryover storage is a function of the inflows into Oroville changing from 24 percent increase to -19 percent decreases in average annual inflows as illustrated in Table 8. Oroville tends to have decreased carryover storage in the two drier scenarios, minimal change in the wetter scenario with more warming (Study 9.3), and increased carryover storage in the wetter scenario with less warming (Study 9.2). Figure 40 shows the percentiles for the simulated monthly flows below Thermolito. As expected, the releases increase in the wetter scenarios and suggest increased volumes of flood releases relative to the base and drier climate runs.

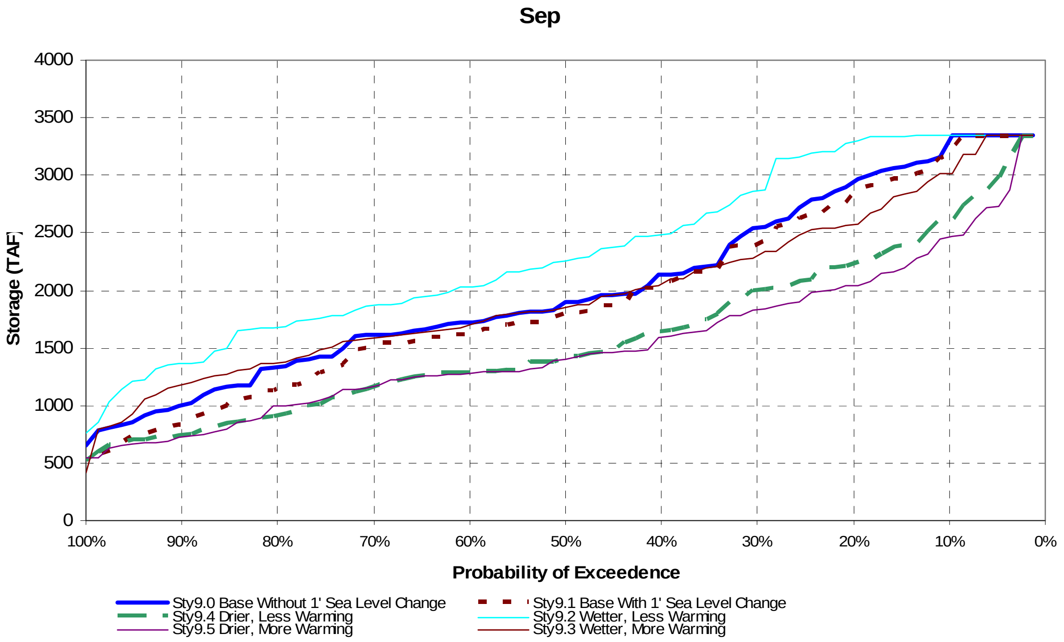


Figure 39. Oroville Reservoir End of September Exceedence

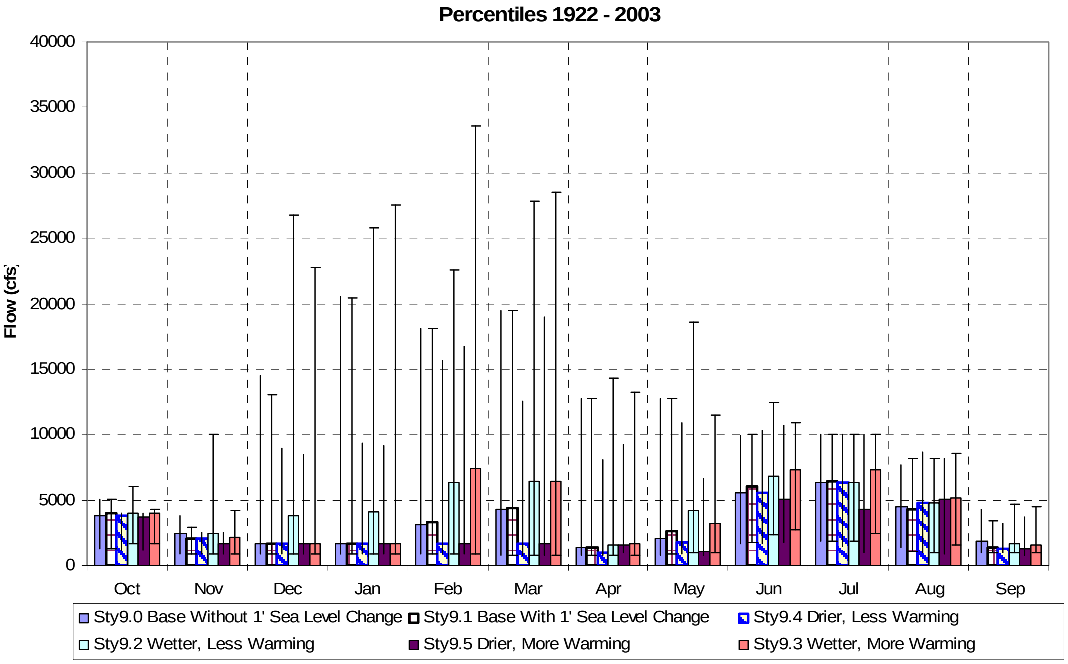


Figure 40. 50th Percentile Flows Below Thermolito with the 5th and 95th as the Whiskers

Figure 41 shows the effects of SLR and regional climate change on simulated carryover storage at Folsom Lake. A decrease in carryover storage was found in almost all studies relative to the base Study 9.0, with the exception being the wetter Study 9.2, which involved wetter and less warming conditions. Figure 42 shows the monthly releases from Nimbus reservoir. The wetter scenarios show increased 50th percentile releases.

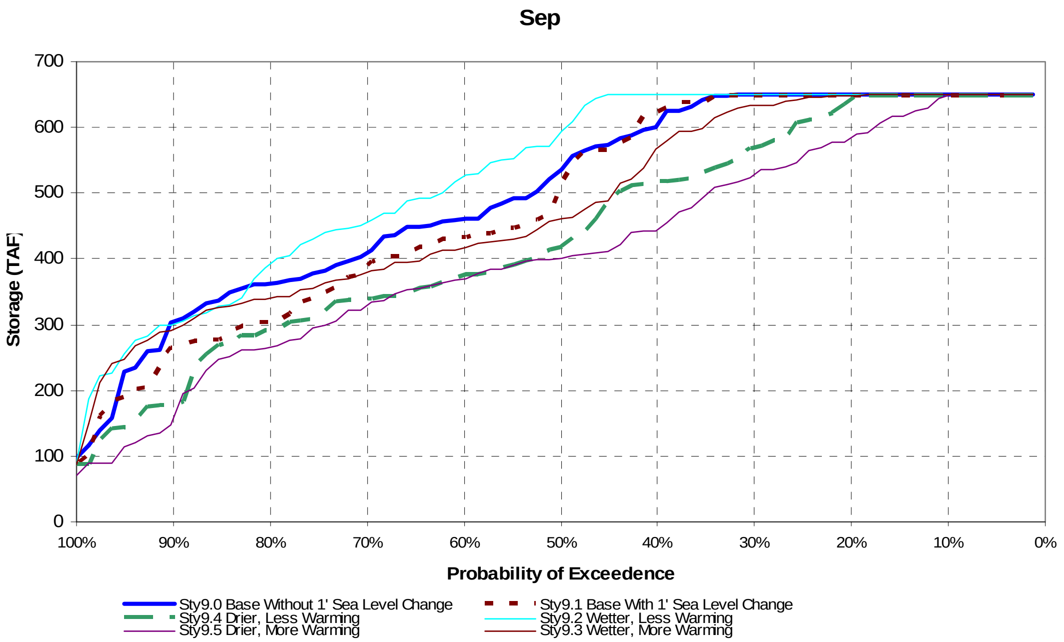


Figure 41. Folsom Reservoir End of September Exceedence

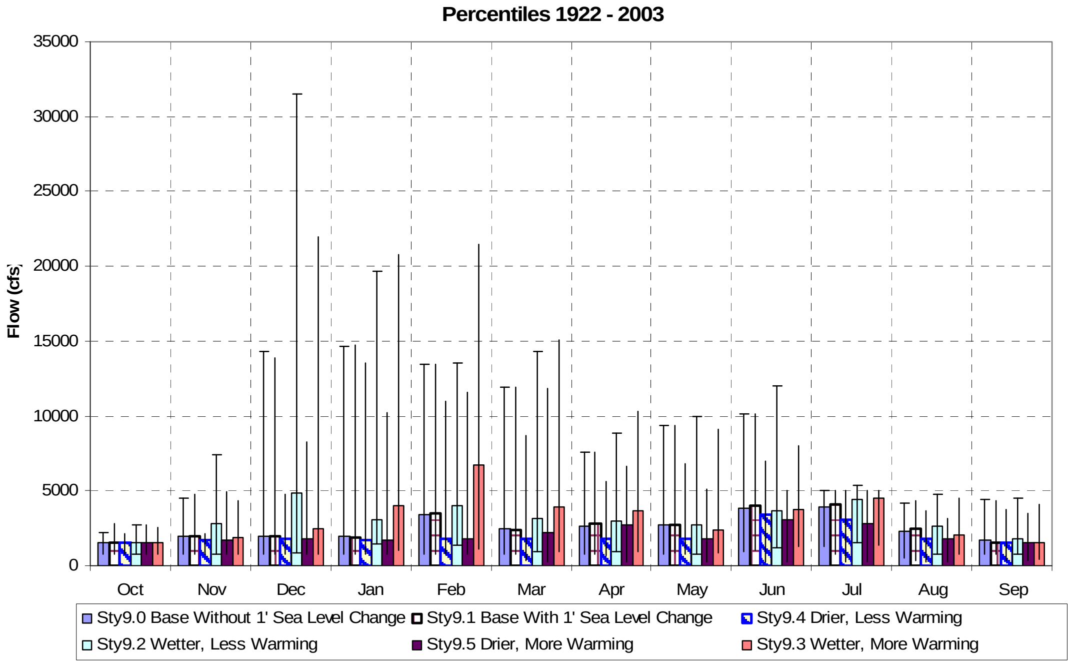


Figure 42. Nimbus 50th Percentile Releases with the 5th and 95th as the Whiskers

Figure 43 shows carryover storage results for New Melones Reservoir. Results suggest that SLR without climate change (Study 9.1) would not have significant effect on New Melones storage relative to the no-SLR simulation (Study 9.0), as portrayed here. For the drier scenarios considered (Studies 9.4 and 9.5), results suggest that current operations strategies would not lead to meeting storage and downstream release objectives. Note that in the case of New Melones (and for Millerton Lake, for which results are not illustrated here), the carryover storage decreases are worse for the “drier, less warming” scenario (Projection 3) than for the “drier, more warming” scenario (Projection 4). This is because the geographic features of these projections over the San Joaquin Valley headwaters show more pronounced drying in Projection 3 than in Projection 4, leading to less reservoir inflow in Projection 3 than in Projection 4 (Table 11).

Figure 44 shows the monthly percentile releases from Goodwin Reservoir to the Stanislaus River, below New Melones Reservoir. Mean-annual Goodwin release diminishes in the drier scenarios (Studies 9.4 and 9.5) relative to the base runs (Studies 9.0 or 9.1) by roughly 200 to 260 cfs (Table 11). Conversely, mean-annual release during the wetter scenarios increases by roughly 170 to 320 cfs (Table 11). Figure 45 shows how the amount of Goodwin release necessary to satisfy the San Joaquin River water quality standard at Vernalis increases during June and July for the drier climate change scenarios (Studies 9.4 and 9.5). Focusing on instances of more extreme release requirements, the results show that the 95th percentile June release in Study 9.4 reaches roughly 1400 cfs, which is significantly greater than the 95th percentile June release values less than 300 cfs found in Studies 9.0 and 9.1.

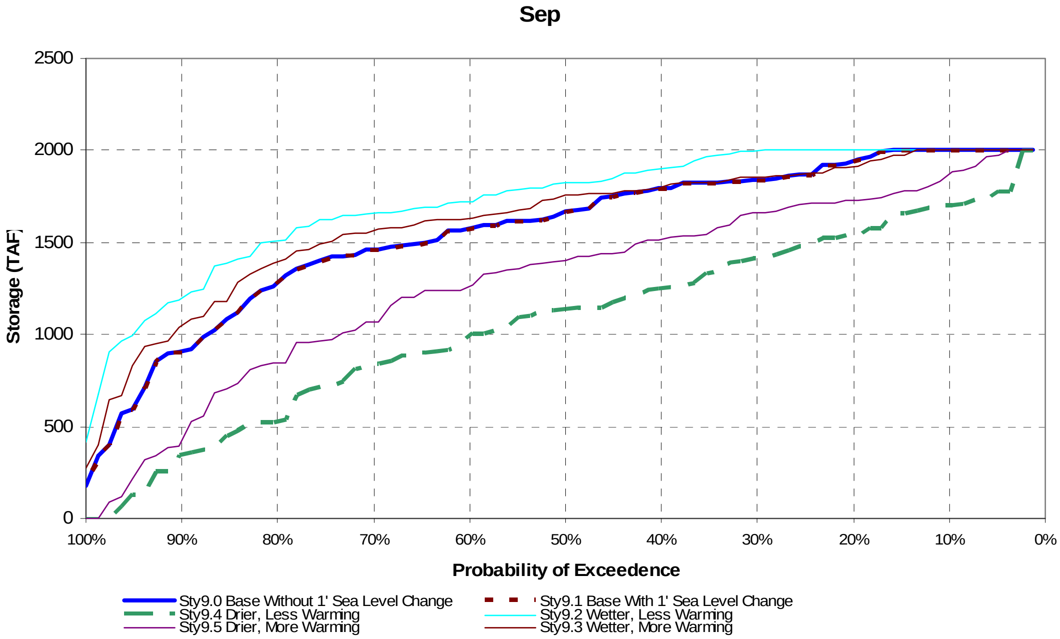


Figure 43. New Melones Reservoir End of September Exceedence

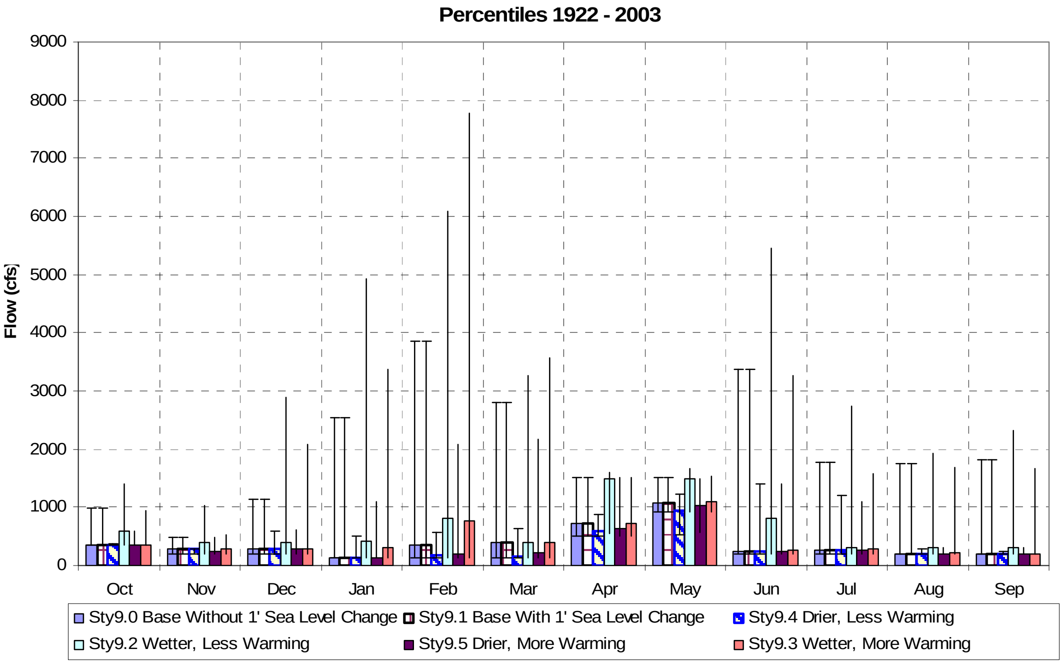


Figure 44. Goodwin 50th Percentile Releases with the 5th and 95th as the Whiskers

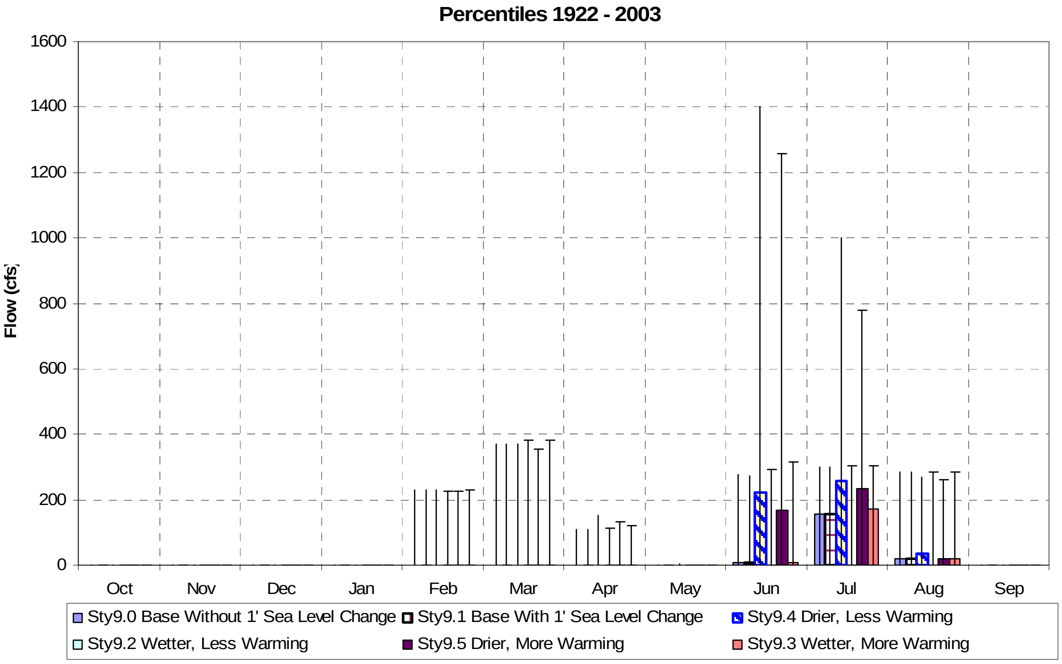


Figure 45. Goodwin 50th Percentile Releases for Water Quality with the 5th and 95th as the Whiskers

4.2.2 Delta Effects: Sacramento-San Joaquin Delta (Delta) effects based on CalSim II results are evaluated by looking at simulated conditions of total Delta inflow, outflow, exports at Banks and Tracy. Delta salinity indicated by the CalSim II's simulated position of the "X2" isohaline upstream of Golden Gate Bridge is also evaluated.

Figure 46 shows the range and distribution of simulated monthly inflows to the Delta, indicated by 5th, 50th, and 95th percentile monthly values during simulation years 1922-2003. The months when Delta inflow would appear to be most affected by the climate change scenarios look to be the winter months due to either increased or decreased reservoir releases in response to wetter or drier conditions. SLR without regional climate change would appear to have minimal effect on mean-annual Delta inflow, based on comparison of Studies 9.1 and 9.0 in Table 11.

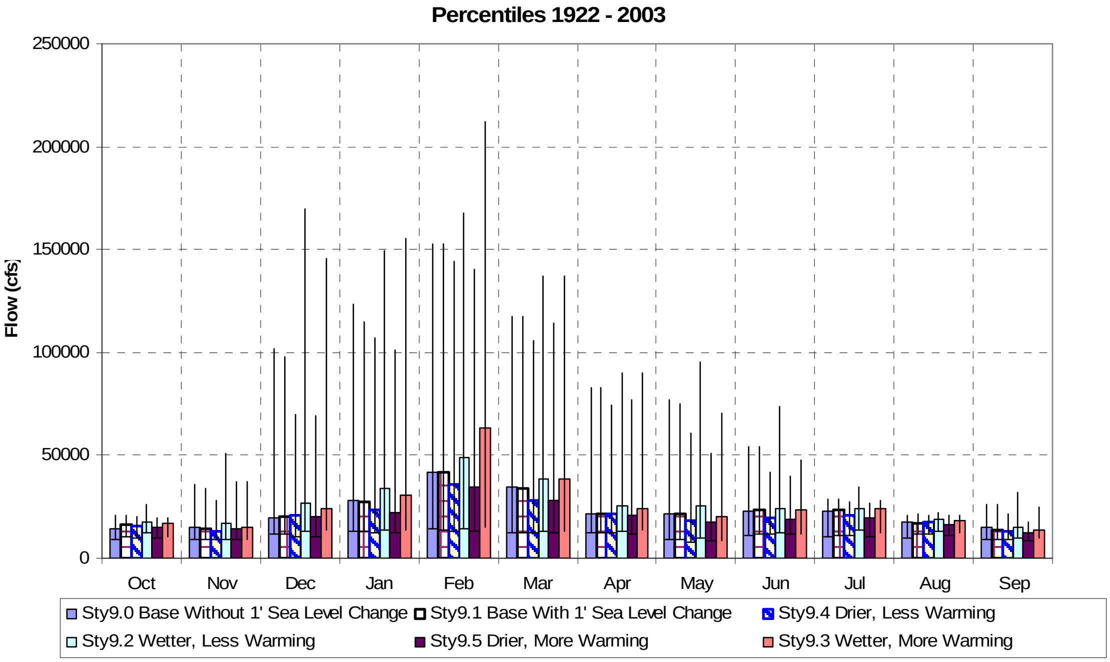


Figure 46. Delta Inflow 50th Percentile with the 5th and 95th as the Whiskers

Figure 47 and Figure 48 show results for monthly required and total delta outflow. The required delta outflow results on Figure 47 show that the major changes in outflow requirements happen during February through June (coincident with the period when X2 position affects delta outflow requirements and upstream release operations), with requirements increasing or decreasing under wetter or drier hydrology, respectively.

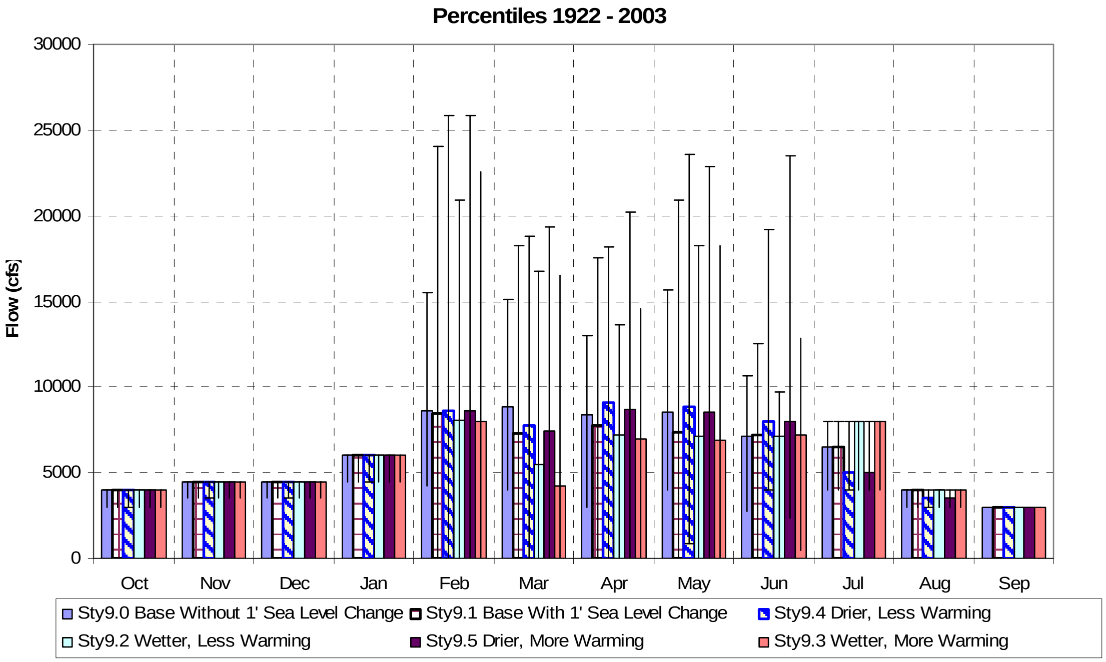


Figure 47. Delta Required Outflow 50th Percentile with the 5th and 95th as the Whiskers

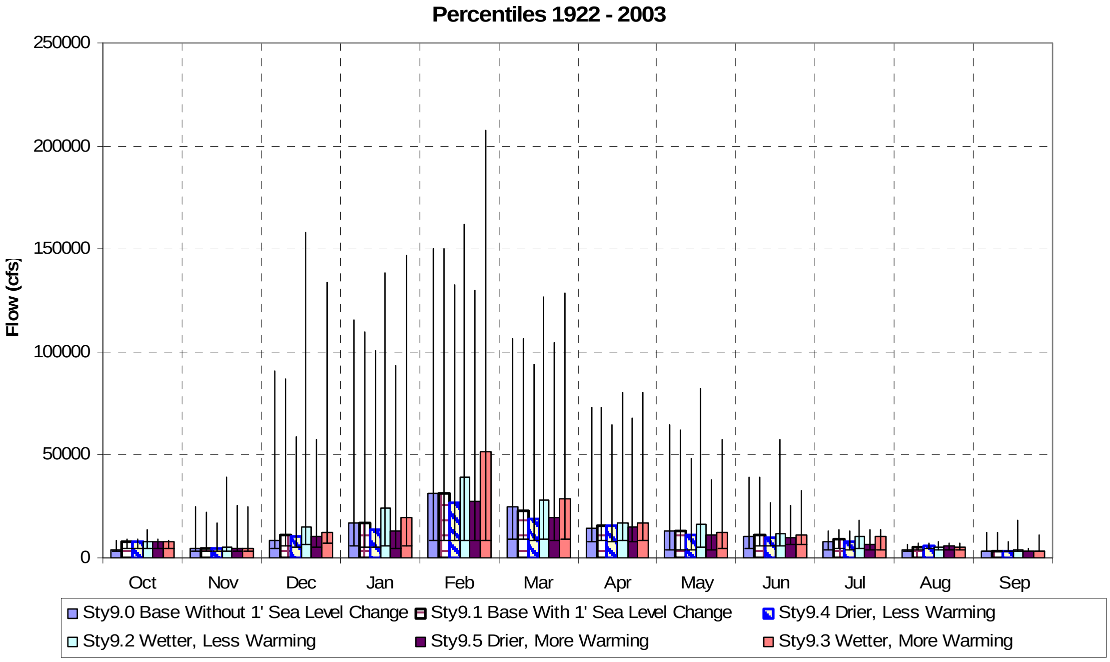


Figure 48. Delta Total Outflow 50th Percentile with the 5th and 95th as the Whiskers

Mean-annual combined exports at Jones and Banks were found to decrease by about 300 TAF under SLR without regional climate change (Table 12). Relative to SLR without climate change (Study 9.1), combined exports under the drier scenarios (Studies 9.4 and 0.5) show roughly 420 to 660 TAF decreases in mean-annual volume, whereas combined exports under the wetter scenarios (Studies 9.2 and 9.3) show 300 to 540 TAF increases.

The long-term monthly average rate of pumping at Banks decreases in the drier scenarios (Studies 9.4 and 9.5 relative to Study 9.1) by roughly 450 to 500 cfs (Table 12), and increases in the wetter scenarios (Studies 9.2 and 9.3 relative to Study 9.1) by roughly 280 to 480 cfs. Figure 49 shows the monthly pumping rates at Banks. Summer pumping looks to be affected the most in the drier scenarios as well as early fall. The wetter scenarios show little to no impact to Banks pumping on a monthly basis with the exception of the autumn-winter months where Banks has increased its pumping rate. Monthly Jones pumping rates, shown on Figure 50, would be affected on a monthly basis similar to those of Banks. After accounting for SLR effects (Study 9.1 relative 9.0), summer pumping looks to be the most affected by climate change during June-September under drier conditions (Studies 9.4 and 9.5) and during for February-July under wetter conditions (Studies 9.2 and 9.3).

Table 12. Total Annual Jones + Banks Pumping (TAF)

	9.0 - Base Without 1' Sea Level Change	9.1 - Base With 1' Sea Level Change	9.2 - Wetter, Less Warming	9.3 - Wetter, More Warming	9.4 - Drier, Less Warming	9.5 - Drier, More Warming
Average	6002	5711	6274	6017	5329	5133
Min	2197	1960	2061	2022	1608	1694
Max	8153	8103	8247	8044	8024	7988

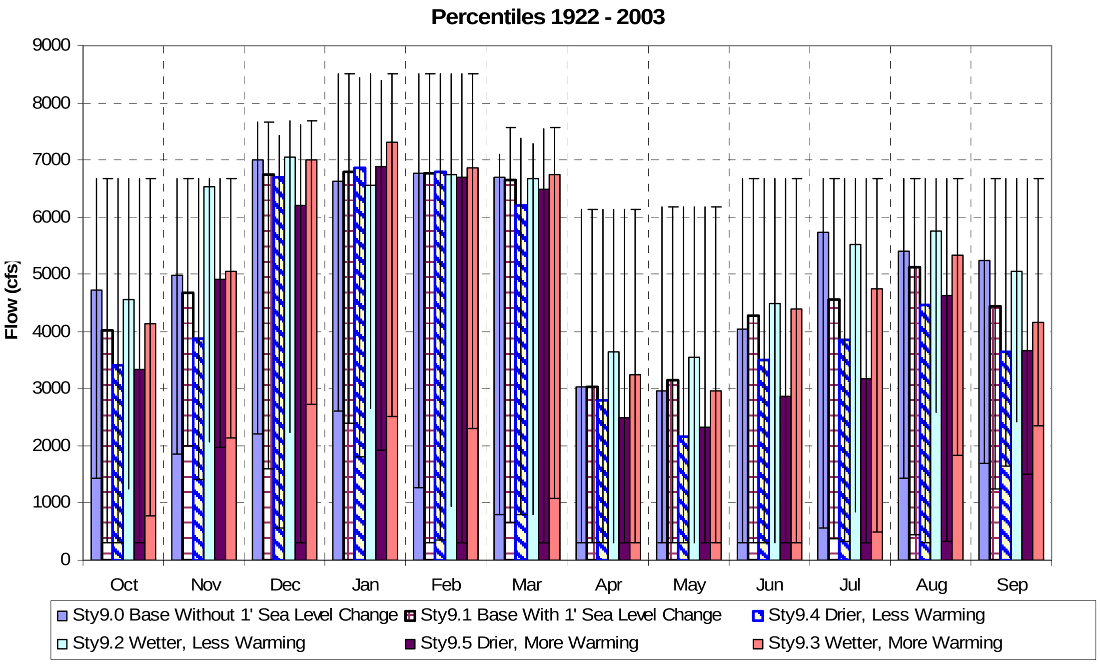


Figure 49. Monthly Banks Pumping the bars represent 50th Percentile with the 5th and 95th as the Whiskers

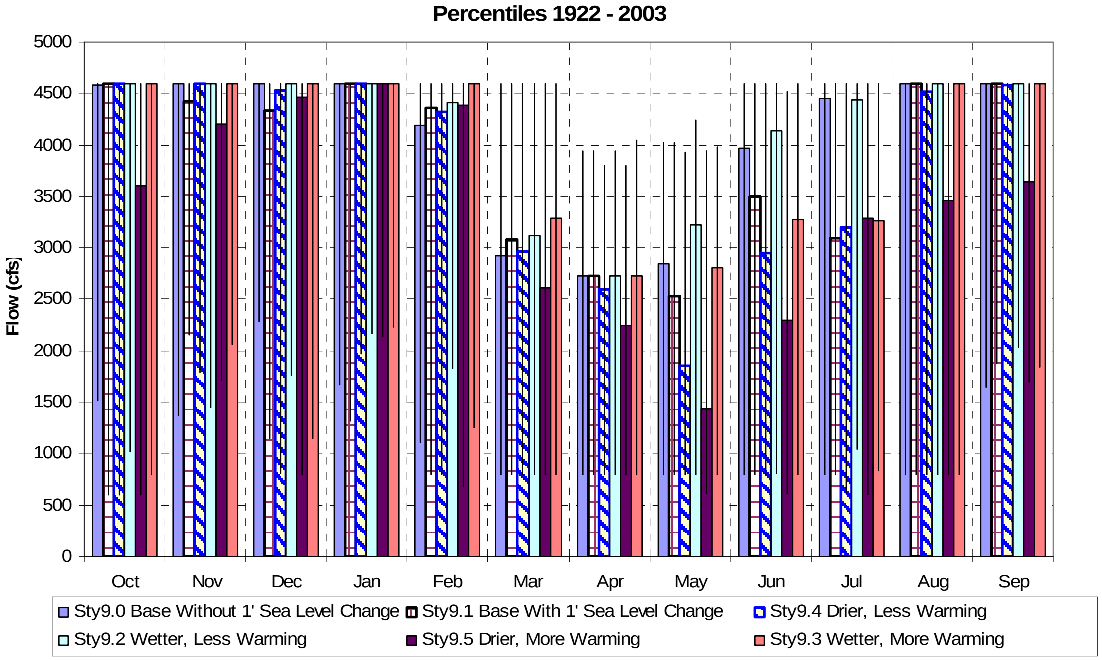


Figure 50. Monthly Jones Pumping the bars represent 50th Percentile with the 5th and 95th as the Whiskers

Impacts to the X2 position are shown in Figure 51 for the months that the projects operate to the requirement (i.e. February through June). The monthly median position are further from the Golden Gate Bridge for drier scenarios and closer for wetter scenarios, while the impact from SLR alone is about a 1 to 4 kilometer position increase (Figure 51).

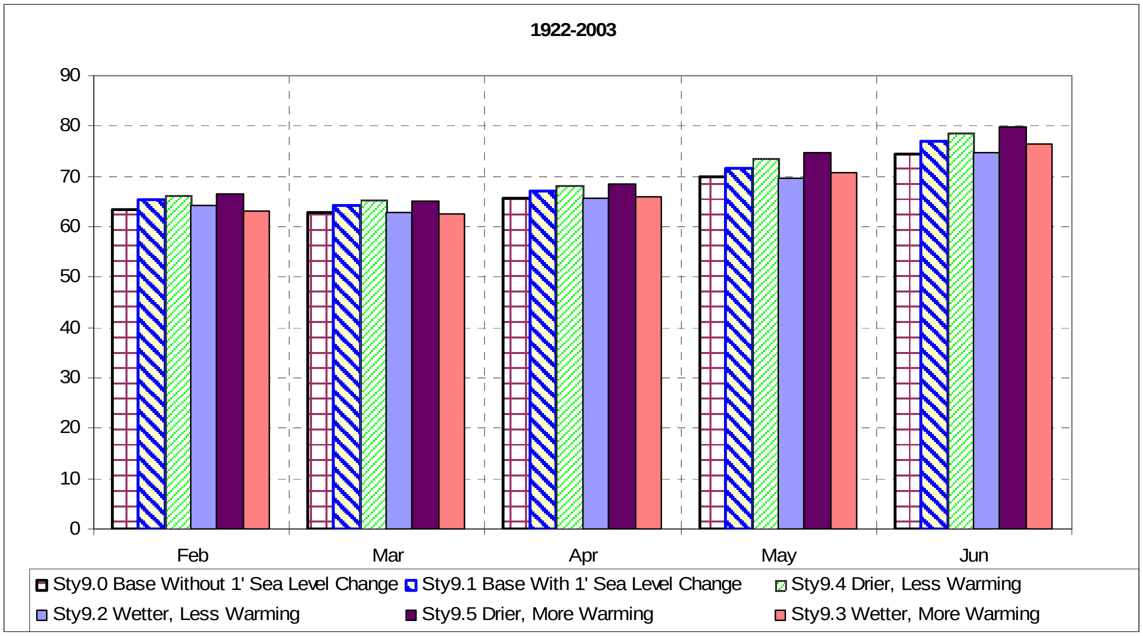


Figure 51. X2 Position the bars represent 50th Percentile with the 5th and 95th as the Whisker

Figure 52 to Figure 54 show the number of days when the X2 position was simulated to be downstream of the given control points for each simulation year, where years are ordered from wetter to drier as classified by the Sacramento 40-30-30 Index (i.e. W (Wet), AN (Above Normal), BN (Below Normal), D (Dry) and C (Critical)) . Note that if the average position for the month was downstream a particular control point, then all the days of that particular month were counted as being downstream of the control point. So the results on Figure 52 through Figure 54 give a gross estimate of day-counts when X2 would be downstream of a given control point. Results from the two drier scenarios suggest a reduced number of days of X2 being positioned downstream of the Roe Island and the Chipps Island control points (e.g., day-counts during AN and BN years on Figure 52 and Figure 53, respectively). There was also a fairly significant reduction in the number of days when the X2 position would be located downstream of the confluence of the San Joaquin and Sacramento River (Figure 54) under the drier scenarios.

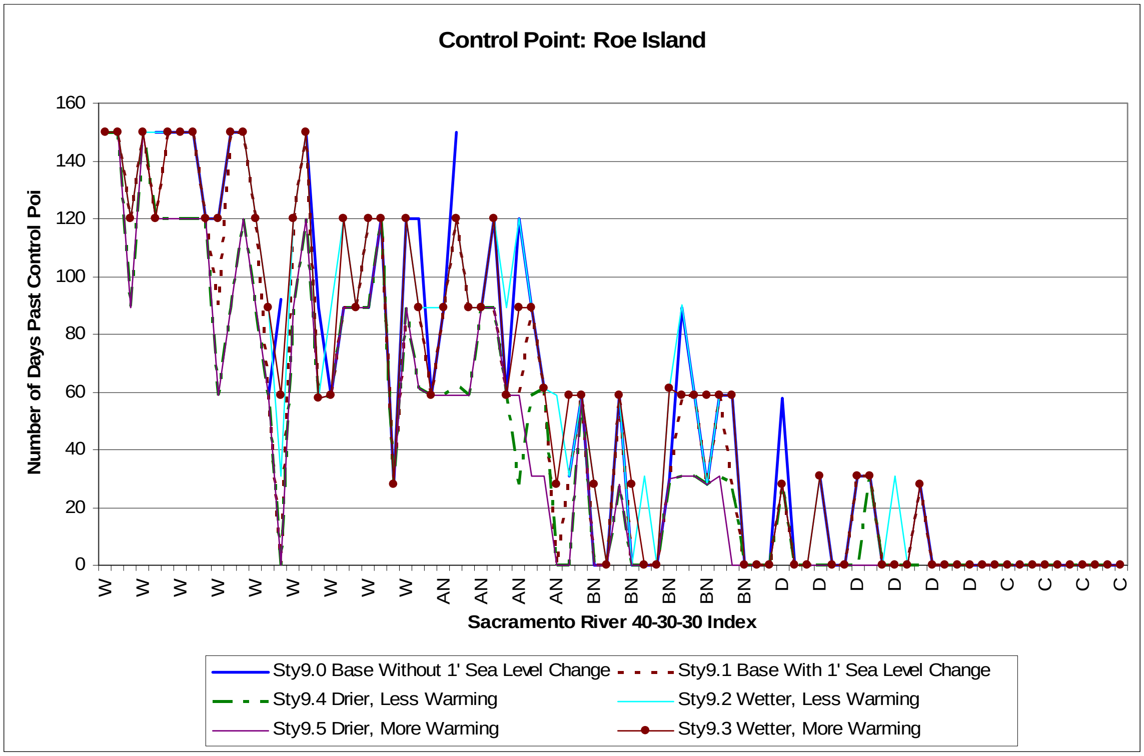


Figure 52. Number of days X2 Position was past the Roe Island sorted by year type

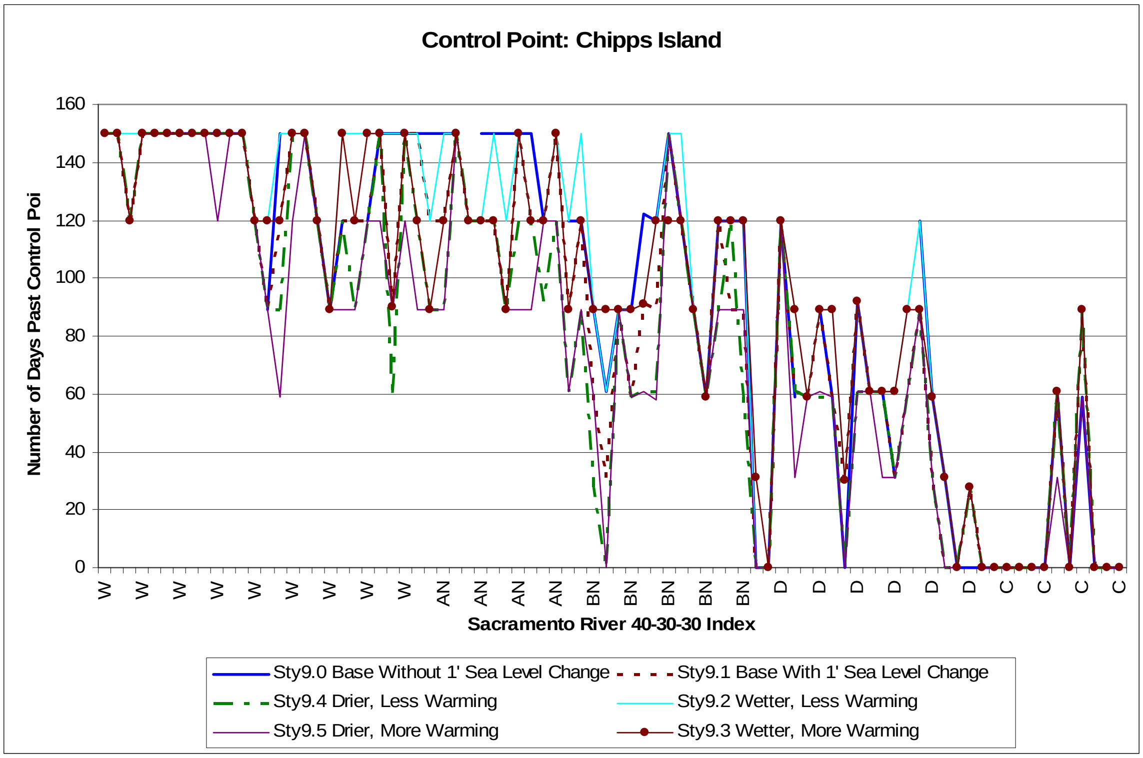


Figure 53. Number of days X2 Position was past the Chipps Island sorted by year type

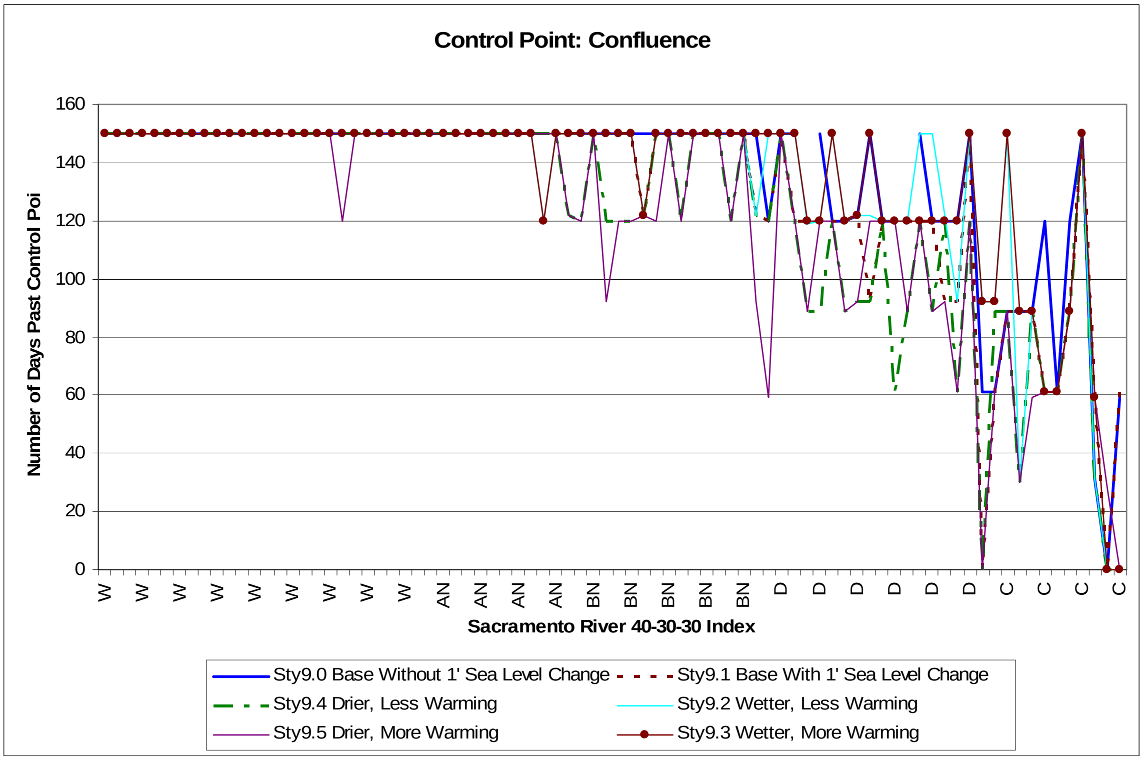


Figure 54. Number of days X2 Position was past the confluence sorted by year type

<u>4.2.3 Effects to Deliveries and San Luis Reservoir Storage</u>: The range and distribution of annual delivery volumes simulated for CVP North of Delta (NOD) and South of Delta (SOD) contractors are shown on Figure 55 and Figure 56, respectively. Similar results for total SWP deliveries to Table A contracts and recipients of Article 56 and Article 21 water are shown on Figure 57. Median effects on CVP NOD deliveries were most pronounced for the “drier, more-warming” scenario (Study 9.5), where median annual delivery being roughly 140 TAF less than the median annual delivery under Study 9.1. In contrast, median annual deliveries to CVP SOD decreased by about 470 TAF when comparing the same two studies; this is in addition to the roughly 120 TAF decrease in median annual delivery associated with SLR (Study 9.1 versus 9.0). Focusing on the wetter scenarios with SLR, only the “wetter, less-warming” scenario (Study 9.2) led to increased the SOD deliveries compared to the Base without SLR (Study 9.0), showing a roughly 100 TAF increase in median-annual delivery. One effect not illustrated is that shortages to the NOD Settlement Contracts occur during the drought sequences within the drier scenarios (Studies 9.4 and 9.5).

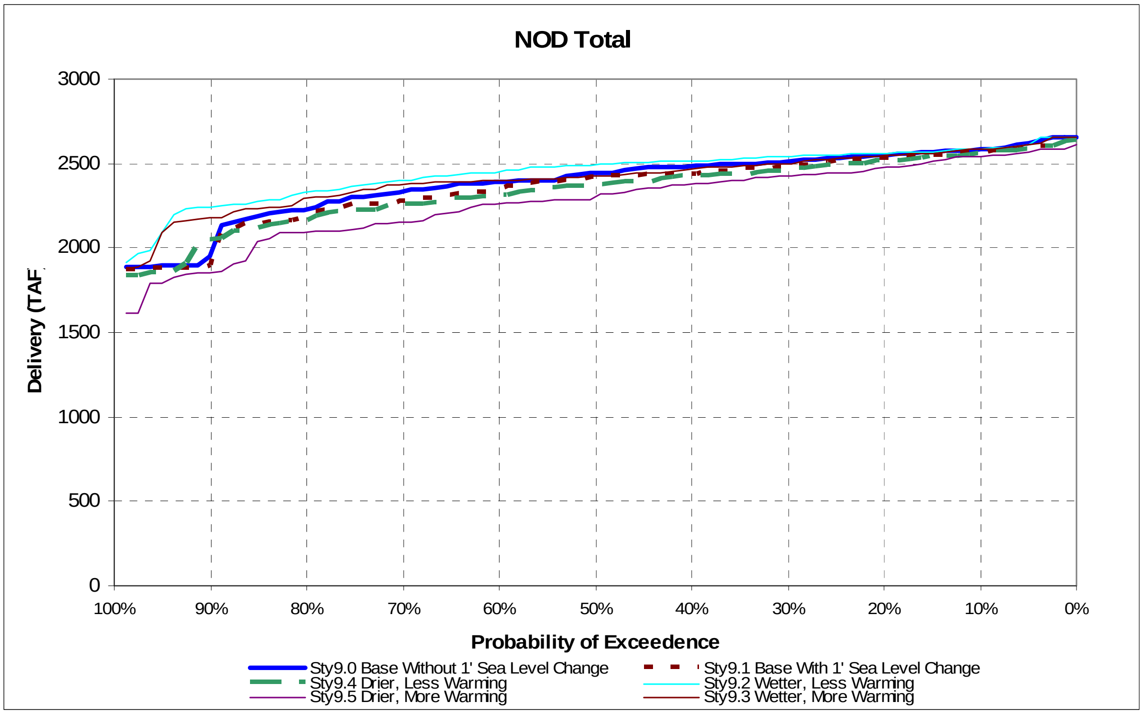


Figure 55. CVP Total NOD Deliveries Exceedence

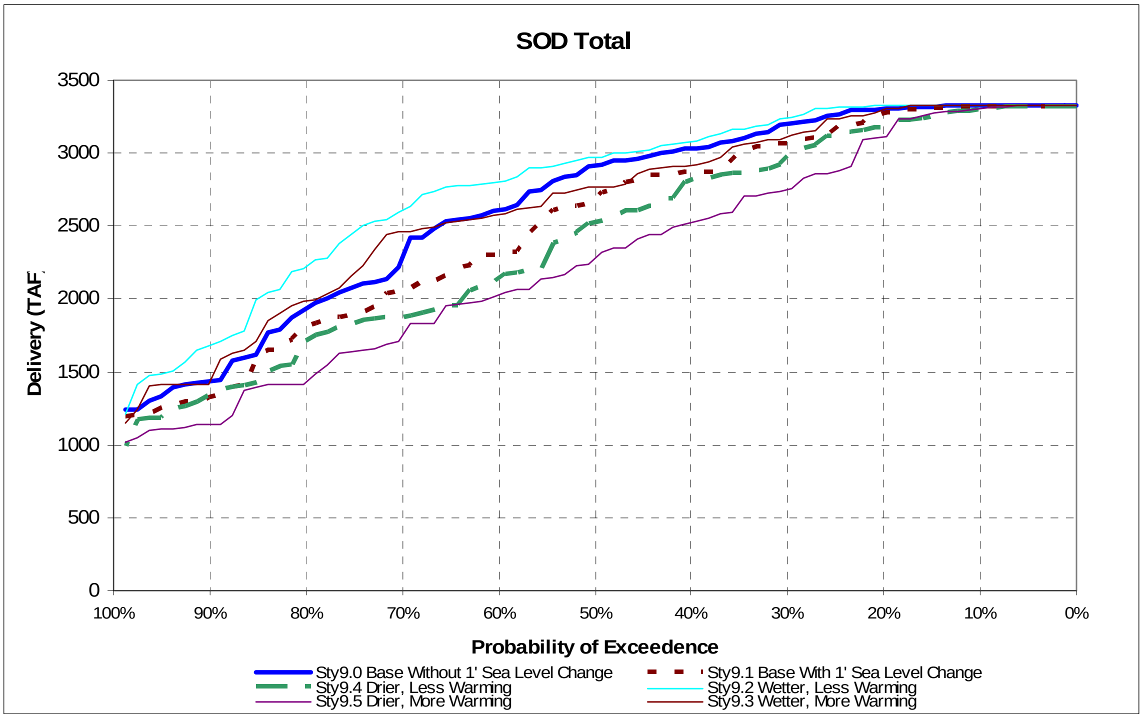


Figure 56. CVP Total SOD Deliveries Exceedence

Annual SWP deliveries were most significantly affected during the drier scenarios of 9.4 and 9.5. Comparing Study 9.1 to 9.0, SLR without regional climate change led to about a 130 TAF decrease in median-annual SWP delivery. The superimposed effects of the regional climate change scenarios (Studies 9.2 through 9.5) varied +200 to -590 TAF.

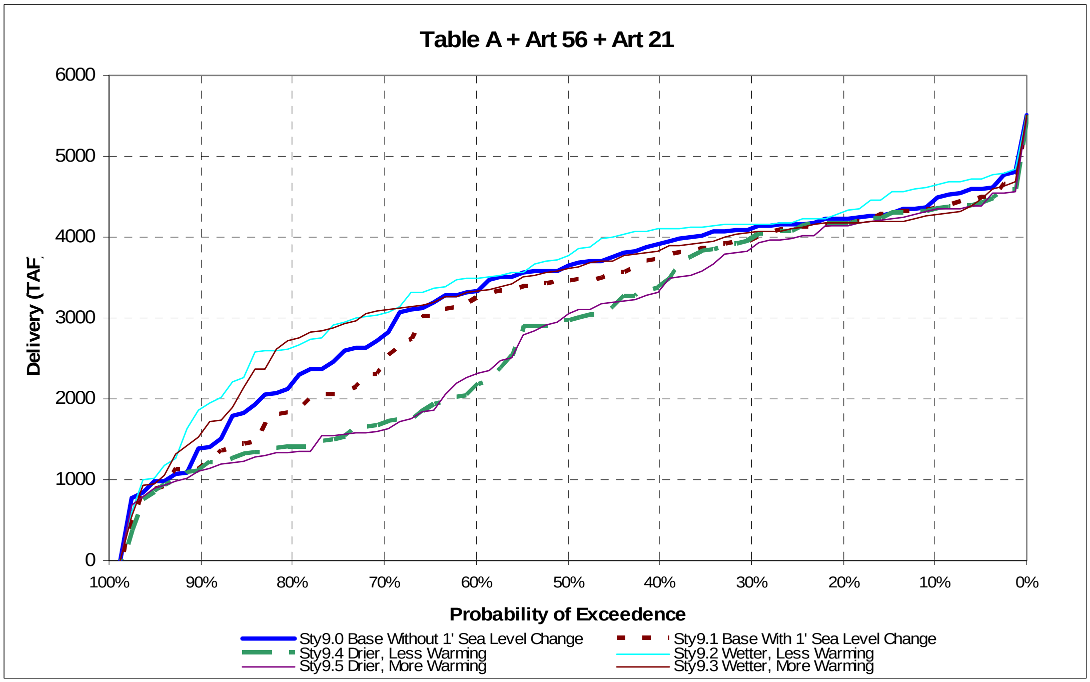


Figure 57. SWP Deliveries Exceedence

Focusing on the Delta export service area, the range and distribution of carryover storage (i.e. end of August storage) in the CVP and SWP portions of San Luis Reservoir are shown on Figure 58 and Figure 59, respectively. The end of August storage was chosen rather than September because August is generally targeted as the time of lowest drawdown for the projects' respective storage reserves in San Luis Reservoir. The figures show that for the drier scenarios the median August drawdown is significantly decreased relative to Studies 9.0 and 9.1, due to reduced late summer Delta exports.

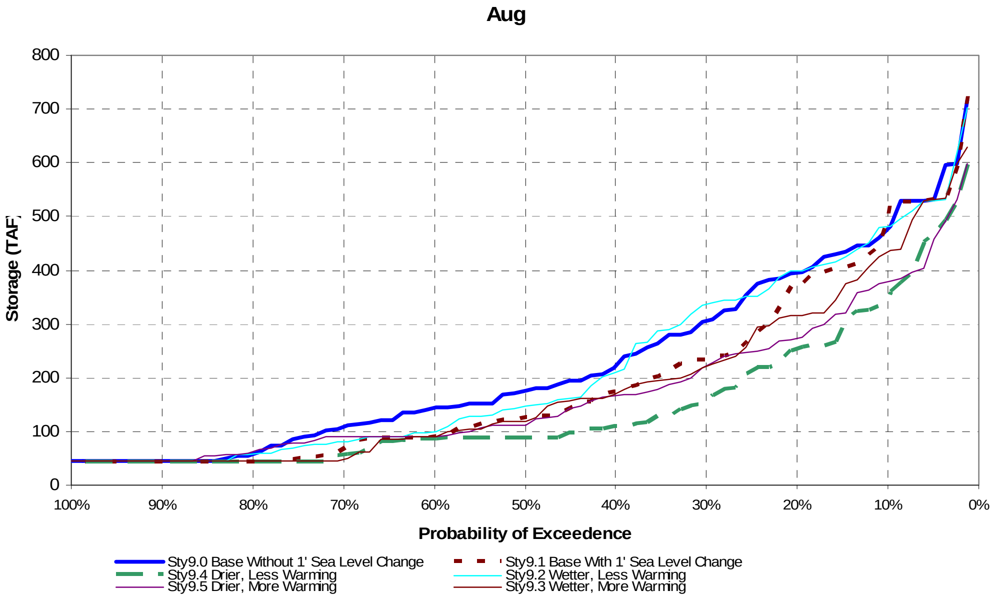


Figure 58. CVP San Luis End of August Exceedence

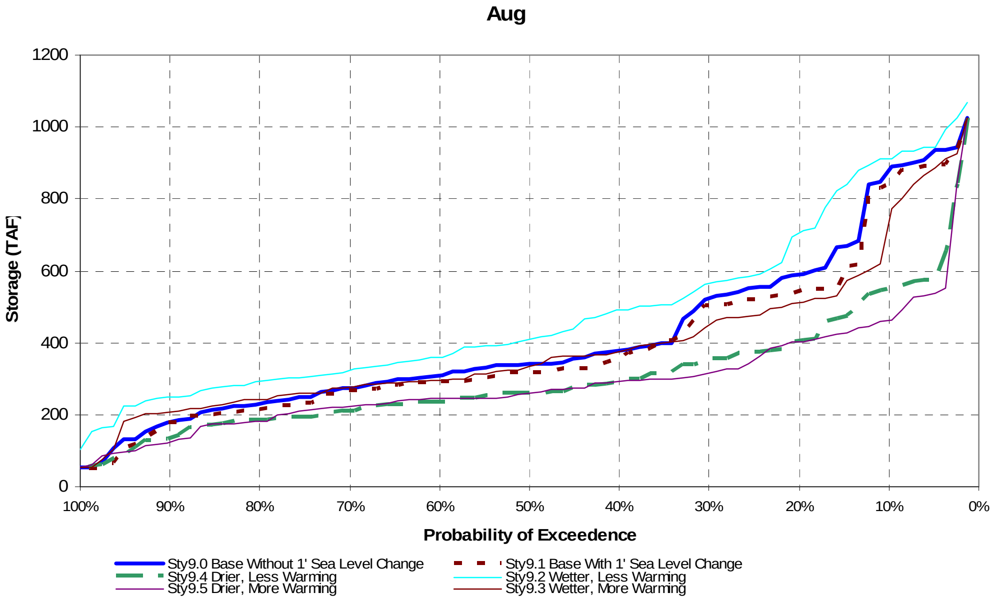


Figure 59. SWP San Luis End of August Exceedence

4.3 Delta Flows and Velocities

As illustrated by preceding results, climate change could affect precipitation and runoff patterns in the Central Valley, which would affect reservoir operations and Delta exports. Since the major inflows into the Delta are controlled by reservoir releases, Delta inflow patterns would be affected as well. Further, Delta impacts from potential sea level rise include higher water levels and degradation of water quality due to increased saltwater intrusion from the ocean through San Francisco Bay.

The following sections focus on simulated Delta flow and velocity results in several channel locations relevant to CVP/SWP operations. Flow and velocity results were evaluated and compared between five delta simulations respectively forced by output from CalSim II Studies 9.1-9.5. These five studies reflect an unchanged regional climate and the four regional climate change assumptions (Section 2.2.4), each paired with the scenario sea level rise described in Section 2.3.2. Note that the CVP/SWP operations used to force these delta simulations reflect some simulated adjustment of operations to lessen impacts of sea level rise on Delta water quality and conveyance. Also, in presenting results, because all of the scenarios use the same sea level rise conditions, the tables and figures show results organized according to regional climate change aspects (wetter versus drier, paired with either more warming or less warming, as labeled in Section 2.2.4).

The Delta Simulation Model 2 (DSM2) was used to represent the flows and velocities for each of the climate change scenarios (Section 3.5). These studies cover a 16-year analysis period that reflects hydrologic variability from water years 1976-1991 (i.e. Oct 1975-Sept 1991) as modified by climate change and system operations. In order to reduce the results into a more digestible amount of information, study-specific data were analyzed by seasons (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec) and by Sacramento 40-30-30 Index water year type:

- ***Wetter Years*** being water years classified as wet or above normal
- ***Driver Years*** being water years classified as below normal, dry, or critical

Limitations related to DSM2 modeling are covered in the DSM2 appendix (Appendix F).

4.3.1 Seasonal Effects of Climate Change on Delta Flows: Four locations were chosen for analysis as shown in Figure 60:

- ***Head of Old River*** flow
- ***Old and Middle River*** flows determined by adding average flows from
    - Old River at Bacon Island
    - Middle River at Middle River
- ***Qwest*** westward Delta flow determined by adding average flows from
    - Three Mile Slough

  - San Joaquin River at Blind Point
  - Dutch Slough
- ***Cross Delta*** flows determined by adding average flows from
  - Georgiana Slough
  - North Fork of the Mokelumne River
  - South Fork of the Mokelumne River

The flow results are summarized in Table 13. Maximum, minimum and quartile values are presented by season and water year type in Table 15 and Table 16. Changes in flow are listed in Table 17 and Table 18. Percent changes in flow are in listed Table 19 and Table 20. Additional results are presented graphically in a spreadsheet in the electronic supplement to this appendix (Appendix S).

Results show that climate change typically had more effect on Delta flows during wetter years than during drier years. This result seems related to how CVP and SWP operations occur with more flexibility during wet years, within the constraints of flood control requirements, compared to drier years when the CVP and SWP operations may be more frequently constrained to maintain in-stream flows and other environmental objectives.

- Head of Old River Flows
  - Remained positive (oceanward) for all scenarios
  - Decreased in winter and spring of wetter years for the drier climate change scenarios
  - Increased in winter of wetter years for the wetter climate change scenarios
  - Changes were minor during drier years for all climate change scenarios
- Old and Middle River Flows
  - Flows were typically negative (landward) except for a flow reversal in winter of wetter years for the wetter, less warming scenario
  - Fall and winter flows are the most sensitive to climate change
  - Negative winter flows decreased for the wetter scenarios and increased for the drier scenarios
  - Negative fall flows increased for the wetter scenarios and decreased for the drier scenarios
- QWEST Flows [westward flows from the Delta towards the ocean]
  - Magnitude and direction of QWEST is affected by climate change scenario and season.
  - Flow direction is
    - typically positive during wetter years except for summer for the drier climate change scenarios
    - always positive in the spring
    - typically negative in the summer of drier years except for the drier, more warming scenario

    - positive in the fall of drier years for the drier climate change scenarios and negative in fall of drier years for the wetter climate change scenarios
  - Winter flows are the most sensitive to climate change and response varies by scenario

- Cross Delta Flows
  - Winter flows were the most sensitive to climate change, flows decreased for the drier climate scenarios and increased for the wetter climate scenarios

<u>4.3.2 Seasonal Effects of Climate Change on Delta Velocity</u>: Four locations were chosen for analysis as shown in Figure 60:

- Head of Old River flow
- Middle River at Middle River
- San Joaquin River at Blind Point
- Georgiana Slough

The velocity results are summarized in Table 14. Maximum, minimum and quartile values are presented by season and water year type in Table 21 and Table 22. Changes in velocity are listed in Table 23 and Table 24. Percent changes in velocity are in Table 25 and Table 26. Additional results are presented graphically in a spreadsheet in the electronic supplement to this appendix (Appendix S).

Results show that climate change typically had more effect on Delta velocities for during wetter years than during drier years. This result is consistent with the Delta flow results

- Head of Old River Velocities
  - Are positive (oceanward) for all scenarios
  - Increased in winter and spring of wet years for the wetter climate change scenarios
  - Decreased in winter and spring of wet years for the drier climate change scenarios
  - Changes were typically less than 0.05ft/s during drier years for all climate change scenarios

- Middle River at Middle River Velocities
  - Are negative (landward) for all scenarios except for a slight reverse flow in winter of the wetter, less warming scenario
  - During wetter years, negative winter velocities decreased for the wetter climate change scenarios and increased for the drier climate change scenarios
  - Changes were typically less than 0.05ft/s for drier climate change scenarios

- San Joaquin River at Blind Point Velocities
  - Are positive (oceanward) for all scenarios
  - Changes were typically less than 0.05ft/s

- Cross Delta Velocities (Georgiana Slough)

- Are positive (oceanward) for all sceanarios
- Increased in winter for the wetter climate change scenarios and decreased in winter for the drier climate change scenarios

Table 13: Trends for Average Changes in Flow for Climate Change Scenarios Relative to the Base Case

Trends and flow directions are based on 50% values from Table 15 - Table 18. Trends are rounded to nearest 250cfs. No shading (white) indicates locations with positive (oceanward) flows. Dark shading (blue) indicates locations with negative (landward) flows. Light shading (yellow) indicates locations with mixed flow regimes (sometimes positive and sometimes negative). Seasons are defined as winter is Jan-Mar, spring is Apr-Jun, summer is Jul-Sep, and fall is Oct-Dec. Wetter year types are those classified as wet or above normal. Drier year types are those classified as below normal, dry or critically dry.

Name	Year Type	Wetter, Less Warming Flow	Wetter, More Warming Flow	Drier, Less Warming Flow	Drier, More Warming Flow
Head of Old River	Wetter	Increased by 1750cfs in spring, 1000cfs in summer, 250cfs in fall, and 750cfs in winter	Increased by 500cfs in winter, decreased by 1500cfs in spring, decreases were less than 250cfs in summer and fall	Decreased by 3500cfs in winter and spring, and decreased by 250cfs in summer and fall	Decreased by 2750cfs in winter and 3000cfs in spring, decreases were less than 250cfs in summer and fall
	Drier	Changes were less than 250cfs	Changes were less than 250cfs	Changes were less than 250cfs	Changes were less than 250cfs
Old and Middle River	Wetter	In winter flows changed from negative 3200cfs (landward) to positive 100cfs (oceanward). The rest of the year, negative (landward) flows decreased by 750cfs in spring, 250cfs in summer, and increased by 500cfs in fall	Negative (landward) flows decreased by 2500cfs in winter, 750cfs in spring, and 250cfs in summer. Negative flows increased by 750cfs in fall.	Negative (landward) flows increased by 3250cfs in winter, 500cfs in spring and 1000cfs in summer. Negative flows decreased by 500cfs in fall.	Negative (landward) flows increased by 1250cfs in winter. Negative flows decreased by 250cfs in spring and by 1750cfs in fall. Summer flow changes were less than 250cfs.
	Drier	Negative (landward) flows increased by less than 250cfs in winter, 750cfs in spring, 1000cfs in summer and 1750cfs in fall.	Negative (landward) flows increased by 500cfs in winter, spring, fall, and 750cfs in summer.	Changes were less than 250cfs in spring and fall. Negative (landward) flows decreased by 750cfs in summer and increased by 500cfs in winter.	Negative (landward) flows decreased by 250cfs in winter, 500cfs in spring, 1000cfs in summer and 750cfs in fall
QWEST	Wetter	Increased by 4000cfs in winter, 3000cfs in spring, 1500cfs in summer and 500cfs in fall	Increased by 3750cfs in winter, changes were less than 250cfs in spring, increased by 250cfs in summer, and decreased by 500cfs in fall	Positive (oceanward) flows decreased by 6500cfs in winter, 1750cfs in spring, 750cfs in summer, and 250cfs in winter.	Positive (oceanward) flows decreased by 4250cfs in winter and 1250cfs in spring, 250cfs in summer. Positive fall flows increased by 250cfs.
	Drier	Negative (landward) winter flows of 0cfs changed to positive (oceanward) flows of 400cfs. Positive spring flows increased by 250cfs. Summer flow changes were less than 250cfs. Positive flows of 200 fall flows changed to negative flow of 300cfs.	Changes were less than 250cfs	Flow changes were less than 250cfs in winter. Positive flows increased by 250cfs in spring and fall, 750cfs in summer.	Flow changes were less than 250cfs in winter. Positive (oceanward) flows increased by 750cfs in spring, summer, and fall.
Cross Delta	Wetter	Increased by 1000cfs in winter, decreased by 250cfs in spring and summer, changes were less than 250cfs in fall	Increased by 2000cfs in winter, 750cfs in spring, and decreased by 750cfs in summer and 500cfs in fall	Decreased by 1250cfs in winter, 500cfs spring and fall, increased by 250cfs in summer	Decreased by 2250cfs in winter, 500cfs in spring, 250cfs in summer and 1000cfs in fall
	Drier	Increased by 250cfs in winter and summer, 750cfs in fall, changes were less than 250cfs in spring	Increased by 500cfs in winter, 250cfs in fall, changes were less than 250cfs in spring and summer	Decreased by 250cfs in winter, summer and fall, decreased by 500cf in spring	Decreased by less than 500cfs in winter, spring and fall, decreased by 750cfs in summer

Table 14: Trends for Average Changes in Delta Velocities for Climate Change Scenarios Relative to the Base Case

Trends and velocity directions are based on 50% values from Table 21 - Table 24. Trends are rounded to nearest 0.05ft/s. No shading (white) indicates locations with positive (oceanward) velocities. Solid shading (blue) indicates locations with negative (landward) velocities. Lighter shading (yellow) indicates locations with mixed velocity regimes (sometimes positive and sometimes negative). Seasons are defined as winter is Jan-Mar, spring is Apr-Jun, summer is Jul-Sep, and fall is Oct-Dec. Wetter year types are those classified as wet or above normal. Drier year types are those classified as below normal, dry or critically dry.

Name	Year Type	Wetter, Less Warming	Wetter, More Warming	Drier, Less Warming	Drier, More Warming
		Velocity	Velocity	Velocity	Velocity
Head of Old River	Wetter	Increased by 0.05ft/s in winter, 0.25-0.50ft/s in spring and summer, and 0.15ft/s in fall	Increased by 0.05ft/f in winter, increased by 0.35ft/s in spring, and changes were less than 0.05ft/s in summer and fall	Decreased by 0.70ft/s in winter, 0.9ft/s in spring, 0.1ft/s in summer and less than 0.15ft/s in fall	Decreased by 0.5ft/s in winter, 0.75ft/s in spring, 0.05ft/s in summer and fall
	Drier	Increased by 0.05ft/s in spring, changes were less than 0.05ft/s in summer, fall and winter	Changes were less than 0.05ft/s	Decreased by 0.05ft/s in winter, spring and summer, decreased by less than 0.05ft/s in fall	Decreased by 0.05ft/s in winter and changes were less than 0.05ft/s in spring, summer and fall
Middle River at Middle River	Wetter	Winter velocities changed negative (landward) 0.1ft/s to nearly 0ft/s. Negative velocity changes were less than 0.05ft/s in spring and summer. Changes were less than 0.05ft/s in fall	Negative (landward) velocities decreased by 0.05ft/s in winter, changes were less than 0.05ft/s in spring, summer and fall	Negative (landward) velocities increased by by 0.1ft/s in winter. Velocity changes were less than 0.05ft/s in spring, summer and fall.	Negative (landward) velocities increased by 0.05ft/s in winter and decreased by 0.05ft/s in fall. Velocity changes were less than 0.05ft/s in spring and summer.
	Drier	Negative (landward) velocities decreased by 0.05ft/s in fall, changes were less than 0.05ft/s in winter, spring and summer	Changes were less than 0.05ft/s	Changes were less than 0.05ft/s	Changes were less than 0.05ft/s
San Joaquin River at Blind Pt.	Wetter	Increased by 0.05ft/s in winter and spring, changes were less than 0.05ft/s in summer and fall	Increased by 0.05ft/s in winter, changes were less than 0.05ft/s in spring, summer and fall	Decreased by 0.05ft/s in winter, changes were less than 0.05ft/s in spring, summer and fall	Decreased by 0.05ft/s in winter, changes were less than 0.05ft/s in spring, summer and fall
	Drier	Changes were less than 0.05ft/s	Changes were less than 0.05ft/s	Changes were less than 0.05ft/s	Changes were less than 0.05ft/s
Georgiana Slough	Wetter	Increased by 0.10ft/s in winter, 0.05ft/s in spring, 0.25ft/s in fall, and changes were less than 0.05ft/s in summer	Increased by 0.15ft/s in winter, changes were less than 0.05ft/s in spring, summer and fall	Decreased by 0.1ft/s in winter and fall, increased by 0.05ft/s in summer and changed less than 0.05ft/s in spring	Decreased by 0.15ft/s in winter, 0.10ft/s in spring, 0.05ft/s in summer and fall
	Drier	Changes were less than 0.05ft/s	Increased by 0.05ft/s in winter, spring and fall, and changes were less than 0.05ft/s in summer	Decreased by 0.05ft/s in winter, spring and summer, changes were less than 0.05ft/s in fall	Decreased by 0.05ft/s in winter, summer and fall, and 0.1 ft/s in spring

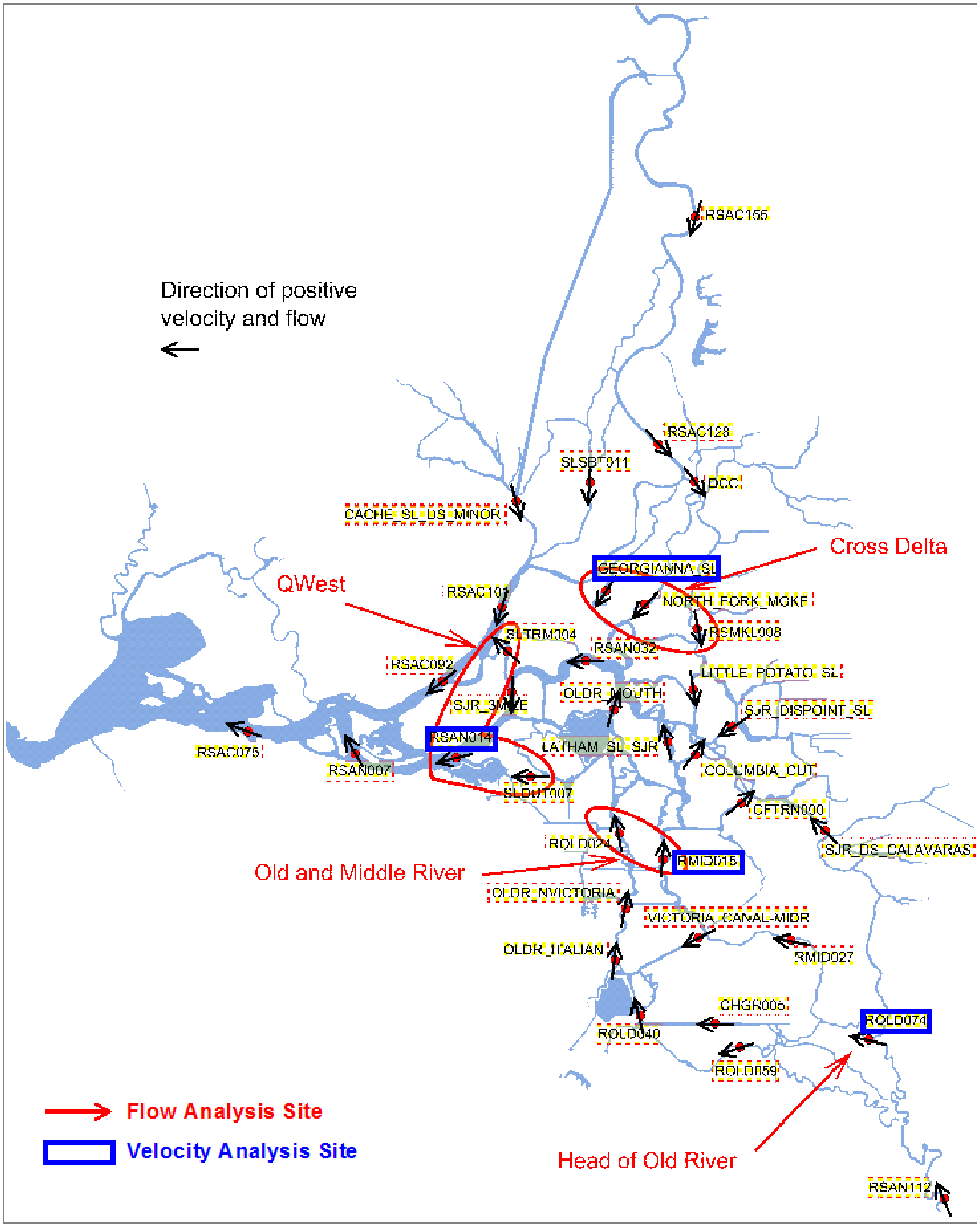


Figure 60. DSM2-Hydro analysis locations for flow (cfs) and velocity (ft/s). Arrows represent the direction of positive flow and velocity.

Table 15: DSM2-Hydro tidally filtered daily average flow (cfs) for water years 1976 to 1991 for wetter climate change scenarios
Shading indicates negative (landward) flows. Positive flows are towards the ocean. Base data are the same in Table 15 and Table 16. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

Name	Year Types	Month Range	Base					Wetter, Less Warming					Wetter, More Warming				
			Min	25%	50%	75%	Max	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	1349	3722	8039	9468	16708	1408	5568	8701	10567	17974	1350	4932	8627	11291	18550
		Apr-Jun	0	3685	5707	8645	11252	0	5068	7442	9164	12909	0	2157	4167	8547	11885
		Jul-Sep	449	1889	2102	3978	9682	440	2239	3063	4963	12213	406	1743	2012	3010	8612
		Oct-Dec	112	313	822	1612	9549	112	322	1144	5461	13201	112	321	752	1664	11307
	C D BN	Jan-Mar	578	1021	1367	1683	4575	637	1057	1370	1779	6363	637	1093	1376	1742	7728
		Apr-Jun	0	0	606	1133	4163	0	0	735	1202	5474	0	0	673	1171	4027
		Jul-Sep	214	314	384	449	1244	202	329	389	491	1931	190	314	391	463	1444
		Oct-Dec	131	257	408	1042	1612	160	265	433	1059	2227	155	260	399	1058	1861
Old and Middle River	W AN	Jan-Mar	-10896	-6733	-3180	5100	22138	-10321	-5610	94	7920	24229	-10340	-5744	-555	8693	25160
		Apr-Jun	-9316	-5840	-4015	-693	12606	-9394	-5124	-3347	1183	14326	-8525	-5525	-3182	-925	14585
		Jul-Sep	-11350	-8709	-7526	-6793	3258	-11723	-8291	-7259	-6022	9579	-9463	-7967	-7270	-6540	-1793
		Oct-Dec	-11595	-9764	-7528	-4080	6749	-11595	-9561	-8094	-3879	15507	-11595	-9725	-8293	-4043	11925
	C D BN	Jan-Mar	-11345	-8206	-5811	-3671	766	-11344	-7636	-5925	-3313	-267	-11344	-8612	-6377	-4186	-372
		Apr-Jun	-9490	-4555	-2439	-1865	-555	-8275	-4719	-3137	-2149	-482	-9102	-5222	-2912	-1964	-234
		Jul-Sep	-11959	-8619	-5276	-4092	-1132	-12339	-8325	-6258	-3939	-882	-11746	-7731	-5990	-4286	-583
		Oct-Dec	-11213	-7839	-6565	-4660	-326	-11502	-10118	-8299	-5212	-1687	-11222	-8547	-7055	-4796	-392
QWEST	W AN	Jan-Mar	-6574	6496	17895	33459	71816	-6552	9410	21975	38206	77058	-6825	12946	21760	41638	78955
		Apr-Jun	-4603	3672	6819	16307	46694	-4285	5299	9846	20458	50574	-4590	3932	6708	14821	51392
		Jul-Sep	-5226	-1140	405	3421	26442	-5381	75	1798	4390	34053	-3994	-854	740	2673	17883
		Oct-Dec	-11968	-891	1475	5921	43199	-10791	-799	1977	9127	63503	-11237	-1304	937	5810	54501
	C D BN	Jan-Mar	-11554	-2331	-21	2332	11441	-10823	-1957	446	2448	18108	-11338	-2575	-18	2020	17987
		Apr-Jun	-7833	76	1634	3345	8902	-7116	114	1897	3676	8515	-7555	-148	1572	3302	8560
		Jul-Sep	-6955	-1600	-162	1138	6148	-6900	-1514	-227	1297	5034	-6431	-1301	-172	1242	5178
		Oct-Dec	-11923	-1707	178	2028	7002	-12037	-2247	-264	1648	5767	-11785	-1774	195	1839	6789
Cross Delta	W AN	Jan-Mar	4630	8704	13143	16306	23616	5342	9527	14193	16979	25965	5109	10864	15158	17440	29161
		Apr-Jun	3296	4427	6497	9757	18349	3381	4856	6112	9872	19128	3213	4078	7323	8956	18829
		Jul-Sep	5464	6448	7066	8611	11596	5200	6164	6881	7574	10475	5069	5972	6430	8492	10444
		Oct-Dec	2159	5448	7331	9106	17428	2185	5365	7391	9714	22800	2171	5157	6916	8717	20272
	C D BN	Jan-Mar	2174	3284	4108	5804	10507	2151	3324	4448	6250	13008	2134	3468	4456	6408	12933
		Apr-Jun	1458	2596	3572	4778	9422	1549	2767	3530	5297	9345	1521	2816	3543	4912	9823
		Jul-Sep	3644	4876	5638	7571	9210	2556	4991	5867	7219	9642	2830	4962	5613	7346	9443
		Oct-Dec	1875	4006	5376	6448	9609	2193	4630	6176	7048	10088	2113	4374	5540	6908	10413

Table 16. DSM2-Hydro tidally filtered daily average flow (cfs) for water years 1976 to 1991 for drier climate change scenarios

Shading indicates negative (landward) flows. Positive flows are towards the ocean. Base data are the same in Table 15 and Table 16. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

Name	Year Types	Month Range	Base					Drier, Less Warming					Drier, More Warming				
			Min	25%	50%	75%	Max	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	1349	3722	8039	9468	16708	1348	2951	4495	7080	14338	1347	3228	5323	8823	18182
		Apr-Jun	0	3685	5707	8645	11252	0	1608	2432	6105	10492	0	2040	2762	6707	11622
		Jul-Sep	449	1889	2102	3978	9682	395	491	1849	2258	5630	402	511	1927	2504	5968
		Oct-Dec	112	313	822	1612	9549	112	284	522	1557	8693	111	275	700	1610	9008
	C D BN	Jan-Mar	578	1021	1367	1683	4575	661	1023	1298	1531	3148	584	1016	1310	1544	3434
		Apr-Jun	0	0	606	1133	4163	0	0	524	1018	2199	0	0	522	967	2904
		Jul-Sep	214	314	384	449	1244	186	294	350	414	1115	202	293	355	417	1182
		Oct-Dec	131	257	408	1042	1612	131	254	375	923	1629	106	249	381	870	1620
Old and Middle River	W AN	Jan-Mar	-10896	-6733	-3180	5100	22138	-11017	-8454	-6368	-1875	18085	-11018	-8363	-4360	1616	24586
		Apr-Jun	-9316	-5840	-4015	-693	12606	-8838	-5660	-4458	-2545	10193	-7793	-4734	-3673	-1624	13746
		Jul-Sep	-11350	-8709	-7526	-6793	3258	-10959	-9488	-8476	-7403	-4947	-11093	-8490	-7520	-6514	-3975
		Oct-Dec	-11595	-9764	-7528	-4080	6749	-11592	-9570	-7090	-4364	2692	-11595	-9522	-5789	-3140	3915
	C D BN	Jan-Mar	-11345	-8206	-5811	-3671	766	-11344	-8295	-6270	-2114	-17	-11343	-7309	-5451	-2400	-105
		Apr-Jun	-9490	-4555	-2439	-1865	-555	-8619	-3452	-2311	-1745	-560	-7367	-2563	-2032	-1577	-555
		Jul-Sep	-11959	-8619	-5276	-4092	-1132	-10322	-6409	-4499	-3466	-1024	-10853	-5711	-4275	-3371	-1383
		Oct-Dec	-11213	-7839	-6565	-4660	-326	-11253	-8462	-6418	-3810	341	-11236	-7928	-5776	-2900	336
QWEST	W AN	Jan-Mar	-6574	6496	17895	33459	71816	-6915	4733	11456	18506	62135	-7296	5480	13635	25127	76519
		Apr-Jun	-4603	3672	6819	16307	46694	-4790	2288	4982	9346	40762	-3972	3069	5662	9170	47956
		Jul-Sep	-5226	-1140	405	3421	26442	-5262	-1652	-326	1341	10976	-5058	-1129	273	2005	8864
		Oct-Dec	-11968	-891	1475	5921	43199	-10970	-665	1209	4478	34664	-11951	-554	1666	5473	36036
	C D BN	Jan-Mar	-11554	-2331	-21	2332	11441	-11914	-2393	9	1962	9714	-11955	-1903	74	2267	7714
		Apr-Jun	-7833	76	1634	3345	8902	-7198	395	1919	3586	9258	-6221	817	2258	3763	8593
		Jul-Sep	-6955	-1600	-162	1138	6148	-6752	-748	500	1905	6150	-5355	-491	612	1892	5690
		Oct-Dec	-11923	-1707	178	2028	7002	-10344	-1661	490	2551	7737	-9683	-1264	851	2905	10217
Cross Delta	W AN	Jan-Mar	4630	8704	13143	16306	23616	4359	8008	12013	14968	21386	3982	7498	10903	15635	21323
		Apr-Jun	3296	4427	6497	9757	18349	3201	3957	5936	9104	16566	2960	3675	6023	7769	17482
		Jul-Sep	5464	6448	7066	8611	11596	4946	6737	7867	8461	11306	4760	6153	6802	7962	11315
		Oct-Dec	2159	5448	7331	9106	17428	2133	4952	6971	9333	15201	2159	5191	6362	8663	14828
	C D BN	Jan-Mar	2174	3284	4108	5804	10507	1872	3021	3780	4975	10435	1786	3046	3708	4974	10477
		Apr-Jun	1458	2596	3572	4778	9422	1580	2460	3152	4962	8666	1503	2409	3032	5003	7445
		Jul-Sep	3644	4876	5638	7571	9210	3320	4669	5294	5867	8206	3223	4396	5009	5792	9001
		Oct-Dec	1875	4006	5376	6448	9609	1897	3922	5139	6578	9303	1830	3858	5025	6128	9922

Table 17: Changes in flow (cfs) relative to the base case for wetter climate change scenarios

Shading indicates reductions in flow. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

			Wetter, Less Warming					Wetter, More Warming				
Name	**Year Types**	**Month Range**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**
Head of Old River	W AN	Jan-Mar	59	1845	663	1099	1267	1	1210	589	1823	1842
		Apr-Jun	0	1382	1736	519	1657	0	-1528	-1540	-97	633
		Jul-Sep	-9	350	961	985	2531	-43	-147	-90	-968	-1069
		Oct-Dec	0	9	323	3849	3651	0	8	-70	52	1757
	C D BN	Jan-Mar	60	37	3	96	1788	60	72	9	58	3153
		Apr-Jun	0	0	128	69	1311	0	0	67	38	-137
		Jul-Sep	-11	15	5	42	688	-24	0	7	14	200
		Oct-Dec	29	7	25	16	615	24	3	-9	15	249
Old and Middle River	W AN	Jan-Mar	575	1122	3274	2820	2091	556	989	2625	3593	3021
		Apr-Jun	-77	716	668	1876	1720	791	315	833	-232	1979
		Jul-Sep	-373	418	267	771	6321	1887	742	255	253	-5051
		Oct-Dec	0	203	-566	201	8758	0	39	-765	37	5176
	C D BN	Jan-Mar	1	570	-114	358	-1034	1	-407	-566	-516	-1138
		Apr-Jun	1215	-164	-697	-284	72	388	-667	-473	-99	321
		Jul-Sep	-380	294	-983	152	250	212	888	-714	-194	549
		Oct-Dec	-288	-2278	-1734	-552	-1362	-9	-708	-491	-135	-66
QWEST	W AN	Jan-Mar	22	2915	4080	4748	5241	-251	6451	3865	8179	7138
		Apr-Jun	318	1626	3027	4152	3880	13	260	-111	-1486	4698
		Jul-Sep	-155	1215	1393	970	7611	1232	286	335	-748	-8559
		Oct-Dec	1177	92	501	3206	20304	731	-413	-538	-111	11301
	C D BN	Jan-Mar	731	374	467	116	6667	216	-243	3	-311	6546
		Apr-Jun	717	38	263	330	-387	278	-224	-61	-44	-342
		Jul-Sep	54	86	-65	159	-1114	524	299	-10	104	-970
		Oct-Dec	-114	-540	-441	-380	-1235	138	-67	17	-189	-213
Cross Delta	W AN	Jan-Mar	712	823	1050	673	2349	479	2160	2015	1134	5544
		Apr-Jun	85	429	-385	115	779	-83	-349	826	-801	480
		Jul-Sep	-264	-284	-185	-1036	-1121	-395	-476	-636	-119	-1152
		Oct-Dec	26	-83	61	609	5372	12	-291	-415	-389	2844
	C D BN	Jan-Mar	-23	40	340	446	2500	-40	184	348	605	2426
		Apr-Jun	91	171	-42	518	-78	63	221	-29	134	401
		Jul-Sep	-1088	115	229	-352	432	-814	86	-25	-225	234
		Oct-Dec	318	624	800	600	479	238	367	165	460	804

Table 18. Changes in flow (cfs) relative to the base case for drier climate change scenarios
Shading indicates reductions in flow. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Drier, Less Warming					Drier, More Warming				
Name	**Types**	**Range**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**
Head of Old River	W AN	Jan-Mar	-1	-772	-3543	-2389	-2370	-2	-494	-2716	-645	1474
		Apr-Jun	0	-2077	-3275	-2540	-760	0	-1646	-2945	-1938	370
		Jul-Sep	-54	-1399	-254	-1720	-4051	-47	-1379	-176	-1474	-3714
		Oct-Dec	0	-29	-299	-55	-857	0	-38	-121	-2	-541
	C D BN	Jan-Mar	83	2	-68	-153	-1428	6	-5	-56	-139	-1141
		Apr-Jun	0	0	-82	-115	-1964	0	0	-84	-166	-1259
		Jul-Sep	-28	-19	-34	-35	-129	-12	-21	-29	-32	-61
		Oct-Dec	0	-4	-33	-119	17	-25	-8	-27	-172	9
Old and Middle River	W AN	Jan-Mar	-121	-1721	-3188	-6975	-4053	-122	-1630	-1180	-3484	2448
		Apr-Jun	478	180	-443	-1852	-2413	1523	1106	342	-931	1140
		Jul-Sep	392	-778	-951	-610	-8204	257	219	6	279	-7233
		Oct-Dec	3	193	438	-284	-4057	-1	242	1739	940	-2833
	C D BN	Jan-Mar	1	-89	-460	1557	-784	2	897	360	1271	-871
		Apr-Jun	871	1103	129	120	-6	2123	1992	407	288	0
		Jul-Sep	1637	2210	777	626	107	1106	2908	1001	721	-251
		Oct-Dec	-40	-623	147	851	666	-23	-89	789	1760	662
QWEST	W AN	Jan-Mar	-341	-1763	-6439	-14953	-9681	-722	-1016	-4261	-8332	4703
		Apr-Jun	-187	-1384	-1837	-6960	-5932	632	-603	-1157	-7137	1262
		Jul-Sep	-36	-512	-731	-2080	-15466	168	11	-133	-1416	-17578
		Oct-Dec	998	226	-267	-1443	-8535	17	337	191	-448	-7163
	C D BN	Jan-Mar	-360	-62	30	-369	-1727	-402	428	95	-64	-3727
		Apr-Jun	635	318	285	241	357	1612	741	625	418	-308
		Jul-Sep	202	852	663	767	2	1599	1108	775	754	-458
		Oct-Dec	1579	46	313	523	734	2240	444	673	877	3214
Cross Delta	W AN	Jan-Mar	-271	-697	-1130	-1337	-2231	-647	-1206	-2240	-671	-2294
		Apr-Jun	-95	-470	-561	-653	-1783	-336	-751	-474	-1988	-868
		Jul-Sep	-518	288	800	-149	-290	-704	-296	-265	-649	-280
		Oct-Dec	-26	-496	-359	227	-2227	0	-257	-968	-443	-2599
	C D BN	Jan-Mar	-302	-263	-329	-829	-73	-388	-238	-400	-830	-31
		Apr-Jun	122	-135	-420	184	-756	45	-187	-540	225	-1977
		Jul-Sep	-324	-207	-343	-1704	-1003	-421	-480	-629	-1779	-208
		Oct-Dec	23	-84	-236	130	-306	-45	-148	-350	-320	313

Table 19. Percent change in flow (%) relative to the base case for wetter climate change scenarios

Shading indicates reductions in flow. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

			Wetter, Less Warming					Wetter, More Warming				
Name	Year Types	Month Range	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	4	50	8	12	8	0	33	7	19	11
		Apr-Jun	1625	38	30	6	15	-1168	-41	-27	-1	6
		Jul-Sep	-2	19	46	25	26	-9	-8	-4	-24	-11
		Oct-Dec	0	3	39	239	38	0	3	-8	3	18
	C D BN	Jan-Mar	10	4	0	6	39	10	7	1	3	69
		Apr-Jun	2641	387	21	6	31	-7220	-107	11	3	-3
		Jul-Sep	-5	5	1	9	55	-11	0	2	3	16
		Oct-Dec	22	3	6	2	38	18	1	-2	1	15
Old and Middle River	W AN	Jan-Mar	5	17	103	55	9	5	15	83	70	14
		Apr-Jun	-1	12	17	271	14	8	5	21	-34	16
		Jul-Sep	-3	5	4	11	194	17	9	3	4	-155
		Oct-Dec	0	2	-8	5	130	0	0	-10	1	77
	C D BN	Jan-Mar	0	7	-2	10	-135	0	-5	-10	-14	-149
		Apr-Jun	13	-4	-29	-15	13	4	-15	-19	-5	58
		Jul-Sep	-3	3	-19	4	22	2	10	-14	-5	48
		Oct-Dec	-3	-29	-26	-12	-418	0	-9	-7	-3	-20
QWEST	W AN	Jan-Mar	0	45	23	14	7	-4	99	22	24	10
		Apr-Jun	7	44	44	25	8	0	7	-2	-9	10
		Jul-Sep	-3	107	344	28	29	24	25	83	-22	-32
		Oct-Dec	10	10	34	54	47	6	-46	-36	-2	26
	C D BN	Jan-Mar	6	16	2244	5	58	2	-10	12	-13	57
		Apr-Jun	9	50	16	10	-4	4	-294	-4	-1	-4
		Jul-Sep	1	5	-40	14	-18	8	19	-6	9	-16
		Oct-Dec	-1	-32	-248	-19	-18	1	-4	10	-9	-3
Cross Delta	W AN	Jan-Mar	15	9	8	4	10	10	25	15	7	23
		Apr-Jun	3	10	-6	1	4	-3	-8	13	-8	3
		Jul-Sep	-5	-4	-3	-12	-10	-7	-7	-9	-1	-10
		Oct-Dec	1	-2	1	7	31	1	-5	-6	-4	16
	C D BN	Jan-Mar	-1	1	8	8	24	-2	6	8	10	23
		Apr-Jun	6	7	-1	11	-1	4	8	-1	3	4
		Jul-Sep	-30	2	4	-5	5	-22	2	0	-3	3
		Oct-Dec	17	16	15	9	5	13	9	3	7	8

Table 20. Percent change in flow (%) relative to the base case for drier climate change scenarios

Shading indicates reductions in velocity. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Drier, Less Warming					Drier, More Warming				
Name	**Types**	**Range**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**
Head of Old River	W AN	Jan-Mar	0	-21	-44	-25	-14	0	-13	-34	-7	9
		Apr-Jun	-915	-56	-57	-29	-7	-604	-45	-52	-22	3
		Jul-Sep	-12	-74	-12	-43	-42	-11	-73	-8	-37	-38
		Oct-Dec	0	-9	-36	-3	-9	0	-12	-15	0	-6
	C D BN	Jan-Mar	14	0	-5	-9	-31	1	0	-4	-8	-25
		Apr-Jun	-3158	-103	-13	-10	-47	-3390	-58	-14	-15	-30
		Jul-Sep	-13	-6	-9	-8	-10	-5	-7	-7	-7	-5
		Oct-Dec	0	-1	-8	-11	1	-19	-3	-7	-17	1
Old and Middle River	W AN	Jan-Mar	-1	-26	-100	-137	-18	-1	-24	-37	-68	11
		Apr-Jun	5	3	-11	-267	-19	16	19	9	-134	9
		Jul-Sep	3	-9	-13	-9	-252	2	3	0	4	-222
		Oct-Dec	0	2	6	-7	-60	0	2	23	23	-42
	C D BN	Jan-Mar	0	-1	-8	42	-102	0	11	6	35	-114
		Apr-Jun	9	24	5	6	-1	22	44	17	15	0
		Jul-Sep	14	26	15	15	9	9	34	19	18	-22
		Oct-Dec	0	-8	2	18	205	0	-1	12	38	203
QWEST	W AN	Jan-Mar	-5	-27	-36	-45	-13	-11	-16	-24	-25	7
		Apr-Jun	-4	-38	-27	-43	-13	14	-16	-17	-44	3
		Jul-Sep	-1	-45	-180	-61	-58	3	1	-33	-41	-66
		Oct-Dec	8	25	-18	-24	-20	0	38	13	-8	-17
	C D BN	Jan-Mar	-3	-3	143	-16	-15	-3	18	458	-3	-33
		Apr-Jun	8	417	17	7	4	21	970	38	12	-3
		Jul-Sep	3	53	408	67	0	23	69	477	66	-7
		Oct-Dec	13	3	176	26	10	19	26	379	43	46
Cross Delta	W AN	Jan-Mar	-6	-8	-9	-8	-9	-14	-14	-17	-4	-10
		Apr-Jun	-3	-11	-9	-7	-10	-10	-17	-7	-20	-5
		Jul-Sep	-9	4	11	-2	-3	-13	-5	-4	-8	-2
		Oct-Dec	-1	-9	-5	2	-13	0	-5	-13	-5	-15
	C D BN	Jan-Mar	-14	-8	-8	-14	-1	-18	-7	-10	-14	0
		Apr-Jun	8	-5	-12	4	-8	3	-7	-15	5	-21
		Jul-Sep	-9	-4	-6	-23	-11	-12	-10	-11	-23	-2
		Oct-Dec	1	-2	-4	2	-3	-2	-4	-7	-5	3

Table 21. DSM2-Hydro tidally filtered daily average velocity (ft/s) for water years 1976 to 1991 for wetter climate change scenarios
Shading indicates negative (landward) velocities. Positive velocities are towards the ocean. Base data are the same in Table 21 and Table 22. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Base					Wetter, Less Warming					Wetter, More Warming				
Name	Types	Range	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	0.76	1.63	2.48	2.54	3.17	0.79	2.04	2.52	2.59	3.28	0.76	1.90	2.54	2.67	3.33
		Apr-Jun	0.00	1.63	2.10	2.53	2.67	0.00	1.96	2.42	2.57	2.86	0.00	1.08	1.77	2.54	2.71
		Jul-Sep	0.26	0.97	1.06	1.67	2.60	0.25	1.09	1.42	1.91	2.78	0.23	0.90	1.03	1.42	2.56
		Oct-Dec	0.07	0.19	0.46	0.86	2.60	0.07	0.19	0.61	2.03	2.87	0.07	0.19	0.43	0.89	2.69
	C D BN	Jan-Mar	0.32	0.55	0.74	0.89	1.84	0.37	0.59	0.74	0.94	2.23	0.37	0.61	0.75	0.92	2.47
		Apr-Jun	0.00	0.00	0.35	0.64	1.75	0.00	0.00	0.42	0.66	2.07	0.00	0.00	0.39	0.64	1.68
		Jul-Sep	0.12	0.18	0.23	0.27	0.72	0.11	0.19	0.23	0.29	1.02	0.11	0.18	0.23	0.27	0.84
		Oct-Dec	0.08	0.15	0.24	0.57	0.87	0.09	0.16	0.26	0.59	1.14	0.09	0.15	0.24	0.59	0.99
Middle River at Middle River	W AN	Jan-Mar	-0.27	-0.16	-0.08	0.13	0.51	-0.27	-0.14	0.01	0.20	0.55	-0.27	-0.14	-0.01	0.21	0.58
		Apr-Jun	-0.23	-0.15	-0.10	-0.01	0.31	-0.24	-0.12	-0.08	0.04	0.35	-0.21	-0.14	-0.07	-0.01	0.35
		Jul-Sep	-0.29	-0.22	-0.18	-0.16	0.09	-0.30	-0.21	-0.18	-0.14	0.25	-0.23	-0.20	-0.18	-0.16	-0.04
		Oct-Dec	-0.29	-0.25	-0.19	-0.10	0.17	-0.29	-0.24	-0.20	-0.09	0.38	-0.29	-0.25	-0.21	-0.10	0.29
	C D BN	Jan-Mar	-0.29	-0.21	-0.15	-0.09	0.02	-0.29	-0.19	-0.15	-0.08	0.00	-0.29	-0.22	-0.16	-0.10	0.00
		Apr-Jun	-0.23	-0.11	-0.06	-0.04	-0.01	-0.21	-0.12	-0.08	-0.05	-0.01	-0.22	-0.13	-0.07	-0.05	-0.01
		Jul-Sep	-0.30	-0.22	-0.13	-0.10	-0.02	-0.31	-0.21	-0.15	-0.09	-0.02	-0.30	-0.19	-0.15	-0.10	-0.01
		Oct-Dec	-0.29	-0.20	-0.16	-0.12	-0.01	-0.30	-0.26	-0.21	-0.13	-0.04	-0.29	-0.22	-0.18	-0.12	-0.01
San Joaquin River at Blind Point	W AN	Jan-Mar	-0.01	0.14	0.25	0.41	0.80	0.00	0.18	0.30	0.45	0.86	0.00	0.21	0.29	0.49	0.89
		Apr-Jun	0.03	0.11	0.13	0.23	0.53	0.02	0.12	0.16	0.26	0.57	0.03	0.11	0.13	0.21	0.58
		Jul-Sep	0.00	0.05	0.08	0.10	0.30	0.00	0.07	0.09	0.11	0.38	0.01	0.06	0.08	0.10	0.22
		Oct-Dec	-0.04	0.06	0.09	0.13	0.51	-0.03	0.06	0.09	0.20	0.74	-0.03	0.05	0.08	0.17	0.65
	C D BN	Jan-Mar	-0.05	0.05	0.07	0.10	0.20	-0.03	0.05	0.08	0.10	0.25	-0.05	0.05	0.07	0.10	0.25
		Apr-Jun	0.01	0.07	0.09	0.10	0.17	0.01	0.07	0.09	0.11	0.17	0.01	0.07	0.09	0.10	0.17
		Jul-Sep	-0.01	0.05	0.07	0.08	0.13	-0.01	0.05	0.06	0.08	0.12	-0.01	0.05	0.07	0.08	0.12
		Oct-Dec	-0.05	0.05	0.07	0.09	0.14	-0.06	0.05	0.07	0.08	0.13	-0.05	0.05	0.07	0.08	0.13
Georgiana Slough	W AN	Jan-Mar	0.94	1.84	2.31	2.50	2.64	1.25	1.91	2.43	2.53	2.62	1.19	2.07	2.48	2.54	2.66
		Apr-Jun	0.60	0.88	1.01	1.52	2.60	0.64	0.91	1.07	1.65	2.59	0.68	0.86	0.98	1.59	2.60
		Jul-Sep	0.62	0.74	0.80	0.91	1.31	0.61	0.74	0.80	0.90	1.72	0.57	0.69	0.77	0.91	1.32
		Oct-Dec	0.49	0.75	0.93	1.53	2.65	0.49	0.80	1.16	1.94	2.68	0.49	0.77	0.88	1.65	2.67
	C D BN	Jan-Mar	0.57	0.85	1.00	1.23	2.01	0.57	0.85	1.01	1.40	2.68	0.51	0.87	1.05	1.35	2.68
		Apr-Jun	0.51	0.66	0.84	0.97	1.61	0.54	0.75	0.88	0.98	1.92	0.54	0.77	0.90	0.99	1.94
		Jul-Sep	0.49	0.62	0.69	0.87	1.05	0.43	0.63	0.70	0.84	1.08	0.45	0.62	0.68	0.85	1.05
		Oct-Dec	0.48	0.65	0.74	0.85	1.36	0.51	0.72	0.80	0.98	1.69	0.50	0.67	0.78	0.88	1.42

Table 22. DSM2-Hydro tidally filtered daily average velocity (ft/s) for water years 1976 to 1991 for drier climate change scenarios
Shading indicates negative (landward) velocities. Positive velocities are towards the ocean. Base data are the same in Table 21 and Table 22. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month			Base					Drier, Less Warming					Drier, More Warming		
Name	**Types**	**Range**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**
Head of Old River	W AN	Jan-Mar	0.76	1.63	2.48	2.54	3.17	0.76	1.35	1.80	2.31	2.96	0.76	1.46	1.99	2.53	3.30
		Apr-Jun	0.00	1.63	2.10	2.53	2.67	0.00	0.86	1.21	2.16	2.62	0.00	1.02	1.33	2.28	2.70
		Jul-Sep	0.26	0.97	1.06	1.67	2.60	0.23	0.29	0.95	1.13	2.04	0.23	0.30	1.00	1.23	2.12
		Oct-Dec	0.07	0.19	0.46	0.86	2.60	0.07	0.17	0.29	0.83	2.57	0.07	0.16	0.40	0.86	2.59
	C D BN	Jan-Mar	0.32	0.55	0.74	0.89	1.84	0.37	0.56	0.71	0.82	1.45	0.33	0.55	0.73	0.82	1.51
		Apr-Jun	0.00	0.00	0.35	0.64	1.75	0.00	0.00	0.30	0.57	1.10	0.00	0.00	0.30	0.54	1.35
		Jul-Sep	0.12	0.18	0.23	0.27	0.72	0.11	0.17	0.20	0.24	0.65	0.12	0.17	0.20	0.24	0.69
		Oct-Dec	0.08	0.15	0.24	0.57	0.87	0.08	0.15	0.22	0.50	0.88	0.06	0.14	0.23	0.47	0.88
Middle River at Middle River	W AN	Jan-Mar	-0.27	-0.16	-0.08	0.13	0.51	-0.28	-0.21	-0.16	-0.04	0.42	-0.28	-0.21	-0.11	0.05	0.56
		Apr-Jun	-0.23	-0.15	-0.10	-0.01	0.31	-0.22	-0.14	-0.11	-0.06	0.25	-0.19	-0.11	-0.09	-0.03	0.34
		Jul-Sep	-0.29	-0.22	-0.18	-0.16	0.09	-0.27	-0.24	-0.21	-0.18	-0.12	-0.28	-0.21	-0.18	-0.16	-0.10
		Oct-Dec	-0.29	-0.25	-0.19	-0.10	0.17	-0.29	-0.24	-0.18	-0.11	0.07	-0.29	-0.24	-0.14	-0.07	0.10
	C D BN	Jan-Mar	-0.29	-0.21	-0.15	-0.09	0.02	-0.29	-0.21	-0.16	-0.05	0.00	-0.29	-0.18	-0.14	-0.06	0.00
		Apr-Jun	-0.23	-0.11	-0.06	-0.04	-0.01	-0.21	-0.08	-0.05	-0.04	-0.01	-0.18	-0.06	-0.05	-0.04	-0.01
		Jul-Sep	-0.30	-0.22	-0.13	-0.10	-0.02	-0.26	-0.16	-0.11	-0.08	-0.02	-0.27	-0.14	-0.10	-0.08	-0.03
		Oct-Dec	-0.29	-0.20	-0.16	-0.12	-0.01	-0.29	-0.22	-0.16	-0.09	0.01	-0.29	-0.20	-0.14	-0.07	0.01
San Joaquin River at Blind Point	W AN	Jan-Mar	-0.01	0.14	0.25	0.41	0.80	-0.01	0.13	0.19	0.28	0.71	-0.02	0.13	0.21	0.33	0.83
		Apr-Jun	0.03	0.11	0.13	0.23	0.53	0.02	0.09	0.12	0.16	0.47	0.03	0.10	0.13	0.16	0.54
		Jul-Sep	0.00	0.05	0.08	0.10	0.30	0.00	0.05	0.07	0.08	0.17	0.00	0.05	0.07	0.09	0.17
		Oct-Dec	-0.04	0.06	0.09	0.13	0.51	-0.03	0.06	0.08	0.11	0.43	-0.04	0.06	0.09	0.12	0.44
	C D BN	Jan-Mar	-0.05	0.05	0.07	0.10	0.20	-0.06	0.05	0.07	0.09	0.16	-0.06	0.05	0.07	0.09	0.16
		Apr-Jun	0.01	0.07	0.09	0.10	0.17	0.01	0.07	0.09	0.10	0.17	0.02	0.08	0.09	0.11	0.17
		Jul-Sep	-0.01	0.05	0.07	0.08	0.13	0.00	0.06	0.07	0.09	0.13	0.01	0.06	0.07	0.09	0.12
		Oct-Dec	-0.05	0.05	0.07	0.09	0.14	-0.04	0.05	0.07	0.09	0.15	-0.01	0.06	0.08	0.09	0.16
Georgiana Slough	W AN	Jan-Mar	0.94	1.84	2.31	2.50	2.64	0.90	1.80	2.21	2.49	2.65	0.87	1.59	2.18	2.46	2.63
		Apr-Jun	0.60	0.88	1.01	1.52	2.60	0.74	0.90	1.04	1.36	2.60	0.70	0.83	0.91	1.24	2.59
		Jul-Sep	0.62	0.74	0.80	0.91	1.31	0.57	0.76	0.85	0.90	1.17	0.56	0.70	0.77	0.87	1.06
		Oct-Dec	0.49	0.75	0.93	1.53	2.65	0.49	0.73	0.85	1.29	2.62	0.49	0.70	0.87	1.48	2.60
	C D BN	Jan-Mar	0.57	0.85	1.00	1.23	2.01	0.45	0.80	0.93	1.18	1.82	0.44	0.79	0.93	1.15	1.84
		Apr-Jun	0.51	0.66	0.84	0.97	1.61	0.55	0.68	0.80	0.90	1.56	0.53	0.68	0.76	0.86	1.54
		Jul-Sep	0.49	0.62	0.69	0.87	1.05	0.46	0.59	0.66	0.72	0.99	0.46	0.58	0.63	0.71	1.01
		Oct-Dec	0.48	0.65	0.74	0.85	1.36	0.49	0.64	0.74	0.84	1.22	0.49	0.62	0.70	0.85	1.25

Table 23. Changes in velocity (ft/s) relative to the base case for wetter climate change scenarios

Shading indicates reductions in velocity. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Wetter, Less Warming					Wetter, More Warming				
Name	Types	Range	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	0.03	0.42	0.05	0.06	0.11	0.00	0.28	0.07	0.13	0.16
		Apr-Jun	0.00	0.33	0.32	0.04	0.18	0.00	-0.55	-0.33	0.01	0.04
		Jul-Sep	-0.01	0.12	0.36	0.25	0.19	-0.03	-0.07	-0.04	-0.25	-0.03
		Oct-Dec	0.00	0.01	0.15	1.18	0.28	0.00	0.01	-0.03	0.03	0.10
	C D BN	Jan-Mar	0.05	0.03	0.00	0.05	0.39	0.05	0.05	0.00	0.03	0.64
		Apr-Jun	0.00	0.00	0.07	0.02	0.33	0.00	0.00	0.04	0.00	-0.06
		Jul-Sep	-0.01	0.01	0.00	0.02	0.30	-0.01	0.00	0.00	0.01	0.12
		Oct-Dec	0.02	0.01	0.02	0.02	0.28	0.01	0.00	0.00	0.02	0.13
Middle River at Middle River	W AN	Jan-Mar	0.00	0.02	0.08	0.07	0.05	0.00	0.02	0.06	0.08	0.07
		Apr-Jun	-0.01	0.02	0.02	0.05	0.04	0.02	0.01	0.02	0.00	0.05
		Jul-Sep	-0.01	0.01	0.01	0.02	0.16	0.05	0.02	0.01	0.00	-0.13
		Oct-Dec	0.00	0.01	-0.02	0.01	0.21	0.00	0.00	-0.02	0.00	0.13
	C D BN	Jan-Mar	0.00	0.01	0.00	0.01	-0.03	0.00	-0.01	-0.01	-0.01	-0.03
		Apr-Jun	0.02	0.00	-0.02	-0.01	0.00	0.01	-0.02	-0.01	0.00	0.00
		Jul-Sep	-0.01	0.01	-0.03	0.01	0.01	0.00	0.02	-0.02	0.00	0.01
		Oct-Dec	-0.01	-0.06	-0.05	-0.01	-0.04	0.00	-0.01	-0.01	0.00	0.00
San Joaquin River at Blind Point	W AN	Jan-Mar	0.01	0.03	0.04	0.04	0.06	0.01	0.07	0.04	0.08	0.09
		Apr-Jun	-0.01	0.02	0.03	0.04	0.04	0.00	0.00	0.00	-0.02	0.05
		Jul-Sep	0.00	0.01	0.01	0.01	0.07	0.01	0.00	0.00	-0.01	-0.08
		Oct-Dec	0.01	0.00	0.00	0.07	0.23	0.01	0.00	-0.01	0.04	0.14
	C D BN	Jan-Mar	0.02	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05
		Apr-Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Jul-Sep	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01
		Oct-Dec	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.01
Georgiana Slough	W AN	Jan-Mar	0.31	0.06	0.11	0.03	-0.02	0.25	0.23	0.17	0.04	0.03
		Apr-Jun	0.04	0.03	0.06	0.13	-0.01	0.08	-0.02	-0.02	0.07	0.00
		Jul-Sep	-0.01	0.01	0.00	-0.01	0.40	-0.05	-0.04	-0.03	0.00	0.01
		Oct-Dec	0.00	0.05	0.24	0.41	0.04	0.00	0.01	-0.04	0.13	0.03
	C D BN	Jan-Mar	0.00	-0.01	0.02	0.17	0.67	-0.06	0.02	0.05	0.11	0.67
		Apr-Jun	0.03	0.09	0.04	0.01	0.31	0.02	0.11	0.05	0.02	0.33
		Jul-Sep	-0.07	0.01	0.02	-0.02	0.04	-0.04	0.00	0.00	-0.02	0.00
		Oct-Dec	0.04	0.07	0.06	0.13	0.33	0.03	0.02	0.04	0.03	0.06

Table 24. Changes in velocity (ft/s) relative to the base case for drier climate change scenarios
Shading indicates reductions in velocity. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Drier, Less Warming					Drier, More Warming				
Name	Types	Range	Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	0.00	-0.27	-0.68	-0.23	-0.21	0.00	-0.17	-0.48	-0.01	0.13
		Apr-Jun	0.00	-0.77	-0.89	-0.37	-0.05	0.00	-0.61	-0.77	-0.25	0.03
		Jul-Sep	-0.03	-0.68	-0.12	-0.54	-0.55	-0.03	-0.67	-0.07	-0.44	-0.48
		Oct-Dec	0.00	-0.02	-0.17	-0.02	-0.02	0.00	-0.03	-0.06	0.00	-0.01
	C D BN	Jan-Mar	0.05	0.00	-0.03	-0.07	-0.38	0.01	0.00	-0.02	-0.07	-0.33
		Apr-Jun	0.00	0.00	-0.05	-0.07	-0.65	0.00	0.00	-0.05	-0.09	-0.40
		Jul-Sep	-0.01	-0.01	-0.03	-0.02	-0.07	0.00	-0.01	-0.02	-0.03	-0.03
		Oct-Dec	0.00	0.00	-0.02	-0.07	0.02	-0.01	-0.01	-0.01	-0.10	0.01
Middle River at Middle River	W AN	Jan-Mar	0.00	-0.05	-0.08	-0.17	-0.09	0.00	-0.04	-0.03	-0.08	0.06
		Apr-Jun	0.01	0.01	-0.01	-0.05	-0.06	0.04	0.03	0.01	-0.02	0.03
		Jul-Sep	0.01	-0.02	-0.02	-0.02	-0.21	0.01	0.01	0.00	0.00	-0.19
		Oct-Dec	0.00	0.01	0.01	-0.01	-0.10	0.00	0.01	0.05	0.03	-0.07
	C D BN	Jan-Mar	0.00	0.00	-0.01	0.04	-0.02	0.00	0.02	0.01	0.03	-0.02
		Apr-Jun	0.02	0.03	0.00	0.00	0.00	0.06	0.05	0.01	0.01	0.00
		Jul-Sep	0.04	0.06	0.02	0.02	0.00	0.03	0.08	0.02	0.02	-0.01
		Oct-Dec	0.00	-0.01	0.00	0.02	0.02	0.00	0.00	0.02	0.05	0.02
San Joaquin River at Blind Point	W AN	Jan-Mar	0.00	-0.01	-0.06	-0.13	-0.09	-0.01	-0.01	-0.04	-0.08	0.03
		Apr-Jun	-0.01	-0.02	-0.01	-0.06	-0.06	0.00	-0.01	-0.01	-0.07	0.01
		Jul-Sep	0.00	0.00	-0.01	-0.02	-0.13	0.00	0.00	0.00	-0.01	-0.14
		Oct-Dec	0.01	0.00	0.00	-0.02	-0.08	0.00	0.00	0.00	-0.01	-0.08
	C D BN	Jan-Mar	0.00	0.00	0.00	-0.01	-0.05	0.00	0.00	0.00	0.00	-0.04
		Apr-Jun	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
		Jul-Sep	0.01	0.01	0.01	0.01	-0.01	0.02	0.01	0.01	0.01	-0.01
		Oct-Dec	0.02	0.00	0.00	0.00	0.01	0.04	0.00	0.01	0.01	0.02
Georgiana Slough	W AN	Jan-Mar	-0.05	-0.04	-0.10	-0.01	0.01	-0.07	-0.26	-0.13	-0.05	0.00
		Apr-Jun	0.14	0.02	0.03	-0.16	0.01	0.10	-0.06	-0.10	-0.28	-0.01
		Jul-Sep	-0.04	0.03	0.05	-0.01	-0.15	-0.06	-0.03	-0.03	-0.04	-0.26
		Oct-Dec	0.00	-0.02	-0.08	-0.24	-0.03	0.00	-0.06	-0.05	-0.05	-0.05
	C D BN	Jan-Mar	-0.12	-0.06	-0.06	-0.06	-0.19	-0.13	-0.07	-0.07	-0.09	-0.17
		Apr-Jun	0.04	0.02	-0.04	-0.07	-0.04	0.02	0.02	-0.08	-0.11	-0.07
		Jul-Sep	-0.04	-0.03	-0.03	-0.15	-0.05	-0.04	-0.05	-0.06	-0.16	-0.04
		Oct-Dec	0.01	-0.02	0.00	-0.01	-0.14	0.01	-0.03	-0.04	0.00	-0.11

Table 25. Percent change in velocity (%) relative to the base case for wetter climate change scenarios
Shading indicates reductions in velocity. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

	Year	Month	Wetter, Less Warming					Wetter, More Warming				
Name	**Types**	**Range**	**Min**	**25%**	**50%**	**75%**	**Max**	**Min**	**25%**	**50%**	**75%**	**Max**
Head of Old River	W AN	Jan-Mar	4	26	2	2	3	0	17	3	5	5
		Apr-Jun	-633	20	15	1	7	487	-34	-16	0	2
		Jul-Sep	-3	13	34	15	7	-11	-7	-3	-15	-1
		Oct-Dec	0	4	33	137	11	0	4	-7	3	4
	C D BN	Jan-Mar	15	6	0	6	21	15	9	0	3	35
		Apr-Jun	-408	-48	19	4	19	207	139	11	1	-4
		Jul-Sep	-7	4	0	8	41	-12	0	1	3	17
		Oct-Dec	24	5	8	4	32	19	1	-2	4	15
Middle River at Middle River	W AN	Jan-Mar	2	14	111	51	9	1	14	86	63	13
		Apr-Jun	-5	15	20	440	13	8	5	22	-23	15
		Jul-Sep	-3	5	3	12	173	18	9	3	3	-141
		Oct-Dec	0	3	-8	7	127	0	0	-12	3	75
	C D BN	Jan-Mar	0	7	-1	9	-109	0	-6	-10	-15	-120
		Apr-Jun	10	-4	-34	-16	38	4	-16	-23	-6	45
		Jul-Sep	-3	4	-20	5	29	-1	11	-15	-4	64
		Oct-Dec	-3	-29	-29	-12	-624	0	-7	-9	-2	-23
San Joaquin River at Blind Point	W AN	Jan-Mar	121	24	16	9	8	90	48	14	19	12
		Apr-Jun	-25	15	22	18	7	0	-1	-1	-7	9
		Jul-Sep	-130	22	16	8	24	1090	5	1	-6	-26
		Oct-Dec	17	7	3	50	44	17	-7	-8	26	27
	C D BN	Jan-Mar	34	7	4	3	24	4	-5	-1	0	23
		Apr-Jun	71	1	3	4	-1	48	-2	-1	0	-1
		Jul-Sep	-37	2	-1	2	-8	10	4	1	1	-6
		Oct-Dec	-1	-9	-3	-3	-7	3	0	0	-3	-5
Georgiana Slough	W AN	Jan-Mar	32	3	5	1	-1	26	12	7	2	1
		Apr-Jun	6	3	6	9	0	14	-3	-2	4	0
		Jul-Sep	-2	1	0	-2	31	-8	-6	-4	0	1
		Oct-Dec	-1	6	26	27	1	-1	2	-5	8	1
	C D BN	Jan-Mar	1	-1	2	14	33	-11	2	5	9	33
		Apr-Jun	6	13	5	1	20	5	16	6	2	21
		Jul-Sep	-14	1	2	-3	4	-8	0	-1	-2	0
		Oct-Dec	7	10	8	15	24	5	3	5	4	4

Table 26. Percent change in velocity (%) relative to the base case for drier climate change scenarios
Shading indicates reductions in velocity. Year type classifications: W=wet, AN=above normal, BN=below normal, D=dry, C=critically dry.

Name	Year Types	Month Range	Drier, Less Warming					Drier, More Warming				
			Min	25%	50%	75%	Max	Min	25%	50%	75%	Max
Head of Old River	W AN	Jan-Mar	0	-17	-27	-9	-7	0	-10	-20	0	4
		Apr-Jun	-284	-47	-42	-15	-2	-332	-37	-37	-10	1
		Jul-Sep	-11	-70	-11	-32	-21	-12	-69	-6	-26	-18
		Oct-Dec	0	-12	-37	-3	-1	0	-16	-13	0	0
	C D BN	Jan-Mar	14	0	-4	-8	-21	2	-1	-2	-8	-18
		Apr-Jun	12	-58	-14	-11	-37	36	-26	-14	-15	-23
		Jul-Sep	-12	-7	-11	-8	-9	2	-5	-10	-9	-4
		Oct-Dec	0	-2	-9	-12	2	-16	-5	-6	-17	1
Middle River at Middle River	W AN	Jan-Mar	-1	-28	-108	-132	-18	-1	-26	-40	-65	11
		Apr-Jun	6	4	-16	-406	-18	17	21	8	-205	9
		Jul-Sep	5	-9	-13	-10	-233	2	3	-1	3	-204
		Oct-Dec	0	3	5	-5	-58	0	3	25	26	-40
	C D BN	Jan-Mar	0	0	-9	45	-82	0	12	6	37	-91
		Apr-Jun	10	25	6	7	17	24	47	18	16	16
		Jul-Sep	15	27	14	17	12	10	35	19	20	-24
		Oct-Dec	-1	-7	2	18	309	0	1	13	40	306
San Joaquin River at Blind Point	W AN	Jan-Mar	-49	-10	-24	-32	-11	-98	-8	-17	-19	4
		Apr-Jun	-33	-15	-10	-28	-11	-1	-9	-7	-30	1
		Jul-Sep	7	-8	-11	-17	-44	165	-2	-6	-13	-46
		Oct-Dec	26	5	-5	-16	-16	3	4	2	-8	-15
	C D BN	Jan-Mar	-7	-2	-4	-5	-23	-8	5	-1	-3	-18
		Apr-Jun	98	5	1	2	2	249	12	4	4	-2
		Jul-Sep	69	13	9	8	-5	184	18	10	9	-6
		Oct-Dec	28	3	4	5	5	77	8	9	9	16
Georgiana Slough	W AN	Jan-Mar	-5	-2	-4	-1	0	-8	-14	-6	-2	0
		Apr-Jun	23	2	3	-11	0	16	-6	-10	-18	0
		Jul-Sep	-7	4	6	-1	-11	-9	-5	-4	-5	-20
		Oct-Dec	0	-3	-8	-16	-1	0	-8	-5	-3	-2
	C D BN	Jan-Mar	-20	-7	-6	-5	-10	-22	-8	-7	-7	-8
		Apr-Jun	8	4	-5	-7	-3	3	3	-9	-11	-4
		Jul-Sep	-7	-4	-4	-17	-5	-8	-7	-8	-19	-4
		Oct-Dec	3	-3	0	-1	-10	2	-5	-6	0	-8

4.4 Water Temperatures

Expected results from reservoir water temperature analyses include the following:

- Air temperature increases lead to increased water temperature of reservoir inflow, and reduction in “cold water” supply (i.e. reservoir volume with water temperature less than threshold temperature specific to Lake Shasta, Lake Oroville, and Folsom Lake) entering into the summer-fall stream temperature management season.
- Annual precipitation increase or decrease either offsets or amplifies the effect of air temperature increase on “cold water” supply.
- Air temperature increases lead to increased river heating downstream of CVP and SWP reservoirs, and increased demand on release of “cold water” supply during the summer-fall stream temperature management season in order to maintain management performance associated with Base climate conditions.
- The combined effects of air temperature increase on cold water supply and downstream cold water demand somewhat offset the potential beneficial of increase annual precipitation.

To attempt to meet temperature objectives during the temperature operation season, the Shasta Dam temperature control device (TCD) functions to select water temperatures in the 47˚F to 52˚F range. Therefore, a good index of the volume of cold water available, annually, is the lake volume that is less than 52˚F during late April/early May. The potential impact of climate change on the cold-water pool in Lake Shasta is shown on Figure 61. Results show that the wetter scenarios result in a general tendency to have greater cold-water pool volumes than the drier climate scenarios. It also shows that in “base” years with greatest cold-water pool volumes, all of the climate change scenarios resulted in pool-volume reductions, pointing to the relatively significant effect of warming for this response metric compared to precipitation changes.

Because temperature objectives differ for the American River, Folsom Lake volume less than 58˚F during late May/early June functions as the cold-water pool index. Temperature objectives for the Feather River appear to be more similar to the American River; therefore, the same index was selected. The potential impact of climate change on the cold-water pool volumes in Lake Oroville and Folsom Lake are shown in Figure 62 and Figure 63, respectively. Similar trends were found at these reservoirs as with Folsom Lake and Lake Oroville.

With respect to effects on managed downstream river temperatures and salmon mortality, results are provided in the electronic Appendix S. In general, reduced cold-water pool volumes at the beginning of the summer-autumn season lead to a general tendency of increased river temperatures during spring-autumn and associated effects on salmon mortality.

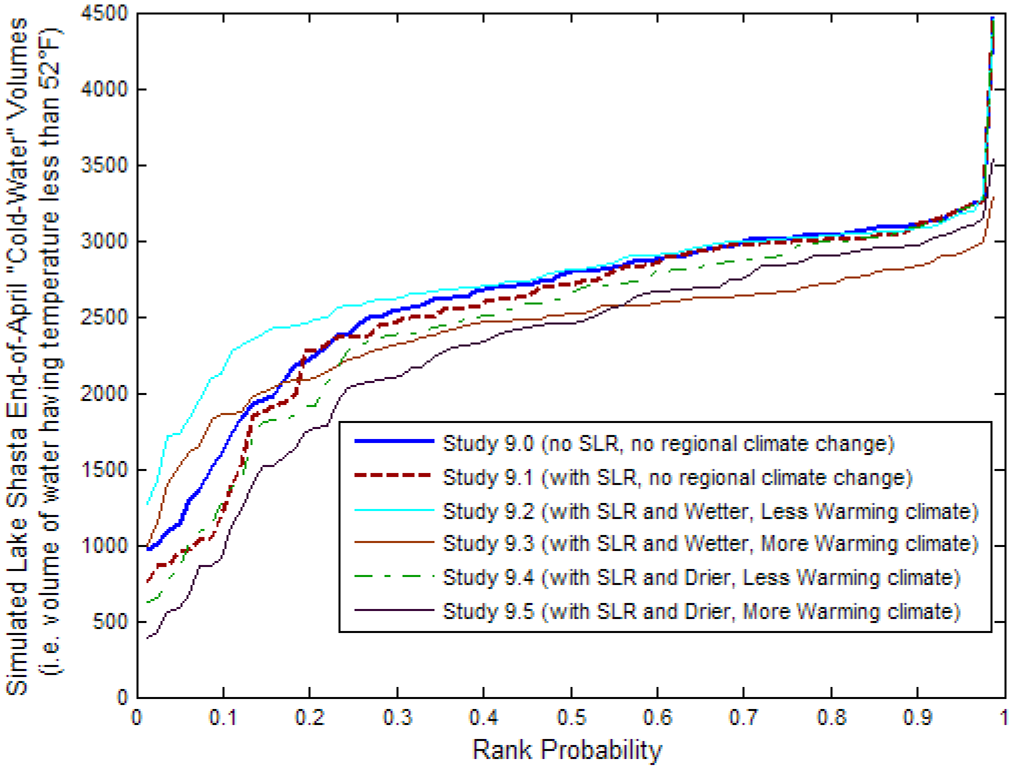


Figure 61 Rank-distribution of 1922-2002 simulated cold-water volumes at Lake Shasta, End-of-April

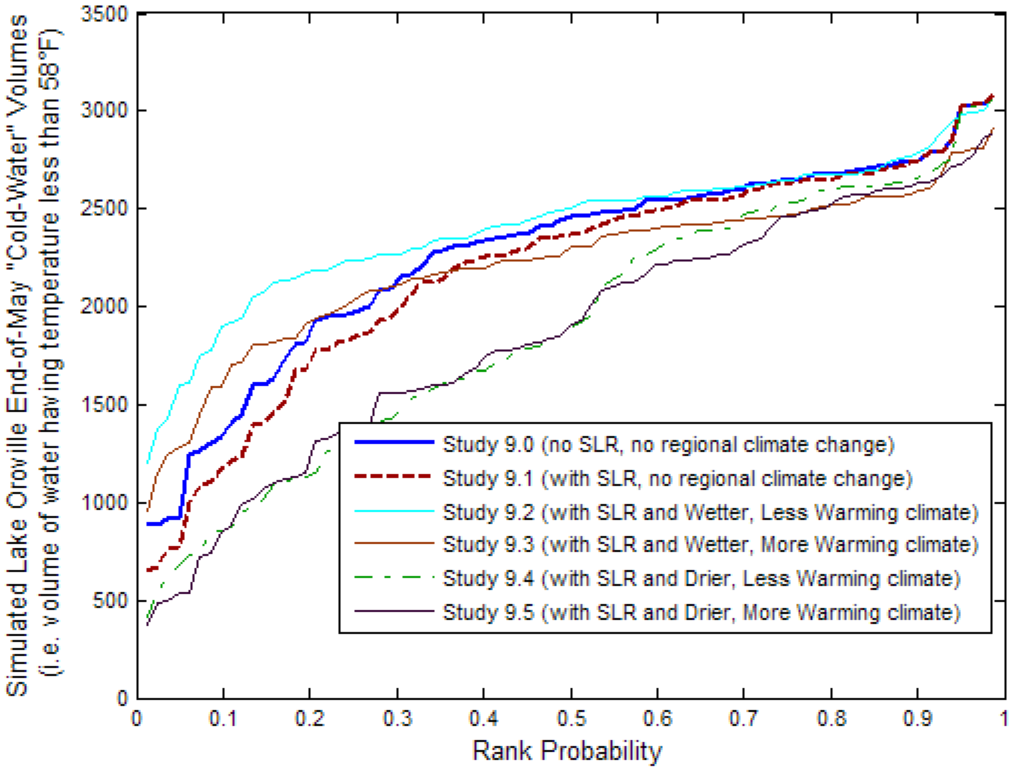


Figure 62 Rank-distribution of 1922-2002 simulated cold-water volumes at Lake Oroville, End-of-May

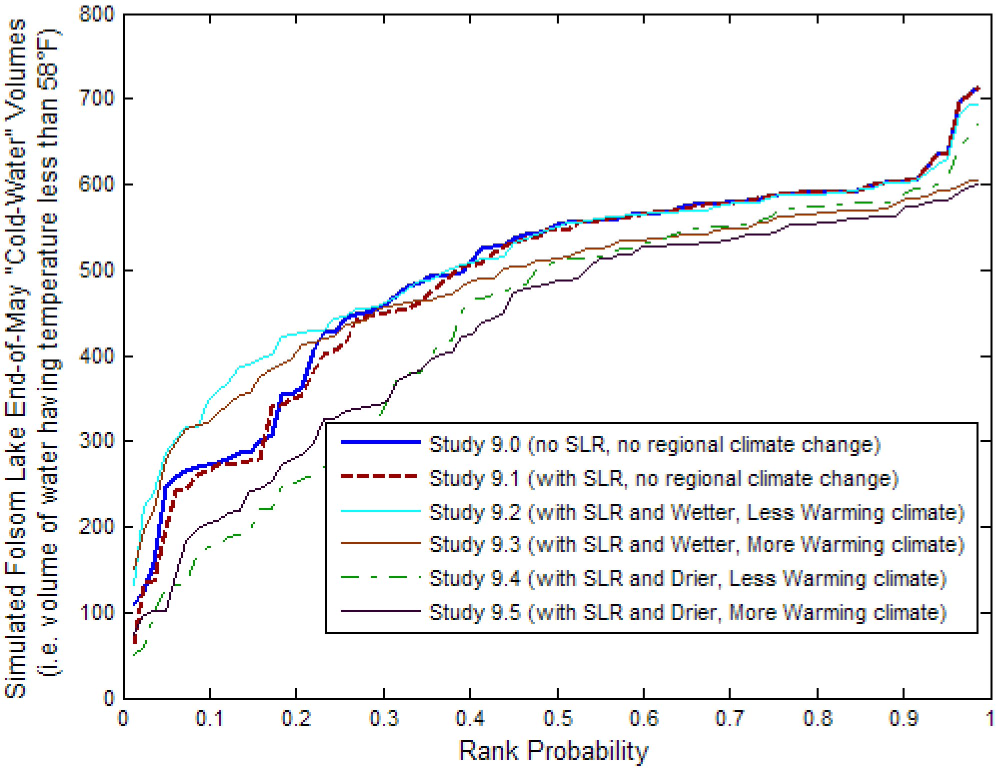


Figure 63 Rank-distribution of 1922-2002 simulated cold-water volumes at Folsom Lake, End-of-May

Chapter 12 5.0 UNCERTAINTIES

This sensitivity analysis is designed to provide some quantitative illustration on how CVP/SWP water supply, operations, and operations-dependent conditions might respond to range of future climate possibilities. The study was designed to take advantage of best available datasets and model tools, and to follow methodologies documented in peer-review literature. However, there are a number of analytical uncertainties that are not reflected in study results, including uncertainties associated with the following analytical areas:

- global climate forcing: Although the study considers climate projections representing a range of GHG emission paths, the uncertainties associated with these pathways are not represented in this analysis. Such uncertainties include those introduced by assumptions about technological and economic developments, globally and regionally; how those assumptions translate into global energy use involving GHG emissions; and biogeochemical analysis to determine the fate of GHG emissions in the oceans, land and atmosphere. Also, not all of the uncertainties associated with climate forcing are associated with GHG assumptions. Considerable uncertainty remains in associated with natural forcings, with the cooling influence of aerosols being regarded as the most uncertain on a global scaled (e.g., Figure SPM-2 in IPCC 2007).

- global climate simulation: While this study considers climate projections produced by state-of-the-art coupled ocean-atmosphere climate models (i.e. CMIP3 models discussed in Section 1.4), and these models have shown an ability to simulate the influence of increasing GHG emissions on global climate (IPCC 2007), there are still uncertainties about our understanding of physical processes that affect climate, how to represent such processes in climate models (e.g., atmospheric circulation, clouds, ocean circulation, deep ocean heat update, ice sheet dynamics, sea level, land cover effects from water cycle, vegetative other biological changes), and how to do so in a mathematically efficiently manner given computational limitations.

- climate projection bias-correction: This study is designed on the philosophy that climate model biases toward being too wet, too dry, too warm or too cool should be identified and accounted for as *bias-corrected* climate projections data prior to use in implications studies like this sensitivity analysis. Bias-correction of climate projections data affects results on incremental runoff and water supply response, as shown on a recent study of Colorado River Basin runoff impacts using both bias-corrected and non-bias-corrected versions of the same source climate projections (*D. Lettenmaier, presentation at Colorado State University "Hydrology Days 2008", 26 March 2008*).

- climate projection spatial downscaling: This study uses the empirical BCSD technique to produce spatially disaggregated climate projections data on a monthly time-step. Although this technique has been to support numerous water resources impacts studies in California (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, Maurer 2007, Anderson et al. 2008), uncertainties remain about the limitations of empirical downscaling methodologies. One potential limitation relates to how empirical methodologies require use of historical reference information on spatial climatic patterns at the downscaled spatial resolution. These finer-grid patterns are implicitly related to historical large-scale atmospheric circulation patterns, which would presumably change with global climate change. Application of the historical finer-grid spatial patterns to guide downscaling of future climate projections implies an assumption that the historical relationship between finer-grid surface climate patterns and large-scale atmospheric circulation is still valid under the future climate. In other words, the relationship is assumed to have *stationarity*. In actuality, it is possible that such stationarity will not hold at various space and time scales, over various locations, and for various climate variables. However, the significance of potential non-stationarity in empirical downscaling methods and the need to utilize alternative downscaling methodologies remains to be established.

- generating weather sequences consistent with climate projections: This study uses a technique to generate weather sequences consistent with the monthly downscaled climate projections. This technique has been used to support numerous water resources impacts studies (e.g., Van Rheenan et al. 2004, Maurer and Duffy 2005, Maurer 2007, Anderson et al. 2008). However, other techniques might have been considered. Preference among available techniques remains to be established.

- natural systems response: This study analyzes natural runoff response to changes in precipitation and temperature while holding other watershed features constant. Other watershed features might be expected to change as climate changes and affect runoff (e.g., potential ET given temperature changes, vegetation affecting ET and infiltration, etc.). In the VIC application, potential ET change was automatically accounted for given changes in weather inputs. In the SacSMA/Snow17 model-applications, potential ET estimates are inputs and were not adjusted. Similarity in tool-specific results suggests that potential ET adjustment (which differs from simulated *actual* ET) may not have been a crucial aspect of the runoff analysis. On the matter of land cover response to climate change, the runoff models' calibrations would have to change if land cover changed because the models were calibrated to represent the historical relationship between weather and runoff as mediated by historical land cover. Adjustment to watershed land cover and model parameterizations were not considered due to lack of available information to guide such adjustment.

- social systems response: This study does not quantify the effects of changing water demands at the district- or municipal-scale. Such responses depend on demand management flexibility and socioeconomic drivers within these districts and municipalities. Model-applications and methodologies for relating climate changes to demand management responses among CVP/SWP district customers under existing institutional and regulatory constraints remain to be established. Additionally, lack of available model-applications and methodologies prevented quantitative treatment of other potential social responses to climate change that might translate into constraint changes for CVP/SWP operations (e.g., change in flood protection values below CVP/SWP reservoirs that determine reservoir flood control constraints on water supply storage; change in environmental management values that determine instream flow priorities by river tributary and during which times of the year; change in recreational values that determine water levels management at CVP/SWP reservoirs). In addition to how societal drivers could trigger changes in flood control, there could also be natural drivers associated with hydrologic response to climate change. For example, warming climate may affect storm-discharge relationships and reoccurrence expectations in watersheds above major CVP/SWP reservoirs, potentially necessitating flood control changes even if societal flood protection values do not change.

- discretionary operators' response: This study reflects a simulated operator through rules and constraints defined in CalSim II. The simulated operator is generally “unresponsive” to the climate change, as simulated. The only responsive exception is that the CalSim II annual water allocation rules (i.e. “WSI-DI” curves) were adjusted to consistent with inflow and inflow-related changes associated with Projection #1 through #4, which represents operators having an adjusted understanding of water supply possibility in any given year, and associated annual allocations that can be supported over the long term. In reality, just as external social systems might respond to a changing climate, it is reasonable to expect that CVP/SWP operators might react in other ways to a changing climate, within limitations permitted by current institutions, regulations, and contracts.

- water temperature analysis: This study presumes that as climate changes, the current stream-temperature management paradigms constraining CVP and SWP operations will continue unchanged. In reality, its questionable whether there might be shifts in multi-species management objectives in CVP and SWP tributaries, or shifts in objective priorities at various times during the calendar year.

Chapter 13 6.0 REFERENCES

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