Bay-Delta Conservation Plan EIR/EIS Appendix 5A

Section D: Additional Modeling Information

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Outline

D.1. Introduction

Section D includes additional technical information related to the modeling of BDCP EIR/EIS Alternatives. This section primarily focuses on the approaches used to incorporate the effects of projected climate change and sea level rise in the future, and the effects of various BDCP actions such as the north Delta intakes, Fremont Weir modifications, and large-scale tidal marsh restoration in the Delta, in the physical modeling performed for BDCP. Detailed information related to the development of robust analytical tools that can simulate the effects of proposed BDCP elements are included in this section. In addition, it also includes several sensitivity analyses performed in support of bracketing uncertainty associated with some of the key assumptions.

This section is primarily a compilation of various technical memoranda, reports and figures previously prepared for use in the BDCP Effects Analysis, and/or for use in various BDCP lead agency and stakeholder engagement processes. The formats, figure numbers and the table numbers in the individual reports/memoranda were not changed because the reports or the memos were incorporated in their entirety. The following technical reports are included as separate Attachments to the Section D, because of the large file size:

Attachment 1:	DSM2 Recalibration for Bay-Delta Conservation Plan
Attachment 2:	Evaluation of Tidal Marsh Restoration Effects using RMA Bay-Delta Model
Attachment 3:	Evaluation of Sea Level Rise Effects using UNTRIM San Francisco Bay-Delta Model
Attachment 4:	DSM2 Corroboration for Modeling Tidal Marsh Restoration and Sea Level Rise Effects in the Sacramento-San Joaquin Delta
Attachment 5:	Tidal Marsh Restoration Sensitivity Analysis
Attachment 6:	CALSIM II and DSM2 Models Schematics used for Bay-Delta Conservation Plan Modeling

D.2. Bay-Delta Conservation Plan Methodology for Incorporating Climate Change

The methodology for incorporating and analyzing the effects of future climate change in the Bay Delta Conservation Plan and Delta Habitat Conservation and Conveyance Program environmental processes was developed in agreement with the lead agencies. A technical subgroup comprised of key staff at the Department of Water Resources, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and National Marine Fisheries Service have met over the course of 2009 and early 2010 to discuss the merits of various approaches and methods, and provide input for selection of the approach. A whitepaper was prepared summarizing the methodology for selection and application of climate scenarios specific to this process, discussion and selection of sea level rise scenarios, and the use of these climate change projections in the primary analytical tools for the BDCP planning analyses. The recommended approach for incorporating the climate change effects in the BDCP planning process included selection of five “ensemble-informed” climate scenarios for each future analysis period. This whitepaper is included here in its entirety to provide the reader with the understanding of the background information and the approach used to incorporate climate change and sea level rise effects in the BDCP analyses.

Bay-Delta Conservation Plan – Methodology for Incorporating Climate Change

June 4, 2010

Executive Summary

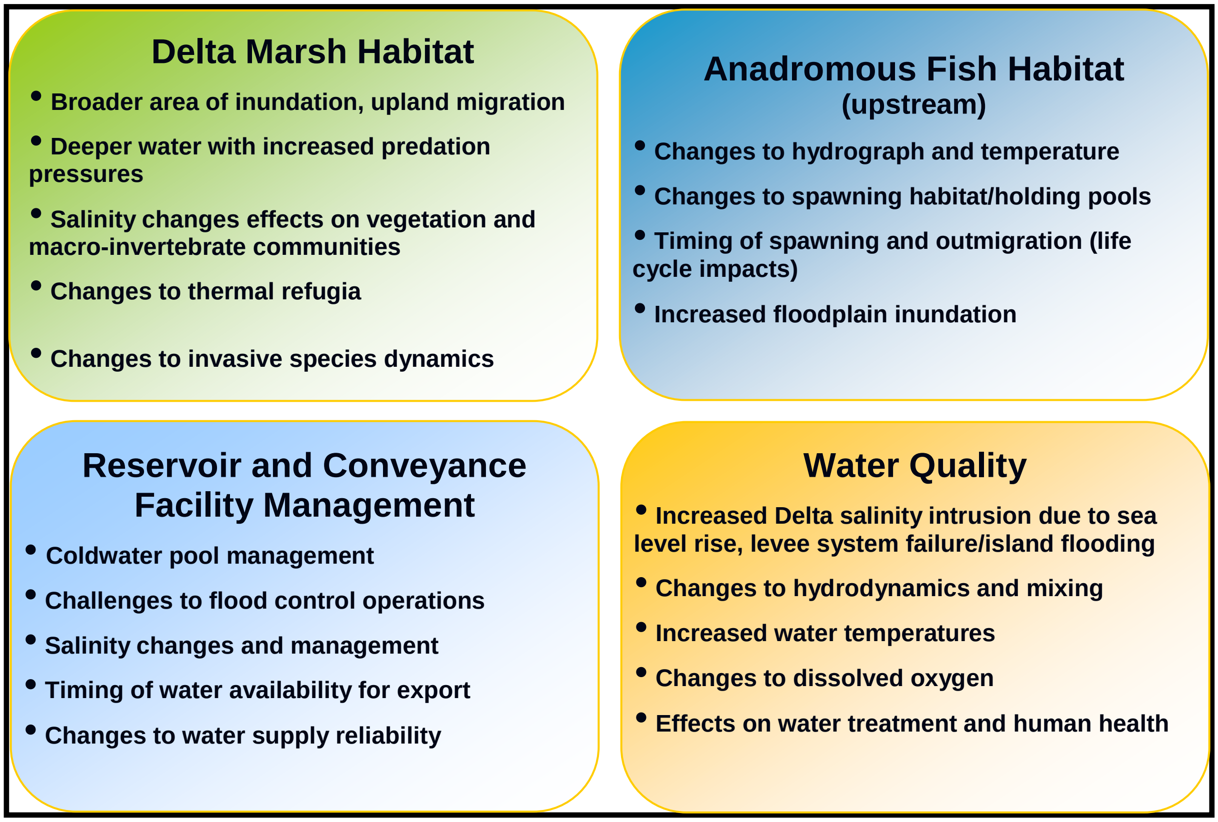
The Bay Delta Conservation Plan and Delta Habitat Conservation and Conveyance Program environmental processes require a coordinated effort for incorporating and analyzing the effects of future climate change. This paper summarizes a methodology for selection and application of climate scenarios specific to this process, discussion and selection of sea level rise scenarios, and the use of these climate change projections in the primary analytical tools to be used in the BDCP planning. A technical subgroup comprised of key staff at the Department of Water Resources, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and National Marine Fisheries Service have met over the course of 2009 and early 2010 to discuss the merits of various approaches and methods. The recommended approach consists of the selection of five "ensemble-informed" climate scenarios for each future analysis period. These regional climate scenarios utilize ensemble subsets of the 112 available downscaled climate projections to characterize the range of future climate possibilities indicated by the current state of global climate models. Importantly, the scenarios are derived from multiple projections, rather than a single GCM projection, thus reducing the "noise" primarily associated with multi-decadal variability and sampling of GCM period changes.

Analysis of the effects and impacts of the BDCP will be performed at three timelines: approximately 2015, 2025, and 2060. Regional climate change scenarios and sea level rise estimates are provided for the two long-term periods. Mean annual temperatures are projected to increase by up to 3 °C and mean annual precipitation changes range from -20% to +20 by 2060 in the American River watershed. The proposed method of incorporating of climate changes preserves both the projected changes in mean climate and the projected changes in climate variability. Mid-range sea level rise estimates selected for use at the two long-term timelines are 15 centimeters (6 inches) by 2025 and 45 centimeters (18 inches) by 2060. These estimates are derived from review of various sources used by DWR, recommendations by the CALFED Independent Science Board, and recent guidance from the Army Corps of Engineers. It should be stressed that these estimates are for use in the impacts and effects analysis of the BDCP, but more conservative estimates or adaptive approaches could be considered for critical infrastructure siting and design. Finally, an analytical process is documented that attempts to be broad in the sampling of climate change uncertainty, but specific enough to make the BDCP analytical efforts tractable.

Climate Change and Relation to the Bay Delta Conservation Plan

The effects analysis for the Bay Delta Conservation Plan (BDCP) is designed to support the needs of the BDCP Habitat and Conservation Plan (HCP)/Natural Community Conservation Plan (NCCP), Biological Assessment, and biological resources section of the Environmental Impact Report/Environmental Impact Statement (EIR/S). A coordinated effort between state (Department of Water Resources [DWR], Department of Fish and Game [DFG]) and federal (U.S. Bureau of Reclamation [Reclamation], U.S. Fish and Wildlife Service [FWS], and National Marine Fisheries Service [NMFS]) agencies has begun to ensure that the analytical processes and tools are being applied to support common needs of the multiple environmental documents. Climate change represents an important future uncertainty that will need to be addressed in the assessments for future time periods.

The BDCP process seeks to develop a long-term conservation strategy for the recovery of species and restoration of their habitats, while providing reliable water supplies for municipal and agricultural contractors of the State Water Project (SWP) and the Central Valley Project (CVP). The conservation strategy consists of habitat restoration, new water facilities, water operations, and other stressor reduction measures to achieve the plan goals. Several of the core elements of the BDCP, such as delta marsh habitat, upstream anatropous fish habitat, reservoir and conveyance facility management, and water quality, are likely to be affected by climate change. Figure 1 below highlights some potential changes to these core elements under a future with climate change.



Delta Marsh Habitat

- Broader area of inundation, upland migration
- Deeper water with increased predation pressures
- Salinity changes effects on vegetation and macro-invertebrate communities
- Changes to thermal refugia
- Changes to invasive species dynamics

Anadromous Fish Habitat (upstream)

- Changes to hydrograph and temperature
- Changes to spawning habitat/holding pools
- Timing of spawning and outmigration (life cycle impacts)
- Increased floodplain inundation

Reservoir and Conveyance Facility Management

- Coldwater pool management
- Challenges to flood control operations
- Salinity changes and management
- Timing of water availability for export
- Changes to water supply reliability

Water Quality

- Increased Delta salinity intrusion due to sea level rise, levee system failure/island flooding
- Changes to hydrodynamics and mixing
- Increased water temperatures
- Changes to dissolved oxygen
- Effects on water treatment and human health

Figure 1. Potential climate change impacts to BDCP core elements.

While the BDCP is unlikely, by itself, to provide sufficient adaptation for the potential effects of climate change, it is important to understand the potential for such BDCP-based adaptation. Most importantly for the environmental documents is a logical and defensible approach for incorporating climate change in disclosure of impacts and effects. This paper provides background information on climate change as related to the BDCP and outlines several approaches for incorporating climate change in the impact assessment processes. A multi-agency technical sub-group was formed to review these approaches, to suggest modifications or additions, and to recommend one approach to the technical management teams of the BDCP and the Delta Habitat Conservation and Conveyance Program (DHCCP).

Climate Change Overview

A growing body of evidence indicates that Earth's atmosphere is warming. Records show that surface temperatures have risen about 0.7°C since the early twentieth century and that 0.5°C of this increase has occurred since 1978 (National Academies of Sciences [NAS] 2006 summary, U.S. Global Change Research Program [USGRP] 2001). Observed changes in oceans, snow and ice cover, and ecosystems are consistent with this warming trend (NAS 2006; Intergovernmental Panel on Climate Change [IPCC] 2001, 2007). The temperature of Earth's atmosphere is directly related to the concentration of atmospheric greenhouse gases. Growing scientific consensus suggests that climate change will be inevitable as the result of increased concentrations of greenhouse gases and related temperature increases (IPCC 2001, 2007; Kiparsky and Gleick 2003).

Earth's climate has exhibited variability and has changed over time. The extremes of the 100,000-year ice-age cycles and "mega-droughts" have been well-documented. The period of the last 10,000 years has been generally warm and stable, and the last millennium, over which current societies have developed, has been one of the most stable climatological periods observed (California Environmental Protection Agency [CalEPA] 2006). Observations in the 20th century indicate rapid climate change (IPCC 2001, 2007; NAS 2006). The National Academy of Sciences (2006) recently supported the conclusion that it is likely that the past few decades exhibited higher global mean surface temperatures than during any comparable period of the preceding four centuries. Additionally, 11 years between 1995 and 2006 rank among the 12 warmest years in the instrumentation record (1850 - 2006) for global surface temperature (IPCC 2007).

Climate Variability and Climate Change

In common terms, one can think of "climate" as the "average weather" conditions over some extended period. The IPCC (2001) provides a more rigorous definition of climate as the "statistical description in terms of the mean and variability of relevant parameters over a period of time ranging from months to thousands or millions of years." Parameters measured are most often surface variables such as temperature, precipitation, and wind. Data are typically averaged in 30-year periods as defined by the World Meteorological Organization. "Climate change" is the shift in the average weather, or trend, that a region experiences. This change may be due to natural processes, or to anthropogenic factors that affect the composition of the atmosphere. Thus, climate change cannot be represented by single annual events nor individual anomalies. That is, a single large flood event or particularly hot summer is not an indication of climate change, while a series of floods or warm years that statistically change the average precipitation or temperature over time may indicate climate change.

"Climate variability", refers to the deviation from the average climate. For example, an individual year that is drier or hotter than average would indicate variability, but may not indicate a shift in the trend as would be defined as climate change.

Mechanics of Climate Change

The temperature on Earth is regulated by a system commonly described as exhibiting the "greenhouse effect." The greenhouse effect is a natural phenomenon in which atmospheric gases, primarily water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3), allow solar radiation to pass through the atmosphere and warm Earth's surface. As Earth's surface warms, infrared radiation is emitted back to the atmosphere. Greenhouse gases in the atmosphere absorb some of this radiation and re-emit it back to Earth, causing the surface to gain more heat (NAS 2006) (Figure 2). Changes in atmospheric gases can result in changes in Earth's temperature, thus influencing climate.

Changes in the atmospheric abundance of greenhouse gases, as well as modifications to the land surface, alter the energy balance of the climate system. Greenhouse gases are contributed to the atmosphere by both natural and anthropogenic sources. Evidence suggests that the rates of contribution of greenhouse gases to the atmosphere were in balance with mechanisms for their removal prior to the early 1800's (North et al., 1995). Data on atmospheric carbon dioxide concentration indicate a cyclical pattern. The concentration of carbon dioxide (CO_2) in the atmosphere has risen about 30% since the late 1800's and is now higher than it has been in at least the last 400,000 years (USGRP 2001) (Figure 3). While there is some continued debate as to the causes of increasing concentrations of carbon dioxide, the climate effects and implications for water resource planning remain. Rising concentrations of CO_2 (Figure 4) and other greenhouse gases are intensifying Earth's natural greenhouse effect. Global projections of population growth and assumptions about energy use indicate that the CO_2 concentration will continue to rise, likely reaching between two and three times its late-19th-century level by 2100 (USGRP 2001).

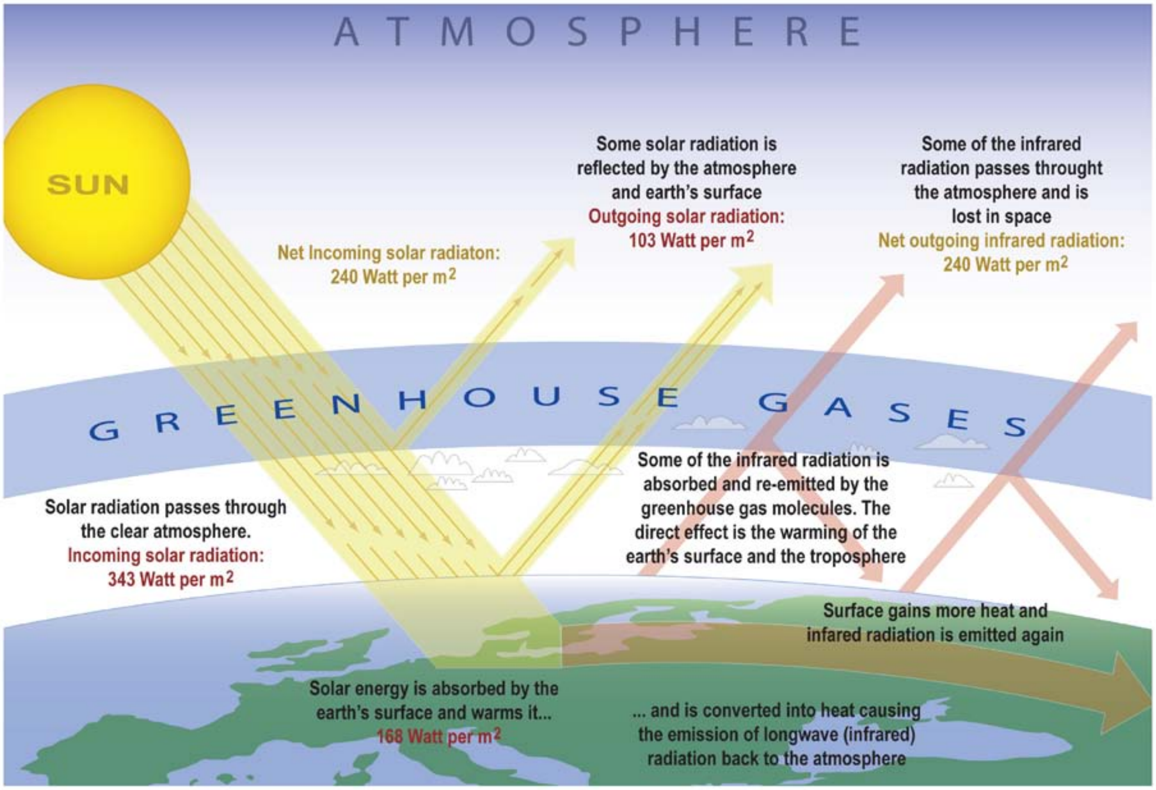


FIGURE 2. THE GREENHOUSE EFFECT (ADAPTED FROM NAS 2006)

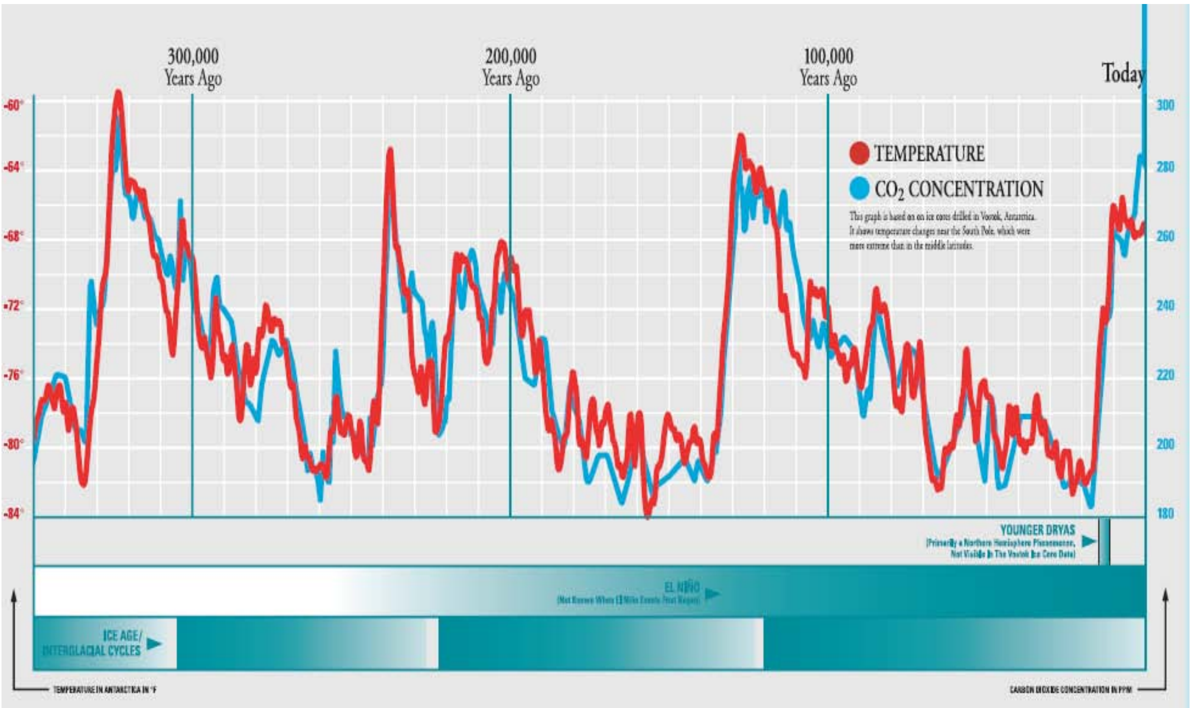


FIGURE 3. CARBON DIOXIDE IN EARTH'S ATMOSPHERE OVER TIME (SOURCE: NAS 2006

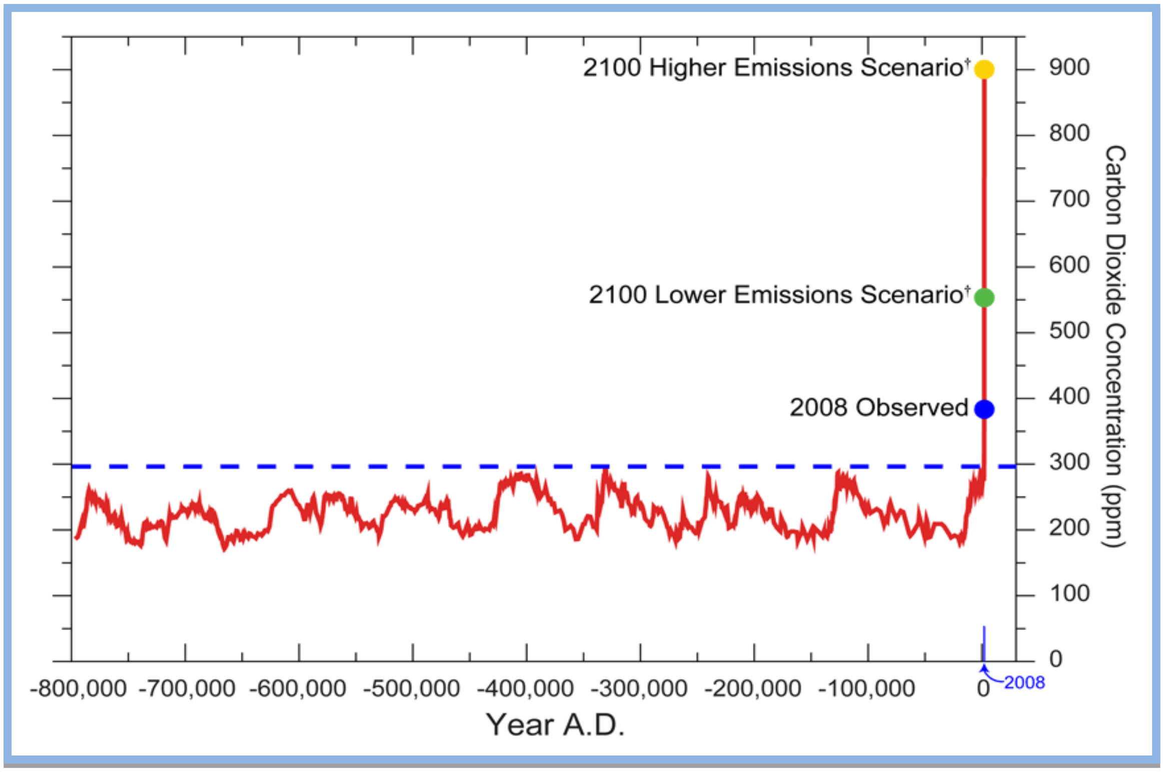


FIGURE 4. 800,000 YEAR RECORD OF CARBON DIOXIDE CONCENTRATION (SOURCE: U.S. GLOBAL CHANGE RESEARCH PROGRAM, 2009).

Observed Trends and Future Projections of California's Climate

Temperature

Observed climate and hydrologic records indicate that more substantial warming has occurred since the 1970s and that this is likely a response to the increases in greenhouse gas (GHG) increases during this time (Figure 5). Historical simulations with global climate models (GCMs) exhibit a similar response providing a basis for our understanding of causal mechanisms. The current suite of GCMs, when simulated under future GHG emission scenarios and current atmospheric GHGs, exhibit warming, globally and regionally over California (Figure 6). In the early part of the twenty-first century, the amount of warming produced by either the higher emission A2 scenario is not very different from the lower emission B1 scenario, but becomes increasing larger through the middle and especially the latter part of the century. Six GCMs selected by the California Climate Action Team (CAT) for their 2009 scenarios project, project a mid-century temperature increase of about 1°C to 3°C (1.8°F to 5.4°F) and end-of-century increase from about 2°C to 5°C (3.6°F to 9°F). The upper part of this range is a considerably greater warming rate than the historical rates estimated from observed temperature records in California (Bonfils et al. 2008).

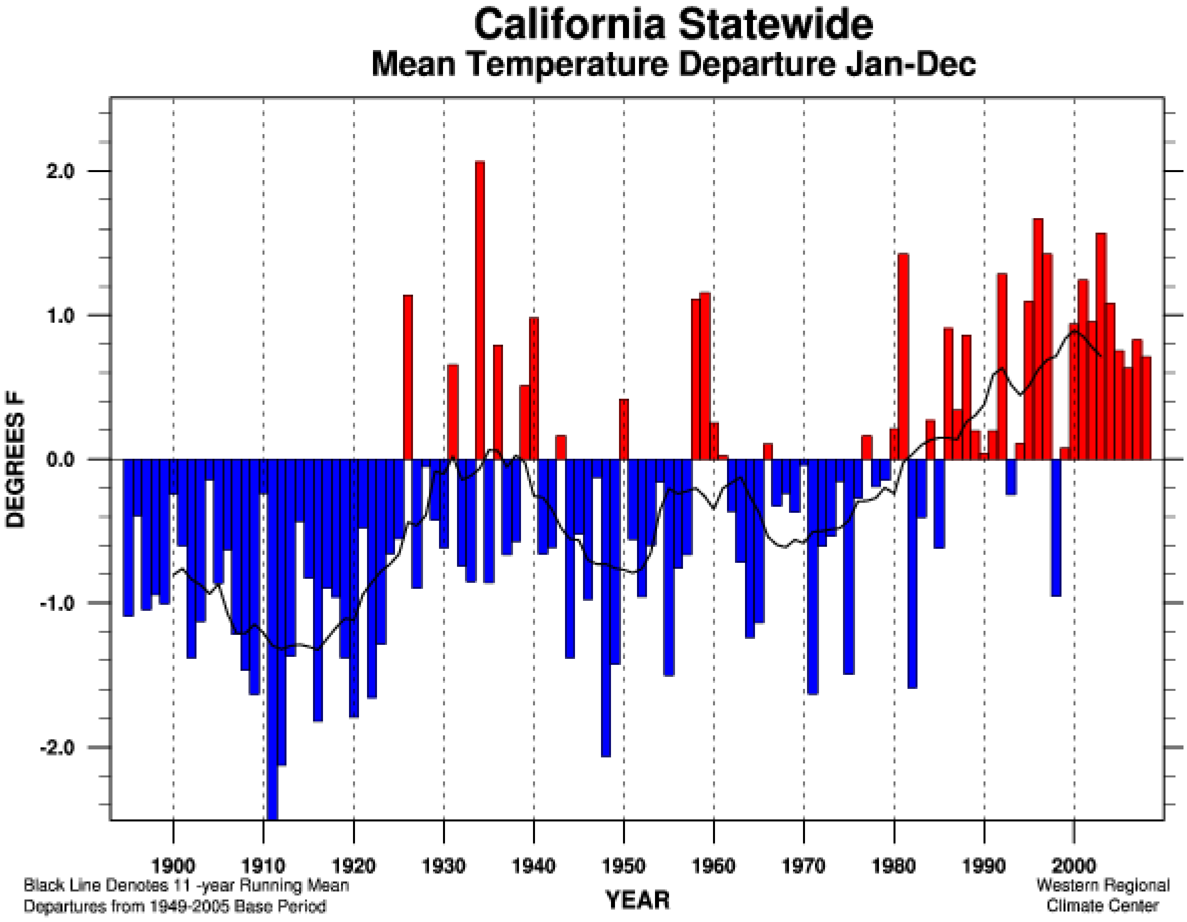


Figure 5. Historical observed California statewide mean annual temperature departure (Western Regional Climate Center, 2009).

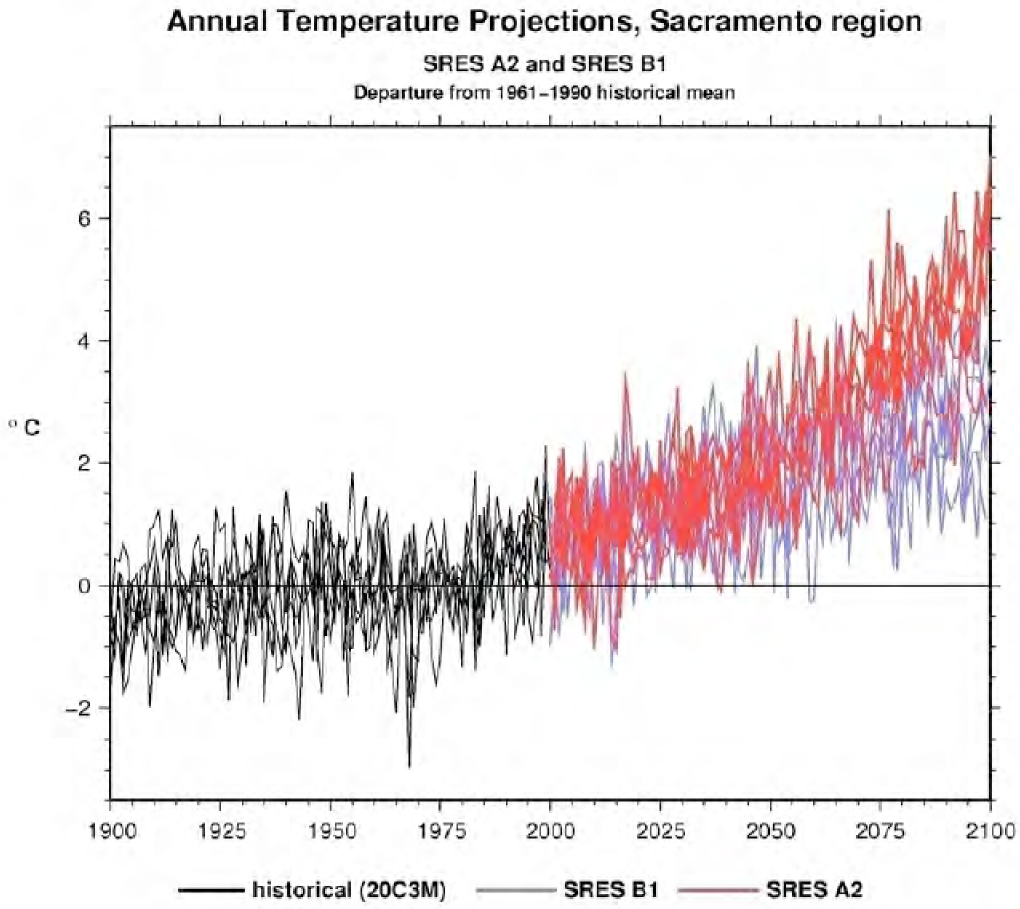


Figure 6. Simulated historical and future annual temperature projections for the Sacramento Region (Cayan et al, 2009).

Precipitation

Precipitation in most of California is dominated by extreme variability, both seasonally, annually, and over decade time scales (Figure 7). The GCM simulations of historical climate capture the historical range of variability reasonably well (Cayan et al, 2009), but historical trends are not well captured in these models. Projections of future precipitation are much more uncertain than those for temperature. While it is difficult to discern strong trends from the full range of climate projections, the 6 GCMs that were selected for the California study demonstrate a drying trend in the 21st century (Figure 8). The precipitation projection uncertainty is largest is northern part of the state with a stronger tendency toward drying in the southern part of the state. However, even for hydrologic model simulations with mean precipitation virtually unchanged, there were large impacts on snowpack accumulation, runoff, and soil moisture.

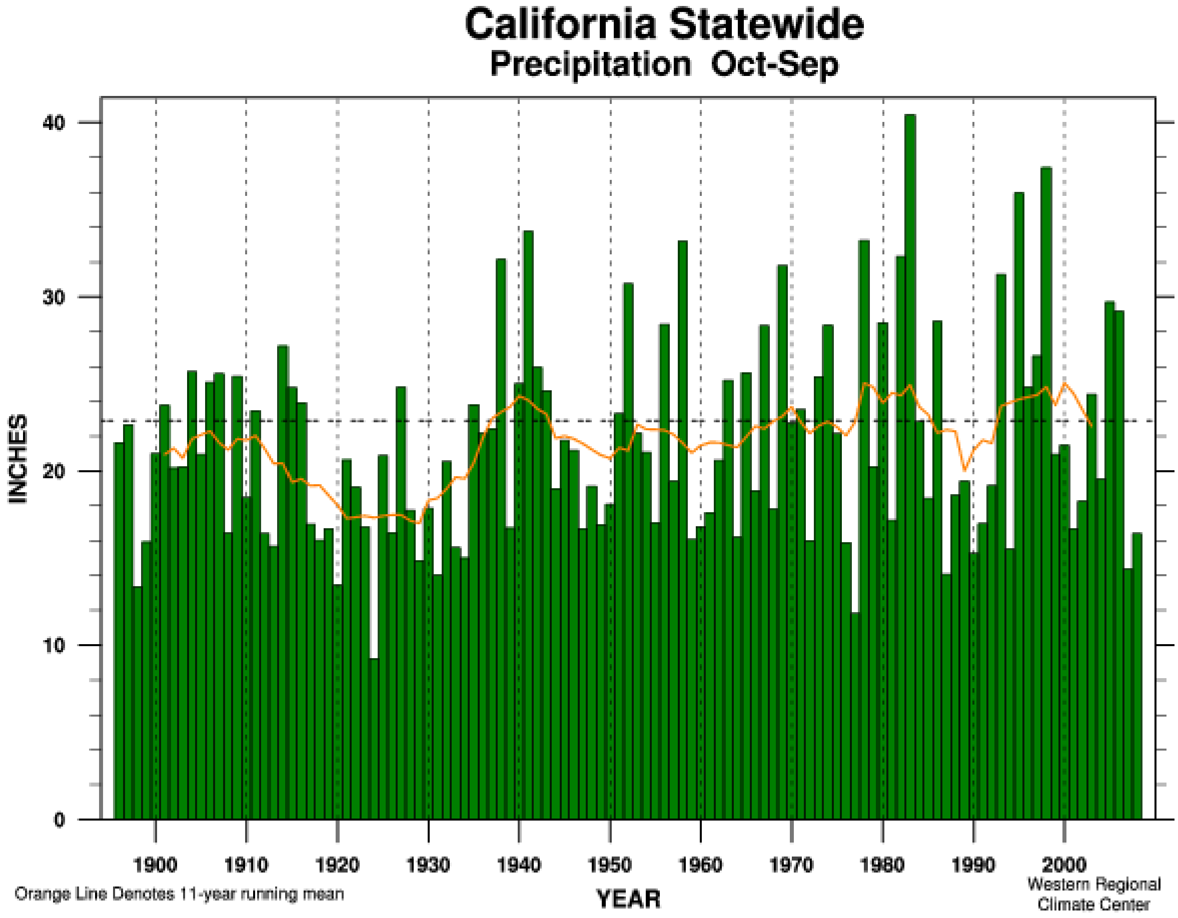


Figure 7. Historical observed California statewide water year precipitation (Western Regional Climate Center, 2009).

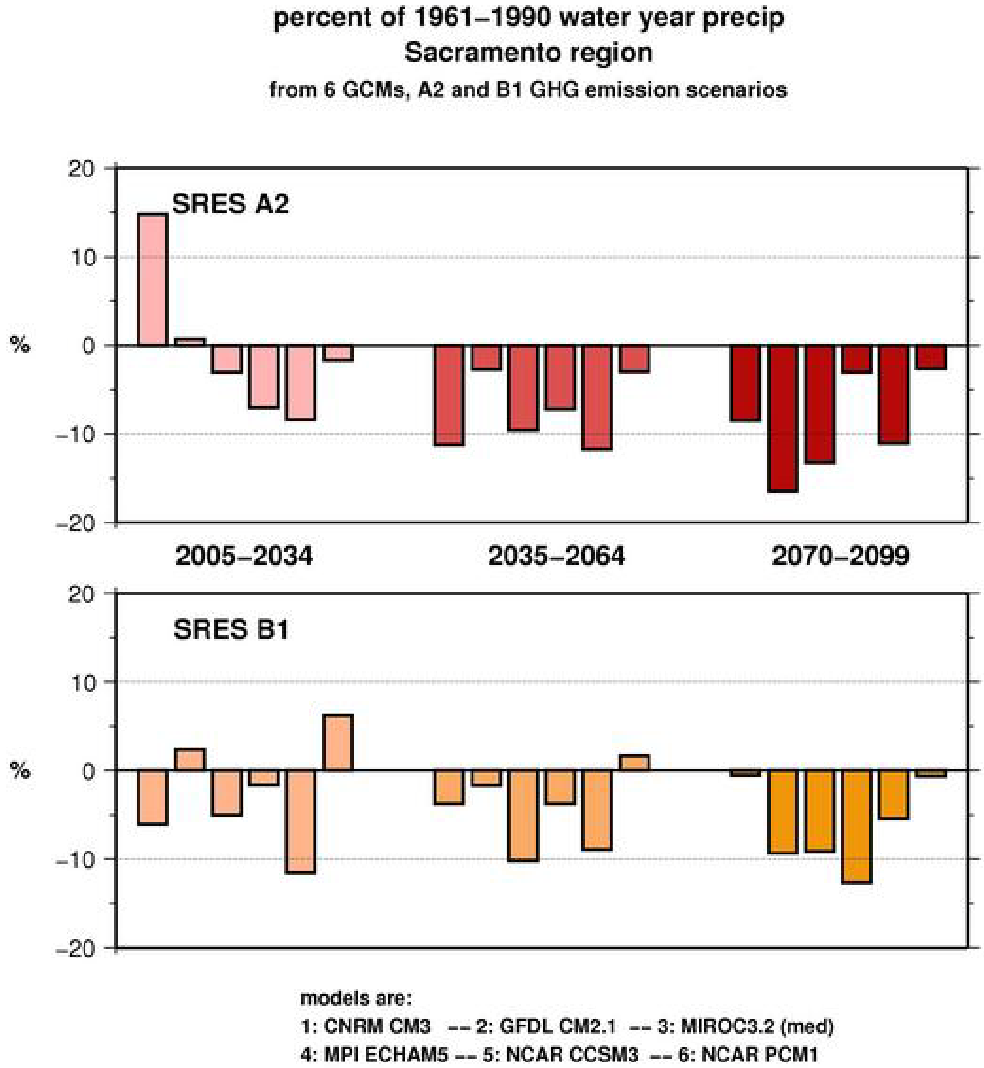


Figure 8. Simulated future water year change in precipitation for IPCC's Special Report on Emission Scenarios (SRES) A2 and B1 scenarios for the Sacramento Region (Cayan et al, 2009).

Sea Level Rise

Global and regional sea levels have been increasing steadily over the past century and are expected to continue to increase throughout this century. Over the past several decades, sea level measured at tide gages along the California coast has risen at rate of about 17 - 20 centimeters (cm) per century (Cayan et al 2009). While there is considerable variability amongst gages along the Pacific Coast (Figure 9), primarily reflecting local differences in vertical movement of the land and length of gage record, this observed rate in mean sea level is similar to the global mean trend (NOAA 2009). The observed mean sea level trend reported by NOAA (2009) for the San Francisco tide gage (station 9414290), located near Golden Gate, is about 2 mm/yr (Figure 10).

Sea levels are projected to increase at a more rapid rate in the future due to increased thermal expansion of water in the oceans due to global warming, and changes in the freshwater input to the oceans from melting of glaciers and ice sheets, and changes in water storage on land (Ramsdorf 2007). Global estimates of sea level rise made in the most recent assessment by the IPCC (2007) indicate a range of 18-59 cm this century. However, since the release of the IPCC Fourth Assessment Report, advances have occurred in the understanding of sea level rise. These advances in the science have led to strong criticism of the approach used by the IPCC. Recent work by Ramsdorf (2007), Pfeifer (2009), and others suggests that the sea level rise may be substantially greater than the IPCC projections. Empirical models based on the observed relationship between global temperatures and sea level have been shown to perform better that the IPCC models in reconstructing recent observed trends. Ramsdorf (2007) demonstrated that such a relationship when applied to the range of emission scenarios of IPCC (2007), results in a mid-range rise this century of 70-100 cm (28-39 inches), with a full range of variability of 50-140 cm (20-55 inches) (Figure 11). Indeed, these empirical relationships were the basis for the recommendations for the Delta Vision made by the CALFED Independent Science Board (Healy 2007).

In the most recent CAT assessment (2009), sea level rise projections were derived based on empirical relationships described by Ramsdorf (2007). From the scenarios selected for the CAT report, sea level rise by 2050 is projected to be 30-45 cm (12-18 inches) higher than 2000 levels (Figure 12). Recently the U.S. Army Corps of Engineers [USACOE] (2009) issued guidance on incorporating sea level change in civil works programs. The guidance reviews the existing literature and suggests use of a range of sea level change projections, including the "high probability" of accelerating global sea level rise. The ranges of future sea level rise were based on the empirical procedure recommended by the National Research Council [NRC] (1987) and updated for recent conditions. The three scenarios included in the USACOE guidance suggest end of century sea level rise in the range of 50-150 cm (20-59 inches); consistent with the range of projections by Ramsdorf (2007).

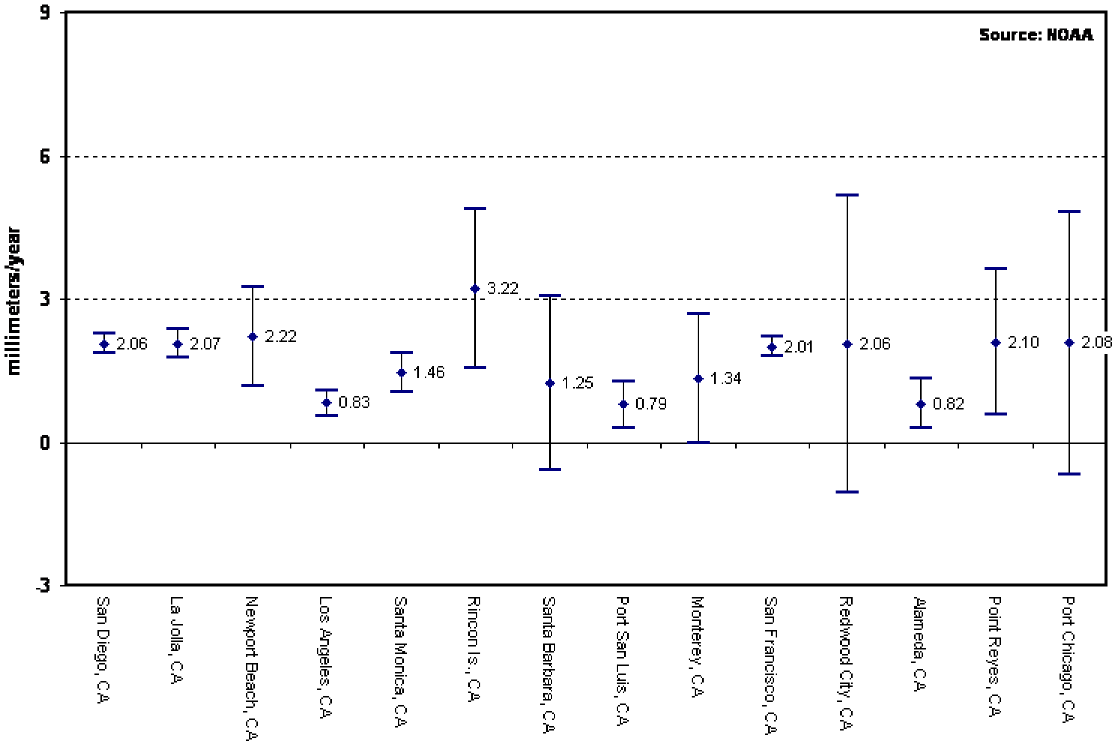


Figure 9. Observed mean sea level trends for tide gages along the Pacific Coast (NOAA 2009). *The graphs compare the 95% confidence intervals of the mean sea level trends. Trends with the narrowest confidence intervals are based on the longest data sets. Trends with the widest confidence intervals are based on only 30-40 years of data. The graphs give an indication of the differing rates of vertical land motion, given that the absolute global sea level rise is believed to be 1.7-1.8 millimeters/year.*

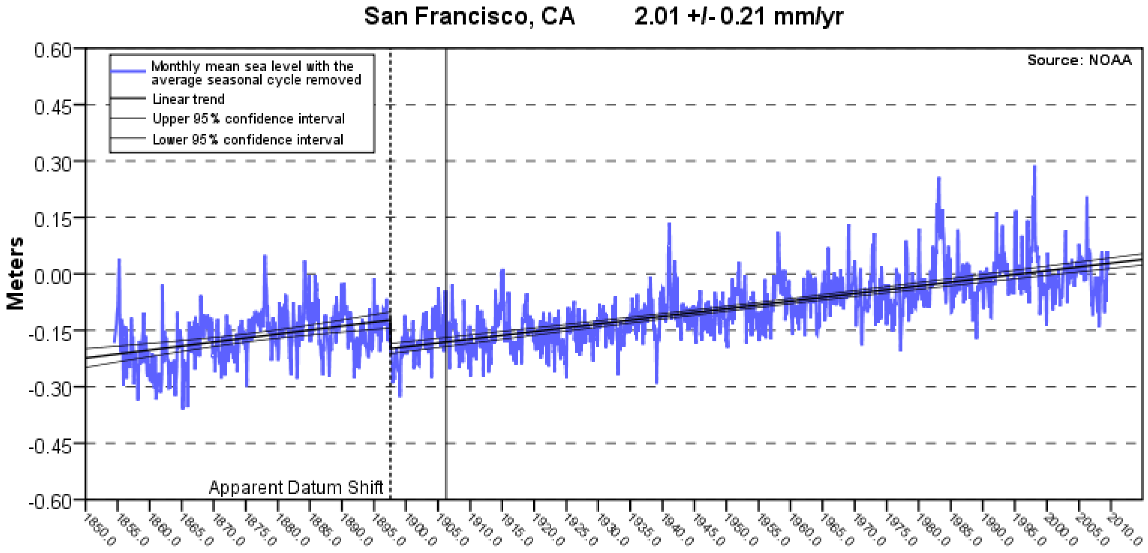


Figure 10. Observed mean sea level trend for the San Francisco tide gage near Golden Gate (NOAA 2009). *The mean sea level trend is 2.01 millimeters/year with a 95% confidence interval of +/- 0.21 mm/yr based on monthly mean sea level data from 1897 to 2006 which is equivalent to a change of 0.66 feet in 100 years.*

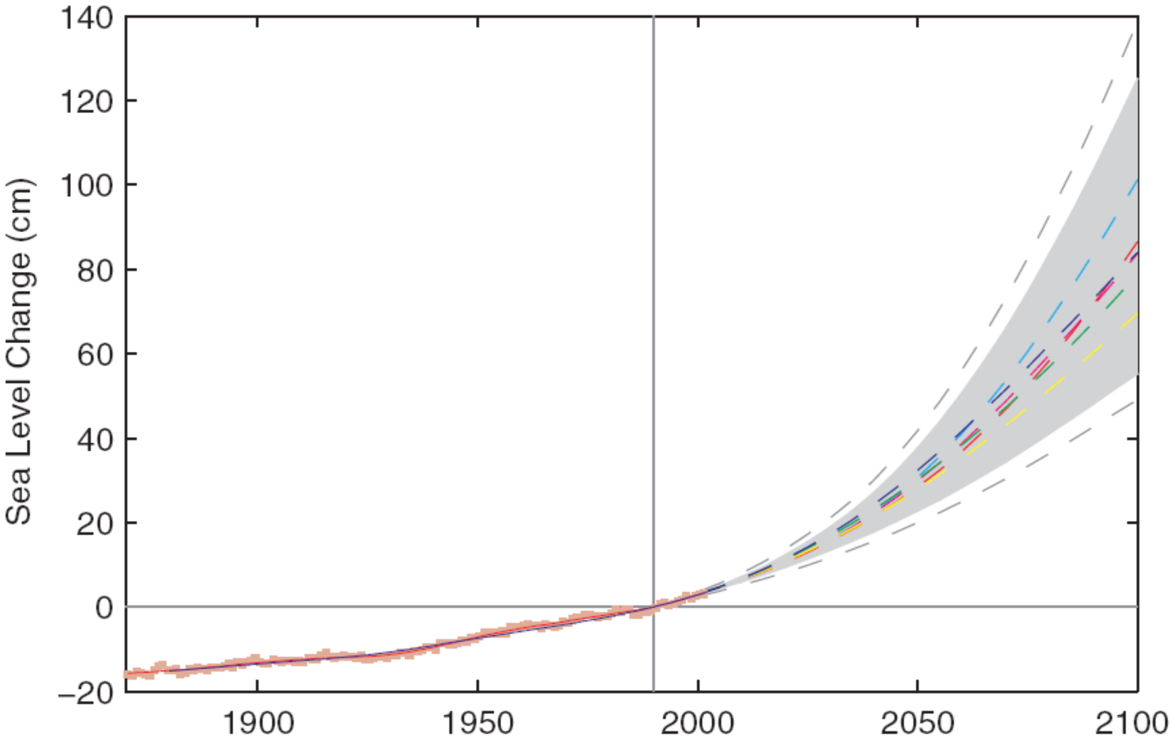


Figure 11. Past global mean sea level and future mean sea level based on global mean temperature projections (Ramsdorf 2007).

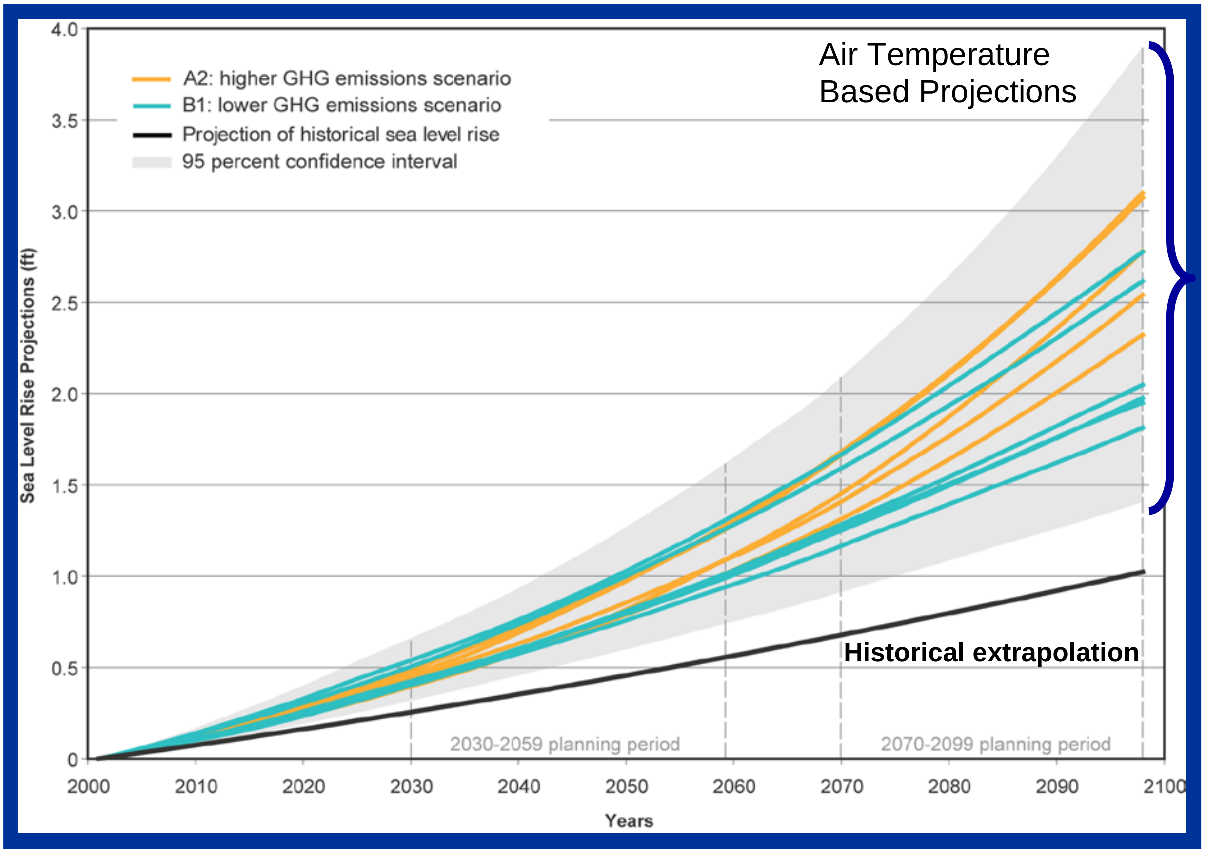


Figure 12. DWR-generated future sea level rise projections based on 12 CAT scenario projections using Ramsdorf method (Chung et al 2009).

Ocean Conditions

Global climate change in the future is expected to affect ocean conditions in ways that will impact marine populations directly (distribution, health, survival and production in response to conditions) and indirectly (shifts in ecosystem trophic structure and productivity). Osgood (2008) identifies five climate change issues of greatest concern to the California Current ecosystem (CCE).

Generally warmer ocean conditions due to global climate change will cause a northward shift in the distribution of most species, and possibly the creation of reproductive populations in new regions. Existing faunal boundaries tied to geographic features are likely to remain strong, but their resiliency to shifts in ocean conditions is not known. Warmer surface temperatures have also increased stratification of the coastal CCE (Palacios et al., 2004), which Roemmich and McGowan (1995) credited for a long-term decline in zooplankton biomass.

The strength, and timing of seasonal coastal upwelling, when the shelf-slope zooplankton community transitions between a winter-time (warm water) community and a spring-summer upwelling (cold water) community, affects species including zooplankton, krill, salmon, sablefish, some rockfish, and sea birds. Coastal upwelling has become stronger over the past several decades due to climate change (Bakun, 1990). Regional climate models project that not only will upwelling-favorable winds will be stronger in summer, but that the peak in seasonal upwelling will occur later (Snyder et al., 2003). Animals such as whiting, sardines, shearwaters, leatherback turtles, killer whales, and blue whales that migrate both to and within the CCE to take advantage of prey associated with the seasonal cycle of production, and time their movements and reproduction with peaks in the seasonal cycles of production, may have to adjust the timing of such activities.

Decadal variations in water mass characteristics such as salinity, oxygen, nutrients, and chlorophyll are linked to shifts in regional and large-scale circulation (Parrish et al., 2000; DiLorenzo et al., 2008). Basin-scale adjustments in North Pacific circulation due to changing global winds may be a principal factor in these decadal fluctuations within the CCE, and can explain variations in regional water mass characteristics and related biological variables. The source waters that feed into the California Current exert some control the over the phytoplankton and zooplankton assemblage, and ecosystem structure and production (Hooff and Peterson, 2006). If upwelling strengthens due to global climate change, cold-water species will be favored in the coastal upwelling zones.

Global climate change will lead to a more volatile climate with greater extreme events on intraseasonal to interannual scales. For the CCE this will mean more frequent and severe winter storms, with greater wind mixing, higher waves and coastal erosion. More extreme precipitation events and years will impact coastal circulation and stratification. Increased physical variability could negatively affect living marine resources. For example, a three-month delay to the 2005 upwelling season resulted in a lack of significant plankton production and massive recruitment failure for several fish, birds and mammal populations (Sydeman et al., 2006; Mackas et al., 2006; Schwing et al., 2006). Some global climate models predict a higher frequency of El Niño events, while others predict the intensity of these events will be stronger. This may greatly reduce primary and secondary production in the CCE, with negative effects transmitted up the food chain.

Future changes in freshwater and river conditions (freshwater quality and flow) will likely have a great effect on the production of salmon and other anadramous and estuarine species, and for coastal populations whose habitats include ocean fronts and river plumes. Climate models project greater (lesser) annual precipitation for northern (southern) California in the 21st Century, more extreme winter precipitation events, and a more rapid spring melt leading to a shorter, more intense spring period of river flow and freshwater discharge. This will greatly alter coastal stratification and mixing, riverine plume formation and evolution, and the timing of transport of anadramous populations to and from the ocean.

In addition, recent monitoring of the CC coastal waters has shown that changes in the chemistry due to climate change, including ocean acidification (refz), hypoxia (Bograd et al., 2008), and nutrient levels (DiLorenzo et al., 2009), may have a substantial effect on marine species. However these are emerging issues, with much still to be learned about their future impacts.

Recent State and Federal Approaches for Incorporating Climate Change in California

California Climate Action Team Report, 2006

The Climate Action Team (CAT) series of reports represented the state's response to the governor's 2005 order establishing targets for greenhouse gas emissions and requiring biennial reporting by state agencies. DWR's report *Progress on Incorporating Change into Management of California's Water Resources* describes progress made to incorporate climate change into water resources planning and management, tools, and methodologies. The report describes potential changes to precipitation and runoff, sea level, water demand, and fisheries. The water management analyses included in this report utilized the results from four downscaled climate projections (2 global climate models [GCMs] x 2 emission scenarios) described in CalEPA (2006): PCM A2, GFDL A2, PCM B1, and GFDL B1. Hydrologic analyses were performed using the macro-scale Variable Infiltration Capacity (VIC) model for each major watershed. The effects on runoff were analyzed for a historic period centered around 1976 (1961-1990) and for a climate change future period centered around 2050 (2035-2064). The fractional changes in runoff from historic gage measurements and future scenarios were then applied as monthly perturbation ratios to adjust the inflows to the CALSIM II model to reflect the climate change future. Model simulations were performed by the DWR to analyze the long-term potential impacts to SWP and CVP delivery capability. A sea level rise of 1 foot (~30 cm) was considered in the DSM2 modeling of delta hydrodynamics and water quality. However, these effects of sea level rise were not integrated into the CALSIM II system operations analysis modeling.

Salton Sea Ecosystem Restoration Program, Programmatic Environmental Impact Report, 2007

The California Resources Agency prepared the draft PEIR for the Salton Sea Ecosystem Restoration Program in 2006 and finalized in 2007. The PEIR involved the development and evaluation of restoration alternatives for the stabilizing water levels and salinity for a portion of the Salton Sea. The Salton Sea is almost solely dependent on agricultural return flows for its supply and has no outlet other than evaporation. Due to the significant uncertainty regarding future water management within the drainage area and effects of climate change on the evaporation of the Salton Sea, an uncertainty analysis was performed in the PEIR in which the range of factors affecting inflow and evaporation were assessed. Water surface evaporation was correlated to temperature and climate change effects on the Sea were estimated through the use of the same four climate projections described in DWR (2006). Due to the lack of water right and flow guarantees to the Salton Sea, the program alternatives were adjusted in order to respond to a conservative level of inflow and evaporation assumptions based on the uncertainty analysis. In this case, climate change effects were incorporated directly in the development of the alternatives and were not specifically analyzed for CEQA significance determinations. However, two sets of inflow assumptions were incorporated in the PEIR, one which included a more strict definition of "reasonable and foreseeable" changes and another which included a broader definition. The latter set of inflows and evaporation rates incorporated possible climate change effects, while the former did not.

State Water Project Reliability Report, 2007

DWR's State Water Project Delivery Reliability Report (DWR 2007) is prepared to assist local agencies, cities and counties using SWP water in integrated water supply planning. The Delivery Reliability report considered the issue of climate and hydrologic uncertainty, along with regulatory uncertainty, in the assessment of long-term delivery reliability of the SWP. Four future climate change scenarios, identical to those utilized in DWR's 2006 report, were used to reflect potential changes to future hydrologic conditions. The SWP delivery reliability under assumptions of historical hydroclimate and the four climate change futures were assessed through CALSIM II modeling of SWP and CVP operations. As with the 2006 report, the potential effects of sea level rise on the operation of the SWP and CVP were not integrated into the analysis as tools to perform such a function were still in development.

Monterey Amendment to the State Water Project Contracts, including the Kern Water Bank and associated actions as part of a Settlement Agreement (Monterey Plus), Final Environmental Impact Report, 2010

The Monterey Plus EIR prepared by the DWR is aimed at identifying potential environmental impacts resulting from modifications to water supply contracts. The EIR includes analyses of a Baseline, a Proposed Project, four different No Project alternatives, and one additional alternative. Analyses were performed for these alternatives using the CALSIM II model, which uses historical hydrological data for the period of record, to simulate river flows in the Sacramento and San Joaquin valleys and in the Delta and operations of the State Water Project (SWP) and the Central Valley Project (CVP). In addition, because the Monterey Plus EIR alternatives include differing SWP allocation procedures that are not modeled explicitly in the CALSIM II model, a post-processing routine was used to determine the SWP deliveries to each individual SWP contractor in each alternative.

Independent climate change analyses were not conducted for the Monterey Plus EIR, and significance findings for the proposed project were not based on scenarios that included climate change effects. However, the EIR included a discussion of the results of previous and on-going studies of climate change that have been conducted by the DWR and others as well as a climate change sensitivity analysis. The sensitivity analysis was performed using the results from the GFDL B1 scenario reported in DWR's 2006 report. The GFDL B1 scenario was selected because it had the largest average annual impact on SWP deliveries relative to the Base scenario. Revised operational time series results were then entered into the Monterey Plus EIR post-processing routine to determine the SWP deliveries to each SWP contractor under each scenario's allocation rules.

Operations Control and Plan, 2008

The Biological Assessment for the Continued Long-Term Operations of the Central Valley Project and State Water Project, referred to as the OCAP BA, was prepared in 2008 to evaluate the effect of the project operations on listed species and critical habitat. Appendix R presented a sensitivity analysis of potential climate change implications to CVP/SWP operations and system conditions. The analyses included a range of future climate change and sea level rise possibilities that may occur over the consultation horizon of the OCAP (i.e. 2030). The analyses included in the appendix were also directly utilized in the subsequent Biological Opinions for delta smelt (USFWS 2008) and salmon (NMFS 2009).

The report considered four regional climate change scenarios, selected from available climate projections to represent a range of 2030 possible climate conditions. Selection of the climate change scenarios was based on the range of projection uncertainty as represented by paired precipitation-temperature changes at various locations over the consultation duration. In short, scenarios that most closely represented the 10th and 90th percentile of the projection range were selected to bracket the range of possible future climates. The selected scenarios varied from: less warming to more warming from historical; and, drier to wetter than historical.

Only one sea level rise assumption was jointly considered with the four regional climate change scenarios. The OCAP study limited the selection of sea level rise to those available in the existing DSM2 Delta hydrodynamic and water quality model configured by the DWR. Considering the limited availability of sea level rise modeling scenarios, the OCAP study selected assumptions of a 1-foot sea level rise coupled with a 10% increase in tidal range. The appendix described this sea level rise assumption as representing the “high end” of the anticipated rise by 2030.

California Climate Action Team Report, 2008-09

In early 2009, California’s Climate Action Team released a series of reports which serve as a summary update of the latest climate change science and response options for decision makers in California. Importantly, this recent update expanded the number of climate change scenarios for consideration to 12 (6 GCMs x 2 emission scenarios) from the four (2 GCMs x 2 emission scenarios) included in the 2006 report. As in the 2006 report, SRES A2 and B1 emission scenarios were selected to represent a range of possible future global conditions. Six GCMs: NCAR PCM, NOAA GFDL version 2.1, NCAR CCSM, MPI ECHAM5, MIROC 3.2 medium resolution model, and the CNRM models were selected for use in the 2008-09 update. The GCMs were selected based on the ability to provide relevant monthly and in some cases daily data. Another rationale in the GCM selection was that the models provide a “reasonable” representation, from their historical simulations, of seasonal precipitation and temperature, variability of annual precipitation, and ENSO. The report indicates, however, that recent studies have shown that the historical model “skill” is not well related to climate change performance.

Projected temperature and precipitation were downscaled to reflect regional climate change projections using two methods: bias correction and spatial downscaling (BCSD) and constructed analogues (CA). The two methods reportedly produced similar results, although DWR found that some key precipitation metrics were not suitably simulated in time for the report using the CA method.

In this most recent assessment, sea level rise projections were derived based on empirical relationships between global mean surface air temperature and global mean sea level as described by Ramsdorf (2007). This method better reproduces historical sea levels but generally produces larger estimates of sea level rise than those indicated by the IPCC (2007) and other recent estimates. However, the method described by Ramsdorf is consistent with the methods used in the recent summary recommendation on sea level rise from the CALFED Independent Science Board (Healy 2008). From the scenarios selected for this report, sea level rise by 2050 is projected to be 30 cm (12 inches) to 45 cm (18 inches) higher than 2000 levels.

From the 12 regional climate scenarios, hydrologic analyses were developed to simulate changes in snowpack accumulation, runoff, and consumptive use for the watersheds draining to the major reservoirs in the Central Valley. In turn, DWR prepared analyses of the potential effects to the SWP/CVP operations and system conditions based on the projected changes in hydrologic conditions and sea level. DWR's analyses focused on a mid-century and end-century periods.

State Water Project Delivery Reliability Report, 2009

DWR's most recent State Water Project Delivery Reliability Report (DWR 2009) again considered the issue of climate and hydrologic uncertainty, along with sea level rise uncertainty, and regulatory uncertainty, in the assessment of long-term delivery reliability of the SWP. In this latest report, however, DWR selected only one future "central" or "median" climate change scenario for assessing delivery estimates. The single future climate scenario was selected from the 12 Climate Action Team scenarios based on the most central estimate of water supply effects. The metrics used for comparison consisted of projected climate and hydrology variables, and their effects on CVP/SWP system exports; namely, temperature, precipitation, total inflow to major reservoirs, shifts in timing of run-off, and Delta exports. Based on these metrics, DWR selected the MPI ECHAM5 global climate model run for the A2 emission scenario. Sea level rise scenarios of 1 foot by mid-century and 2-feet at the end-of-century were presented in this report.

San Joaquin River Restoration Program, 2009

The San Joaquin River Restoration Program EIS is currently in development, but has incorporated climate change in a manner similar to that in the OCAP BA (Brekke, personal communication). Similar to the OCAP BA method, regional climate change scenarios were selected that most closely represented the 10th and 90th percentile of the temperature-precipitation projection range (four scenarios). Expanding on the concept of a "central" or "median" scenario, however, a fifth scenario was added that most closely represented the 50th percentile of the projection range. As with the OCAP BA, sea level rise assumptions were selected as 1-foot mean sea level increase and 10% increase in tidal amplitude.

California Water Plan Update, 2009

The California Water Plan Update 2009/2013 is currently evaluating analytical approaches for incorporating climate change in long-term planning. In the most recent Update 2009 (DWR 2010), DWR makes use of the 12 Climate Action Team climate scenarios for assessing changes to demands. Hydrologic scenarios for the Water Plan are anticipated to apply the same climate scenarios, but continue to be developed. Contrasting from other recent DWR climate studies, the California Water Plan is intending to use the meteorological sequences (seasonal, annual, and decadal-scale variability) generated from global climate models directly in water planning assessments rather than the use of "perturbations" to observed sequences as considered in all previous DWR studies. Results from these analyses are planned for the Update 2013.

Table 1. Summary of recent state and federal approaches for incorporating climate change in California water planning.

Project	**Lead Agency**	**Methodology**	**Climate Change Assumptions**	**Sea Level Rise Assumptions**
California Climate Action Team Report, 2006	DWR	Scenario analysis using four CAT-selected scenarios	Four GCM-emission scenarios derived climatology	1-foot sea level rise at mid-century
Salton Sea Ecosystem Restoration Program PEIR, 2007	Resources Agency	Two future scenarios developed to incorporate broader range of uncertainty, including climate change	Four scenarios from CAT 2006 and assumed normal distribution from historic to highest scenario	Not directly relevant to project
SWP Delivery Reliability Report, 2007	DWR	Sensitivity analysis with CAT 2006 scenarios	Four GCM-emission scenarios derived climatology	Not included in analysis
Monterey Plus Final EIR, 2010	DWR	Sensitivity analysis with most extreme of the CAT 2006 scenarios	Analyzed scenario from CAT 2006 with greatest impact on deliveries	Not included in analysis
Operations Control and Plan, 2008	Reclamation	Sensitivity analysis with bracketing scenarios approach	Selected scenarios that represented 10th and 90th change in temp and precip	1-foot sea level rise at 2030 based on availability of DSM2 simulations
California Climate Action Team Report, 2008-09	DWR	Scenario analysis using Twelve GCM-emission scenarios	Twelve GCM-emission scenarios derived climatology. Selected based	1-foot and 2-foot sea level rise

			on output availability and historical skill.	
SWP Delivery Reliability Report, 2009	DWR	Single “median” projection from CAT 2008 scenarios	Single “median” projection from CAT 2008 scenarios	1-foot sea level rise at mid-century and 2-feet at end-of-century
San Joaquin River Restoration Program, 2009	Reclamation	Sensitivity analysis with bracketing and “median” scenarios approach	Selected scenarios that represented 10th, 50th, and 90th change in temp and precip	1-foot sea level rise at 2030 based on availability of DSM2 simulations
California Water Plan Update 2009/2013	DWR	In-development. Currently documented as use of CAT 2008 scenarios in “transient” mode.	Twelve GCM-emission scenarios from CAT 2008.	1-food and 2-foot sea level rise scenarios documented, but unknown analytical approach.

Potential Approaches for Incorporating Climate Change in BDCP Resource Impact Assessments

Stationarity – the idea that natural systems fluctuate within an unchanging envelope of variability – a foundational concept that permeates training and practice in water-resource engineering (Milly et al 2008)—is increasingly being called into question. Contemporary climate change science suggests that the future may be quite different from the past, requiring new approaches in water planning. Incorporation of climate change in water planning continues to be an area of evolving science, methods, and applications. The methods described in the projects/studies above illustrate the nature of this evolving field. Several potential approaches exist for incorporating climate change in the BDCP effects analysis and resources impact analyses. Currently, there is no standardized methodology that has been adopted by either the State of California or the Federal agencies for use in impact assessments. The courts have ruled that climate change must be considered in the CEQA analysis of long-term water management projects in California, but have not been prescriptive in terms of methodologies to be applied. Climate change could be addressed in either a qualitative and/or quantitative manner; could focus on global climate model projections or recent observed trends; and could explore broader descriptions of observed variability by blending paleoclimate information into this understanding.

In general, consistency with previous state and federal approaches is desirable. However, climate science is continuously improving, requiring new studies to incorporate and improve information from past studies.

Because of the complexity and broad multi-agency participation, the environmental analyses being conducted for BDCP requires a tailored innovative approach to analyzing the impacts of climate change.   Each project lead and responsible agencies will need to issue their own findings on the project. And each of these entities has specific interests and will be looking for analysis specific to their needs. In addition, BDCP/DHCCP will be investigating a range of potential project alternatives that involve different infrastructure configurations and operational parameters, land use changes, and time periods of impact. The uncertain impacts of climate change must then be analyzed on top of all of these variables. Thus, a limited set of climate change scenarios must be selected to facilitate meaningful investigation and disclosure of the potential impacts of the project and alternatives.

Several previously conducted climate change impact studies, most notably the California Climate Action Team Report (2008/9), have focused generally on potential impacts to existing infrastructure and ecosystems. These studies have often favored the analysis of a wide range of climate change scenarios to capture the uncertainty of current projections. The project level analysis being conducted for BDCP must analyze the impacts of climate change on not just existing conditions but on a range of alternative project configurations and to greater detail, significantly expanding the analysis effort. To address this issue, the climate change analysis approach outlined below attempts to balance these competing challenges.

As described in the previous section, several different methodologies have been applied to analyze climate change in recent water planning efforts. The BDCP, because of its scale and scope has the potential to move these analysis efforts forward and establish a new model for future water planning investigations.

BDCP Planning Objectives and Use of Analyses

This section presents potential approaches for incorporation of climate change in BDCP resource impact assessments and effects analyses. A technical sub-group made up of representatives from DWR, Reclamation, DFG, USFWS, and NMFS was formed to discuss the merits of these approaches and present a recommended approach for agency approval.

The assessment of biological impacts of the BDCP is being managed as a coordinated effort between state (DWR, DFG) and federal (Reclamation, FWS, and NMFS) agencies. The analytical processes and tools are being applied to support four major sets of environmental documents:

1. HCP/NCCP
2. EIR/S
3. Biological Assessment
4. Biological Opinions

The climate change approach will need to be consistent across each of these environmental documents and be able satisfy the lead agency needs.

Timelines for Analysis

The BDCP process seeks to develop a long-term conservation strategy for the recovery of species and restoration of their habitats, while providing reliable water supplies for municipal and agricultural contractors of the SWP and CVP. The conservation strategy consists of habitat restoration, new water facilities, water operations, and other stressor reduction measures to achieve the plan goals. The BDCP seeks to obtain a permit for the operation of the SWP and CVP within a specified manner over the next 50-yr period.

Quantitative analyses are being planned for three points in time to adequately disclose the impacts/effects of the BDCP over the 50-yr life of the permit. The three points in time are currently being considered as:

1. ***Near-Term***. Approximately 5 years from issuance of permit (~ 2015) and will include measures that could be put in place prior to the completion and operation of the dual conveyance.
2. ***Early Long-Term***. Approximately 10-15 years from issuance of permit (~ 2020 – 2025) and will include substantial habitat restoration and operation of the dual conveyance system.
3. ***Late Long-Term***. Approximately 40-50 years from issuance of permit (~2050-2060) and will include the full implementation and operation of the BDCP conservation strategy.

Climate change assumptions will need to be developed for each of these three points in time (Figure 14) and a determination of whether the anticipated changes would be detectible under the analytical tools and processes.

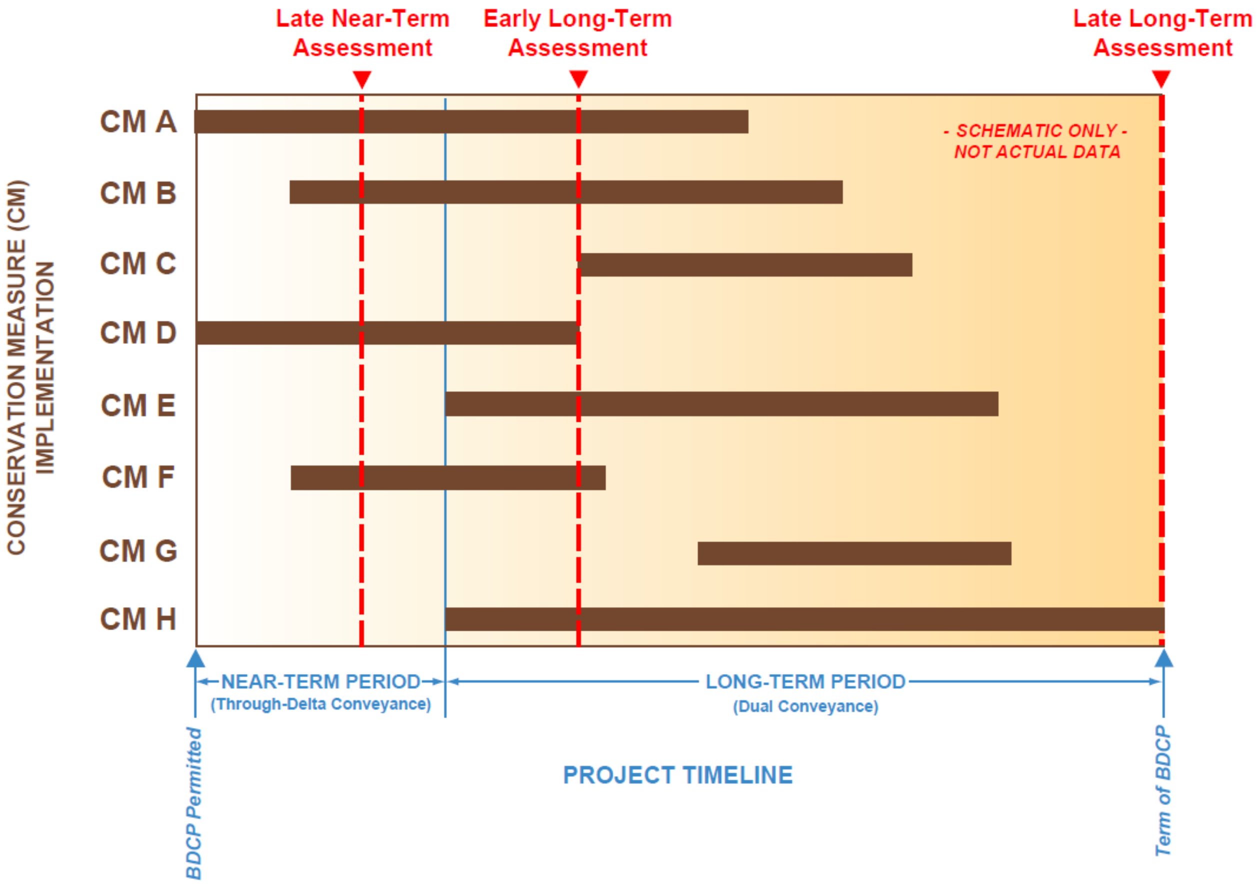
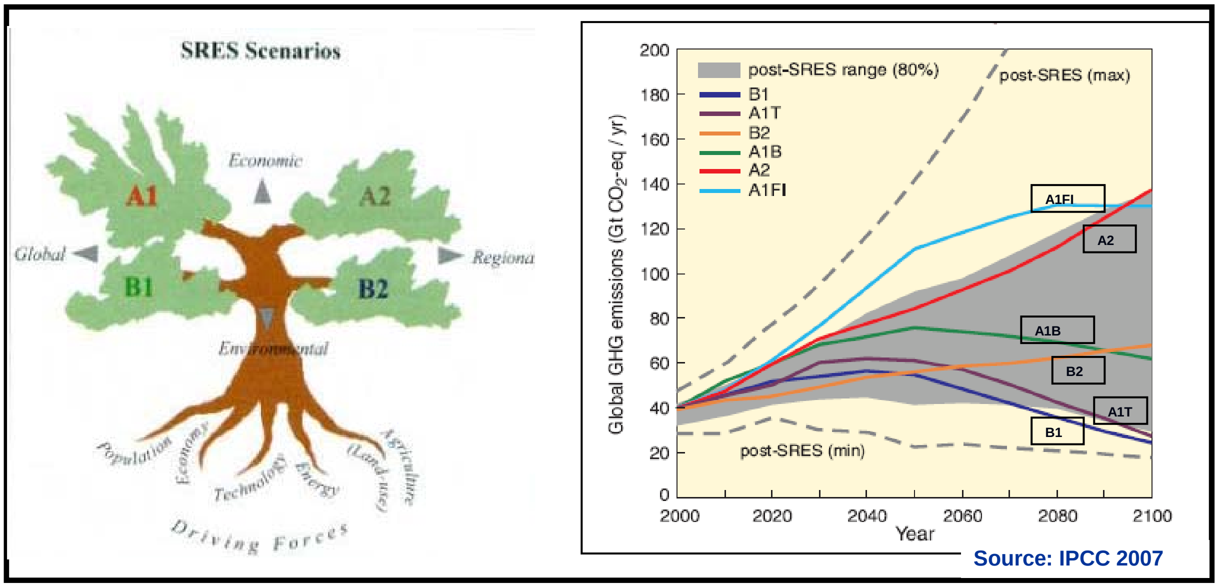


Figure 14. Graphical depiction of BDCP timelines for assessment.

Selection of Representative Climate Scenarios

Future climate change presents the challenge of how to incorporate an uncertain future in water planning. While there is general consensus on some aspects of regional climate change projections (direction of temperature and sea level rise), there are other aspects that are not well understood (precipitation trends in California). Future climate change projections are made primarily on the basis of GCM simulations under a range of future emission scenarios. Currently, there are approximately 20 major GCMs that are supported by national institutions worldwide. While GCMs have improved significantly in recent years, the models continue to have substantial uncertainty, especially for regional conditions. The coarse-scale of global models requires that results must be "downscaled", or applied to a region or watershed. Whether through dynamic or statistical methods, downscaling adds another source of uncertainty to projections. In addition, the range of projections, especially beyond 2030, is governed by assumed future global emissions.

The IPCC (2001, 2007) has developed a range of possible future GHG emission scenarios based on assumptions of fossil fuel use, regional political and social conditions, technologies, population, and governance and associated emissions that could result in the future. The range of emissions are generally well represented through the A2 (higher emissions) and B1 (lower emissions) as can be seen in the Figure 15 below. It should be noted however that the current CO_2 trajectory has been more closely following the A1Fi scenario.



Source: IPCC 2007

Figure 15. IPCC SRES emission scenarios storylines and future global greenhouse gas emissions.

Since it is not practical to simulate the watershed scale effects and system response for all the potential future scenarios, the question of how to select representative climate change scenarios from the vast array of GCM projections is significant. We have identified four potential approaches for use in the BDCP. These are described below:

1. <u>Bracket and "Median" Approach</u>. This approach is similar to what has been utilized for the 2008 OCAP. The approach treats all future projections as equally plausible and selects scenarios that best reflect the *range* of projected temperature and precipitation changes. For example, the 2008 OCAP identified individual projections that best represented the 10th and 90th percentile joint change in temperature and precipitation (Figure 16). This bracketing leads to the selection of four scenarios. Selection of a "median" scenario can be similarly made for the 50th percentile change. This latter approach adds a fifth scenario and is consistent with what is being considered for the San Joaquin River Restoration Program.

    <u>Pros:</u> The benefit of such an approach is that it utilizes the full range of projection uncertainty and does not prejudge particular scenarios or GCMs. The inclusion of a "median" scenario adds a central tendency estimate.

    <u>Cons:</u> The main drawbacks from such an approach is that the bracketing utilizes a single projection to represent each bracketing range, the brackets may be sampling outliers from the projection range, and that the portion of the uncertainty range that

is sampled based on the position of the selected scenario may shift depending on location and climatological period.

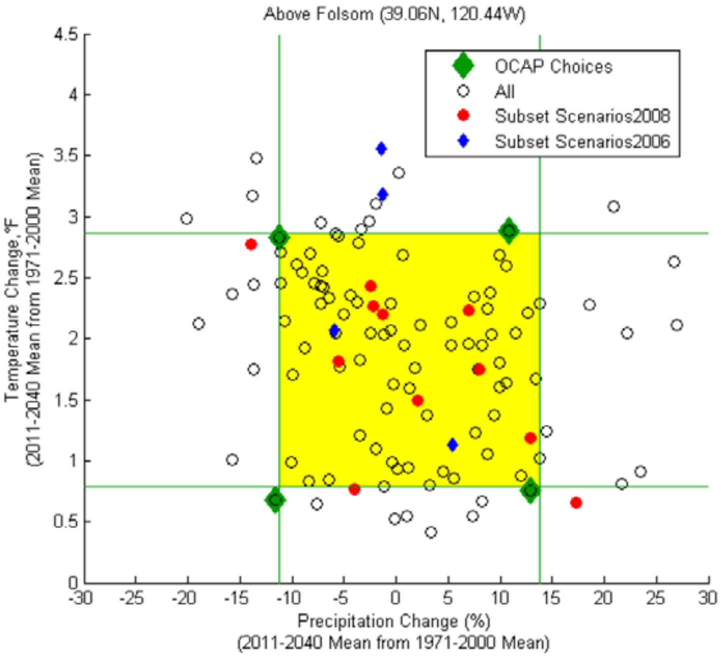


Figure 16. Example "bracket" approach utilized in 2008 OCAP sensitivity analysis.

2. Historical Performance Approach. This approach is similar to what was utilized by the California Climate Action Team (2009). The approach makes use of the historical skill of the GCMs in creating a smaller subset of projections for consideration. The smaller subset of projections can then be analyzed in more detail. The CAT 2009 assessment created a subset of six GCMs and two emission scenarios (total of 12 scenarios) for this purpose. The selection of the six GCMs was made on the basis of particular output availability (i.e. daily or sub-daily) and upon consideration of certain aspects of their historical performance. However, no documentation of the skill assessment has been developed.

   Pros: The benefit of such an approach is that it provides some greater scrutiny of the GCMs in relation to regional performance in simulating historical climate.

   Cons: The main drawback from such an approach is that the range of uncertainty as represented from the selected subset will not represent the range of uncertainty from the full set of projections. This is apparent in the CAT 2009 assessments in which the 12 scenarios are considerably drier than the full projection range. It is also not strongly founded that historical skill is reflective of future climate change performance (Pierce et al 2009, Brekke et al 2008).

3. Multi-Model Ensemble-Informed Approach. A major drawback of the use of any single particular climate projection, or small group of projections, is the issue of multi-decadal variability (or internal model climate variability) that exists in the GCM simulations. For example, a climate projection that may represent the 90th percentile change for one 30-year climatological period may represent a very different percentile change when shifted slightly to another 30-year climatological period (Figure 17b). Similarly, the scenario may represent a 90th percentile at one location in the watershed, but may be closer to the median scenario at another location. That is, the selection of any particular scenario may be biased by the climatological period and locations chosen for the assessments. Recent studies at both global and regional scales have demonstrated the superiority of the multi-model ensemble over the use of a single climate model for characterizing mean climate and climate variability (Pierce et al 2009, Gleckler et al 2008).

   When analyzing the results from multiple models, the multi-decadal variability bias is reduced, largely due to offsetting effect of sampling multiple realizations (Pierce et al 2009). The multi-model ensemble-informed approach makes use of the full range of temperature and precipitation change uncertainty derived from all available projections. Using a similar approach, sub-ensembles can be developed to preference certain climate change trends within the full ensemble (i.e. more warming, drier). The resulting scenarios more closely reflect the median of the sampled projections than the selection of any individual projection. This approach is more fully described in the following section.

   Pros: The benefit of such an approach is that it creates a scenario that is more closely reflective of the ensemble or sub-ensemble median, which is often the goal of ensemble-based methods. Multi-decadal variability bias and spatial inconsistencies of individual projections are largely resolved through the use of ensemble-projections.

   Cons: The main drawback from such an approach is that it collapses the uncertainty of the multiple realizations into one or several representative scenarios. In order to make statements of uncertainty, one would need to refer back to the full projection range.

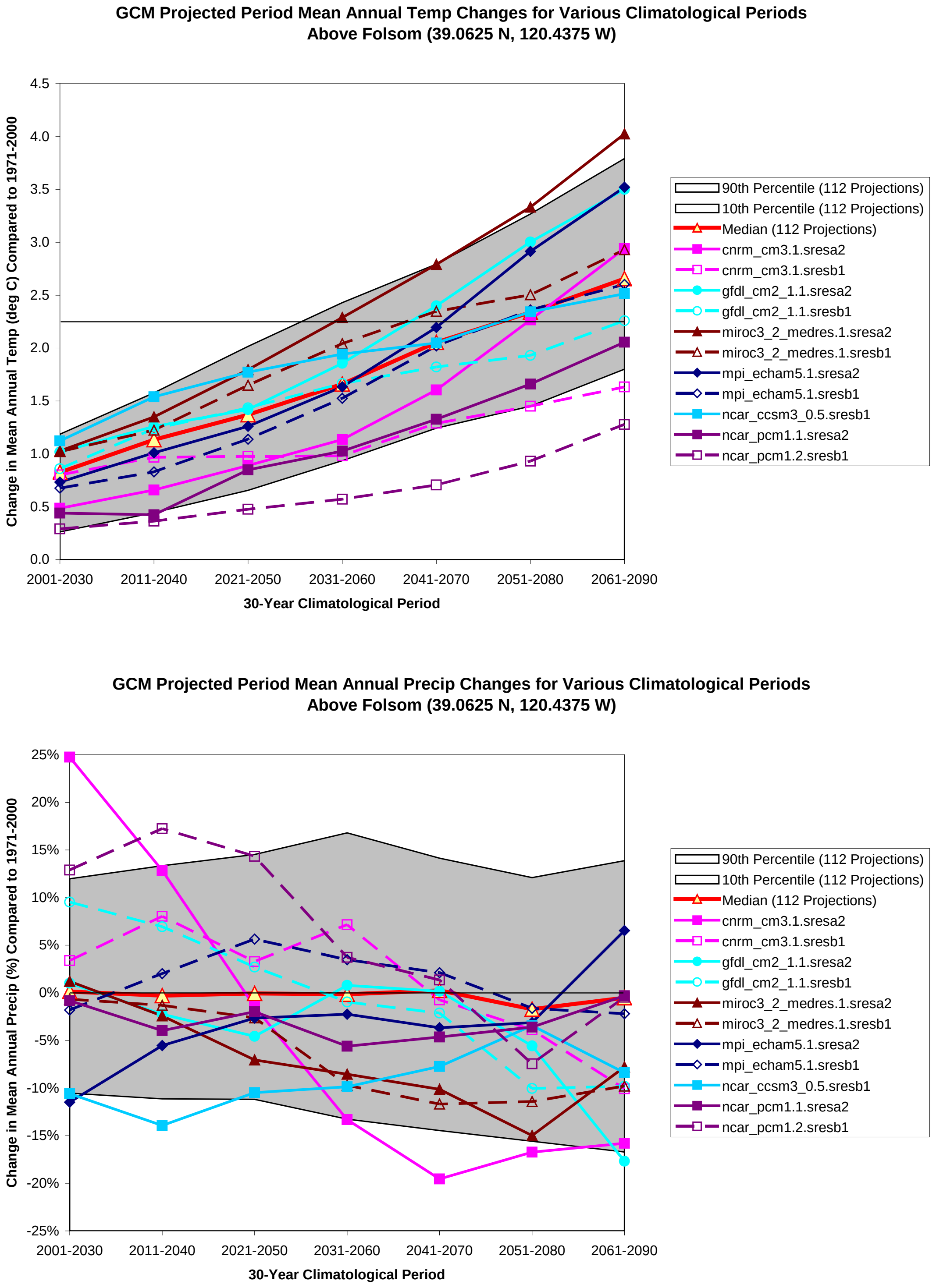


Figure 17. Projected change in mean annual temperature (a) and precipitation (b) for sliding 30-year climatological periods. Gray band indicates the 10th and 90th percentile of the full multi-model ensemble. Red line represents the ensemble mean. Other lines represent projections selected for the CAT 2008 report.

Selected BDCP Climate Scenarios

A technical subgroup was formed with representatives from DWR, Reclamation, USFWS, and NMFS to review the technical merits of several approaches for incorporating climate change into BDCP analytical processes. The issues of multi-decadal variability in the sampling of any one GCM projection and the superiority of multi-model projections over any one single projection were emphasized by the group members. These and other comments received from the group members led to the recommendation of the following criteria to guide the selection of climate scenarios:

1. Select a limited range of scenarios broad enough to reflect the uncertainty with GCM projections and emission scenarios but limited enough to facilitate quantitative analysis of potential projects and alternatives;
2. Select scenarios that reduce the "noise" inherent with any particular GCM projection due to multi-decadal variability that often does not preserve relative rank for different locations and time periods;
3. Select an approach that incorporates both the mean climate change trend and changes in variability; and
4. Select time periods that are consistent with the major phases used in BDCP planning.

The selected approach for development of climate scenarios for the BDCP incorporates three fundamental elements. First, it relies on sampling of the ensemble of GCM projections rather than one single realization or a handful of individual realizations. Second, it includes scenarios that both represent the range of projections as well as the central tendency of the projections. Third, it applies a method that incorporates both changes to the mean climate as well as to the variability in climate. These elements are described further in the sections below.

Downscaled Climate Projections

A total of 112 future climate projections used in the IPCC AR4, subsequently bias-corrected and statistically downscaled (BCSD), were obtained from Lawrence Livermore National Laboratory (LLNL) under the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3). This archive of contains climate projections generated from 16 different GCMs developed by national climate centers (Table 2) and for SRES emission scenarios A2, A1b, and B1. Many of the GCMs were simulated multiple times for the same emission scenario due to differences in starting climate system state, thus the number of available projections is greater than simply the product of GCMs and emission scenarios. These projections have been bias corrected and spatially downscaled to 1/8th degree (~12km) resolution over the contiguous United States through methods described in detail in Wood et al. 2002, Wood et al. 2004, and Maurer 2007.

TABLE 2
General Circulation Models used in the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) Database

Modeling Group, Country	WCRP CMIP3 I.D.
Bjerknes Centre for Climate Research	BCCR-BCM2.0
Canadian Centre for Climate Modeling & Analysis	CGCM3.1 (T47)
Meteo-France / Centre National de Recherches Meteorologiques, France	CNRM-CM3
CSIRO Atmospheric Research, Australia	CSIRO-Mk3.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.0
US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies, USA	GISS-ER
Institute for Numerical Mathematics, Russia	INM-CM3.0
Institut Pierre Simon Laplace, France	IPSL-CM4
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)
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA	ECHO-G
Max Planck Institute for Meteorology, Germany	ECHAM5/ MPI-OM
Meteorological Research Institute, Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research, USA	CCSM3
National Center for Atmospheric Research, USA	PCM
Hadley Centre for Climate Prediction and Research / Met Office, UK	UKMO-HadCM3

Climate Periods

Climate change is commonly measured over a 30-year period. Changes in temperature and precipitation for any particular scenario are compared to a historical period. The historical period of 1971-2000 is selected as the reference climate since it is the currently established climate normal used by NOAA and represents the most recent time period. Corresponding to the long-term timelines of the BDCP analysis, in which climate change is likely to be relevant, future climate periods are identified as approximately 2025 (2011-2040) [early long-term] and 2060 (2046-2075) [late long-term]. The difference in mean annual temperature and precipitation among the two future periods and historic period were identified as the climate change metric.

Multi-Model Ensemble and Sub-Ensembles

The recommended approach makes use of all 112 downscaled climate projections of future climate change described in the previous section. The group of multi-model, multi-emission scenario projections is termed the ensemble. Individual model-emission scenario projections are termed "members" of the ensemble. It is often useful to characterize climate change projections in terms of the simulated change in annual temperature and precipitation compared to an historical reference period. At any selected 30-yr future climatological period, each projection represents one point of change amongst the others. This is graphically depicted in Figure 18 for a region in Feather River watershed.

Since the ensemble is made up of many projections, it is useful to identify the median (50th percentile) change of both annual temperature and annual precipitation (dashed blue lines). In doing so, the state of climate change at this point in time can be broken into quadrants representing (1) drier, less warming, (2) drier, more warming, (3) wetter, more warming, and (4) wetter, less warming than the ensemble median. These quadrants are labeled Q1-Q4 in Figure 18. In addition, a fifth region (Q5) can be described that samples from inner-quartiles (25th to 75th percentile) of the ensemble and represents a central region of climate change. In each of the five regions the sub-ensemble of climate change projections, made up of those contained within the region bounds, is identified. The Q5 scenario is derived from the central tending climate projections and thus favors the consensus of the ensemble.

Through extensive coordination with the State and Federal teams involved in the BDCP, the bounding scenarios Q1-Q4 were refined in April 2010 to reduce the attenuation of climate projection variability that comes about through the use of larger ensembles. A sensitivity analysis was prepared for the bounding scenarios (Q1-Q4) using sub-ensembles made up of different numbers of downscaled climate projections. The sensitivity analysis was prepared using a "nearest neighbor" (k-NN) approach. In this approach, a certain joint projection probability is selected based on the annual temperature change-precipitation change (i.e. 90th percentile of temperature and 90th percentile of precipitation change). From this statistical point, the "k" nearest neighbors (after normalizing temperature and precipitation changes) of projections are selected and climate change statistics are derived. Consistent with the approach applied in OCAP, the 90th and 10th percentile of annual temperature and precipitation change were selected as the bounding points. The sensitivity analysis considered using the 1-NN (single projection), 5-NN (5 projections), and 10-NN (10 projections) sub-ensemble of projections. These were compared to the original quadrant scenarios which commonly are made up of 25-35 projections and are based on the direction of change from 50th percentile statistic.

The very small ensemble sample sizes exhibited month by month changes that were sometimes dramatically different than that produced by adding a few more projections to the ensemble. The 1-NN approach was found to be inferior to all other methods for this reason. The original quadrant method produced a consensus direction of change of the projections, and thus produced seasonal trends that were more realistic, but exhibited a slightly smaller range due to the inclusion of several central tending projections. The 5-NN and 10-NN methods exhibited slightly wider range of variability than the quadrant method which was desirable from the “bounding” approach. In most cases the 5-NN and 10-NN projections were similar, although they differed at some locations in representation of season trend. The 10-NN approach (Figure 18) was found to be preferable in that it best represented the seasonal trends of larger ensembles, retained much of the “range” of the smaller ensembles, and was guaranteed to include projections from at least two GCM-emission scenario combinations (in the CMIP3 projection archive, up to 5 projections – multiple simulations – could come from one GCM-emission scenario combination). The State and Federal representatives agreed to utilize the following climate scenario selection process for BDCP:

(1) the use of the original quadrant approach for Q5 as it provides the best estimate of the consensus of climate projections and
(2) the use of the 10-NN method to developing the Q1-Q4 bounding scenarios.

An automated process has been developed that generates the monthly and annual statistics for every grid cell within the Central Valley domain and identifies the members of the sub-ensemble for consideration in each of the five scenarios.

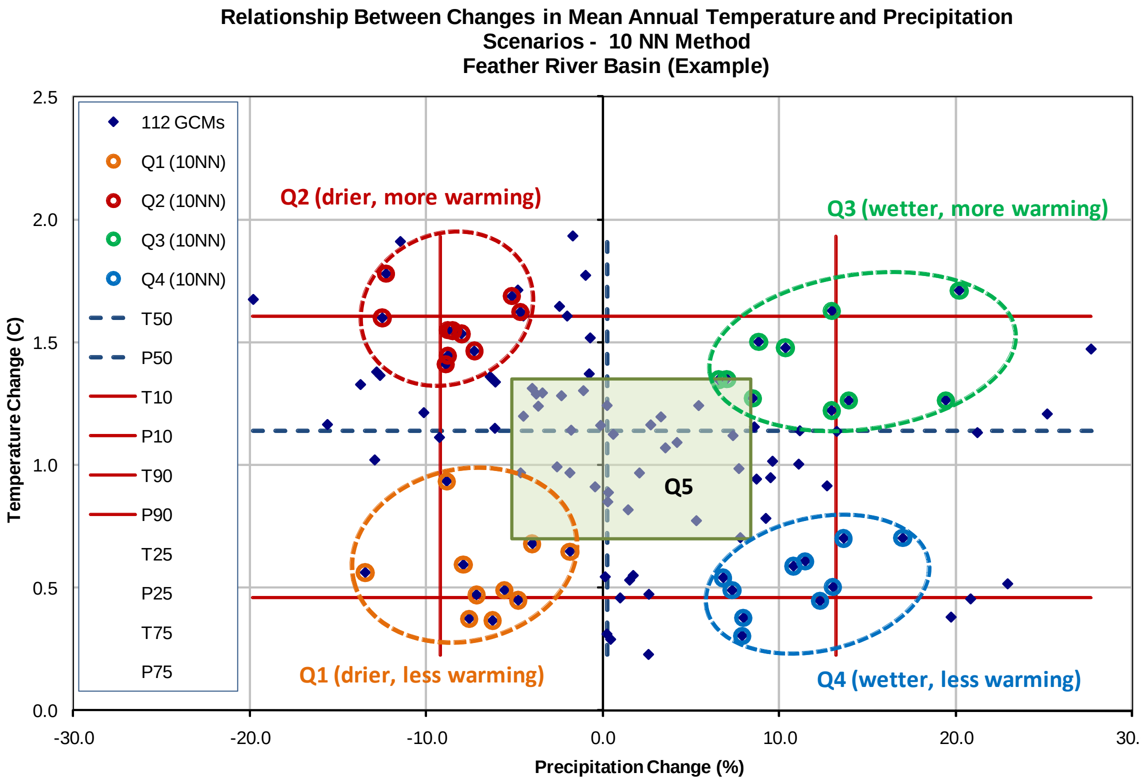


Figure 18. Example downscaled climate projections and sub-ensembles used for deriving climate scenarios (Q1-Q5), Feather River Basin at 2025. The Q5 scenario is bounded by the 25th and 75th percentile joint temperature-precipitation change. Scenarios Q1-Q4 are selected to reflect the results of the 10 projections nearest each of 10th and 90th joint temperature-

precipitation change bounds. Note: the temperature and precipitation changes are normalized before determining the nearest neighbors.

Incorporating Changes in Mean Climate and Climate Variability

Climate is usually defined as the "average" condition of weather over a period of time. More rigorously, climate can be defined as the "statistical description" in terms of mean and variability of the relevant quantities over a period of time ranging from months to millions of years (IPCC TAR). The standard averaging period defined by the World Meteorological Organization (WMO) is 30 years. The parameters that are most often associated with the description of climate state are temperature, precipitation, and wind speed. Thus, climate change refers to a shift in the statistical properties of climate variables over extended periods of time.

One difficulty that arises in implementing climate change into long-term water resources planning is that the natural variability is often greater than the magnitude of change expected over several decades. In many water resource management areas, it is the extreme events (droughts and floods) that drive the decision-making and long-range planning efforts. Thus, there is a need to combine the climate change signal with the range of natural variability observed in the historical record.

In many current climate change analyses, only the mean state of climate change is analyzed through the use of the "delta" method. In this method, temperature and/or precipitation are adjusted by the mean shift from one future 30-year period to a historical 30-year period. However, climate change is unlikely to manifest itself in a uniform change in values. In fact, the climate projections indicate that the changes are nonlinear and shifts in the probability distributions are likely, not just the mean values. In other analyses, a transient 30-year depiction of climate is used and compared against a similar 30-year historical period. Hydrologic analyses are performed and summarized as the "mean" change between the future and base periods. This latter approach is roughly what has been applied in the OCAP and CAT processes. The difficulty with this approach is that the natural observed variability may be large and not fully present in the 30-year period, resulting in truncated variability. Also, because the sequence of variability is different under each period it is difficult to make comparisons between the resulting hydrologic variables beyond the mean response.

In order to incorporate both the climate change signal and the natural variability in the longer-term observed record, the recommended approach is to create an expanded time series which allows use of the long-term observed records. The approach is similar to that applied by the Climate Impacts Group for development of hydrologic scenarios for water planning in the Pacific Northwest (Wood et al 2002, Salathe et al 2007, Hamlet et al 2009), applied in the Lower Colorado River, Texas studies (CH2M HILL 2008), and recent Reclamation planning (Reclamation 2010). The approach uses a technique called "quantile mapping" which maps the statistical properties of climate variables from one data subset with the time series of events from a different subset. In this fashion, the approach allows the use of a shorter period to define the climate state, yet maintains the variability of the longer historic record. The quantile mapping approach involves the following steps:

1. Extract a 30-year slice of downscaled climate projections based on the ensemble subset for the quadrant of interest and centered on the year of investigation (i.e. 2025 or 2060)
2. For each calendar month (i.e. January) of the future period, determine the statistical properties (cumulative distribution function, CDF) of temperature and precipitation at each grid cell
3. For each calendar month of the historical period (1971-2000 in our case), determine the statistical properties (CDFs) of temperature and precipitation at each grid cell
4. Develop quantile maps between the historic observed CDFs and the future downscaled climate CDFs, such that the entire probability distribution (including means, variance, skew, etc) at the monthly scale is transformed to reflect the climate scenario
5. Using the quantile maps, redevelop a monthly time series of temperature and precipitation over the observed period (1915 -2003) that incorporates the climate shift of the future period
6. Convert monthly time series to a daily time series by scaling monthly values to daily sequence found in the observed record

The result of the quantile mapping approach is a daily time series of temperature and precipitation that has the range of variability observed in the historic record, but also contains the shift in climate properties (both mean and expanded variability) found in the downscaled climate projection. Figure 19 provides an example of this process a grid cell in the Feather River watershed. As shown in these figure, the precipitation change quantities are not expected to shift uniformly across all percentiles. For example, in this wetting climate scenario, the median (50th percentile) January precipitation is projected to exhibit almost no change from baseline conditions. However, for large precipitation events (i.e. the 90th percentile) January precipitation is projected to increase by almost 2 mm/day (more than 2 inches/month). That is, the climate shift is larger at higher precipitation events and lower at low precipitation events. While this may be different for each climate scenario, future period, spatial location, and month, the need to map the full range of statistic climate shift is important to characterize the projected effects of climate change.

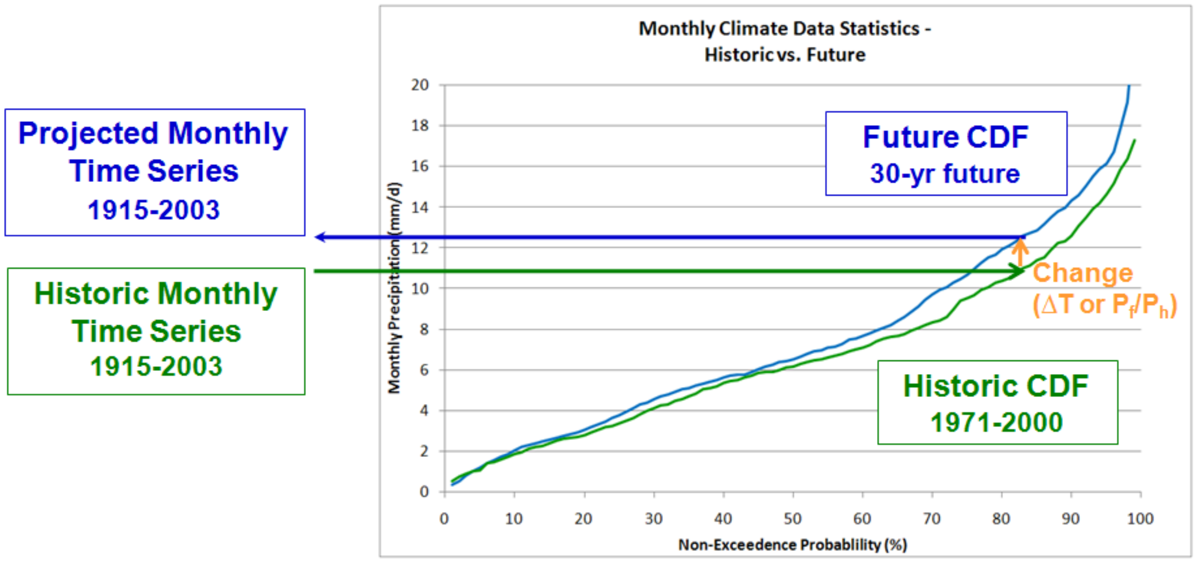


FIGURE 19,
Historical Monthly Precipitation Statistics for a Grid Cell in Feather River Basin (January - EXAMPLE ONLY)

Sea Level Rise Scenarios

In early 2007, the IPCC released their latest assessment of the scientific assessment for projections of future climate. Included in the IPCC AR4 were revised estimates of global mean sea level rise. The IPCC estimates are based on physical models that attempt to account for thermal expansion of oceans and storage changes associated with melt of land-based ice and snowfields (Healy 2007). Since their release, the IPCC AR4 sea level rise estimates have been widely criticized for their failure to include dynamic instability in the ice sheets of Greenland and Antarctica, and for their under-prediction of recent observed increases in sea level.

Due to the limitations with the current state of physical models for assessing future sea level rise, several scientific groups, including the CALFED Independent Science Board (ISB) (Healy 2007), recommend the use of empirical models for short to medium term planning purposes. Both the CALFED ISB and CAT 2009 assessments have utilized the empirical approach developed by Ramsdorf (2007) that projects future sea level rise rates based on the degree of global warming. This method better reproduces historical sea levels and generally produces larger estimates of sea level rise than those indicated by the IPCC (2007). When evaluating all projections of global air temperature, Ramsdorf projects a mid-range sea level rise of 70 – 100 cm (28 – 40 inches) by the end of the century, and when factoring the full range of uncertainty the projected rise is 50 - 140 cm (20 – 55 inches). The CAT scenarios utilized an identical empirical approach, but limited the sea level rise estimates to the degree of warming range from 12 GCM projections selected for that study.

Using the work conducted by Ramsdorf, the projected sea level rise at the early long-term timeline for the BDCP analysis (2025) is approximately 12 - 18 cm (5 - 7 inches). At the late long-term timeline (2060), the projected sea level rise is approximately 30 – 60 cm (12 – 24 inches). These sea level rise estimates are also consistent with those outlined in the recent

USACE guidance circular for incorporating sea-level changes in civil works programs (USACE 2009). Due to the considerable uncertainty in these projections and the state of sea level rise science, it is proposed to use the mid-range of the estimates for each BDCP timeline: 15 cm (6 inches) by 2025 and 45 cm (18 inches) by 2060. In addition, sensitivity scenarios will be prepared to consider sea level rise of up to 60 cm by 2060.

Changes in Tidal Amplitude

As discussed previously, mean sea level has been increasing across the globe and is exhibited on all U.S. coasts and almost all long-term stations. Tidal amplitude appears to be increasing, particulary in the eastern Pacific but the trend is not consistent for all stations on the West Coast. Tidal amplitude can be significantly affected by physical changes in coasts, harbors, bays, and estuaries. At long-term open-ocean stations along the California coast (La Jolla, Los Angeles, San Francisco, and Crescent City), which are less influenced by the physical changes, Flick et al. (2003) found a statistically significant increase in tidal amplitude (MHHW - MLLW), except at Crescent City which showed a slight decreasing trend. At San Francisco, the trend in tidal amplitude was found to be around 3-5% increase per century. Jay (2009) recently completed research into changes in tidal constituents, using long-term stations. Results indicated that on average tidal amplitude along the West Coast increased by about 2.2% per century. San Francisco indicated higher increases, while some stations (Alaska/Canada) were relatively constant. Jay hypothesized that global sea level rise may be influencing the location of the amphidrominc points (locations in the ocean where there are no tides) and thus affecting tidal range. However, Jay notes that it remains unclear whether rapid evolution of tidal amplitudes can be described as a symptom of global climate change.

Inland stations such Alameda and Port Chicago showed larger increases in tidal amplitudes than open ocean stations (9% and 26%, respectively). These inland stations have both short records and may be influenced by physical changes in the Bay. The importance of long-term tide records and open-ocean stations is stressed by both Flick et al and Jay for identifying trends in tidal amplitude due to the 18.6-year periodicity and influence of physical changes. Flick et al discounts the use of these inland stations for trends in tidal amplitude. In addition, Flick et al found that other nearby stations exhibited a decreased tidal amplitude trend (Point Reyes at -12% per century and Monterey at -14% per century).

Due to the considerable uncertainty associated with the tidal amplitude increase and the evolving science relating these changes to climate change and mean sea level rise, it is recommended to include a sensitivity analysis of increased tidal amplitude. The recommendation is to evaluate the effect of an amplitude increase of 5% per century, relying on the published observed trends of Flick et al and Jay and assuming that they would continue in the future. We do not propose using the inland stations trends, adhering to guidance from Flick et al. Thus, it is proposed to include one sensitivity simulation with the UNTRIM model, which incorporates an open-ocean tidal boundary, with increased tidal amplitude of 5% per century to contribute to understanding of the relative effect of amplitude increase in comparison to mean sea level increase.

Understanding Risks due to Levee Failure and Extreme Sea Level Rise

The discussion in the preceding sections relating to sea level rise and tidal amplitude scenarios are based the analyses to be performed to support the HCP and EIR/S processes. ***It is important to distinguish these sea level rise assumptions that are proposed for supporting the environmental analysis from those that may be used for design of critical facilities or infrastructure***. Under the Proposed Project, large-scale tidal marsh restoration is proposed for various areas of the delta with a strong emphasis on areas in the Suisun Marsh and Cache Slough regions. In addition, as the key to water operations, the Proposed Project includes the development and operation of five intakes to be located on the Sacramento River in the vicinity of Hood. The risks to these BDCP investments under large-scale levee failure and sea level rise will be assessed.

Potential delta levee failure scenarios due to seismicity have been developed as part of the Delta Risk Management Study (DRMS). DWR has recommended two levee failure scenarios for analysis. For the purposes of the BDCP planning for the HCP and associated permit, sea level rise was considered for the period extending to the year 2060 (50-year permit). However, for the evaluation of investment risk it is necessary to consider that the infrastructure (restoration and intakes) will function for much longer than the permit. For this reason, it is recommended that a long-term extreme sea level rise estimate for the year 2100 be used in this risk assessment. A sea level rise of 1.4 meters will be considered and combined with increases in tidal amplitude.

Hydrodynamic and water quality modeling will be developed for both large-scale levee failure and sea level rise. Two modeling scenarios will be developed for levee failure, two for sea level rise, and two for the combination of levee failure and sea level rise. Modeling will consist of the breach event, followed by two year simulations to address the changes in hydrodynamics and salt transport. Results will be analyzed with respect to tidal stage, flows, velocities, as well as salinity distribution changes in the delta. Simplifying assumptions will need to be developed to address these scenarios, particularly for bathymetry above top of levees and model grid, and these will be documented. A brief technical write-up will be prepared addressing the assumptions, methodology, results, and analysis. These results will be presented to the BDCP and DHCCP technical and policy teams for consideration in the planning and design efforts.

Analytical Process for Incorporating Climate Change

The analytical process for incorporation of climate change effects in BDCP planning includes the use of several sequenced analytical tools (Figure 20). The GCM downscaled climate projections (DCP), developed through the process described above, are used to create modified temperature and precipitation inputs for the Variable Infiltration Capacity (VIC) hydrology model. The VIC model simulates hydrologic processes on the 1/8th degree scale to produce watershed runoff (and other hydrologic variables) for the major rivers and streams in the Central Valley. The changes in reservoir inflows and downstream accretions/depletions are translated into modified input time series for the CALSIM II model. The CALSIM II simulates the response of the river-reservoir-conveyance system to the climate change derived hydrologic patterns. The CALSIM II model, in turn, provides monthly flows for all major inflow sources to the delta, as well as the delta exports, for input to the DSM2 hydrodynamic model. DSM2 also incorporates the assumptions of sea level rise for an integrated assessment of climate change effects on the estuary.

At each long-term BDCP analysis timeline (Early Long-Term: 2025 and Late Long-Term: 2060), five regional climate change projections will be considered for the 30-year climatological period centered on the analysis year (i.e. 2011-2040 to represent 2025 timeline). DSM2 model simulations will be developed for each habitat condition and sea level rise scenario that is coincident with the BDCP timeline. New Artificial Neural Networks (ANNs) will be developed based on the flow-salinity response simulated by the DSM2 model. These sea level rise-habitat ANNs will be verified and subsequently included in CALSIM II models. The CALSIM II model will then be simulated with each of the five climate change hydrologic conditions in addition to the historical hydrologic conditions.

The CALSIM II simulations will be developed for all alternatives and Future No Project/No Action alternatives. These CALSIM II simulations will provide estimates of the change in operations, upstream storage and river flow conditions, and delta facility and export operations associated with future climate change. DSM2 hydrodynamic and EC simulations will be developed for the Future No Project/No Action, with distinct simulations for each climate change-sea level rise scenario. These DSM2 simulations will provide information related to delta system performance under changes to inflows (pattern and magnitudes), exports, and sea levels. A sensitivity analysis of the delta flow and salinity changes will be performed to determine the relative change associated with hydrology/exports as compared to sea level rise components of climate change. If it is determined that the climate changes to hydrology between the five regional scenarios are significantly less significant to delta conditions than the sea level rise assumption, then only one hydrology scenario will be carried forward to the DSM2 modeling of the alternatives. However, CALSIM II modeling will be performed for all hydrologic scenarios. Table 2 below indicates the model simulations that will be prepared for each climate change assumption.

Model simulation results will be available for biological and other resources teams for scenarios without climate change, for mid-range climate change (Q5), and for bracketing scenarios (Q1-Q4). In general the climate change modeling results will be indicated by the trend of the mid-range climate change scenario with the uncertainty range described by the bracketing scenarios. In this fashion, the impact teams can incorporate differences in impacts of the Proposed Project or Alternatives under a range of future climate assumptions.

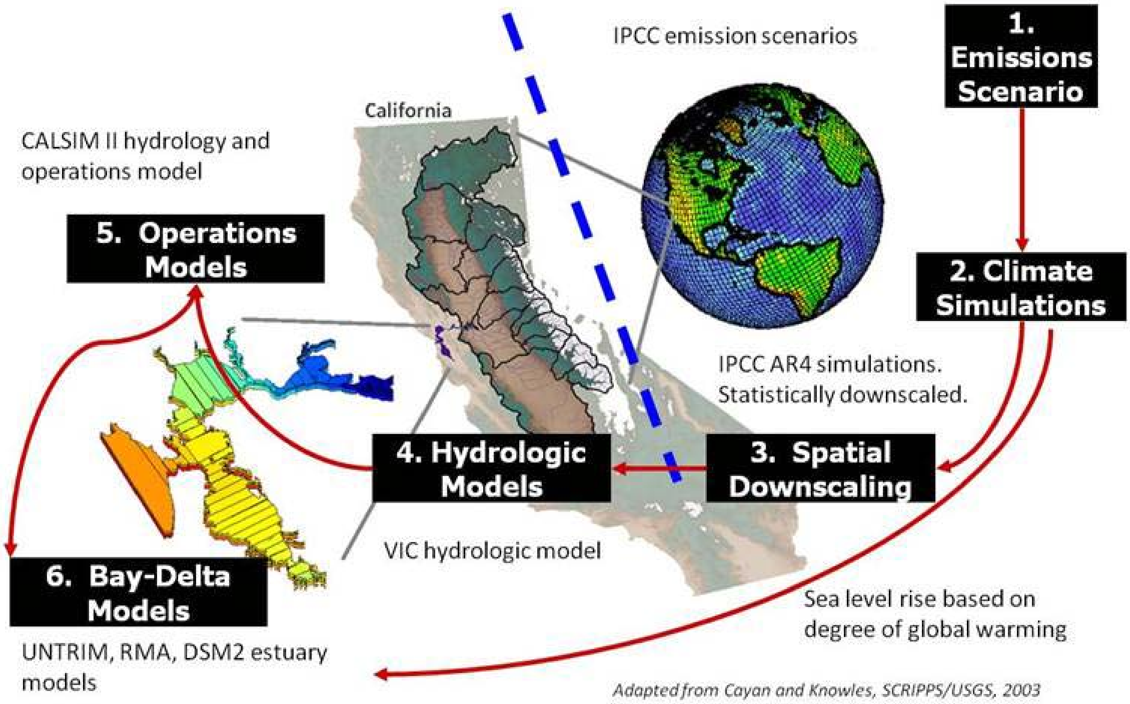


Figure 20. Graphical depiction of the analytical process for incorporating climate change into water planning.

Table 2. Recommended Analytical Tools and Timelines for Consideration of Climate Change Implications

		Uncertainty in Regional Climate Change: Scenarios (Quadrant Approach)					
	SLR (cm)	**No Climate Change**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5 (central)**
Uncertainty in Sea Level Rise	**0**	🟨 NT, ELT, LLT	S	S	S	S	S
	15 (central)	S	🟧 ELT	🟧 ELT	🟧 ELT	🟧 ELT	🟨 ELT
	30	S	▨	▨	▨	▨	▨
	45 (central)	S	🟧 LLT	🟧 LLT	🟧 LLT	🟧 LLT	🟨 LLT
	60	S	▨	▨	▨	▨	▨
	140	S	▨	▨	▨	▨	▨
	140 + 5% amplitude increase	S	▨	▨	▨	▨	▨

NT = Near-Term; ELT = Early Long-Term; LLT = Late Long-Term; S = Sensitivity analysis; FNA = Future No Action

🟨	CALSIM II & DSM2 (FNA + Alternatives)	🟧	CALSIM only (FNA + Alternatives bracketing analysis)	S	Sensitivity Analysis (FNA only)	▨	No modeling

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D.3. Climate Change Modeling

The information included in this section provides an understanding of the simulated changes in climate, hydrology, and operations under the five climate change scenarios selected for BDCP. The scenario selection process and the approach to incorporate climate change effects in the BDCP analyses are described in the previous section. This section also identifies specific CALSIM II inputs modified to incorporate climate change effects and summarizes the limitations in capturing the climate change effects in the BDCP analyses. This section is a compilation of various technical memoranda previously documented to describe the above listed information.

D.3.1. Climate Change Scenarios Results

This section summarizes the projected changes in the temperature and precipitation under each climate change scenario selected for the BDCP, in comparison with the observed climate conditions.

TECHNICAL MEMORANDUM

CLIMATE CHANGE SCENARIOS RESULTS

PREPARED FOR: SAIC

PREPARED BY: CH2M HILL

DATE: January, 2011

Study Objectives

The projected effects of climate and sea level change are incorporated into scenarios and the analysis for the BDCP. The use of scenarios, as described in the methodology, allows consideration of the uncertainty associated with the projections. This section describes climate change results associated with the scenarios and methods described previously. The effects of these changes on hydrology, operations, delta hydrodynamics, water quality, and other factors are described in sections specific to those analytical efforts.

Observed Climate

The Sacramento and San Joaquin River watersheds contains climate zones ranging from the alpine high sierra to the more Mediterranean climate of the valley floor and is fundamentally influenced by climate variability from seasonal to millennial scales. The water supply of the Central Valley is strongly dependent on snowmelt from high elevation portions of the watersheds. Temperature and precipitation vary considerably by season, location, and elevation as shown in Figure 1-1. Warmest temperatures in the Central Valley are in the San Joaquin and Tulare Basins in summer and coolest in the high elevation of the southern Sierra during the winter. Precipitation in most of California is dominated by extreme variability, both seasonally, annually, and over decade time scales. Precipitation is greatest in the northern Sierra, Cascade range, and north coast, and lowest in the southern San Joaquin Valley and Tulare Basin (Figure 1-1).

The climate of the Central Valley exhibits important spatial and seasonal variability. To illustrate this variability, monthly average temperature and precipitation are shown for representative locations in the Feather River watershed, Delta, and in the Tuolumne River watershed. These locations reflect a north-south climate regimes as well as high-low elevation changes.

As illustrated in Figure 1-2, the average temperature varies by over 15°C seasonally at each of the three locations and by almost 10°C across the locations within seasons. Cool winter temperatures at the higher elevation portions of the Sierra cause a considerable portion of the precipitation to fall in the form of snow. At lower elevations, warmer conditions exist and liquid precipitation is the dominant form. The precipitation occurs primarily in the cool season (fall and winter) and contributes the majority of the annual rainfall. Precipitation is strongly dependent on elevation with valley floor precipitation less than one-third of that at higher elevations. Warmer temperatures in the late spring and summer induce snowmelt at the higher elevations. The summer precipitation tends to be short and intense at high elevations, but does not contribute a significant portion of annual total. Temperatures in the valley floor are high in the summer, although buffered by ocean breezes in regions near the Delta. Daytime high temperatures in excess of 37°C (100°F) are not uncommon in the summer.

The long-term annual statewide temperature and precipitation from 1896 to 2009 are shown in Figure 1-3. A significant increase in temperature is apparent in this figure although periods of cooling have occurred historically. Most importantly is the significant warming trend that has occurred since the 1970s. This warming trend is consistent with trends in both the Sacramento and San Joaquin Valleys, across the southwest, and with observed North America and global trends. Annual precipitation shows substantial variability and periods of dry and wet spells. Most notable in the precipitation record is the lack of a significant long-term annual trend, yet the annual variability appears to be increasing. The three highest annual precipitation years appear in the most recent 30-year record.

Projected Climate Change

Climate projections from over 100 General Circulation Models (GCMs) indicate a strong continued warming throughout California. The climate scenarios used in this study are derived from the full ensemble of projections as described in the Methods section. Figure 1-4 shows the annual temperature and precipitation changes for California derived from the central climate scenario (Q5). The Q5 scenario reflects a composite projection from the individual projections that are most close to the median change, and thus best reflect the "consensus" of projections. Figure 1-4 shows the changes for the period 2011-2040 (2025) and 2046-2075 (2060) as compared to the recent historical climatological period of 1971-2000. The projections indicate substantial warming with a median increase in annual temperature of about 1.1 °C by 2025 and 2.2 °C by 2060. All projections are consistent in the direction of the temperature change, but vary in terms of climate sensitivity. The projected temperature change ranges from 0.7 to 1.4 °C by 2025 and from 1.6 to 2.7 °C by 2060 in the scenarios used in the study for the delta region. Warming is projected to be generally higher the further away from the coast, reflecting a continued ocean cooling influence.

Statewide trends in annual precipitation are not as apparent as those for temperature. Roughly half of the projections at 2025 indicate a wetter future while the other half indicate drier conditions when evaluated statewide. Regional trends, however, indicate that it is more likely for the upper Sacramento Valley to experience equal or greater precipitation, while the San Joaquin Valley is likely to experience drier conditions. These trends toward a north-south transition are more pronounced in the 2060 projections than those at 2025. The changes in annual precipitation are on the order of +/- 5% (increase north, decrease south) annually under the Q5 scenario, but are greater than 10% decreases under the Q2 scenario. The north-south transition of precipitation change is likely due to the more northerly push of storm tracks caused in part by increased sea level pressure blocking systems under climate projections (Cayan et al 2008).

Figure 1-5 through Figure 1-10 summarizes projected seasonal changes in temperature and precipitation for the representative locations in the Feather River watershed, Delta, and Tuolumne River watersheds. The figures show the temperature and precipitation for the Observed (1971-2000) and five climate scenarios (Q1-Q5). Figures 1-5 through 1-7 reflect the projected changes for the 2025 period and Figures 1-8 through 1-10 reflect the changes for the 2060 period. Change in temperature is measured in degrees Celsius, while change in precipitation is measured as a percentage.

For a given season and future time period, projected changes in temperature are relatively consistent across all watersheds, with little variation throughout the basin. By 2025, temperatures are projected to increase at least 1.0°C in nearly all watersheds for all four seasons. Spring and summer show the greatest warming, with seasonal temperatures in most watersheds increasing 2°C to 4°C by 2060 depending on the scenario.

Projected changes in seasonal precipitation vary among watersheds and among seasons. On an annual basis, projected precipitation through 2060 is generally within 5 percent of historical precipitation, with the northern locations exhibiting positive change and the southern locations exhibiting negative change. The most significant change in precipitation occurs in spring, during which all watersheds show a decrease in precipitation for each of the future time periods.

Some general statements can be made to summarize the findings related to climate change:

Warming will continue to increase across the state with largest changes in spring and summer and larger changes further away from the coast. Annual median temperature increases are projected to be approximately 1.1 and 2.3 °C for 2025 and 2060, respectively, with less warming in winter and higher warming in summer. Summertime temperatures may increase by 4°C by 2060.

Precipitation patterns continue to be spatially and temporally complex, but trends toward drying are significant in portions of the state. Precipitation patterns are complex due to influence of oceans, storm tracks, Hadley cell expansion, and orographic considerations. A general trend towards drying is present in the south, although slight increases are projected for the Sacramento Valley. Consistent and expansive drying conditions are projected for the spring. For most of the Central Valley, drying conditions are projected in late spring and summer. Projections demonstrate a bi-modal pattern of precipitation changes between the Sacramento Valley and the San Joaquin and Tulare Basins. The hinge-point of wetter versus drier conditions in the winter moves northward with continued warming through time consistent with an expansion of the Hadley cell and more northerly storm tracks (Seager et al 2010). Areas with increases in annual precipitation are almost exclusively those that experience higher winter precipitation increases over springtime decreases.

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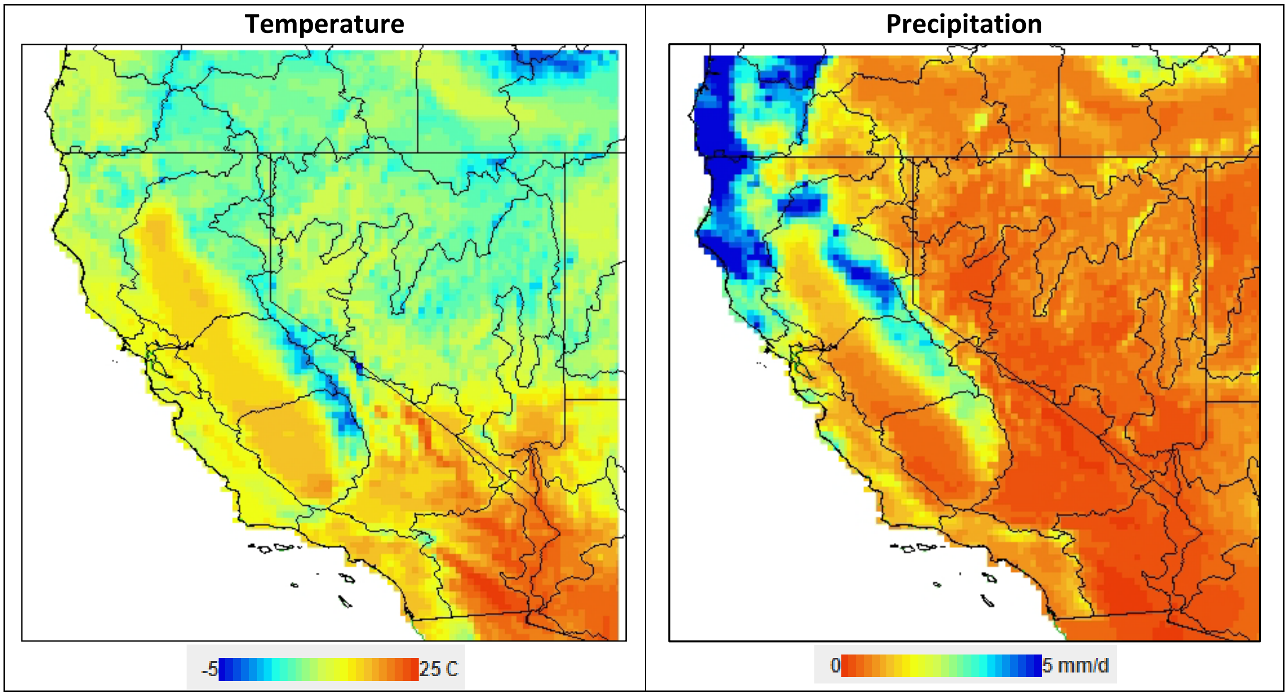
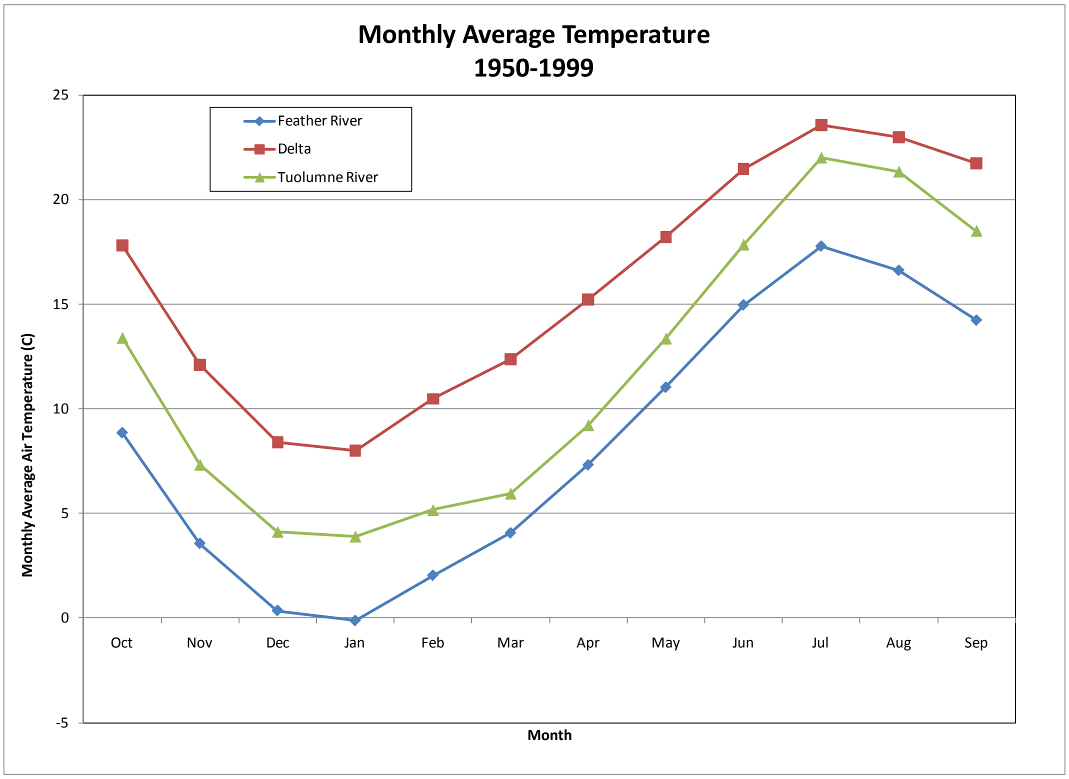


Figure 1-1: Average Annual Temperature (deg C) and Average Annual Precipitation (millimeters/day) for the Period 1950 to 1999 *(Derived from Maurer (2002)*



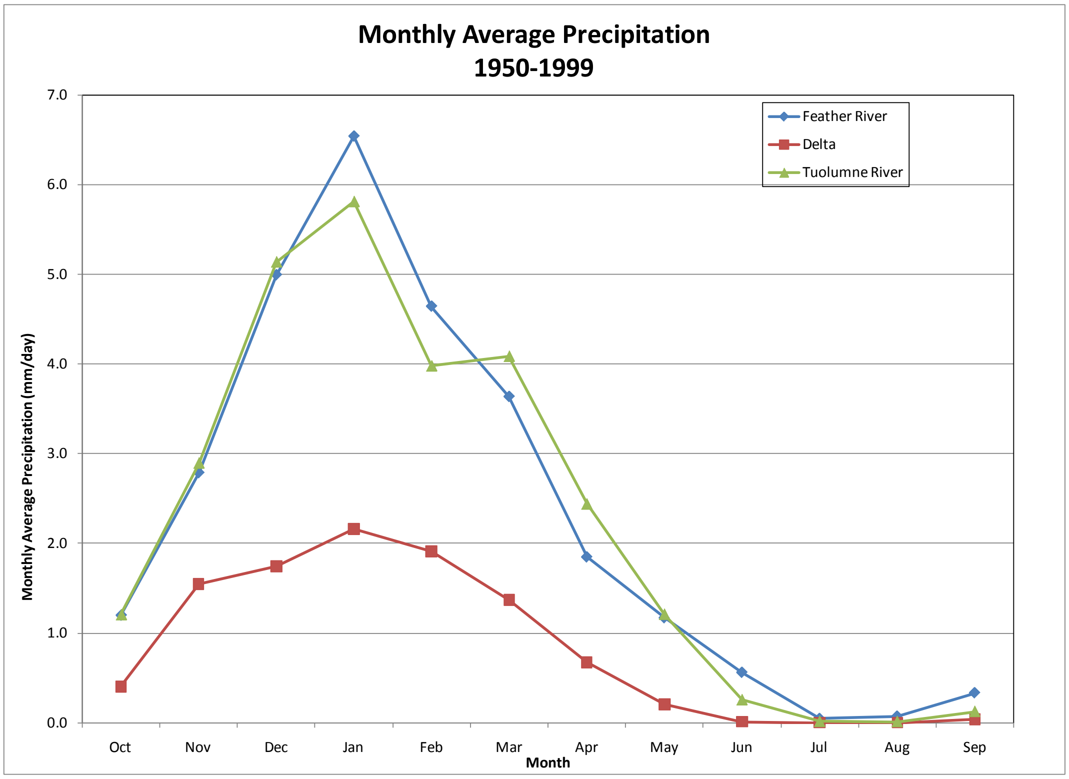
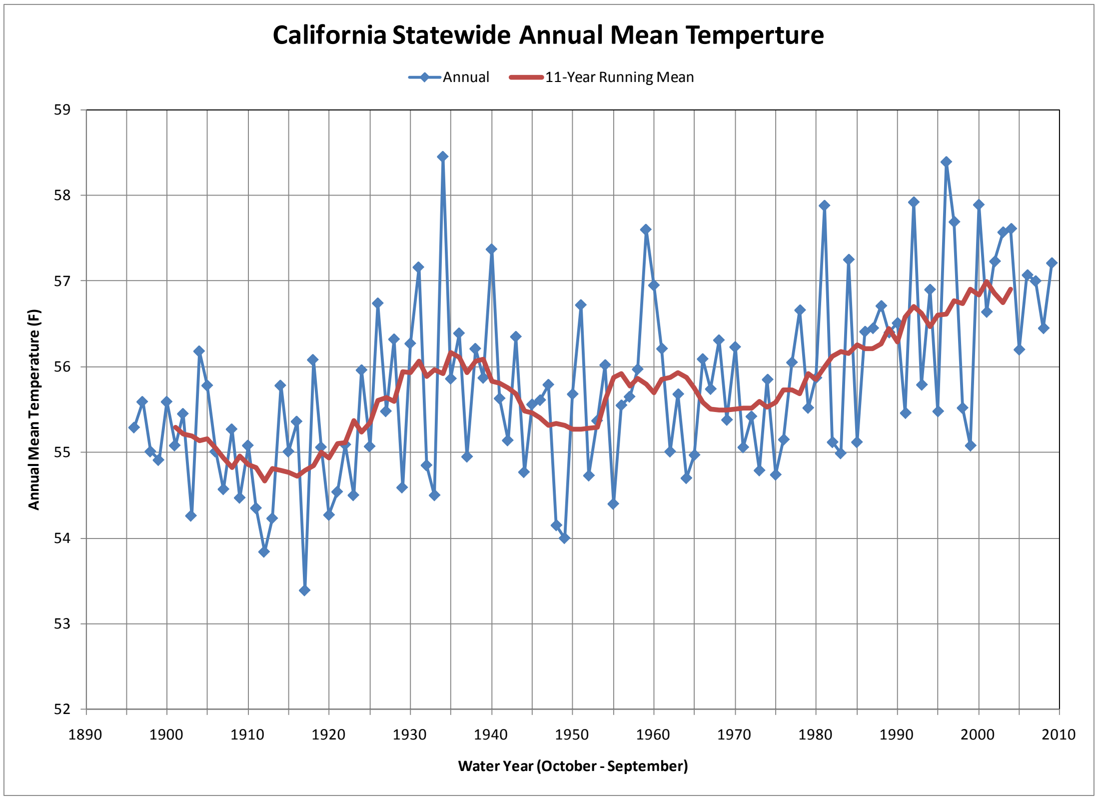


Figure 1-2: Monthly Average Temperature (top) and Precipitation (bottom) for Three Representative Locations in the Central Valley *Derived from Daily Gridded Observed Meteorology (Maurer et al, 2002)*



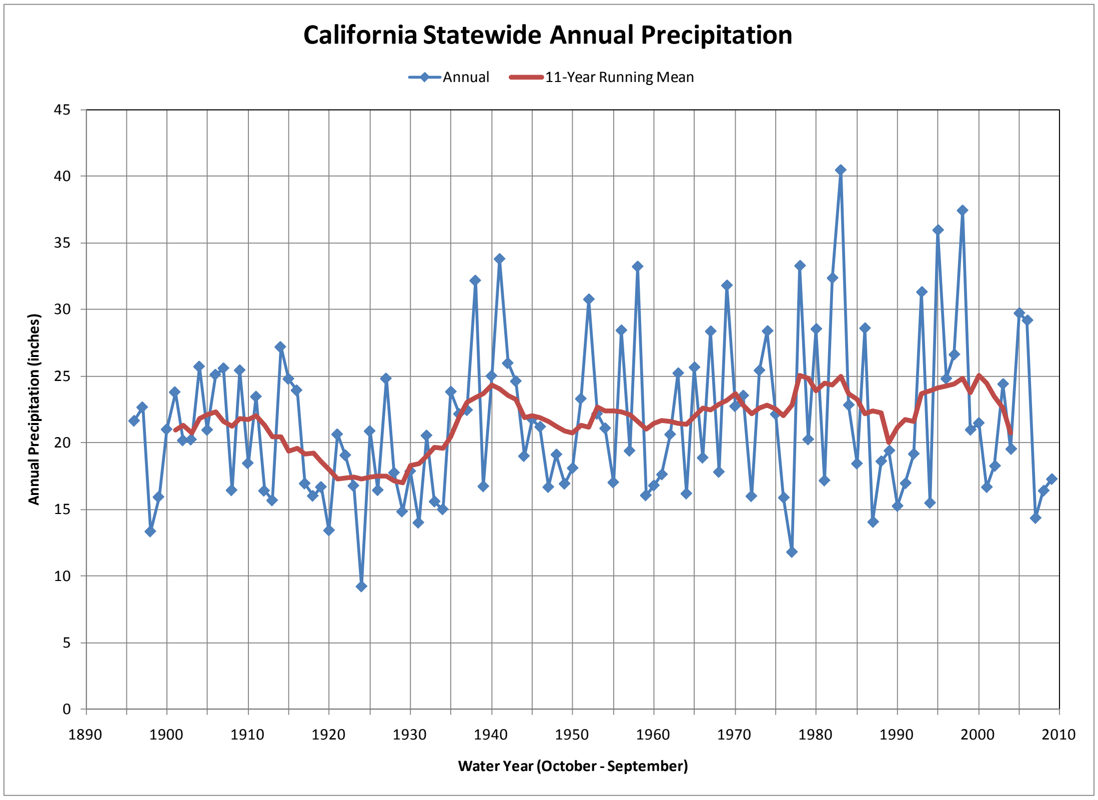


Figure 1-3: (Top) Statewide annual average surface air temperature, 1896-2009 and (Bottom) Annual water year average precipitation (Note: blue: annual values; red: 11-year running mean. Source: Western Regional Climate Center 2011)

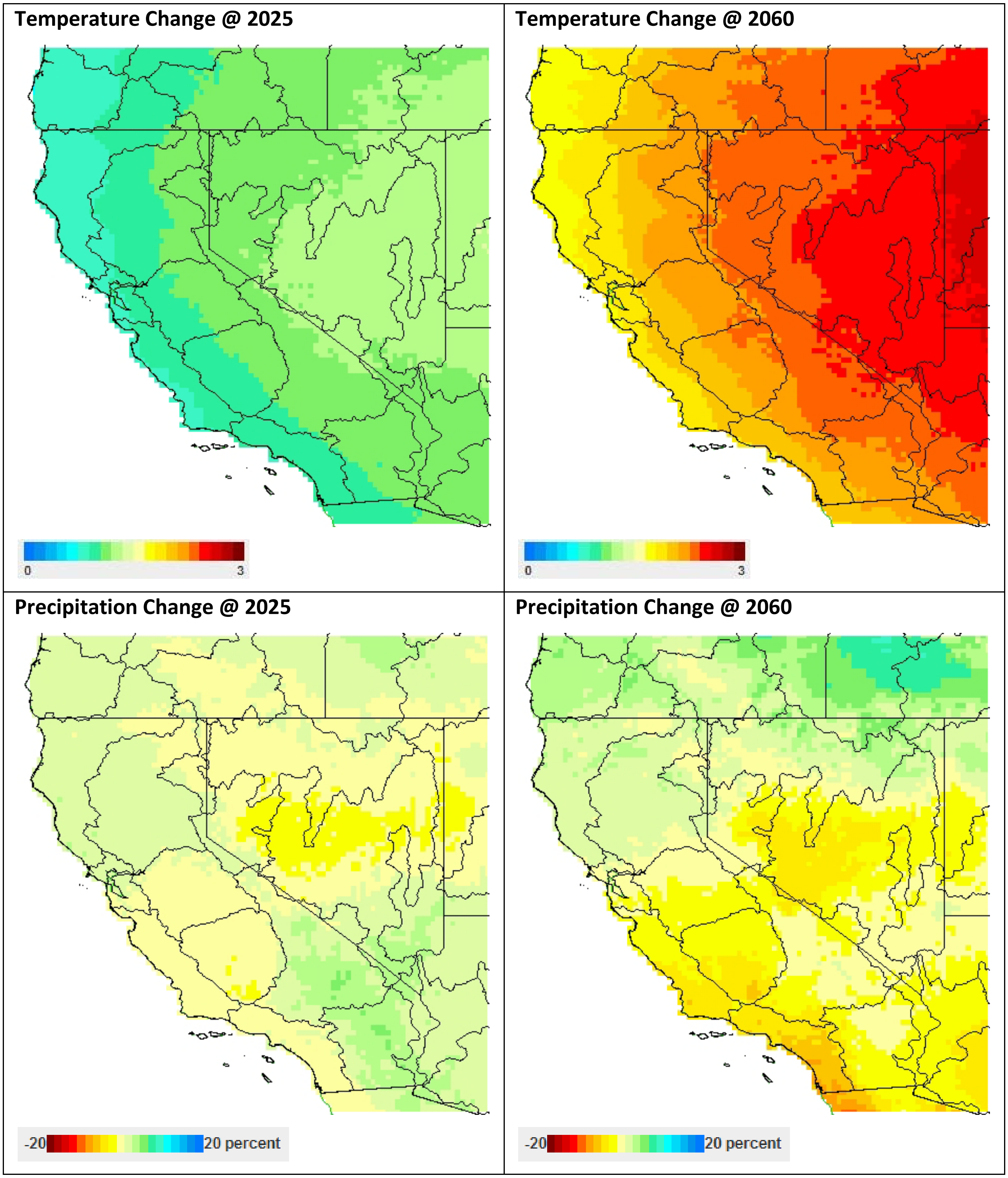


Figure 1-4: Projected Changes in Annual Temperature (top, as degrees C) and Precipitation (bottom, as percent change) for the Periods 2011-2040 (2025) and 2046-2075 (2060) as Compared to the 1971-2000 Historical Period. *Derived from Daily Gridded Observed Meteorology (Maurer et al, 2002)*

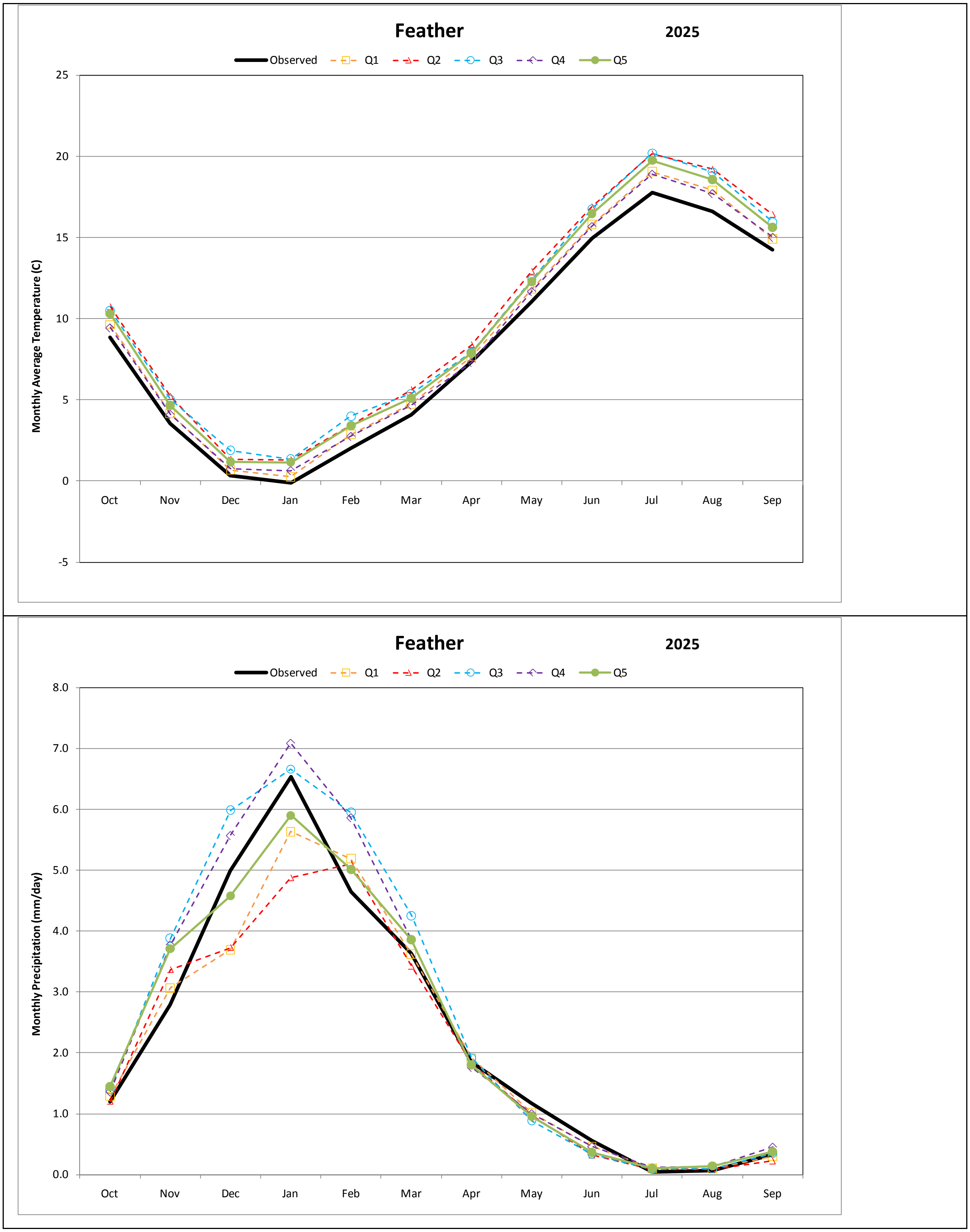


Figure 1-5: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in the Feather River Basin

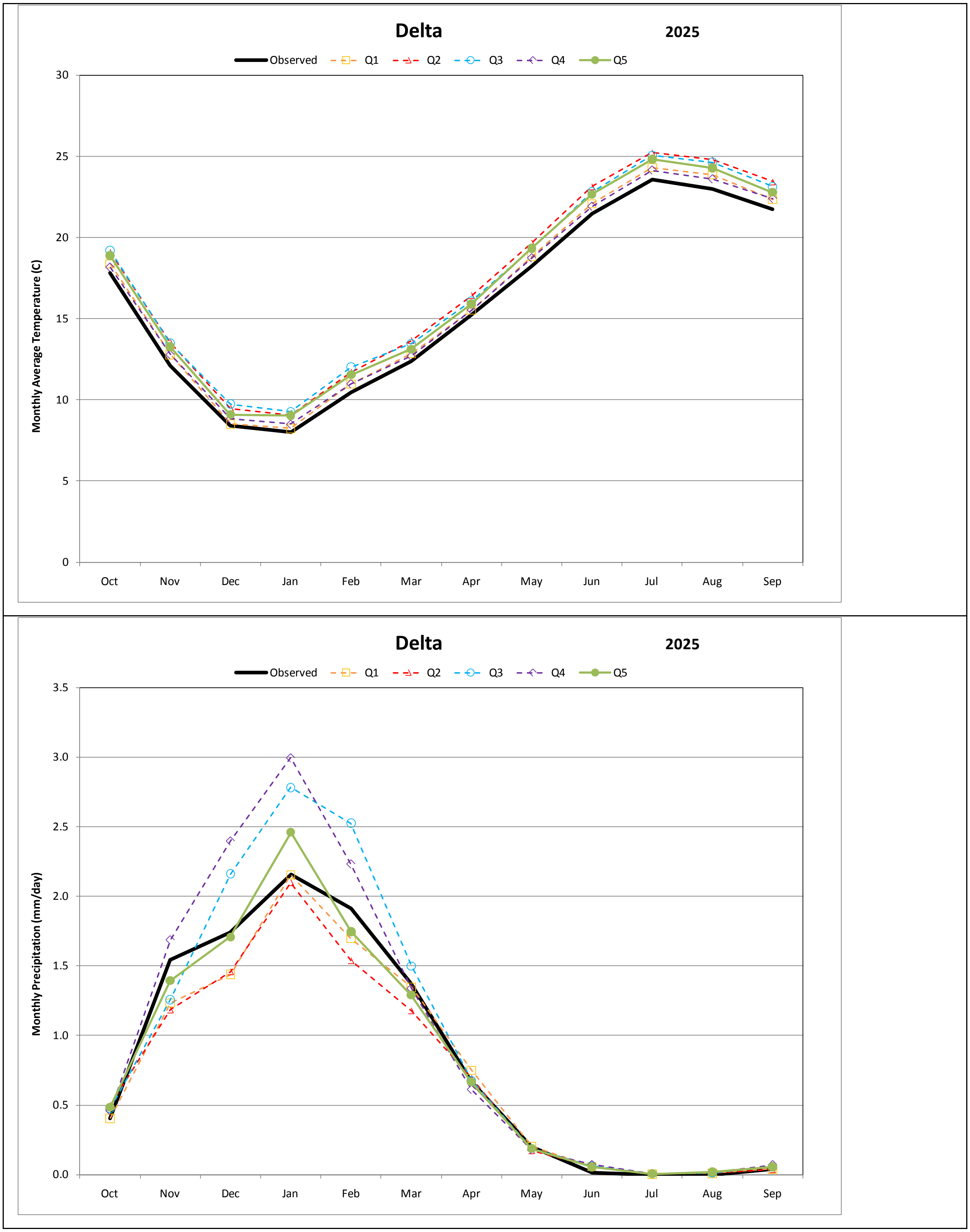
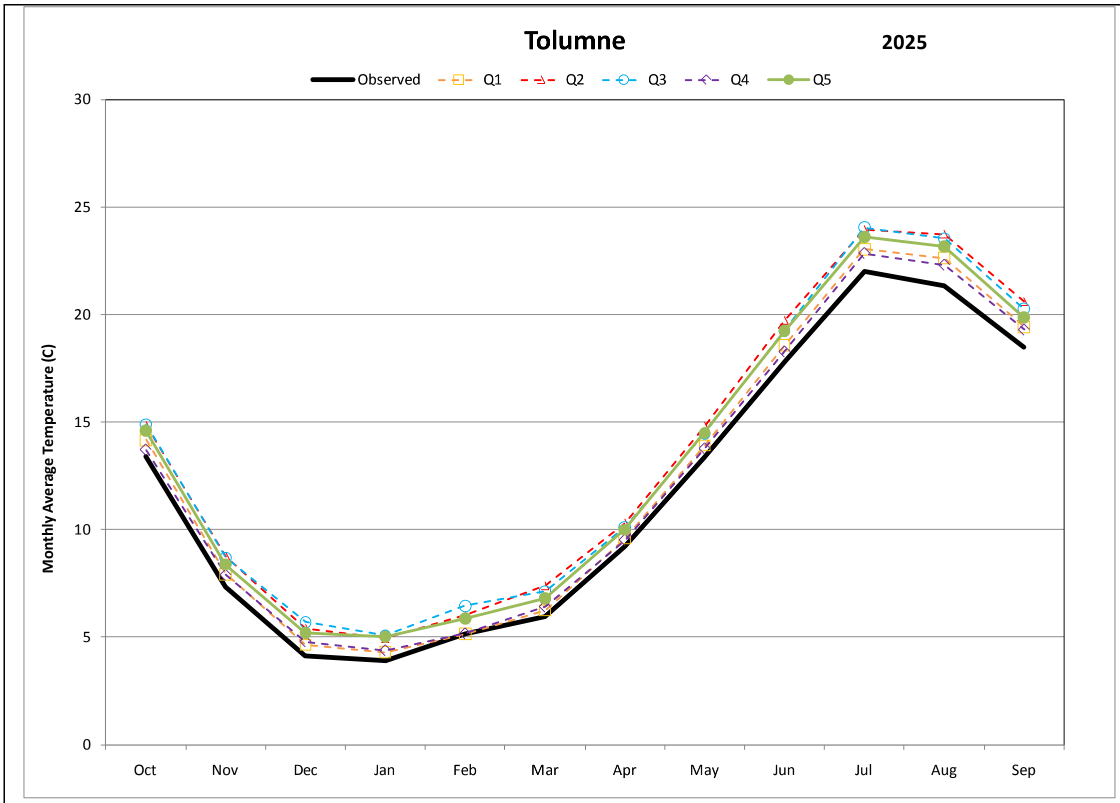
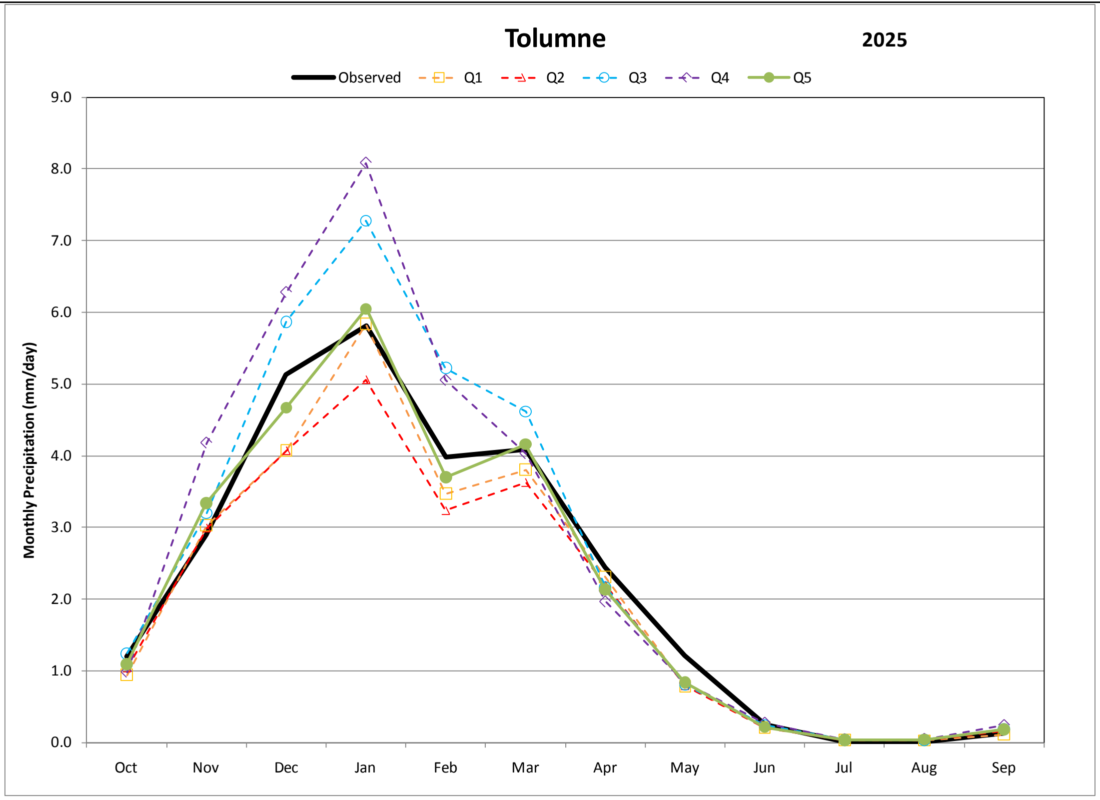


Figure 1-6: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in the Delta





1 Figure 1-7: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in the
2 Tuolumne River Basin

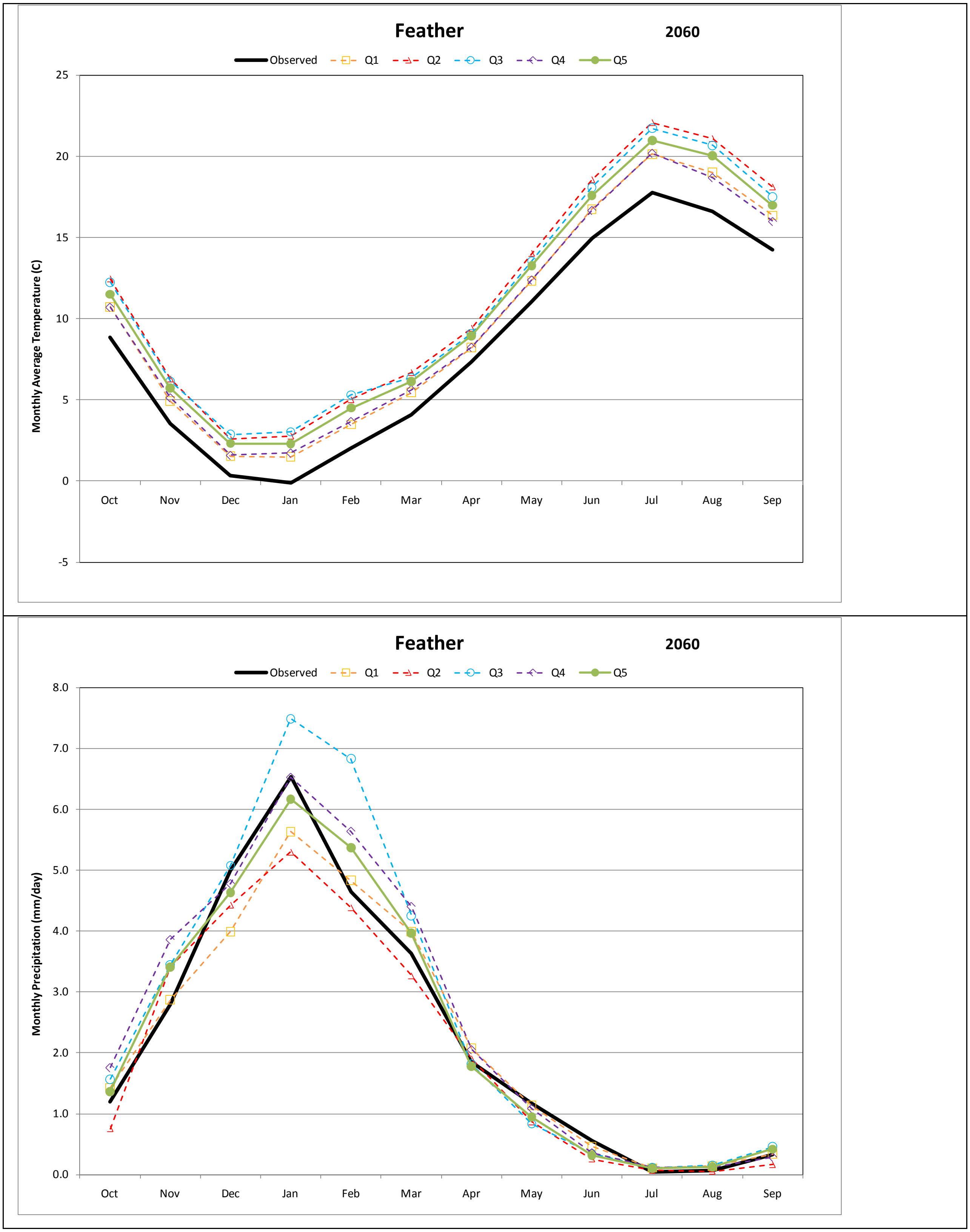
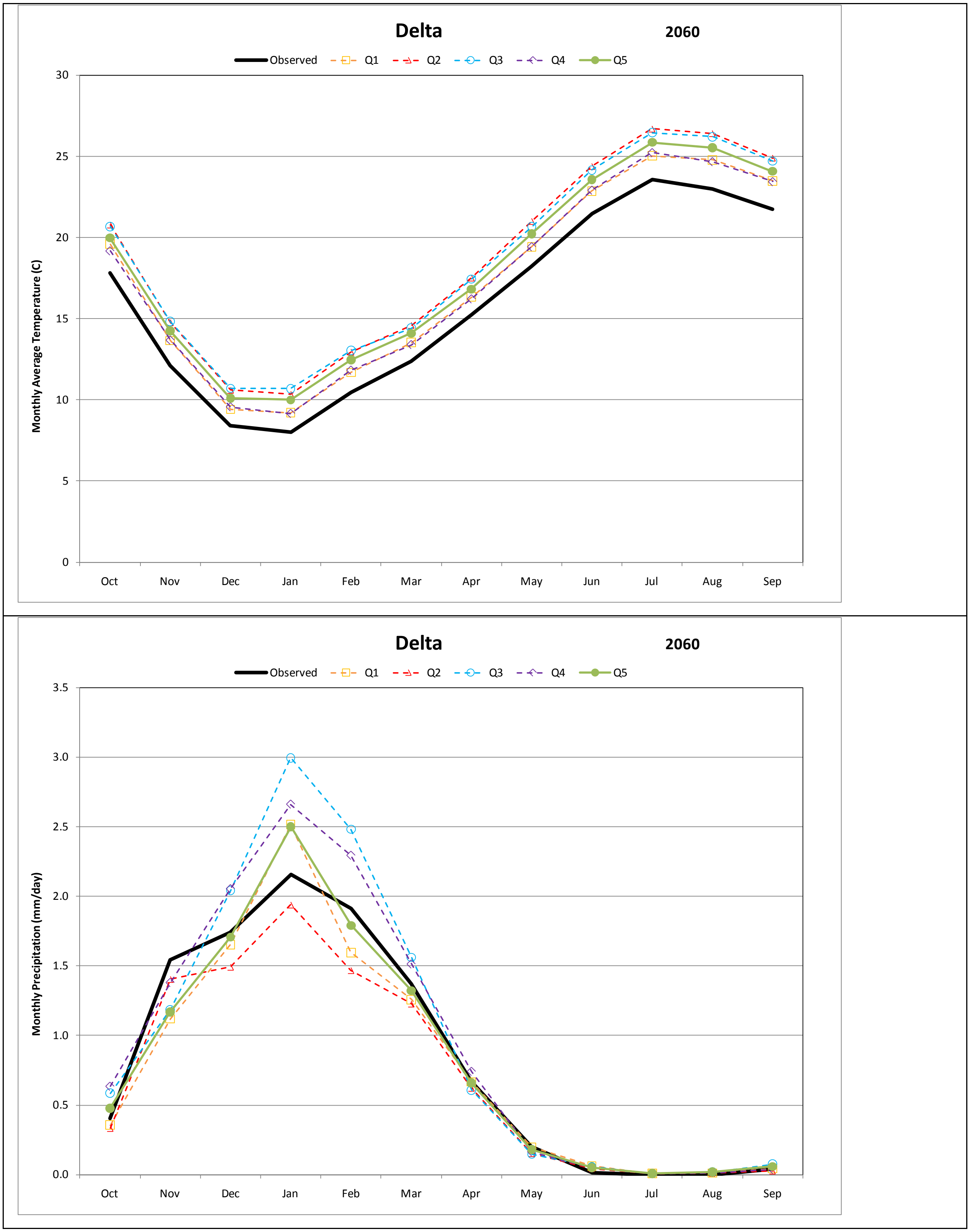
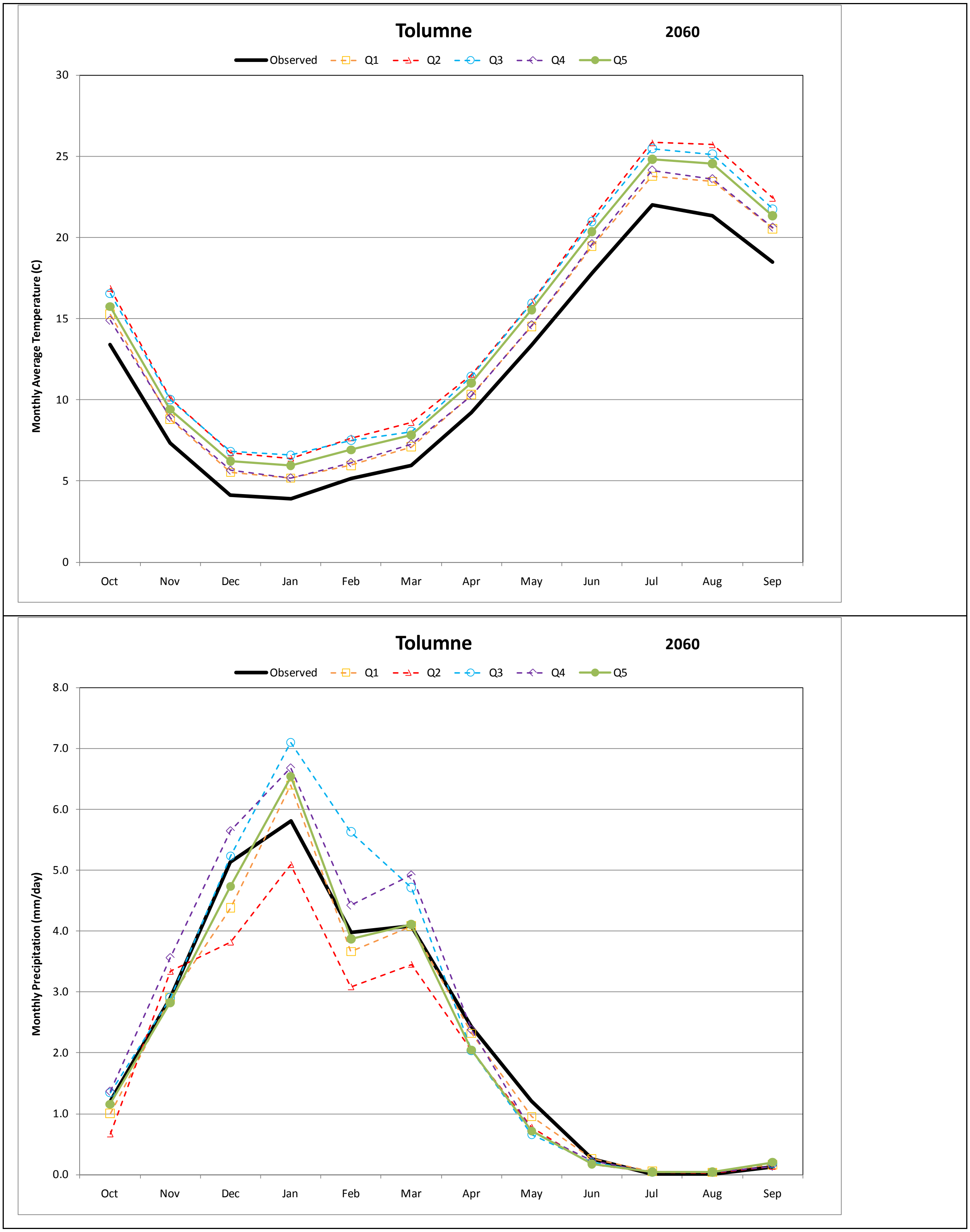


Figure 1-8: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in the Feather River Basin



1 Figure 1-9: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in the
2 Delta



1 Figure 1-10: Projected Changes in Seasonal Temperature (top) and Precipitation (bottom) for a Grid Cell in
2 the Tuolumne River Basin

D.3.2. Changes in Hydrology under Modified Climate

The Variable Infiltration Capacity (VIC) hydrologic model was applied to simulate the hydrologic changes under each of the climate scenarios as described earlier in Section A.8. This section describes the resulting hydrologic changes from the VIC model under the future climate scenarios compared to the current hydrology, which formed the basis of CALSIM II’s climate-modified inputs.

TECHNICAL MEMORANDUM

CHANGES IN HYDROLOGY UNDER MODIFIED CLIMATE

PREPARED FOR: SAIC

PREPARED BY: CH2M HILL

DATE: January, 2011

Study Objectives

The regional hydrologic modeling is necessary to understand the watershed-scale impacts of historical and projected climate patterns on the processes of rainfall, snowpack development and snowmelt, soil moisture depletion, evapotranspiration, and ultimately changes in streamflow patterns. Future projected climate change, downscaled from global climate models (GCMs), suggests substantial warming throughout California and changes in precipitation. The effect of these changes in important to future water management. The VIC hydrologic model has been applied to reflect the hydrologic changes under each of the climate scenarios described earlier. The resulting flow changes are then used to adjust inputs to the CALSIM II systems model to better understand the effect on operations of the federal, state, and local water projects in the Central Valley. This section describes the results related to the hydrologic changes from the VIC regional model under the future climate scenarios.

Hydrologic Processes

The hydrologic processes that describe the interaction between climate and the watershed landscape are critically important in determining water availability and the manner in which the basin response may change under future climate. The regions of greatest precipitation in the Sacramento and San Joaquin River watersheds are those are those at high elevation in the headwaters of the Sacramento, Feather, Yuba, American, Stanislaus, Tuolumne, Merced, and San Joaquin Rivers. Due to cold temperatures these areas accumulate substantial snowpack that it is critical to the total inflow to the Delta. Warming has been observed and is projected to accelerate and causes substantial changes to the timing and form of precipitation in these areas. Recent studies have assessed observed snowpack trends in the southwest. Research by Mote (2005) and Cayan (2001) indicate a general decline in April 1 snow water equivalent (SWE) for Pacific Northwest and the northern Sierra, but increasing trends in the high elevation southern Sierras. Relative losses of SWE tend to be largest at low elevations and strongly suggest a temperature-related effect.

These broad trends of April 1 SWE were generally captured over the calibration period with the VIC model as show in the right of Figure 2-1. The results indicate the significant influence of high elevation on the response of the watersheds. The watersheds of the northern Sierra and Cascades tend to be of lower elevation and snowfall and snowmelt are sensitive the changes in temperature; essentially causing earlier snowmelt or causing more precipitation to fall as rain rather than snow. At high elevation, the snowpack and snowmelt is not as sensitivity to small warming changes due to the presence of the majority of the watershed well above 8000 feet. Mote et al (2008) found that the changes in SWE were not linear with increasing warming trends, but that the watersheds with elevations above 2,500 meters (approximately 8,000 feet) were less sensitive to warming and more sensitive to precipitation changes.

Evapotranspiration is projected to increase substantially throughout the Central Valley. Across the watershed, increases are expected in fall, winter, and spring and substantial decreases in summer as soil moisture is depleted earlier than under historical conditions. In areas receiving increases in precipitation evapotranspiration is projected to increase in spring as higher winter precipitation and earlier snowmelt allow a higher percentage of potential evapotranspirtation to be satisfied. At lower elevations, where snowpack is not significant and warmer temperatures exist, the peak increases in evapotranspiration are earlier in the year, with fall and winter being the highest. Summertime potential evapotranspiration increases significantly but in native areas without irrigation, soil moisture is the limiting factor.

Snowpack is projected to decrease as more precipitation falls as rain rather than snow and warmer temperatures cause an earlier melt. Decreases of snowpack in the fall and early winter are expected in areas where precipitation is not changed or is increased, and is caused by a greater liquid form of precipitation due to warming. Substantial decreases in spring snowpack are expected and projected to be widespread, due to earlier melt or sublimation of snowpack.

Soil moisture represents a portion of the seasonal watershed storage and buffers monthly changes in water availability and consumptive use. The interplay among precipitation, snowpack, evapotranspiration, and runoff cause changes in soil moisture conditions. In general, soil moisture is depleted earlier in the year and deficits persist longer into the late fall and early winter as compared to historical conditions. In regions with overlying snowpack, earlier melt implies earlier contribution to soil moisture storage and an earlier opportunity for evapotranspiration to consumptively use this stored water. In all regions, increased potential evapotranspiration due to warming drives greater consumptive use. However, actual evapotranspiration is governed by water availability and when such soil moisture storage is depleted actual evapotranspiration is curtailed. Overall, the watershed enters the winter season with larger soil moisture deficits and greater opportunity to store and consume winter precipitation.

Runoff (both direct and baseflow), the balance of hydrologic processes of affecting the supply and demand at the local grid-scale, is spatially diverse, but is generally projected to decrease except in some areas of the northern Sierra and Cascades during winter.

Streamflow

The VIC model simulates a daily water balance at approximately 3,000 grid cells throughout the model domain. Routing of grid cell runoff was performed for all the major rivers of the Sacramento River, San Joaquin River, and Tulare Basins. In addition, streamflow routing was performed for the Trinity River. The streamflow was routed to each of the 21 locations identified in Table 2-1. The flow at these locations was necessary to adjust the inflow timeseries and hydrologic indices in the CALSIM II model.

VIC simulates “natural flow” conditions; that is, conditions without the regulation or diversion of river flows. The VIC model was simulated under historical meteorological conditions to represent the “no climate change” condition as described in the Methods section. Five future scenarios were then simulated using the climate adjusted meteorology representative of the Q1 through Q5 climate scenarios. Simulations were performed separately for the climate scenarios at the 2025 projections and 2060 projections.

The annual changes in streamflow at the 18 major locations (over 80% of the contributing flow to the delta) of significance are shown in Figure 2-3. The top figure shows the projected changes under the 2025 conditions for the five climate scenarios and the bottom figure shows the projected changes under the 2060 climate scenarios. In this figure, the locations are ordered from north to south (left to right) to depict a generally trend in hydrologic response consistent with climate projections.

The green line in Figure 2-3 represents the results from the Q5 climate scenario (ensemble median). Changes are small in the northern watersheds, but a trend toward reduced flows is observed in the San Joaquin River basin. By 2060 under the Q5 scenario, the trend toward reduced streamflows in the south are more apparent as is a shift toward the north where the transition occurs from neutral or increased streamflow to decreased streamflows. The overall reductions in runoff are less than 10% by 2025, but up to 20% by 2060.

The streamflow changes from the Q1-Q4 climate scenarios are also show in Figure 2-3 as bars. These scenarios indicate the considerable range of uncertainty that exists in climate projections. The Q1 and Q2 scenarios represent the 10th percentile of precipitation projections and result in decreased streamflows for all watersheds and are always more severe than the Q5 scenario. The Q3 and Q4 scenarios represent the 90th percentile of precipitation projections and are always wetter than the Q5 scenario. The Q5 scenario represents a median based response from the wide range of uncertainty. While the response is wide under these scenarios, it is informative to observe that even under modest increases in precipitation (as in Q5 in the north, and Q3 and Q4) the trend in through time is toward reduced streamflows and for a southerly declining trend. Even under wetter condition, increases in streamflow at 2060 are always less than the increases for the same scenario at 2025.

While annual flows show north-south differences and a general median trend toward reduced streamflow, the monthly flows exhibit a significant shift in timing. Figure 2-4 through Figure 2-13 shows the simulated mean monthly flows from the climate projections for the main eight river index locations at both 2025 and 2060 as compared to the simulated historical conditions. Commensurate with the seasonal changes in temperature, precipitation, and hydrologic processes, the peak streamflow occurs about one to two months earlier in the Trinity River, Sacramento River, Feather River, Yuba River, American River, and Stanislaus River. These changes are due to both potential increases in winter precipitation, more precipitation falling as rain rather than snow, and earlier snow melt due to warming.

The higher elevation watersheds of the San Joaquin River do not show as pronounced a shift in the timing of runoff. The Merced, Tuolumne, and Upper San Joaquin do not show this shift, but rather streamflow is sensitive to the climate scenario and the degree of change in precipitation and overall warming.

Simulations for all watersheds demonstrate a reduced late spring and summer flow patterns. It appears very likely that the hydrology of the delta drainages will exhibit a shift towards more fall-winter variability to reduced variability in the spring and summer due to climate change. Considerable uncertainty exists with respect to absolute projections of the future climate and the hydrologic response reflects this uncertainty. However, the strong trend toward seasonal shifts in runoff, decreasing streamflow in the central and southern watersheds, and expansion of variability are present in these analyses.

The flow changes simulated under the VIC hydrology model are reflected in the CALSIM II model as changes in the historic inflow traces.

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Table 2-1: Listing of flow routing locations included in the VIC modeling.

Abbreviation	**Name**	**Lat**	**Lon**	**VIC Lat**	**VIC Lon**
SMITH	Smith River at Jed Smith SP	41.7917	-124.075	41.8125	-124.063
SACDL	Sacramento River at Delta	40.9397	-122.416	40.9375	-122.438
TRINI	Trinity River at Trinity Reservoir	40.801	-122.762	40.8125	-122.813
SHAST	Sacramento River at Shasta Dam	40.717	-122.417	40.6875	-122.438
SAC_B	Sacramento River at Bend Bridge	40.289	-122.186	40.3125	-122.188
OROVI	Feather River at Oroville	39.522	-121.547	39.5625	-121.438
SMART	Yuba River at Smartville	39.235	-121.273	39.1875	-121.313
NF_AM	North Fork American River at North Fork Dam	39.1883	-120.758	39.1875	-120.813
FOL_I	American River at Folsom Dam	38.683	-121.183	38.6875	-121.188
CONSU	Cosumnes River at Michigan Bar	38.5	-121.044	38.3125	-121.313
PRD_C	Mokelumne River at Pardee	38.313	-120.719	38.3125	-120.813
N_HOG	Calaveras River at New Hogan	38.155	-120.814	38.1875	-120.813
N_MEL	Stanislaus River at New Melones Dam	37.852	-120.637	37.9375	-120.563
MERPH	Merced River at Pohono Bridge	37.7167	-119.665	37.9375	-119.563
DPR_I	Tuolumne River at New Don Pedro	37.666	-120.441	37.6875	-120.438
LK_MC	Merced River at Lake McClure	37.522	-120.3	37.5625	-120.313
MILLE	San Joaquin River at Millerton Lake	36.984	-119.723	36.9375	-119.688
KINGS	Kings River - Pine Flat Dam	36.831	-119.335	37.1875	-119.438
COTTONWOOD	Cottonwood Creek near Cottonwood	40.387	-122.239		
CLEARCREEK	Clear Creek near Igo	40.513	-122.524		
BEARCREEK	Bear River near Wheatland	39.000	-121.407		

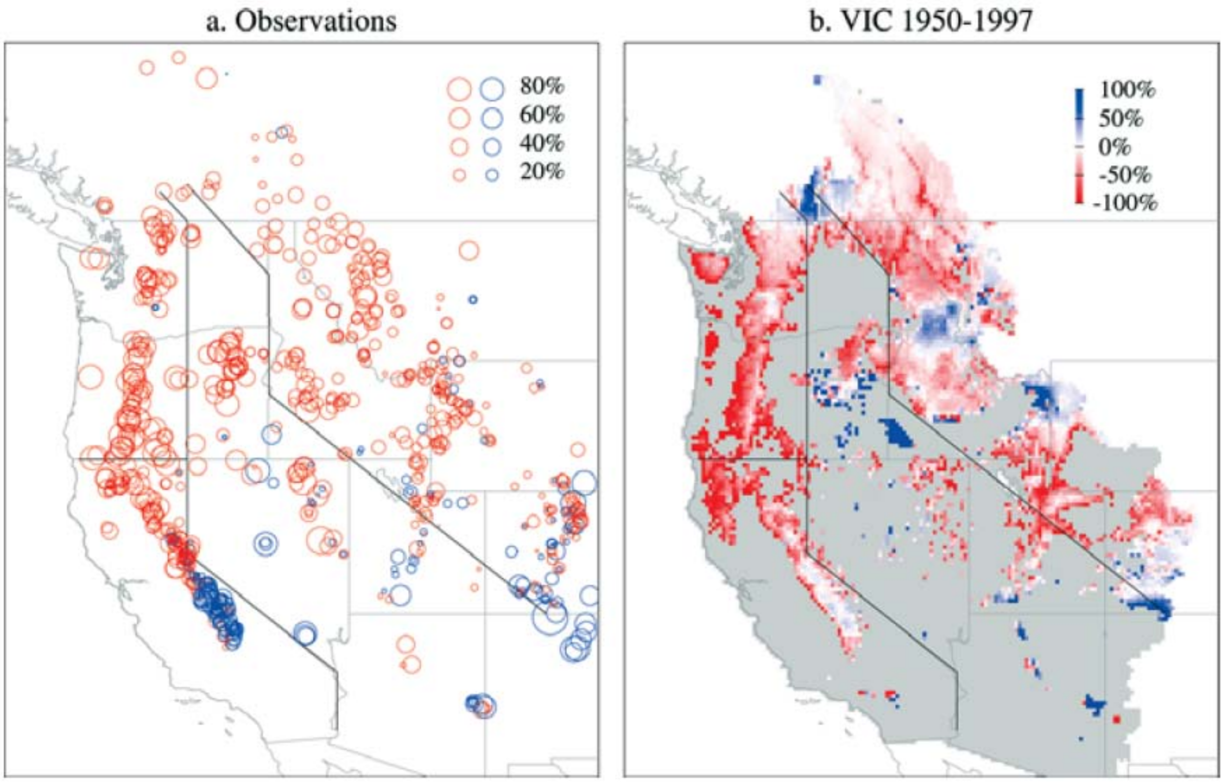
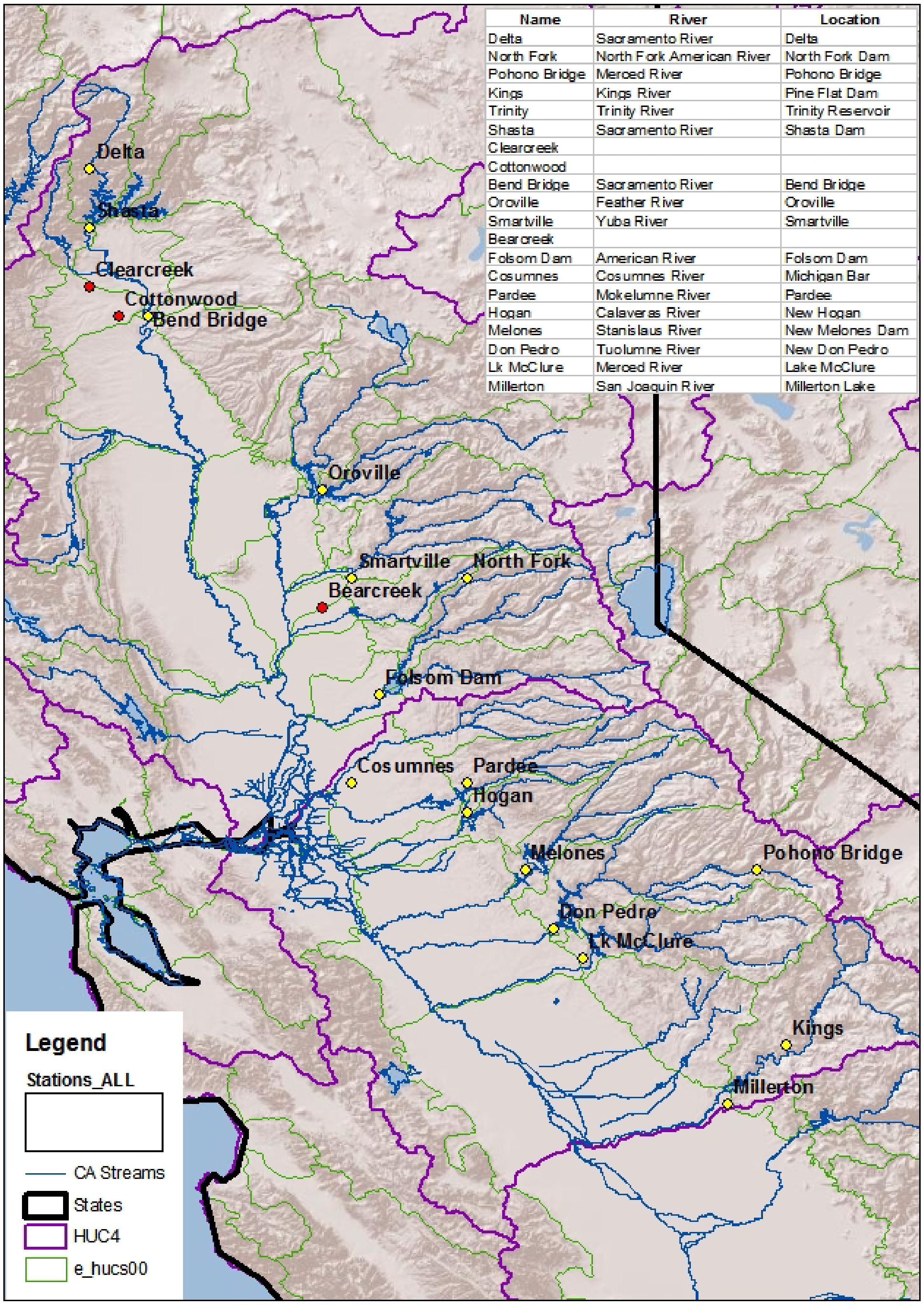
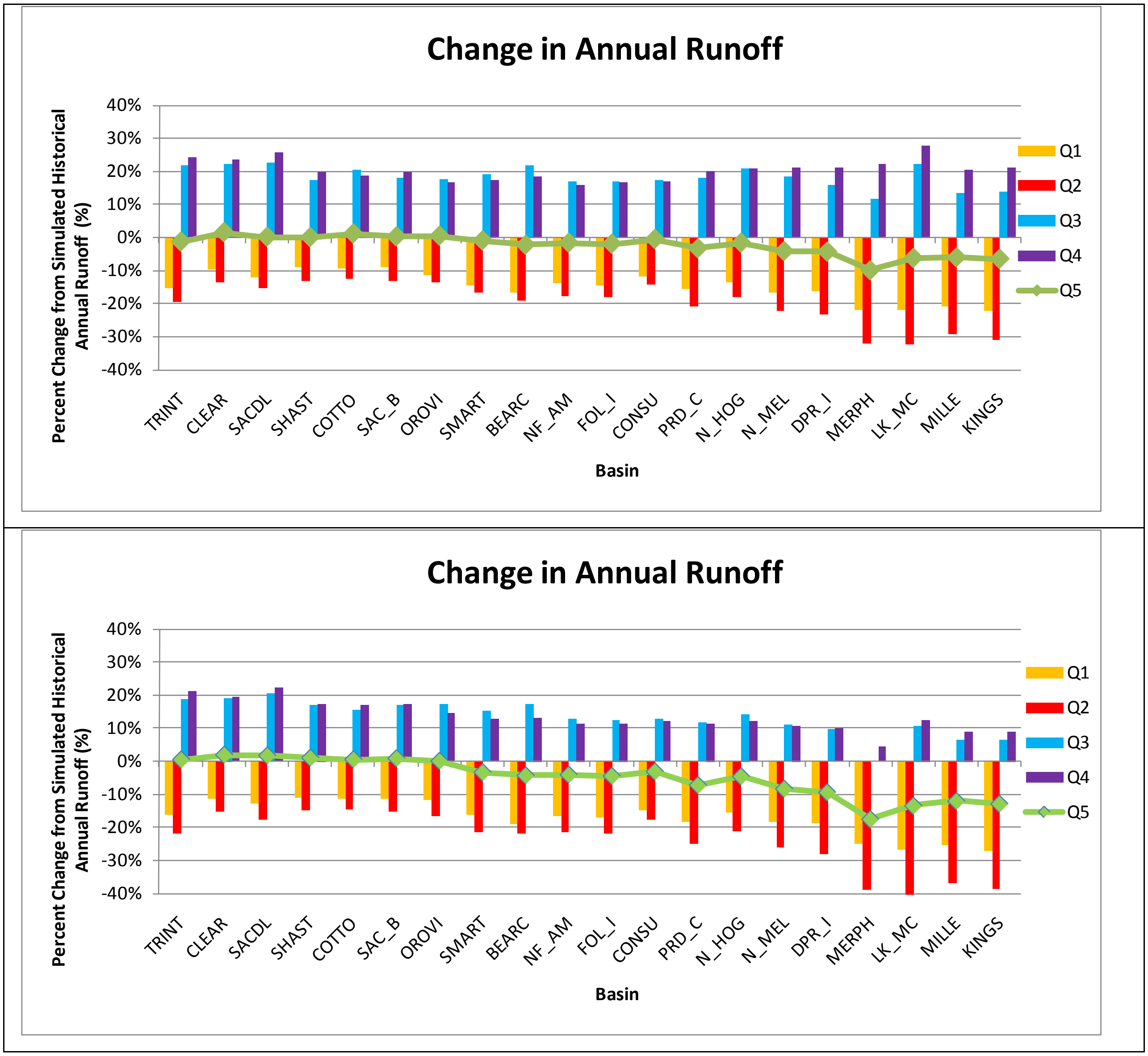


Figure 2-1: Left panel: Linear Trends in April 1 Snow Water Equivalent (SWE) at 824 Locations in the Western U.S. and Canada, 1950 to 1997 (Mote et al 2005)

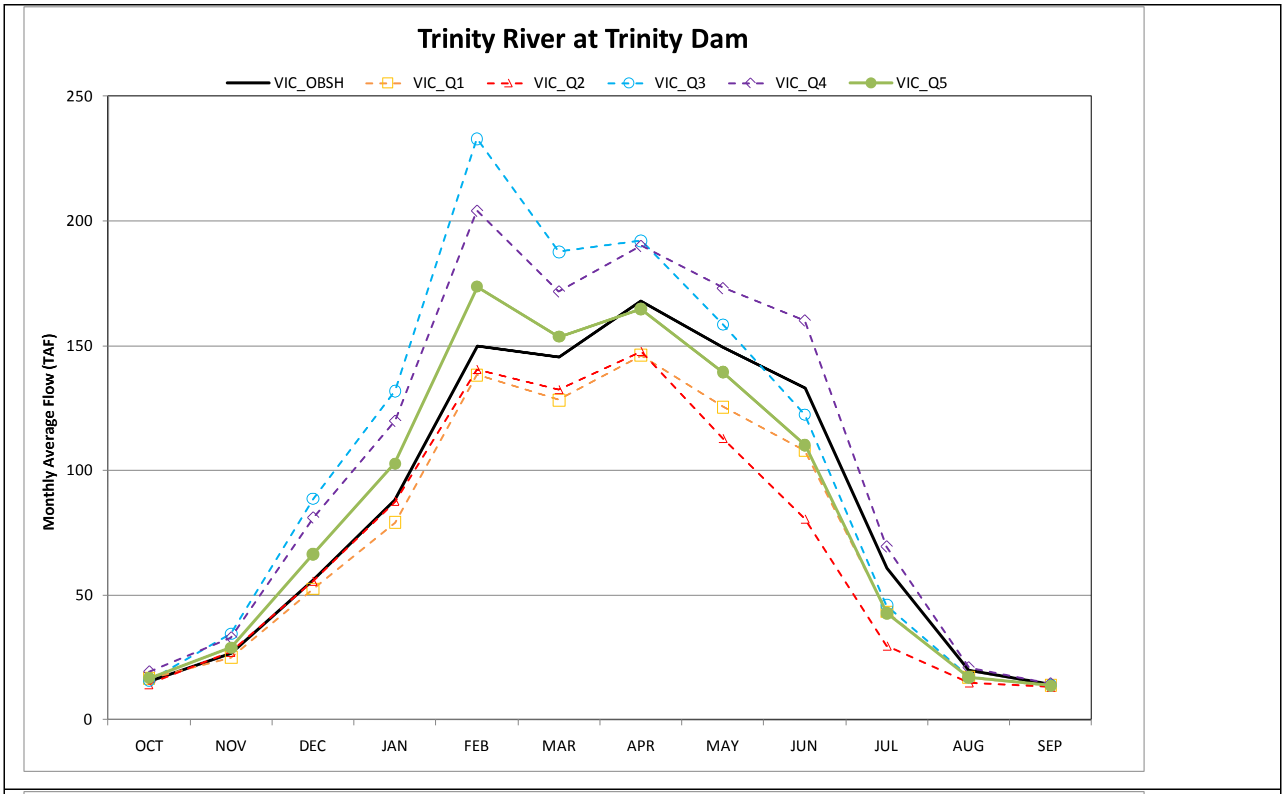


Name	River	Location
Delta	Sacramento River	Delta
North Fork	North Fork American River	North Fork Dam
Pohono Bridge	Merced River	Pohono Bridge
Kings	Kings River	Pine Flat Dam
Trinity	Trinity River	Trinity Reservoir
Shasta	Sacramento River	Shasta Dam
Clearcreek		
Cottonwood		
Bend Bridge	Sacramento River	Bend Bridge
Oroville	Feather River	Oroville
Smartville	Yuba River	Smartville
Bearcreek		
Folsom Dam	American River	Folsom Dam
Cosumnes	Cosumnes River	Michigan Bar
Pardee	Mokelumne River	Pardee
Hogan	Calaveras River	New Hogan
Melones	Stanislaus River	New Melones Dam
Don Pedro	Tuolumne River	New Don Pedro
Lk McClure	Merced River	Lake McClure
Millerton	San Joaquin River	Millerton Lake

Figure 2-2: Location of flow routing locations included in the VIC modeling.



1 Figure 2-3: Simulated Changes in Natural Streamflow for Each of the VIC Simulations (top, 2025 changes;
2 bottom, 2060 changes).



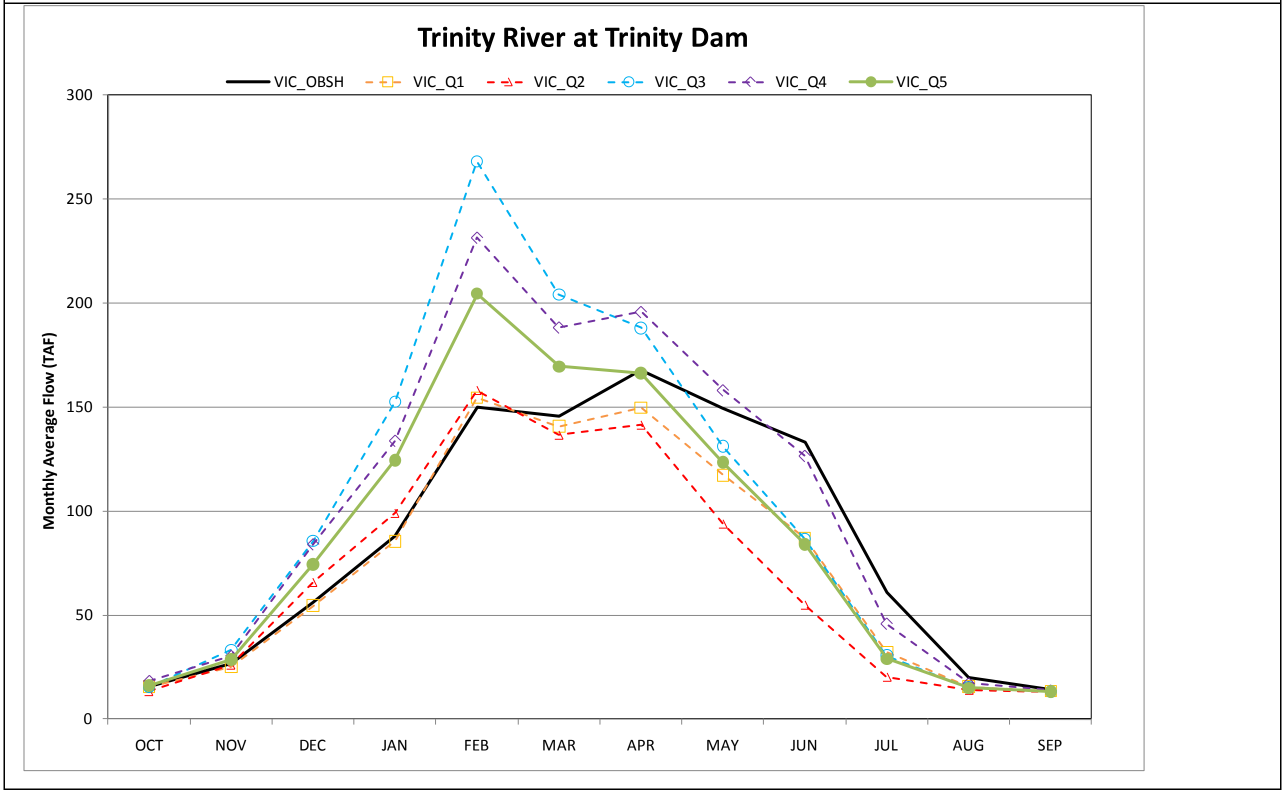
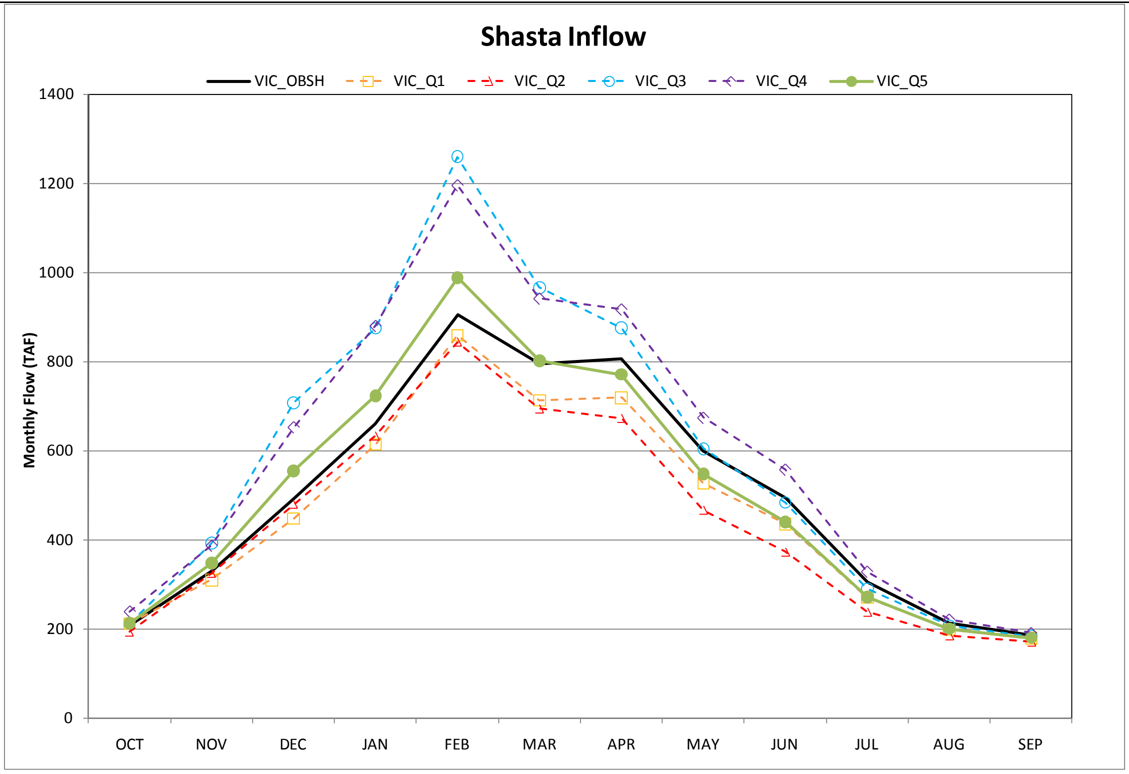


Figure 2-4: Simulated Changes in Monthly Natural Streamflow for Trinity River at Trinity Dam (top, 2025 changes; bottom, 2060 changes).



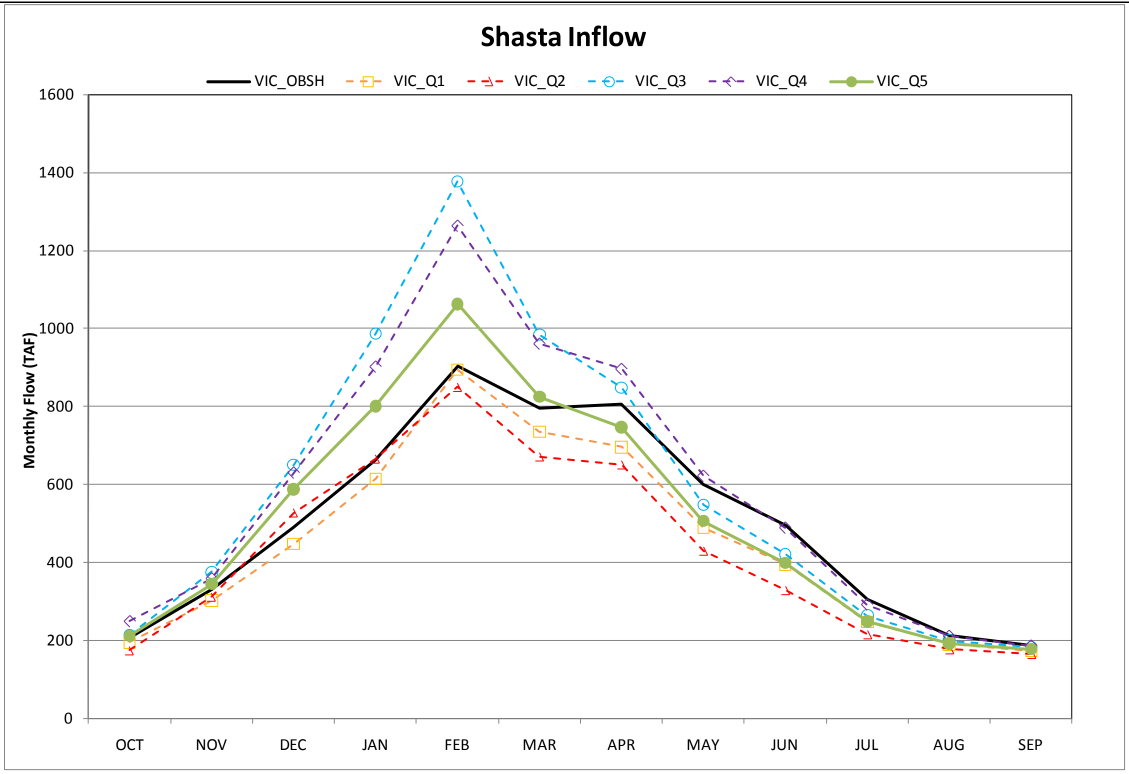


Figure 2-5: Simulated Changes in Monthly Natural Streamflow for Shasta Inflow (top, 2025 changes; bottom, 2060 changes).

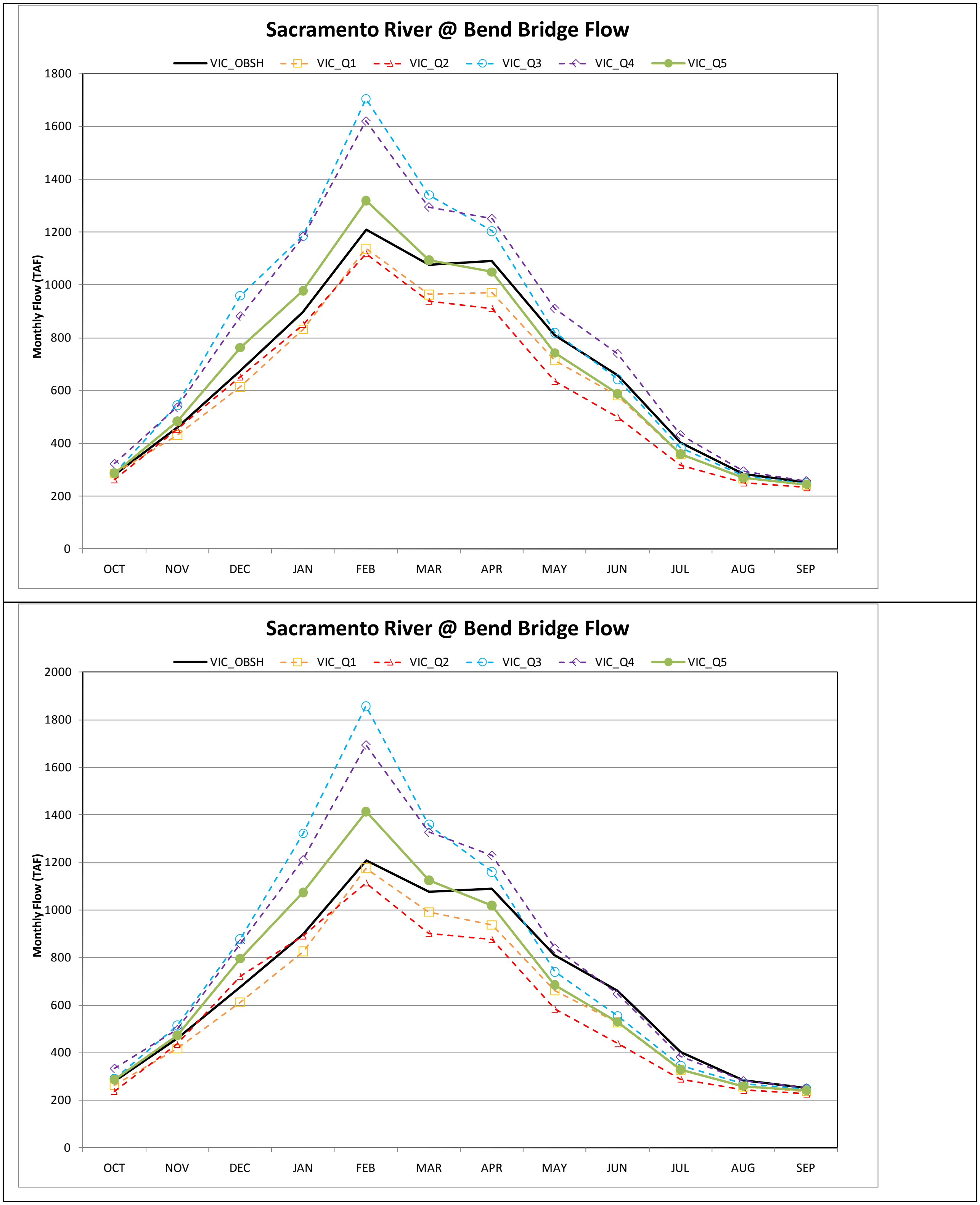
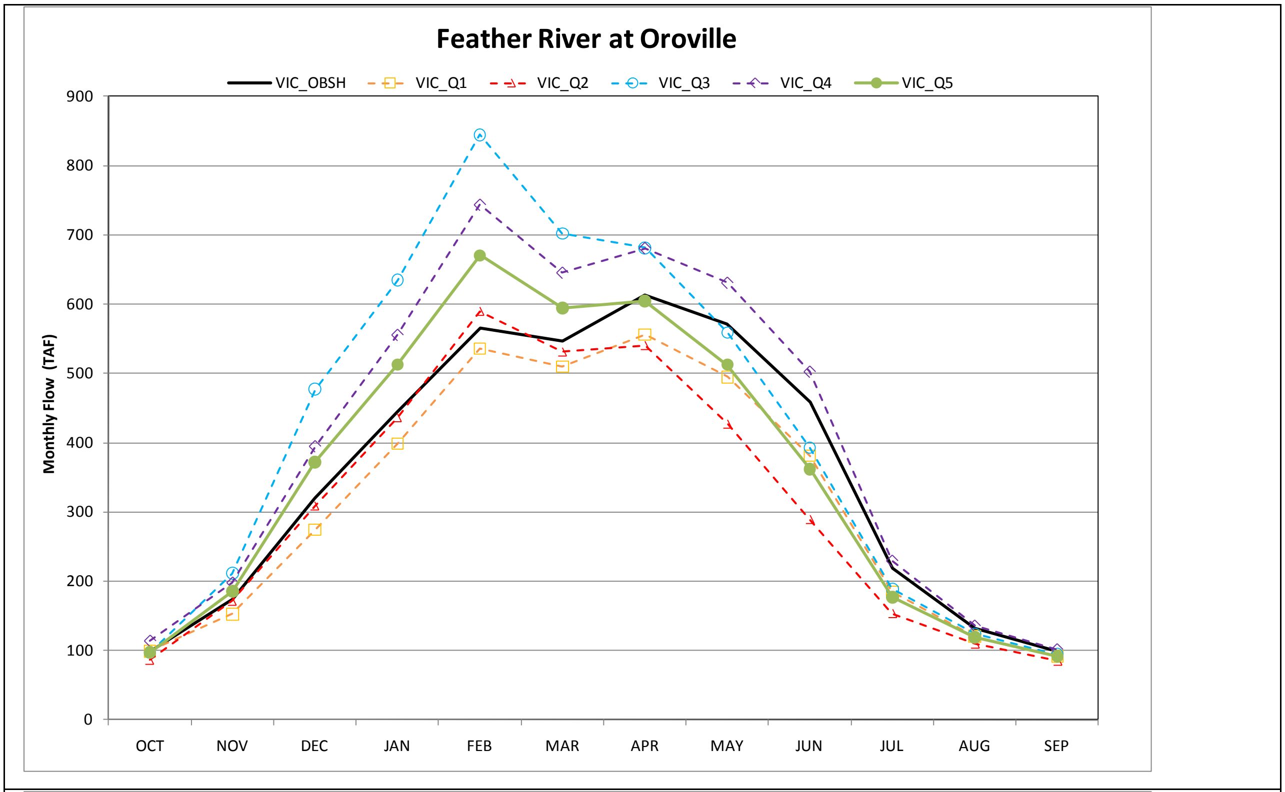


Figure 2-6: Simulated Changes in Monthly Natural Streamflow for Sacramento River at Bend Bridge (top, 2025 changes; bottom, 2060 changes).



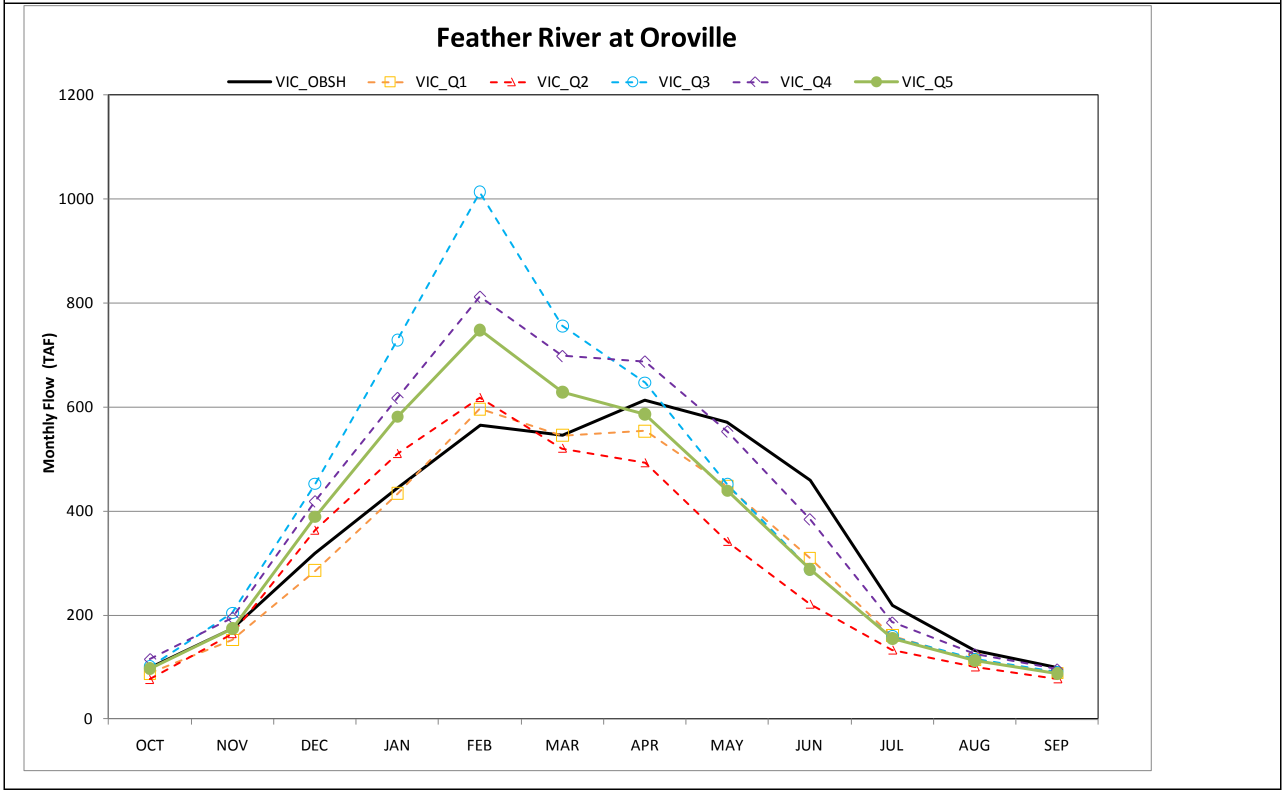
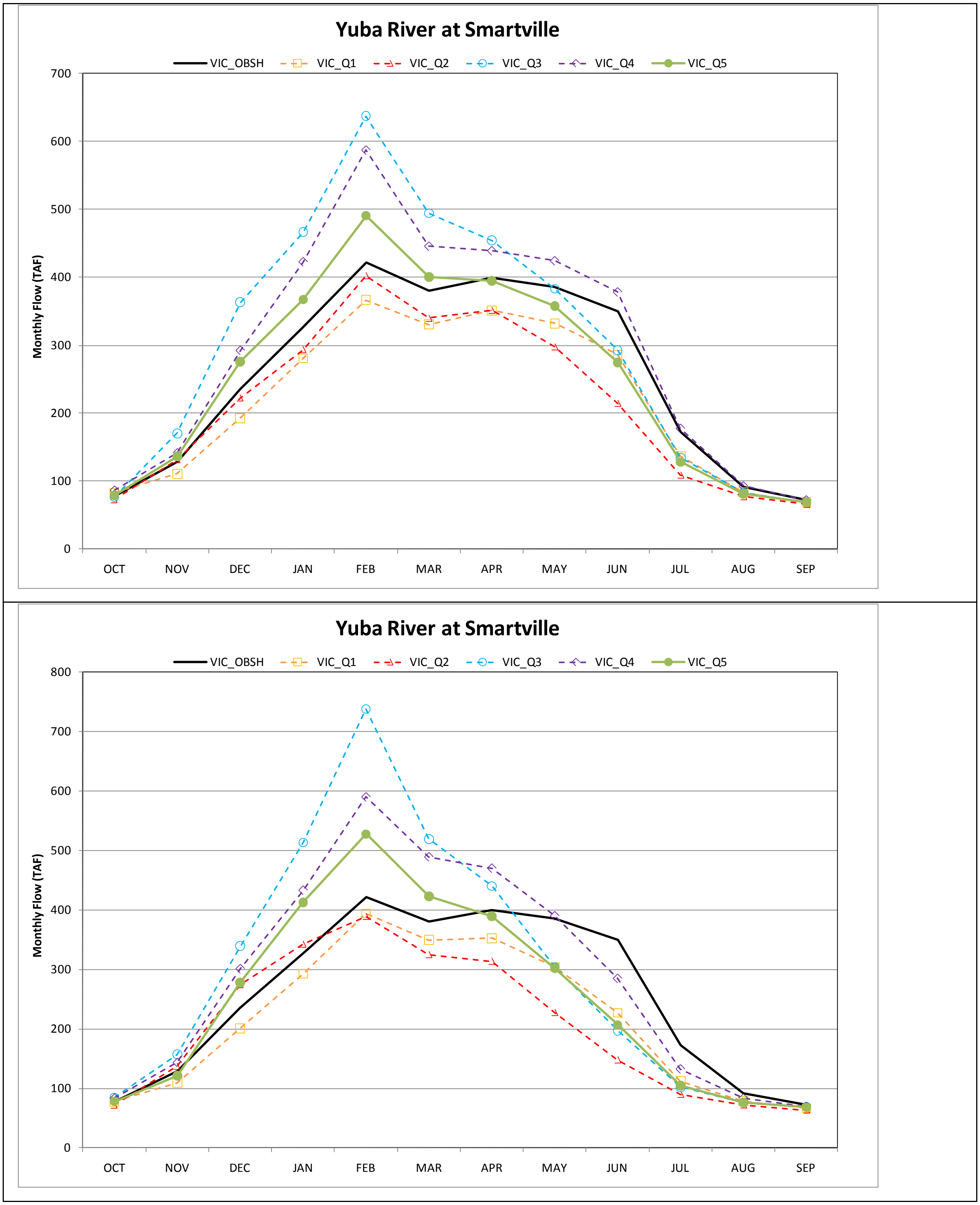
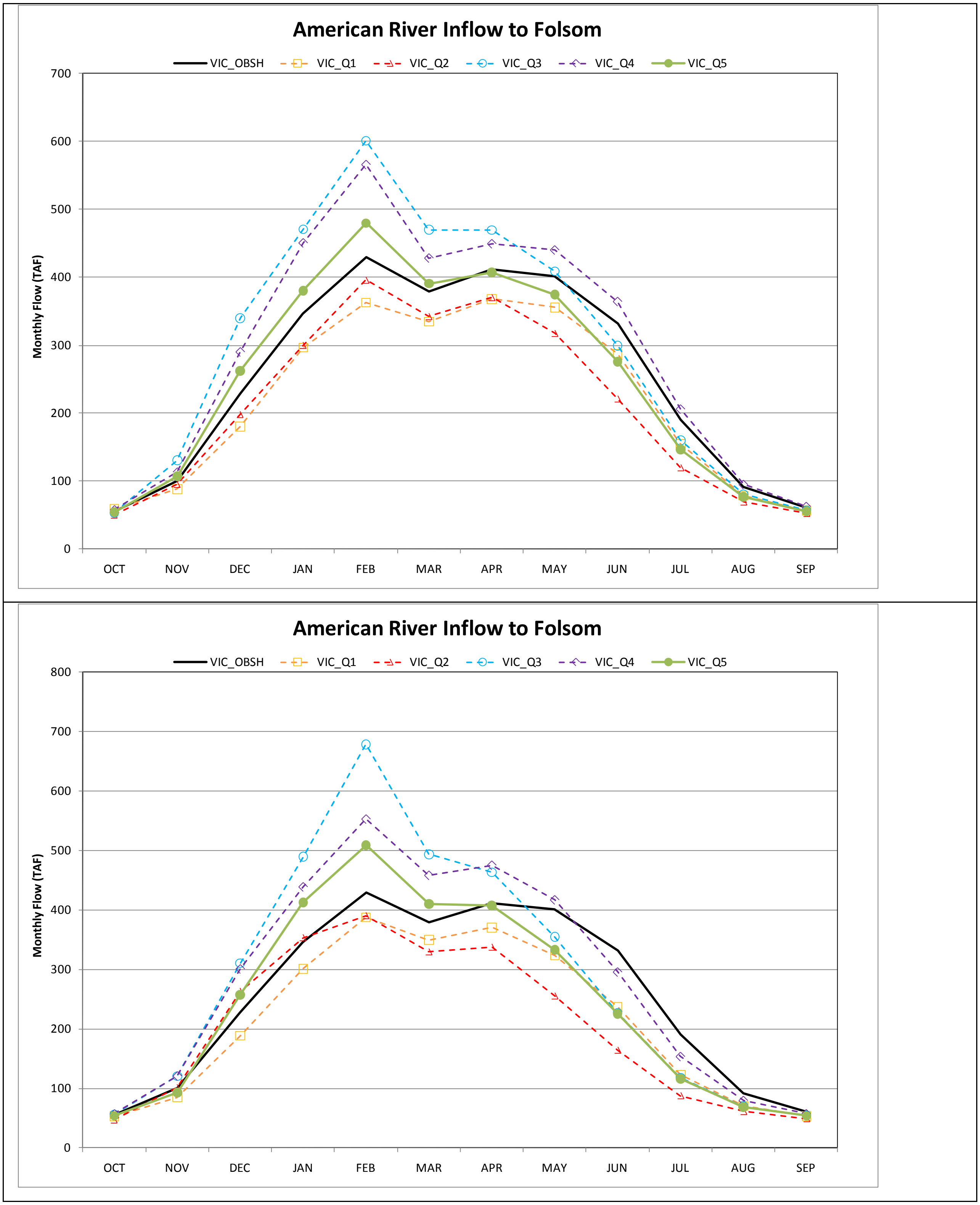


Figure 2-7: Simulated Changes in Monthly Natural Streamflow for Feather River at Oroville (top, 2025 changes; bottom, 2060 changes).



1 Figure 2-8: Simulated Changes in Monthly Natural Streamflow for Yuba River at Smartville (top, 2025
2 changes; bottom, 2060 changes).



1 Figure 2-9: Simulated Changes in Monthly Natural Streamflow for American River Inflow to Folsom (top,
2 2025 changes; bottom, 2060 changes).

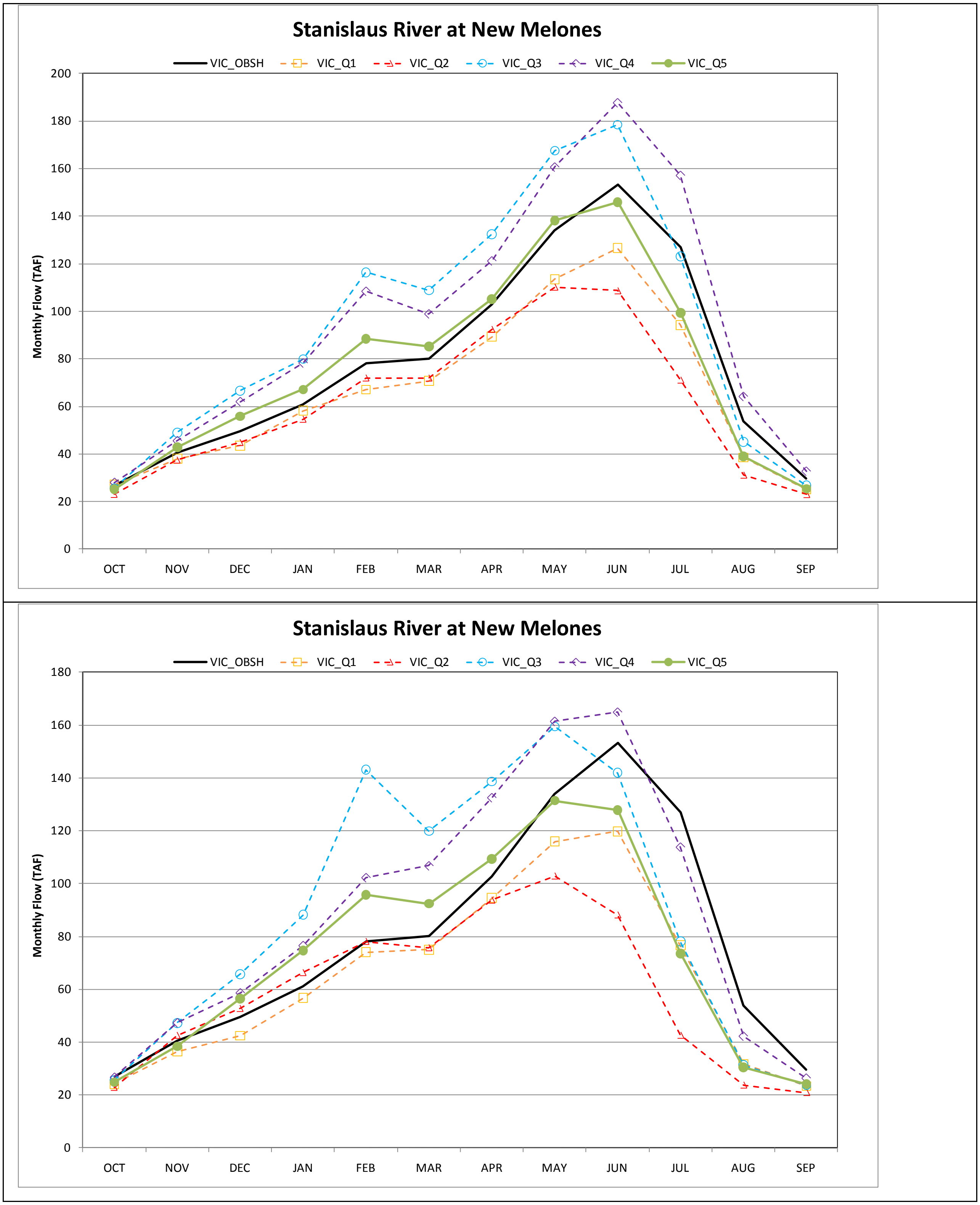


Figure 2-10: Simulated Changes in Monthly Natural Streamflow for Stanislaus River at New Melones (top, 2025 changes; bottom, 2060 changes).

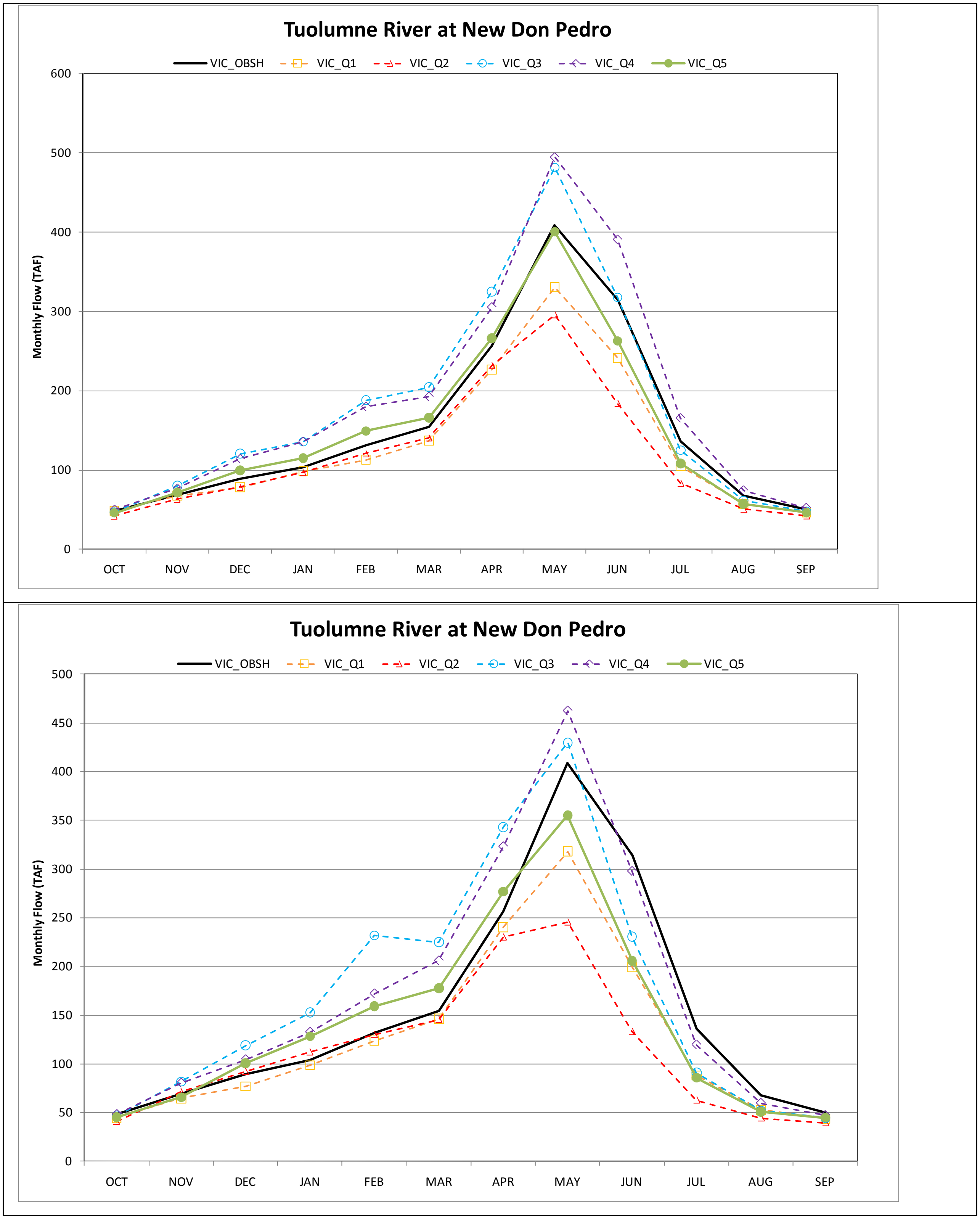


Figure 2-11: Simulated Changes in Monthly Natural Streamflow for Tuolumne River at New Don Pedro (top, 2025 changes; bottom, 2060 changes).

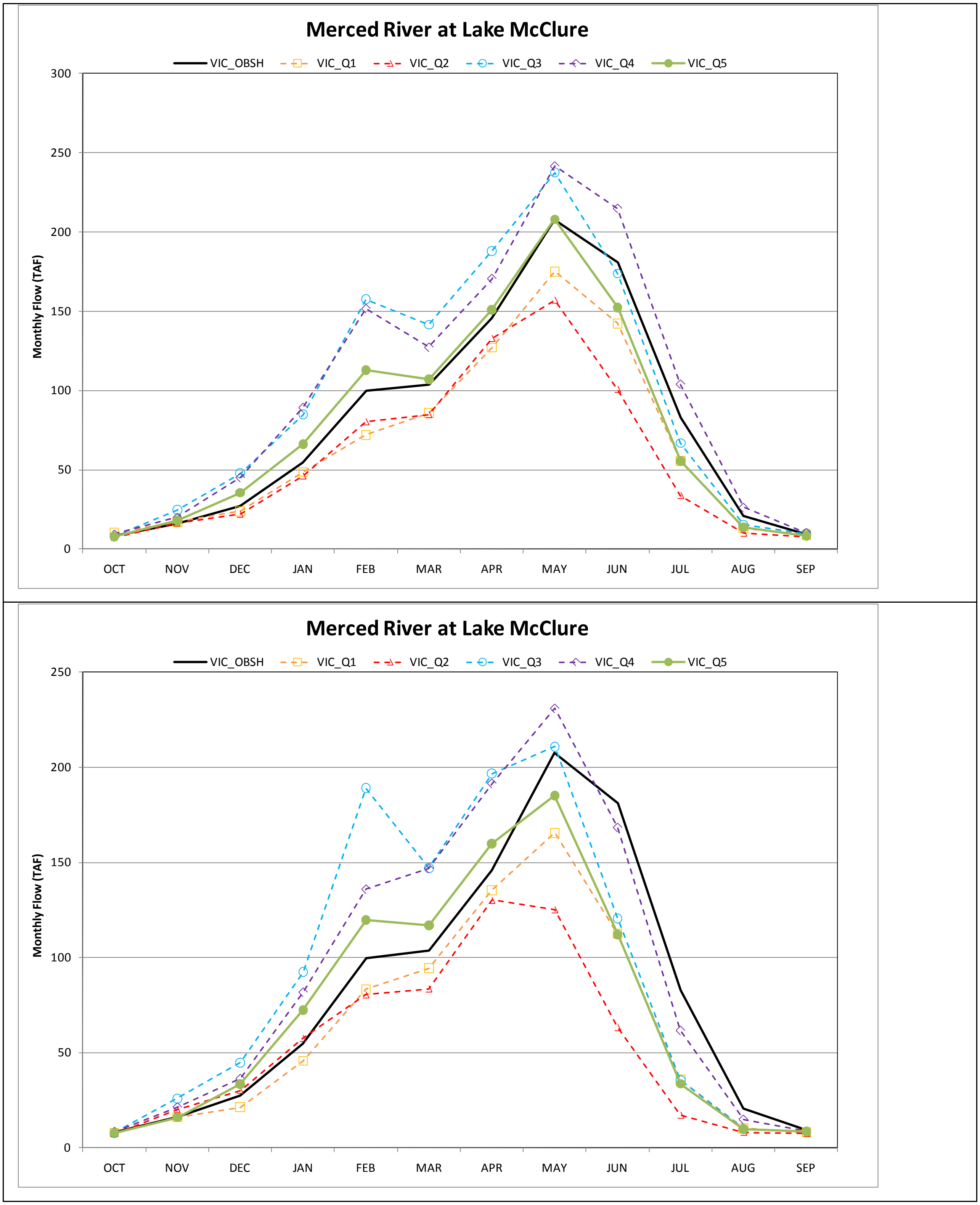


Figure 2-12: Simulated Changes in Monthly Natural Streamflow for Merced River at Lake McClure (top, 2025 changes; bottom, 2060 changes).

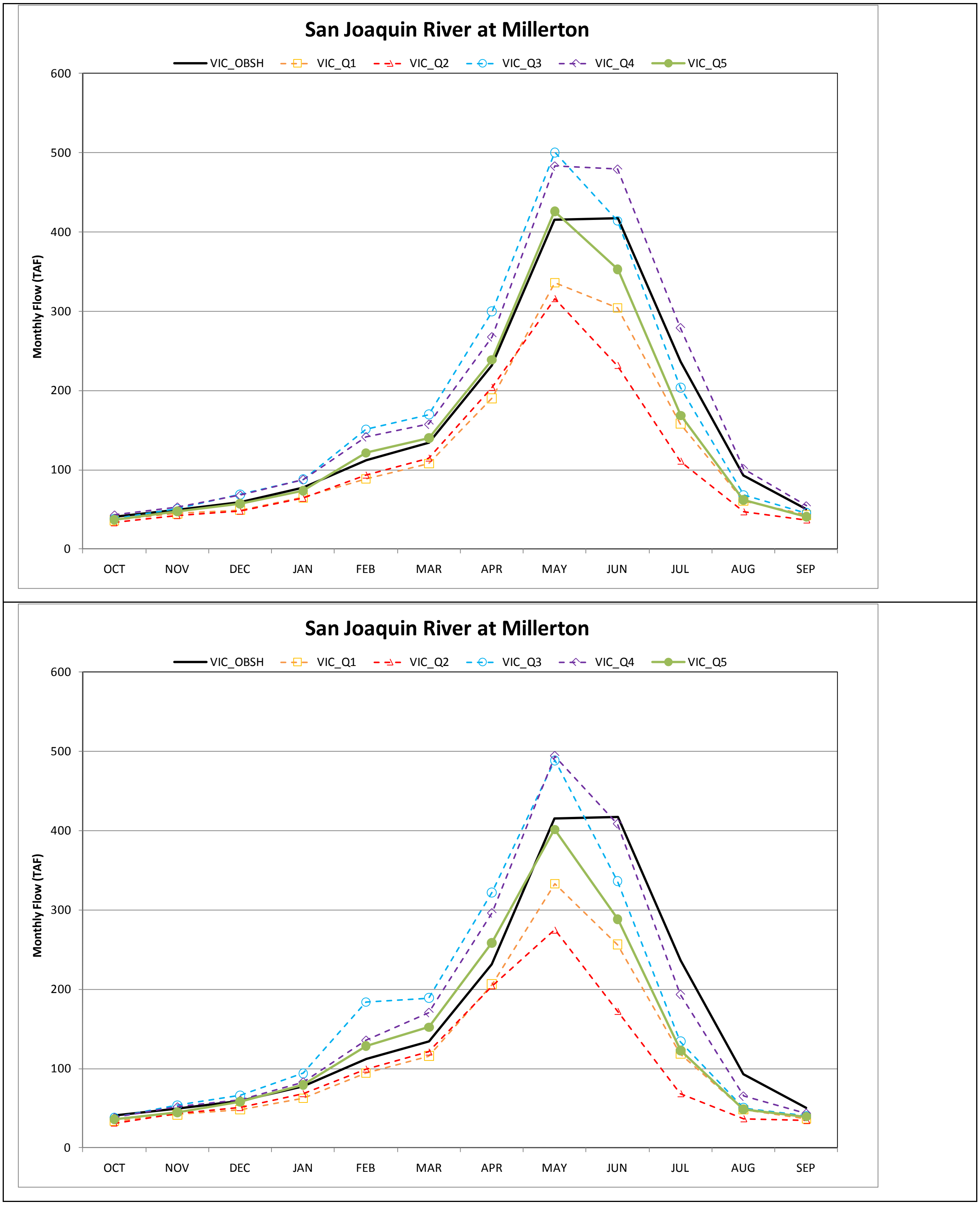


Figure 2-13: Simulated Changes in Monthly Natural Streamflow for San Joaquin River at Millerton (top, 2025 changes; bottom, 2060 changes).

D.3.3. Operations' Sensitivity to Climate Change

BDCP EIR/EIS No Action Alternative and the Alternative 1 were simulated under the five climate change scenarios selected for BDCP. The operations results from these simulations were analyzed to understand the range of uncertainty in the incremental changes between the BDCP EIR/EIS Alternative 1 and the No Action Alternative. This section summarizes key CALSIM II results for the No Action Alternative and Alternative 1 under the five climate scenarios.

TECHNICAL MEMORANDUM

OPERATIONS' SENSITIVITY TO CLIMATE CHANGE

PREPARED FOR:	SAIC
PREPARED BY:	CH2M HILL
DATE:	January, 2011

Study Objectives

The CALSIM II model was applied to evaluate the sensitivity of the BDCP EIR/EIS Alternative 1 to the range of future climate conditions. The discussion in this section summarizes changes in the hydrology and system operations associated with the BDCP EIR/EIS Alternative 1 at Early Long-Term (ELT) relative to the No Action Alternative (Existing Biological Condition) assumptions, under various climate scenarios. The CALSIM II model was used for quantifying the changes in reservoir storage, river flows, delta channel flows, exports, water deliveries, and Yolo Bypass spills under conditions reflecting the operating and physical assumptions of the Alternative 1

Climate Sensitivity Analyses

All simulations described in the BDCP EIR/EIS have used the central climate change scenario (Q5) that is described in the earlier section. This Q5 scenario represents the ensemble-based change from the 20 to 30 climate projections that most closely reflect the ensemble median of change in annual temperature and precipitation. Four other climate scenarios, labeled as Q1, Q2, Q3, and Q4, have also been developed as described earlier. CALSIM II was simulated for the modified hydrologic inputs based on these climate scenarios. Climate sensitivity simulations have been prepared for both Existing Biological Condition (EBC) and Alternative 1 (PP) at 2025 and 2060 time periods. The purpose of conducting these simulations is to help describe the sensitivity in system variables with respect to climate uncertainty.

Figures 3-1 through 3-17 show the system responses for existing climate (black line), Q5 climate scenario (green line), and Q1-Q4 climate scenarios (red, orange, purple, and blue). The results are presented for the Early Long Term (~2025). Several key observations can be made based on these simulations:

- Shasta storage and operations are very sensitive to climate change and results are dependent on the climate scenario selected; three of the five scenarios result in critical low storage conditions in Shasta
- Oroville operations are less sensitive to climate scenarios than Shasta, although the increased flexibility of operations under the Alternative 1 appear to respond more favorably in terms of carryover storage than the comparable existing operations condition under climate change
- Substantial reductions in Sacramento River and San Joaquin River inflow to the Delta are observed the drier climate scenarios; substantial seasonal shifts in runoff of the main contributing watersheds are attenuated by reservoir operations
- Delta outflow is expected to reduce under all climate scenarios during April and June, reflective of the changes in seasonal snowmelt, although winter outflow could be more variable
- Changes in springtime X2 position across all climate scenarios is approximately 5 km, reflecting the uncertainty in estimates of this parameter under a range of climate futures
- Flows that are constrained due to operational objectives or requirements such as Old and Middle River under the EBC scenarios do not show significant sensitivity to climate change futures; however, under the Alternative 1 during periods in which the Old and Middle River flows are not

significantly governing (e.g. February through March) uncertainty in flow estimates are on the order of 2,000 cfs

- Similarly, exports that are significantly constrained under the EBC scenarios are not as sensitive to the selection of climate scenarios, but the sensitivity is increased considerably under the Alternative 1
- Annual exports under the Alternative 1 range from an increase of 800 TAF/YR (Q4 scenario) to a decrease of 700 TAF/YR (Q2 scenario) as compared to the Q5 climate scenario representing the considerable variability in projections of future climate, but the climate uncertainty range is less than half of this amount under the existing configuration reflecting the more restricted operations

Overall the relative changes due to the Alternative 1 operations as compared to the Existing Biological Conditions under the range of futures are similar to that described under the Q5 climate scenario. However, the Alternative 1 incorporates are more flexible operation that tends to show greater operational response (increased storage conditions, increased export variability) under the range of climate scenarios. The Alternative 1 operations generally increase upstream storage conditions as compared to the comparable EBC scenarios, but the effects of climate change under the drier scenarios are more significant than the improvements achieved under the Alternative 1.

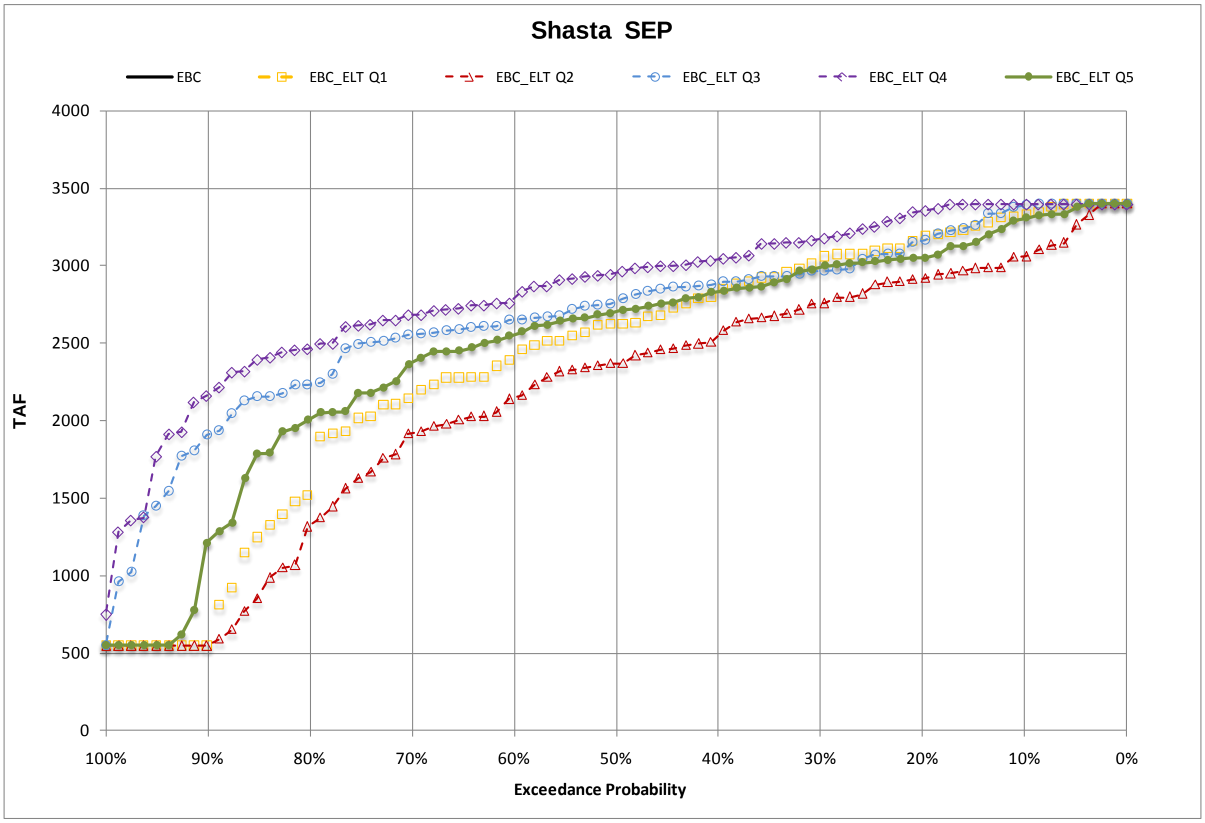


Figure 3-1: Shasta END OF SEPTEMBER Storage Uncertainty for the Existing Biological Conditions scenario

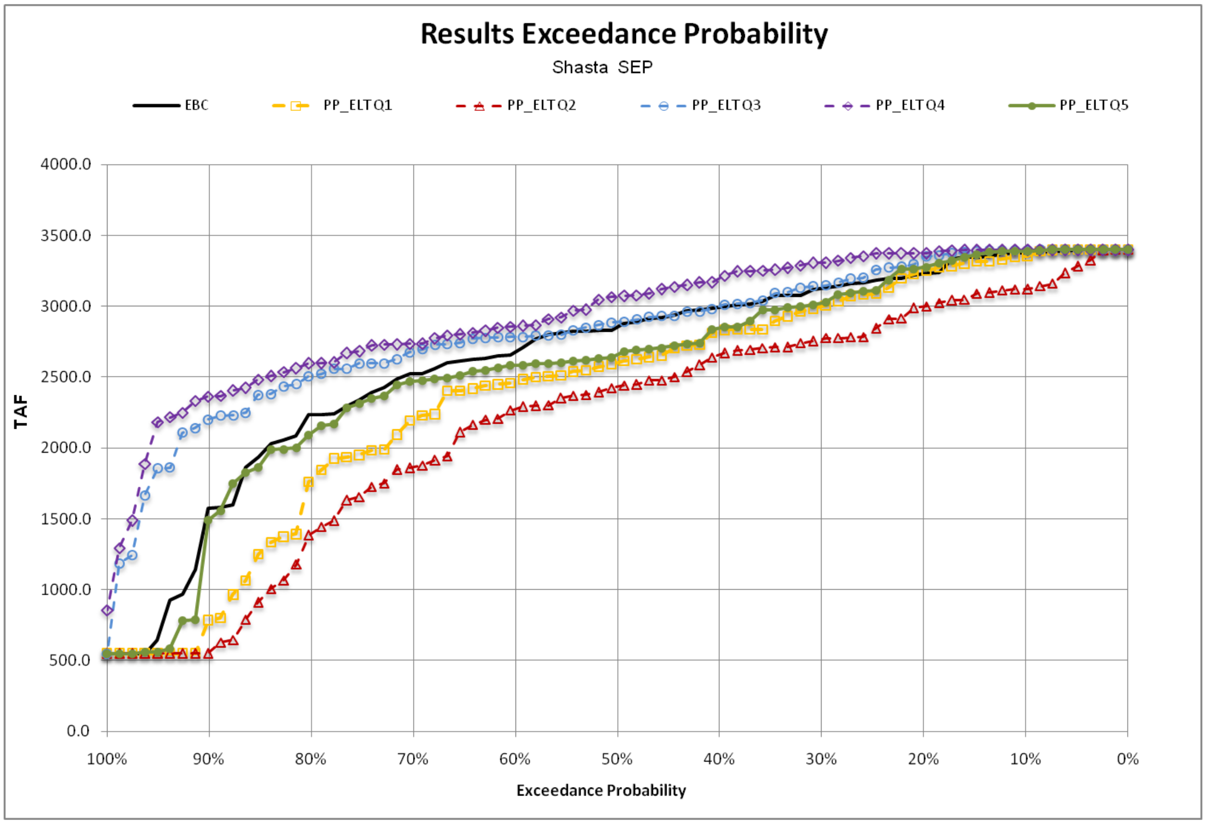


Figure 3-2. Shasta END OF SEPTEMBER Storage Uncertainty for the Alternative 1 Early Long-Term scenario

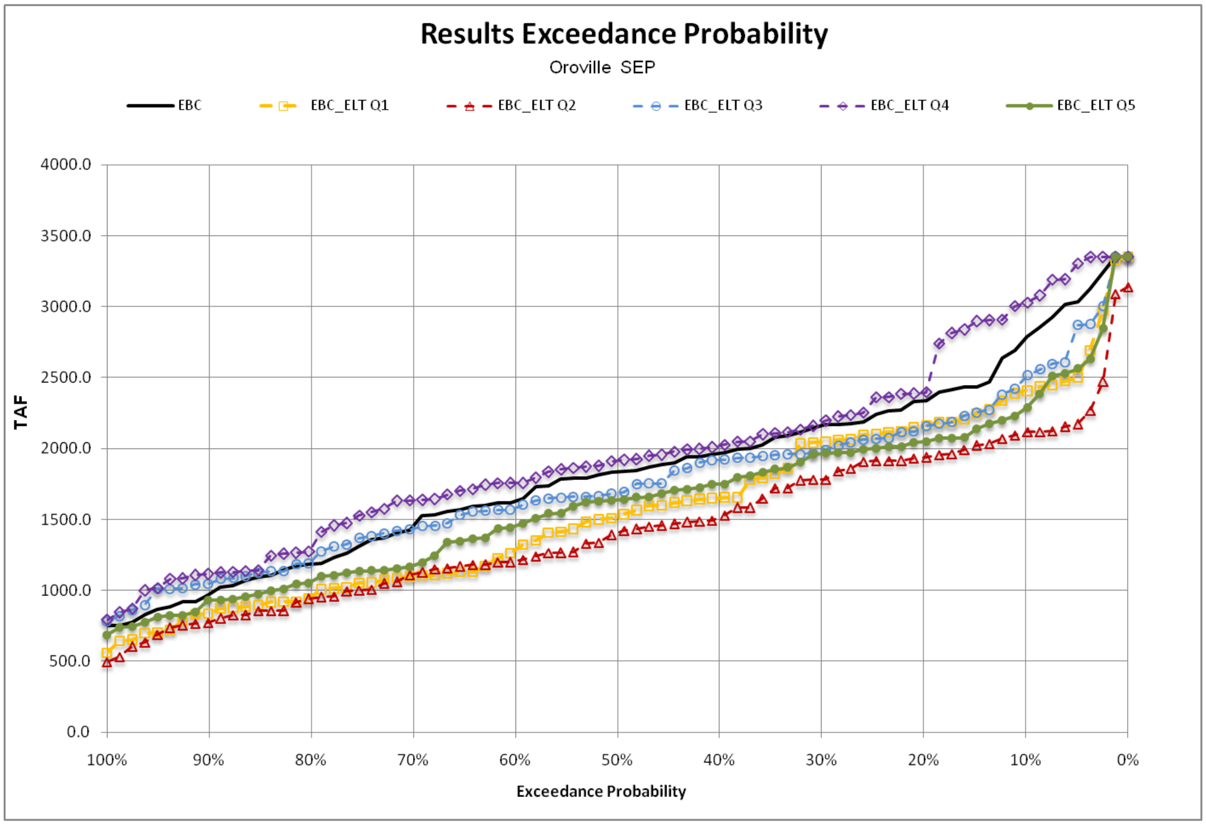


Figure 3-3. Oroville END OF SEPTEMBER Storage Uncertainty for the Existing Biological Conditions scenario

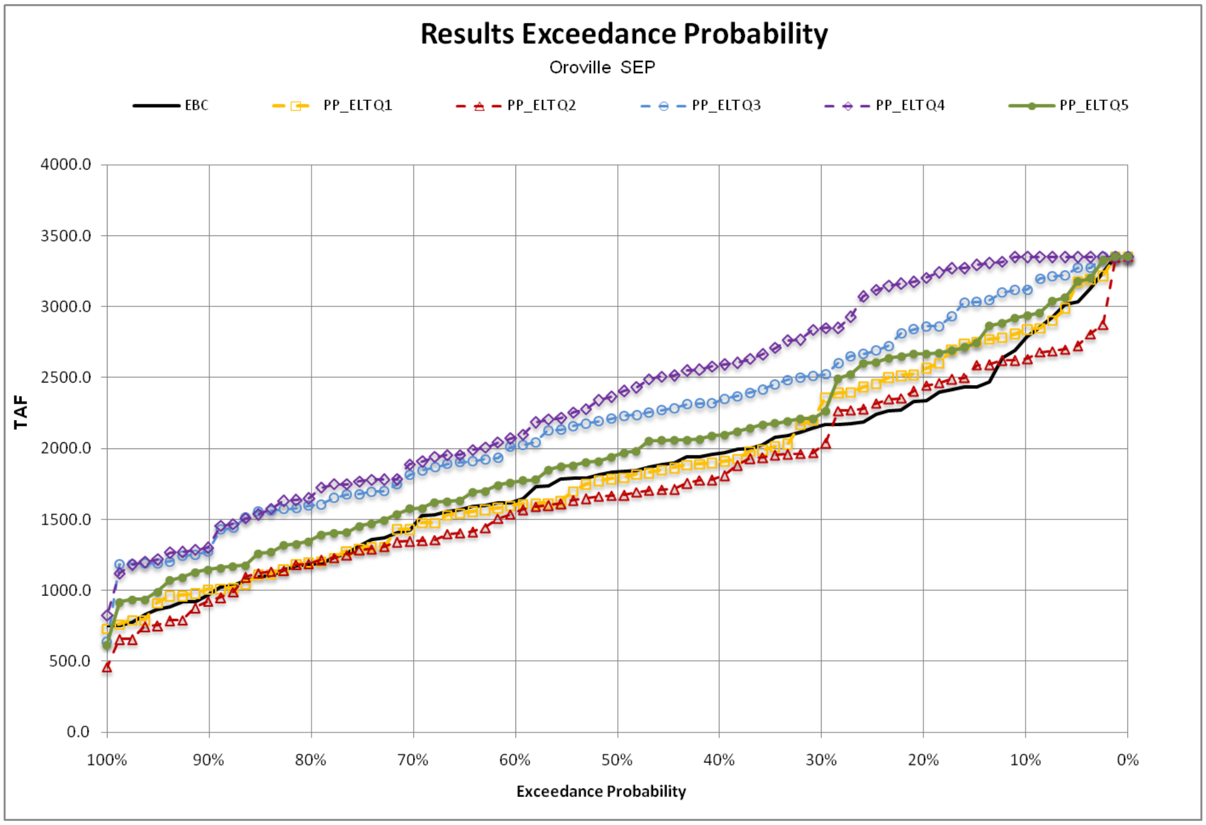


Figure 3-4. Oroville END OF SEPTEMBER Storage Uncertainty for the Alternative 1 Early Long-Term scenario

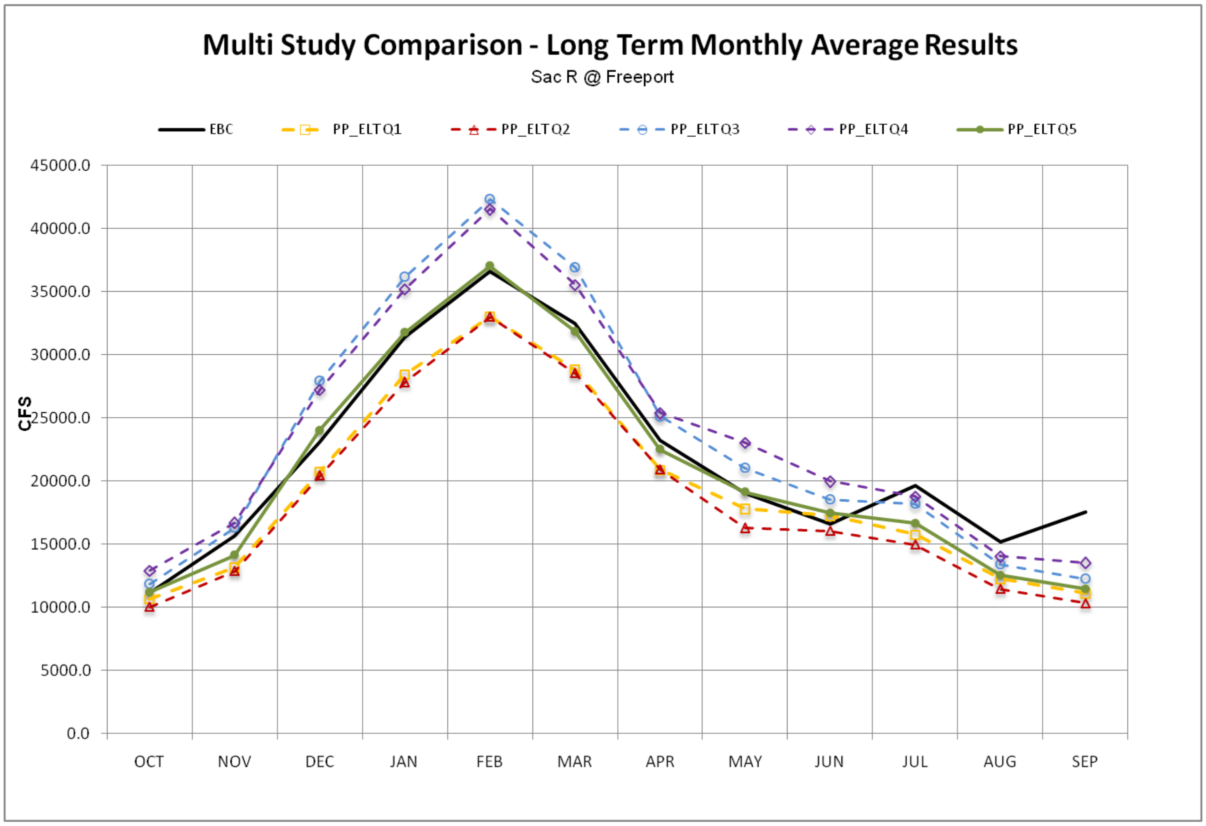


Figure 3-5. Sacramento River flow uncertainty for the Alternative 1 Early Long-Term scenario

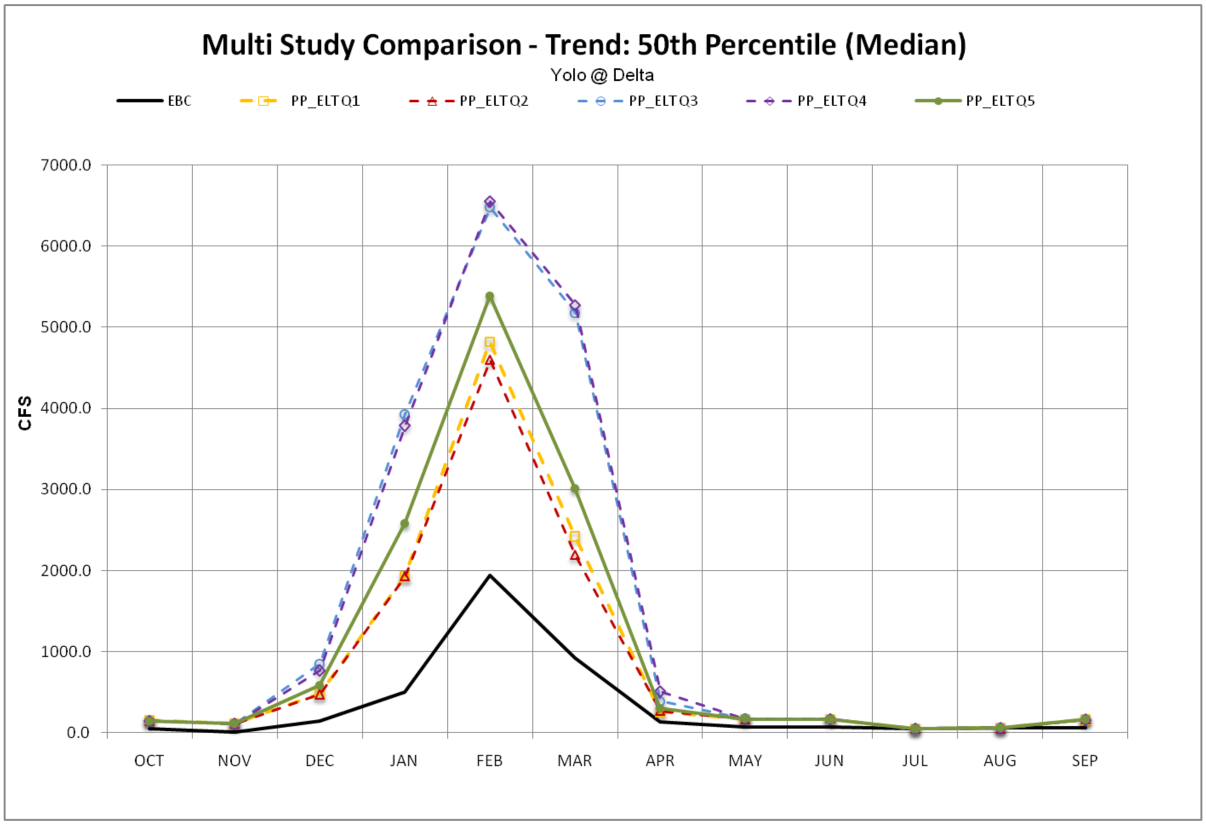


Figure 3-6. Yolo bypass Uncertainty for the Alternative 1 Early Long-Term scenario

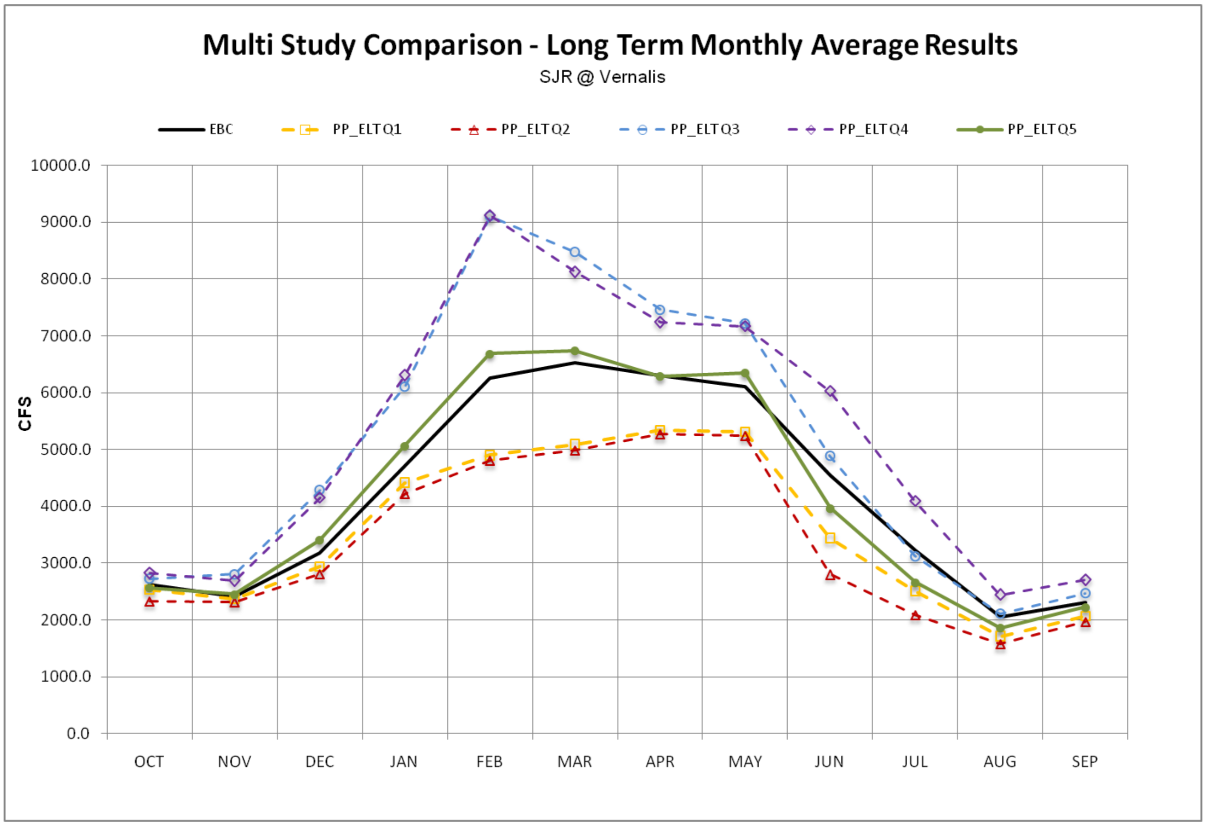


Figure 3-7. San Joaquin River flow uncertainty for the Alternative 1 Early Long-Term scenario

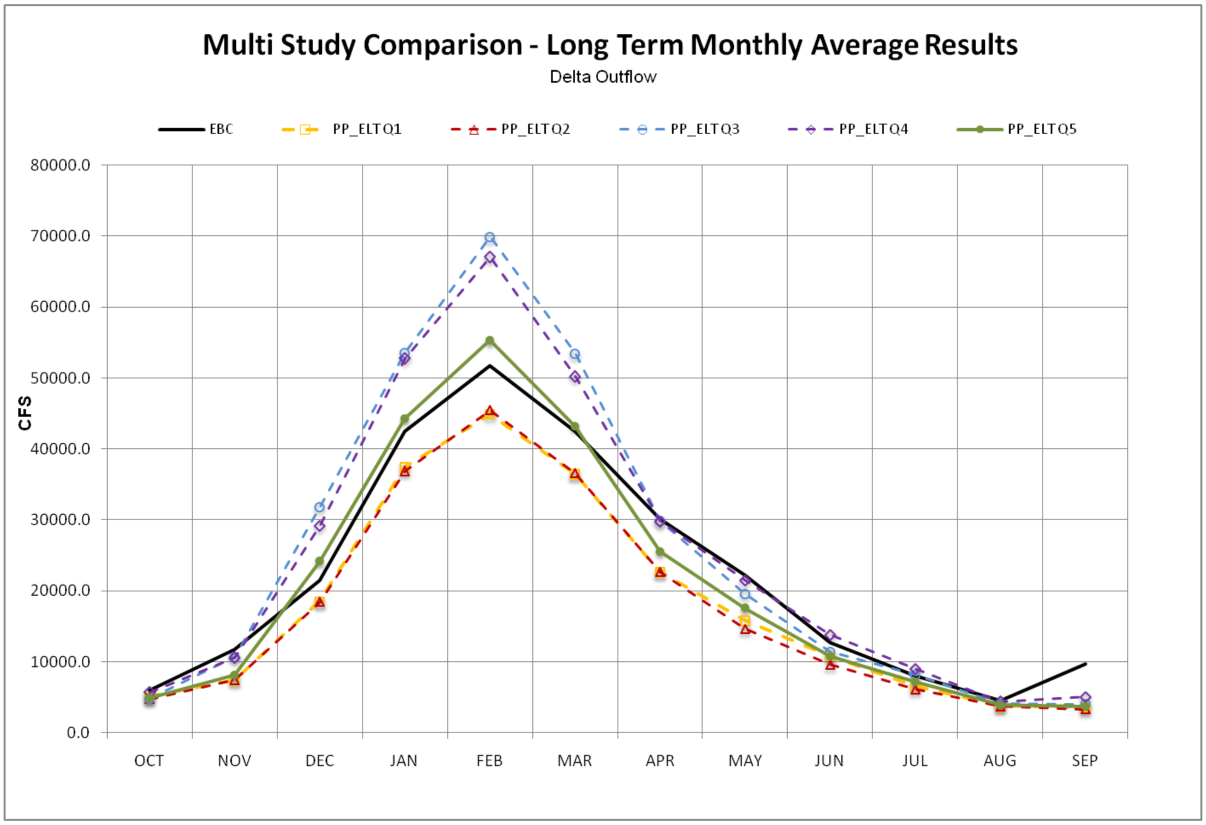


Figure 3-8. Delta outflow uncertainty for the Alternative 1 Early Long-Term scenario

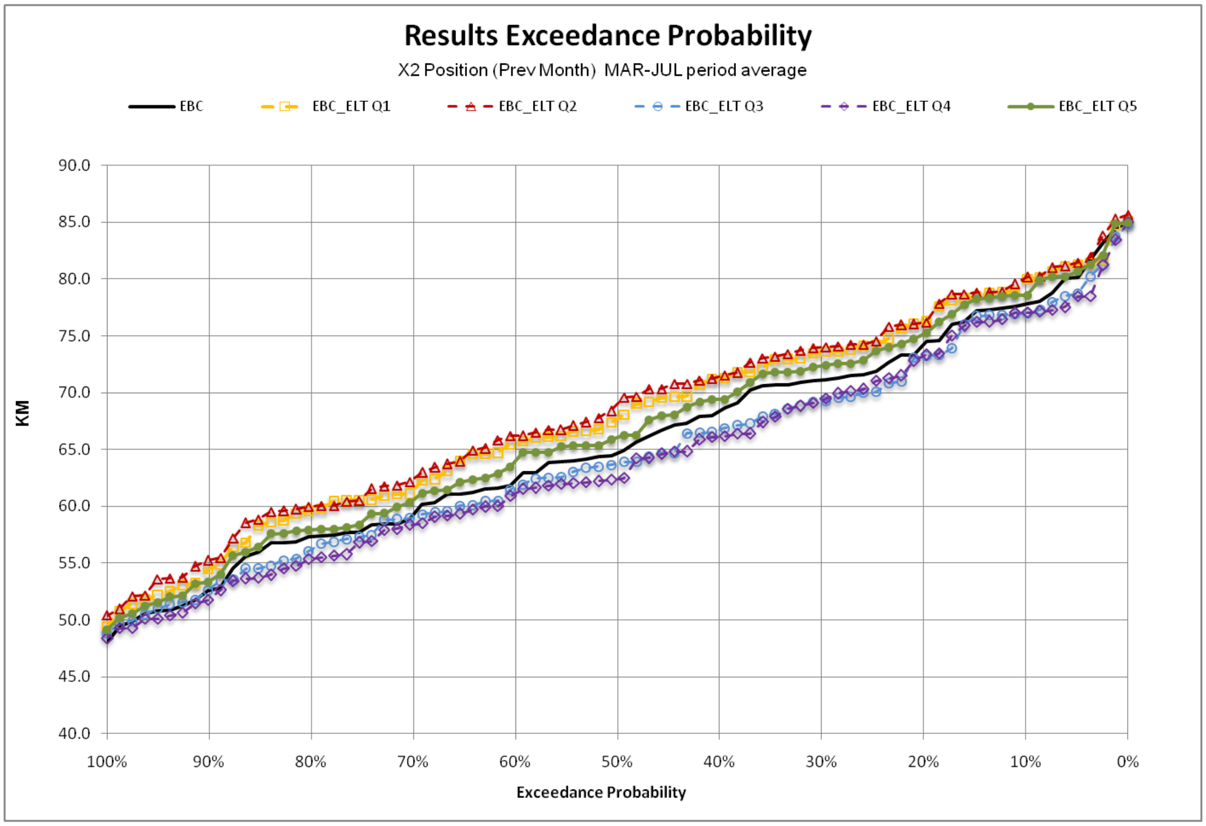


Figure 3-9. Spring X2 uncertainty for the Existing Biological Conditions scenario

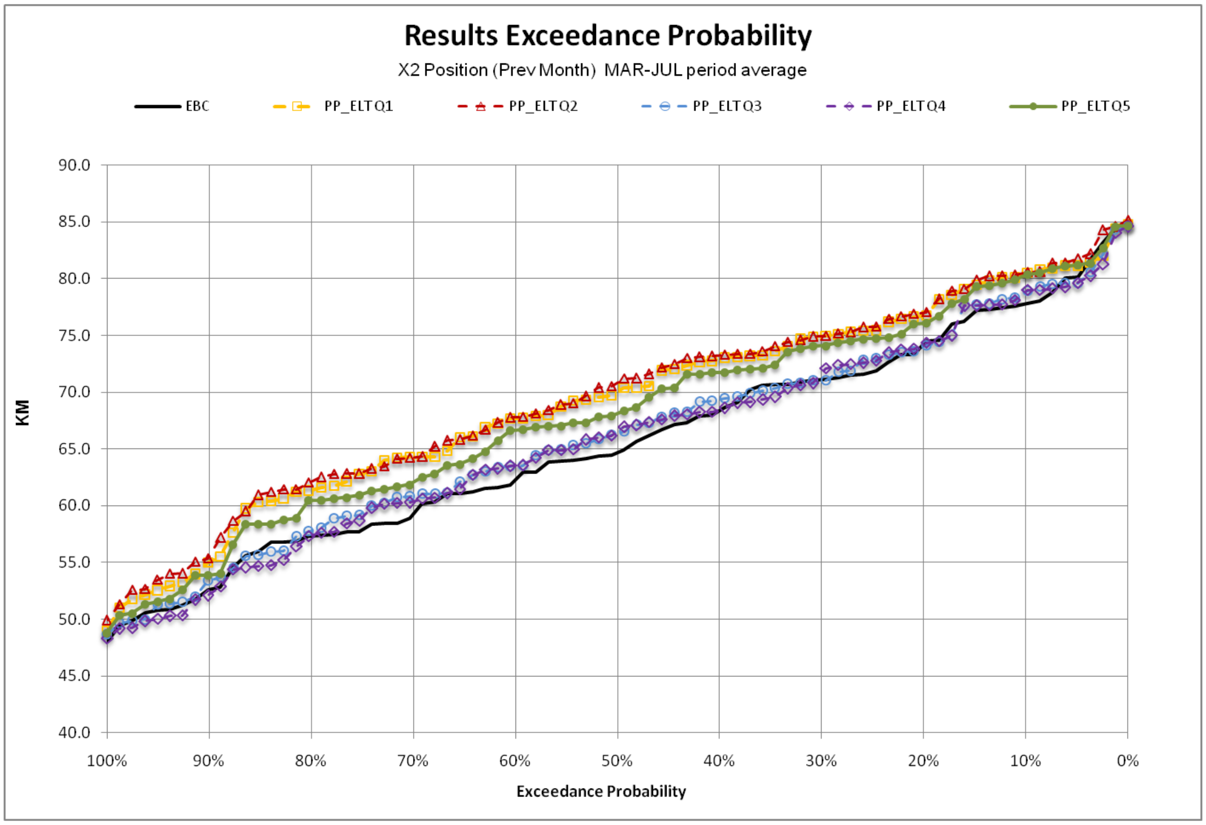


Figure 3-10. Spring X2 uncertainty for the Alternative 1 Early Long-Term scenario

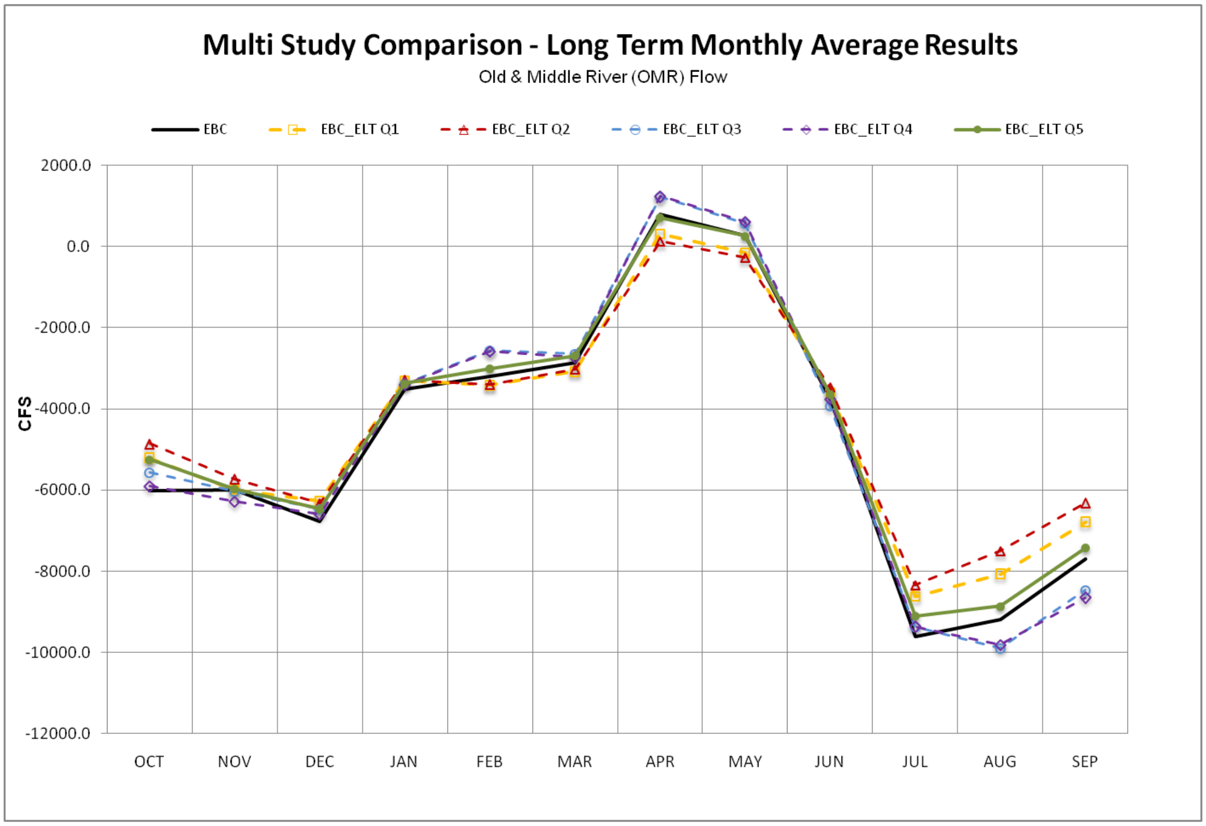


Figure 3-11. Old and Middle River combined flow uncertainty for the Existing Biological Conditions scenario

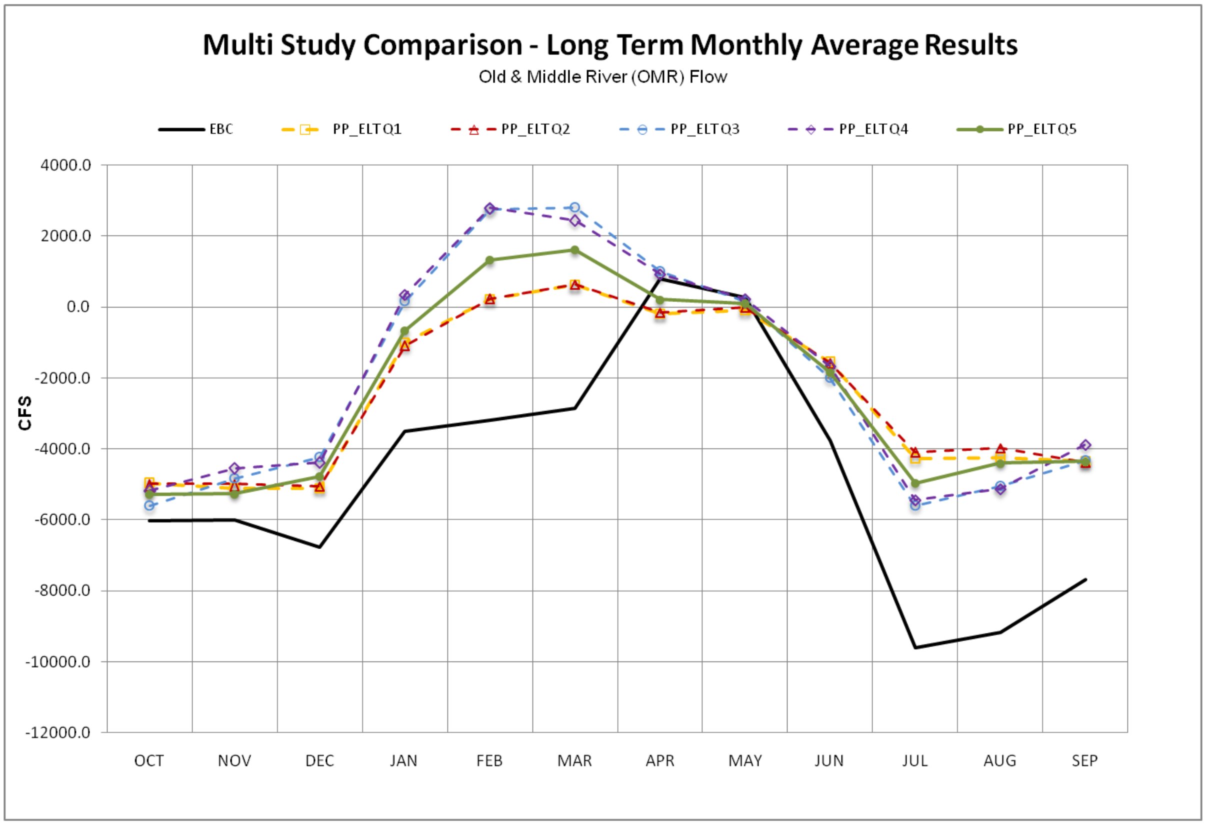


Figure 3-12. Old and Middle River combined flow uncertainty for the Alternative 1 Early Long-Term scenario

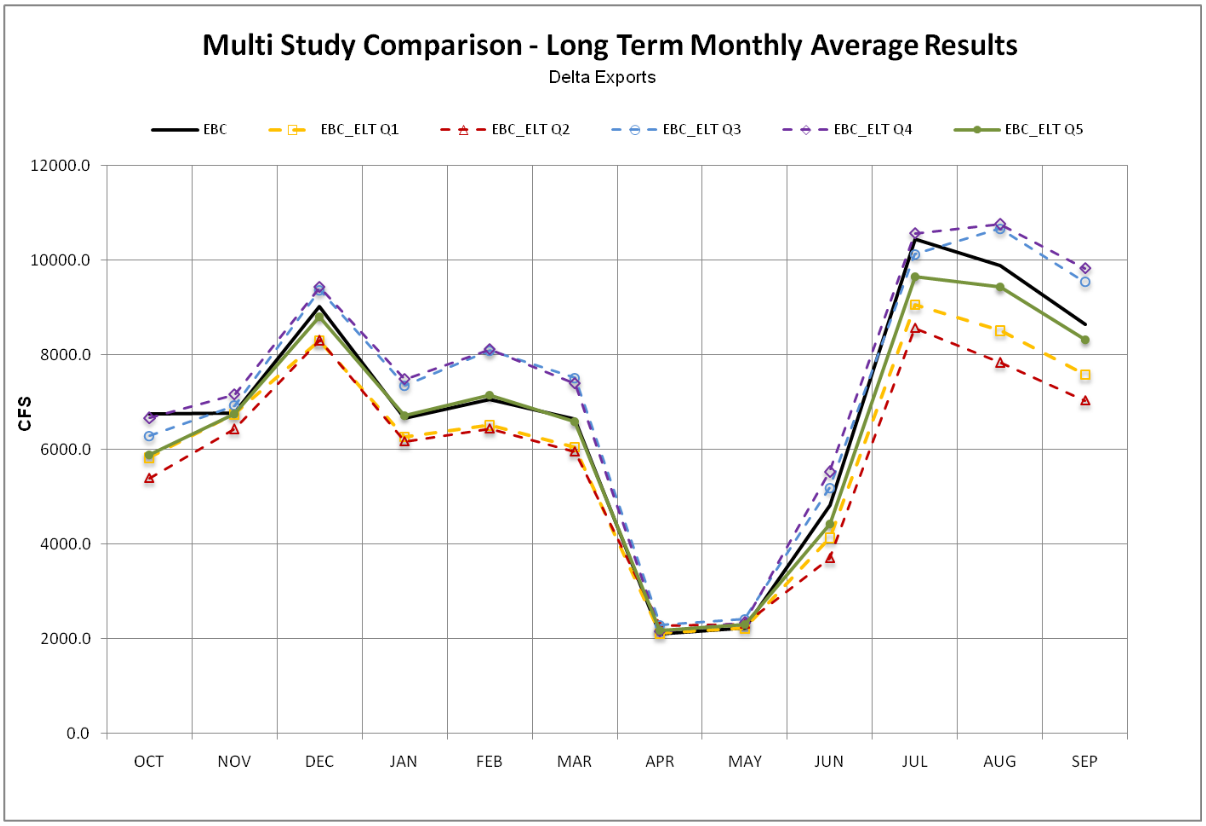


Figure 3-13. Seasonal Export uncertainty for the Existing Biological Conditions scenario

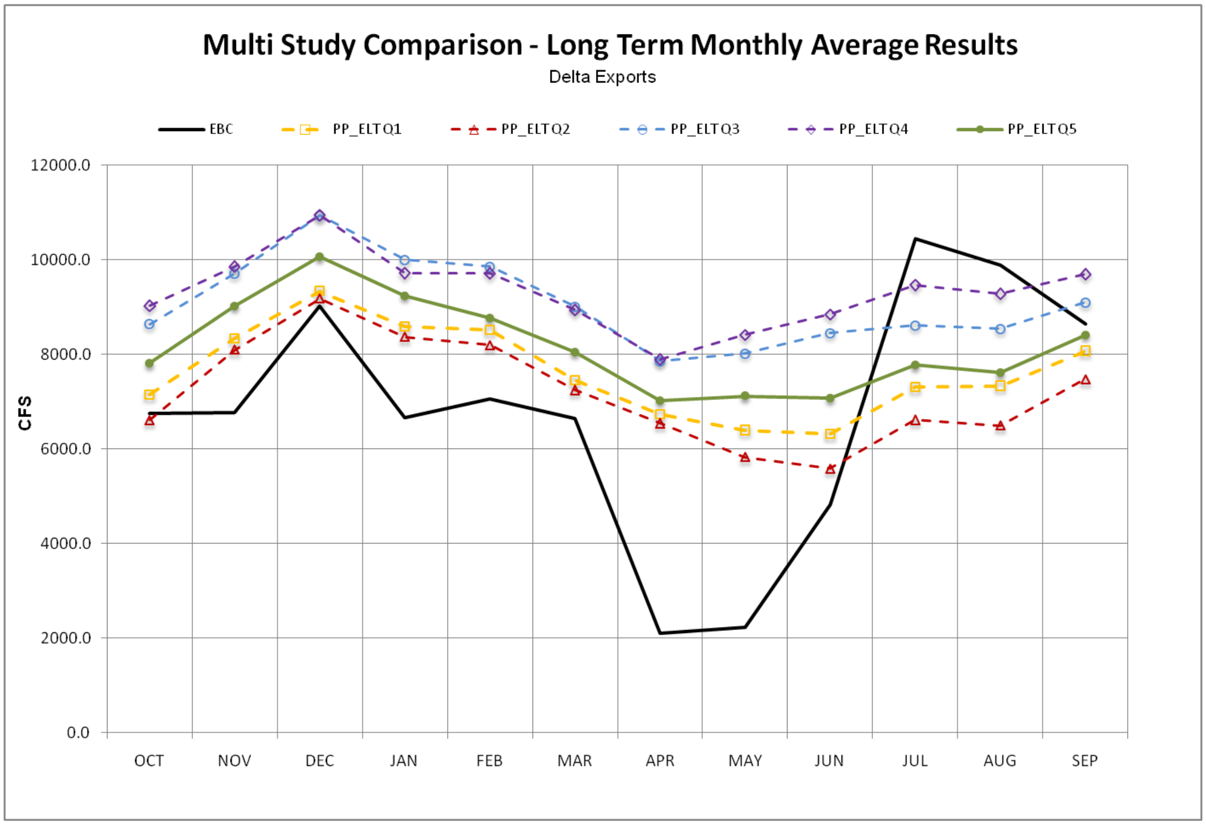


Figure 3-14. Seasonal Export uncertainty for the Alternative 1 Early Long-Term scenario

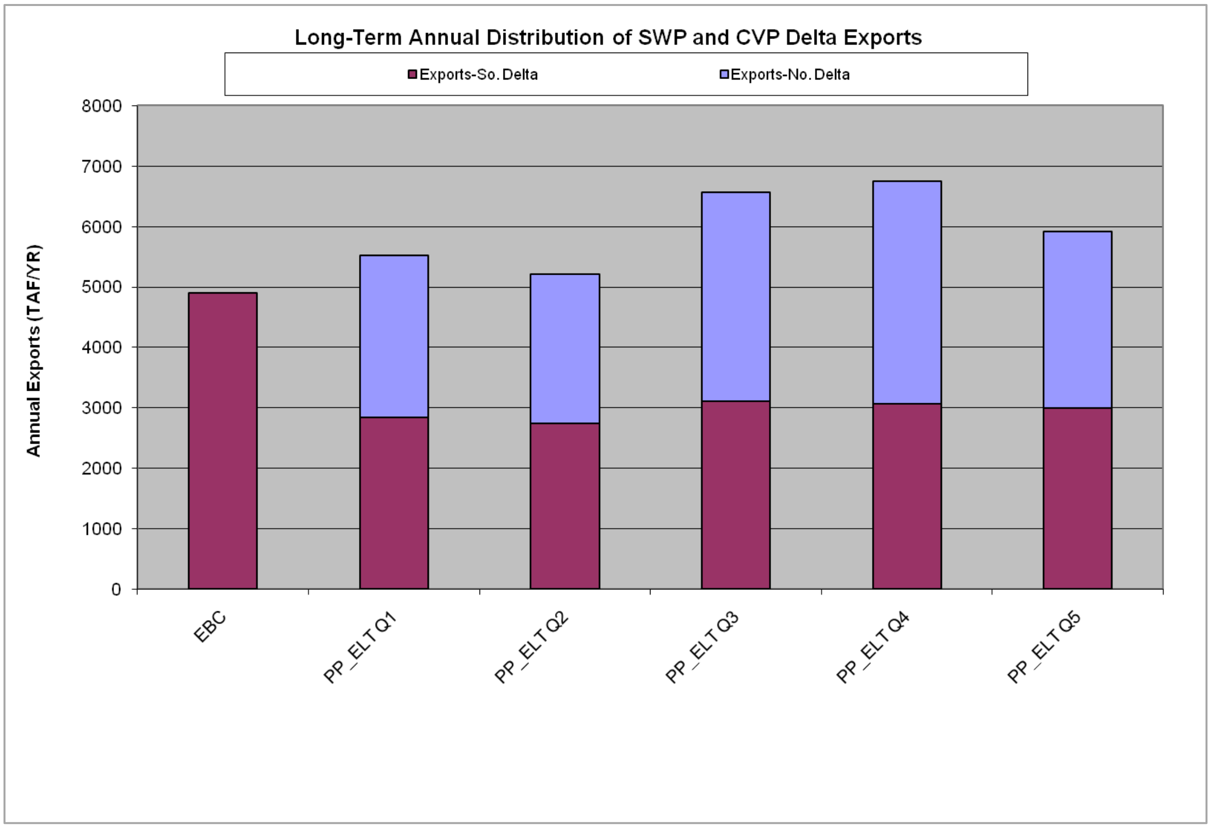


Figure 3-15. Changes in Distribution of Exports for the Alternative 1 Early Long-Term scenario

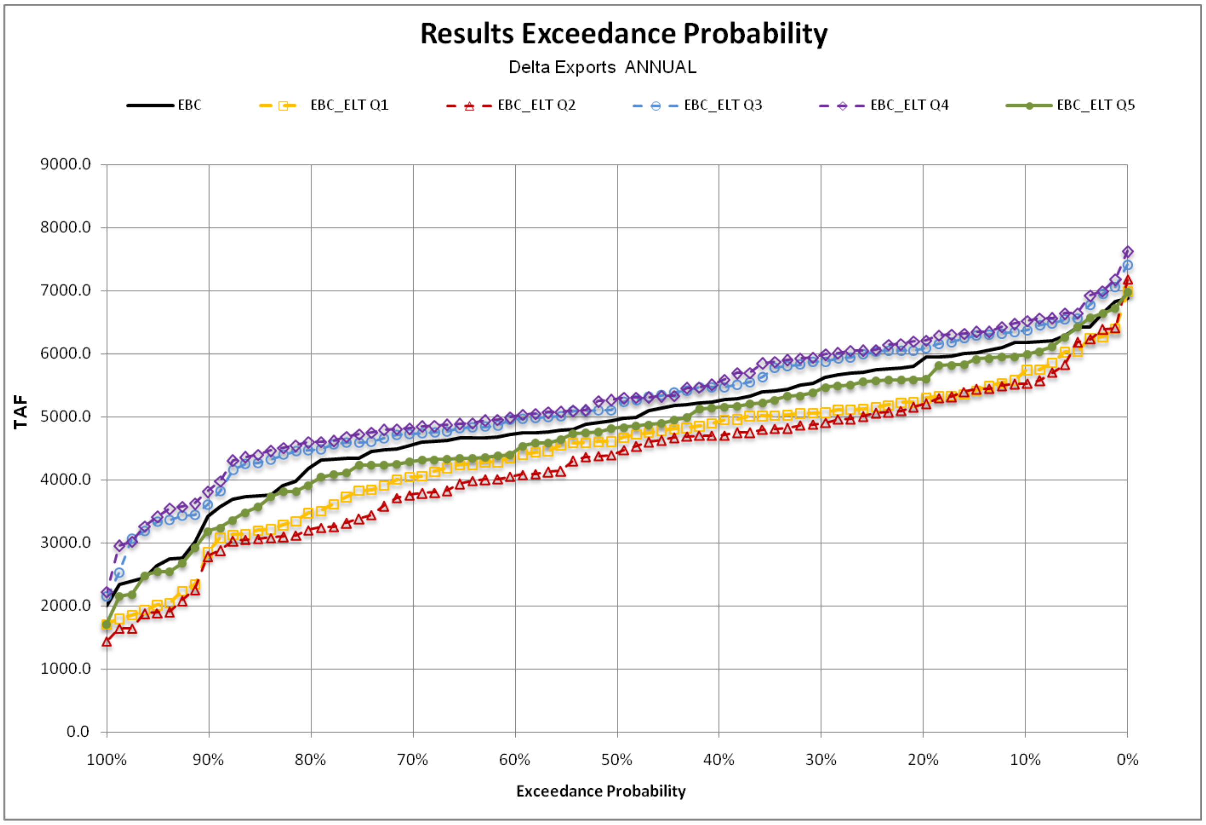


Figure 3-16. Export reliability uncertainty for the Existing Biological Conditions scenario

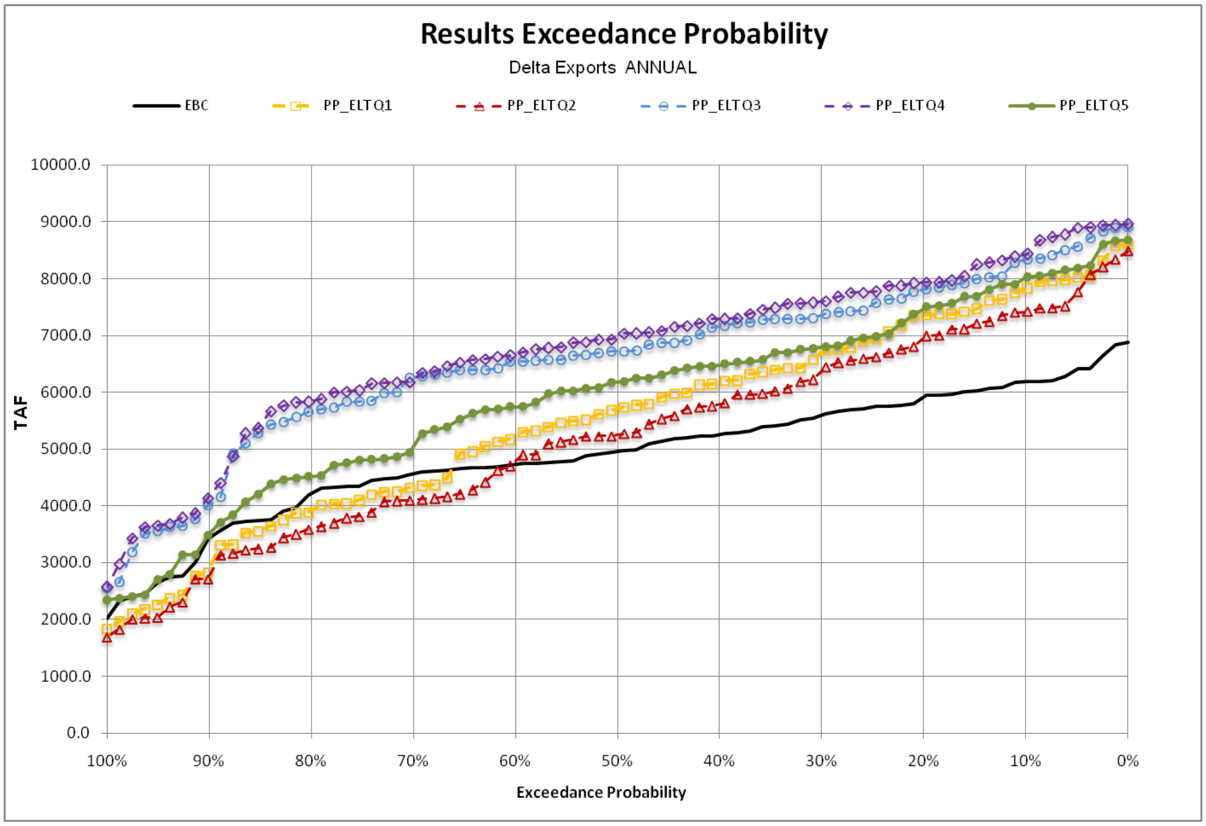


Figure 3-17. Export reliability uncertainty for the Alternative 1 Early Long-Term scenario

D.3.4. Modified CALSIM II Inputs for Climate Change

Updated input data due to climate change represented in CALSIM II are limited to hydrologic parameters that could be estimated by the climate change modeling. The modified parameters are listed below.

Rim Basin Inflows	*Basin Floor Inflows*
Trinity Lake Inflow	Clear Creek Inflow to Sacramento River
Lewiston Lake Inflow	Cottonwood Creek Inflow to Sacramento River
Shasta Lake Inflow	Cow Creek Inflow to Sacramento River
Black Butte Lake Inflow	Battle Creek Inflow to Sacramento River
Lake Oroville Inflow	Paynes Creek Inflow to Sacramento River
Folsom Lake Inflow	Red Bank Creek Inflow to Sacramento River
New Hogan Reservoir	Antelope Creek Inflow to Sacramento River
New Melones Reservoir Inflow	Mill Creek Inflow to Sacramento River
New Don Pedro Reservoir Inflow	Deer Creek Inflow to Sacramento River
Lake McClure Inflow	Elder Creek Inflow to Sacramento River
Eastman Lake Inflow	Thomes Creek Inflow to Sacramento River
Hensley Lake Inflow	Big Chico Creek Inflow to Sacramento River
Millerton Lake Inflow	Butte Creek Spills to Sutter Bypass
	Stony Creek Inflow to Stony Gorge Reservoir
	Little Stony Creek Inflow to East Park Reservoir
	Kelly Ridge Inflow to Feather River
	Yuba River Inflow to Feather River
	Bear River Inflow to Feather River
	American River Upstream Inflow to Folsom Reservoir
	Mokelumne River Inflow to Delta
	Cosumnes River Inflow to Delta

Other

- American River Runoff Forecast
- Feather River Runoff Forecast
- Sacramento River Runoff Forecast
- Water Year Types
  - Sacramento River index
  - San Joaquin River Index
  - Shasta Index
  - Feather River Index
  - American River Index (D893 and 40-30-30)
  - Trinity Index
- Delta Index
- USFWS BiOp Action 3 Temperature Trigger

Several other parameters, such as demand patterns, Delta salinity standards, and flood control curves that are likely to change under future climate cannot be modeled at this time because significant uncertainty exists for the potential adaptation measures. Model assumptions regarding CVP and SWP operations in future without policy decisions by stakeholders would be deemed speculative. Therefore, CALSIM II results for BDCP represent the risks to operations, water users, and the environment in the absence of dynamic adaptation for climate change.

Climate change conditions are found to exacerbate dry hydrologic conditions. As noted elsewhere, under such extreme hydrologic and operational conditions where there is not enough water supply to meet all requirements, CALSIM II utilizes a series of operating rules to reach a solution to allow for the continuation of the simulation. It is recognized that these operating rules are a simplified version of the very complex decision processes that SWP and CVP operators would use in actual extreme conditions. Despite detailed model inputs and assumptions, in very dry years, the model will still sometimes show dead pool conditions that may result in instances in which flow conditions fall short of minimum flow criteria, salinity conditions may exceed salinity standards, diversion conditions fall short of allocated diversion amounts, and operating agreements are not met. Such model results are anomalies that reflect the inability of the model to make real-time policy decisions under extreme circumstances, as the actual (human) operators must do. Thus, any operations simulated due to reservoir storage conditions being near dead pool should only be considered an indicator of stressed water supply conditions under that Alternative, and should not necessarily be understood to reflect literally what would occur in the future. In actual future operations, as has always been the case in the past, the project operators would work in real-time to satisfy legal and contractual obligations given then current conditions and hydrologic constraints.

It should also be noted that the BDCP EIR/EIS is written in a comparative manner, where climate change assumptions are consistent between the No Action Alternative and the BDCP action alternatives. Therefore, the incremental changes under BDCP action alternatives with respect to the No Action Alternative provide indication of the effects related to BDCP action alternatives.

D.4. Yolo Bypass Floodplain Hydraulics

The goal of the Yolo Bypass floodplain hydraulic study is to develop rating curves to define the amount of flow that would spill over a modified Fremont Weir based on a specific Sacramento River flow and to define the amount of inundation that would occur at the flow rate. The derived rating curves are used directly in the CALSIM II model to define the monthly and daily spills over the Fremont Weir and Sacramento Weir when integrated with the system operations and other components of the BDCP Alternatives. This section describes the development of this hydraulic characterization information. In addition, an initial assessment of the inundation characteristics (area, depth, velocity, and travel time) within the Yolo Bypass was conducted. This section also includes a comparison to observed inundation areas and other multi-dimensional modeling efforts under assumed flow rates.

The daily spills derived from CALSIM II are used to evaluate the Fremont Weir and total Yolo Bypass flows, frequency, magnitude, and duration of inundation for both the current conditions and the BDCP Alternatives. This information is then used to study the effects on the food web and various species that use Yolo Bypass. The analysis to determine the biological effects is described in aquatic resources chapter and the BDCP documents.

This section includes a technical memorandum previously documented for use in the BDCP Effects Analysis.

TECHNICAL MEMORANDUM

YOLO BYPASS FLOODPLAIN HYDRAULICS

PREPARED FOR: SAIC

PREPARED BY: CH2M HILL

DATE: January, 2011

Description

The flow from the Sacramento River through the proposed low-elevation section of the Fremont Weir needs to be conveyed downstream to the head of Tule Canal, along the current location of the Toe Drain shown on **Figure 4-1**. Preliminary hydraulic analyses were performed along with hydrologic analysis to ascertain the effectiveness of such a modification of the Weir. This section describes the data sources and methods used to develop an assessment of the frequency and duration of Fremont Weir spills under current and proposed configurations of the Fremont Weir. The characteristics of inundation (area, depth, velocity, and travel time) within the Yolo Bypass are also assessed through the development and application of a preliminary hydraulic model.

The primary objectives of this technical study are to: (1) evaluate the range of increased inundation frequency and duration of the Yolo Bypass as a result of modification to the Fremont Weir and operation, (2) summarize existing knowledge about the anticipated effects of these modifications on covered fish species both within the Yolo Bypass and elsewhere in the Delta and bays, (3) make recommendations to the BDCP Integration Team to facilitate discussion about further refining these operational parameters.

The Bay Delta Conservation Plan (BDCP) Habitat Restoration Technical Team has proposed a modification to the existing Fremont Weir to allow greater frequency of floodplain activation in the Yolo Bypass. Sacramento River flows over the weir, and into the Yolo Bypass, are often limited due to insufficient river stage as compared to the weir crest elevation. By constructing a low-elevation (“notched”) section in the Fremont Weir, lower Sacramento River flows would be necessary to provide the Yolo Bypass with a minimum flow to flood part of the bypass area and sustain inundation to benefit multiple covered fish species. This notched section and associated conveyance were evaluated and are described in this technical memorandum.

Overview of Yolo Bypass Floodplain Hydraulics

Relationship between Sacramento River Flow and Fremont Weir Spills

The two sets of estimated daily averages for stage and flow, Sacramento River Stage at Fremont and Fremont Weir spill flows, were used to develop a correlation between Fremont Weir spill flow and Sacramento River flow (details on section 4.5). The correlation equation was found by a polynomial regression on a filtered daily spill data set. The filtered records reflect years where the same trend was followed for a given range of river flow values. In **Figure 4-2**, the observed Fremont Weir spill data during the period 1984 to 2007 is shown as a function of the Sacramento River flows. As can be observed, for a river flow range of 50,000 to 90,000 cfs, observed records followed the same trend except from records from years: 1984, 1986, 1993, 1999 and 2006. Even though, years 1995 and 1996 follow a different trend, records from these years were considered in the polynomial regression since the divergence takes place outside the mentioned range.

Since the Sacramento River at Fremont gage only contains records from 1984 to present, it was desirable to extend the flow time series using the Sacramento River at Verona gage. The relationship between flows at these two locations for the overlapping period is shown in **Figure 4-3**. This figure indicates a strong correlation between these flows. Therefore, the equation provided on **Figure 4-3** was developed for use in approximating Sacramento River at Fremont flows. The result of this conversion is an extended Sacramento River flow at Fremont time series that was used to evaluate the historical performance of the proposed notch in comparison with the current Fremont Weir configuration.

Using the regression equation described above, the historical Fremont Weir spills into the Yolo Bypass were reconstructed end extended to the 1929-2008 period based on Sacramento River flows at Fremont extended based on Sacramento flows at Verona vs. Sacramento flow at Fremont correlation. **Figure 4-4** shows the correlation between the observed and simulated values for the Sacramento River flow range of 50,000 to 90,000 cfs. The R2 of 0.9171 and the graph indicate that the regression provides a reasonable estimate of spills over the Fremont Weir. The value is not closer to 1.0 due to the outlier data values from 1984, 1986, 1993, and 1999.

This analysis was done for flows below 90,000 cfs. It is important to realize that once flows get higher than that the correlations will change due to the large flows from Sacramento River into the Yolo bypass.

Range of Target Flows in the Yolo Bypass

The range of target flows in the Yolo Bypass was evaluated based on anticipated inundated area, water depth, and travel times. Based on the modeling results and comparison to previous work, it was believed that flows in the range of 3,000 to 6,000 cfs would provide sufficient surface area and water depths for desirable habitat. For these flows, the mean water depths were generally within the 2-3 foot range, velocities were less than 2.0 feet per second, and travel times were in the range of 3-4 days. The anticipated inundated area would range between 11,000 and 21,000 acres.

Modeling Tools

Hydraulic Model Development and Application

The inundation characteristics of Yolo Bypass were evaluated by applying a coarse-level HEC-RAS model of the Yolo Bypass from Fremont Weir to Liberty Island. The model was constructed to evaluate approximate inundated area, water depth, and velocities through the Yolo Bypass at various flow levels. The model should be considered preliminary due to limited extent of Toe Drain bathymetry and limited calibration data sets.

Elevation and Bathymetric Data

The initial HEC-RAS model incorporated cross-sections derived from the USGS National Elevation Dataset (NED) Digital Elevation Model (DEM) (USGS, 2006). The NED DEM represents land and water surface elevation, but does not include bathymetric data. In order to better understand the terrain and spatial influence of smaller flows in the Yolo Bypass, a new elevation dataset based on the U.S Army Corps of Engineers (USACE) Yolo Bypass RMA2 Model (USACE, 2007) was subsequently incorporated. This dataset contained bathymetry for Liberty Island. The USACE dataset was modified to incorporate surveyed cross section information provided by DWR for 14 cross sections (12 locations) between Liberty Island and I-80. The location of the survey points are shown in **Figure 4-5**. Finally, the elevation dataset was modified to estimate the Toe Drain bathymetry from I-80 to the Fremont Weir.

After converting to proper coordinates and vertical datum, a Triangulated Irregular Network (TIN) elevation surface was created with the merge of the USACE model elevation data and DWR survey points. The TIN was then used to generate cross sections of the Yolo Bypass for use in the HEC-RAS model. No cross section data was available for the Toe Drain canal from the Sacramento Weir to near the Fremont Weir. The cross-section of the region was estimated based on the available cross sections for the Toe Drain obtained from the DWR survey.

Boundary Conditions and Hydraulic Parameters

A HEC-RAS steady flow analysis was performed at 100, 250, 500, 1,000, 2,000, 3,000, 4,000, 5,000, 6,000, 7,000, 8,000, 9,000 and 10,000 cfs. The steady flow conditions assumed a downstream water surface elevation of 1.25 m (4.1 ft NAVD 1988), which corresponds to observed average stage data from Yolo Bypass at Liberty Island location (CDEC station LIY). The LIY CDEC station is under tidal influence and could range from 0 to 2.5 m (0 to 8.2 ft)

Model Calibration

A profile of the entire Yolo Bypass with the water surface elevation for 1,000, 5,000 and 10,000 cfs is presented in **Figure 4-6**. The units for elevation and cross section distances are in meters due to the HEC-HAS output data. The profile shows the lowest point of each cross section, from the Fremont Weir to Liberty Island, which represents the Toe Drain or Tule Canal profile. The profile also indicates the approximate location of the surveyed cross sections. Flows greater than 3,000 cfs are expected to begin causing inundation outside of the Toe Drain. **Table 4-1** presents the simulated mean depth, surface area, mean velocity, and travel time for various Fremont Weir flows. The high depth and low surface area for 1,000 and 2,000 cfs flow range is due to the fact that most of the flow stays within the Toe Drain.

Initially, a single Manning's coefficient value was assumed for all cross sections along the length of the bypass. The USACE Yolo bypass 2-D model (USACE, 2007) assumes that 70% of the land is covered by agricultural fields with Manning's coefficient of 0.03. The remaining 30% of land has a significant percentage that is assumed to be covered by wild grassland, with a Manning's coefficient of 0.045. This current modeling effort initially assumed a Manning's coefficient of 0.04 for the entire Yolo Bypass.

Further field observations, like the one presented on **Figure 4-7**, and historic flow-stage observations for Lisbon Weir (**Figure 4-8**), has shown that a lower Manning's coefficient for the Toe Drain would be more appropriate. A range varying from 0.016 to 0.033 of Manning's coefficient was initially selected from Chow (1959) based on the nature of the channel and photographs taken by DWR staff on February 18, 2009 (**Figure 4-7**). **Figure 4-7** also shows that flows on this date, approximately 2,000 cfs, are contained within the banks of the Toe Drain at Lisbon Weir.

The historical Lisbon Weir flow versus stage measurements (**Figure 4-8**) were used to calibrate the model. **Figure 4-8** shows water surface elevation at the Lisbon Weir cross section (HEC-RAS cross section 24842.05) as a function of Toe Drain Manning's coefficient. Based on the field observations (**Figure 4-7**) and the data presented on **Figure 4-8**, the Manning's coefficient of 0.022 was selected for the Toe Drain channel. A Manning's coefficient of 0.04 was retained for the overbank areas outside of the Toe Drain.

The surface area in **Table 4-1** represents more detailed area values then what is obtained directly from HEC-RAS results, which interpolates areas between cross sections. The areas in **Table 4-1** were obtained by transferring the HEC-RAS model results to GIS and computing areas.

Figure 4-9 shows the inundated areas for various flow levels determined from the GIS mapping. Due to the topography of the Yolo Bypass, there is a dramatic increase in surface area as flow exceeds that which can be conveyed in the Toe Drain. At 6,000 cfs flow, approximately 21,500 acres are expected to be inundated, but this value is only increased to 27,100 acres at 10,000 cfs. It should be noted that the surface area values in Table 2 include approximately 3,700 acres of Liberty Island that were assumed constantly inundated. This amount should be subtracted of the total flooded area presented in **Table 4-1** to estimate total new flooded areas. For comparative analysis this is not significant since the Liberty Island flooded area remains practically unchanged through the range of flows considered in this report.

Model Comparison

The results presented on previous sections were compared with results of a linear interpolation model published by Sommer et al. (2004). In Sommer et al., linear interpolation of gage elevations between stations was used to estimate water surface between gages. **Figure 4-10** presents a comparison between the final HEC-RAS model and the model results published by Sommer et al. (2004). The comparison shows that the linear interpolation model in general overestimates areas when compared with the hydraulic HEC-RAS model. A possible explanation for the difference between the linear interpolation and the HEC-RAS model results may be due to the assumption used in the Sommer et al that the water surface elevation has a constant slope, which may not be valid at higher flows. This assumption may overestimate areas if gages are spaced apart by long distances, which is the case of the two gages used in the interpolation model that are covering the area between I-5 and Lisbon Weir. **Figure 4-11** illustrates how possible overestimation could occur in high flows between two gages used in the linear interpolation model. It is also important to note that the HEC-RAS simulations only consider flows over the Fremont Weir and do not account for tributary flows. Although there is a significant difference between the HEC-RAS and the linear interpolation models at higher flows, both models show that the increase in inundated areas is reduced at flows greater than 5,000 cfs.

It is noteworthy to mention that field measurements like the ones presented on **Figure 4-7** and **Figure 4-8**, show that flows below 2,000 cfs are fully contained in the Toe Drain channel, therefore the change in flooded area from 0 to 2,000 cfs is minimal.

A comparison of HEC-RAS modeling results against flooded areas registered by satellite images was also performed. Four spill events with were found among several satellite images. **Table 4-2** lists the 4 events, the estimated flows at Fremont Weir as an average for the last 7 days, and the estimated area delineated from a 300X300m resolution images. The HEC-RAS simulated area results compare well to those estimated from the images. The January 2003 and February 2006 events are included in **Figure 4-10**.

During late 2010 a separate modeling effort attempting to characterize the flow-inundation aspects of the Yolo Bypass was conducted using the MIKE21 two-dimensional model (CBEC 2010). Despite initial efforts suggesting significant differences between the two modeling approaches, the two models result in similar inundation characteristics as shown in Figure 4-12. The MIKE21 model was simulated using transient flows for the Fremont Weir and Westside drainages and includes a new bathymetric data set, while the HEC-RAS model was simulated as steady state conditions with the bathymetry described herein. Both model simulations produce similar inundation acreage values for flows up to 6,000 cfs but show some divergence at higher flows. Overall, the model simulations are similar for the flow range considered in the BDCP.

Modeling Methods

Freemont Weir Model for Current Configuration

Data Sources

The hydrologic analysis is based on the available historical records of the Sacramento River station at Fremont (FRE), managed by the Department of Water Resources (DWR). The data types used were river stage (feet) and river discharge (cfs). The FRE station has records for daily average flows from only 1996 to present date; however, hourly data river stages and river discharge flows are available since 1984. These hourly records were used to estimate daily average values for a more complete time series. **Table 4-3** describes the stage and flow data sources used in this study. Several time series data sets were needed and the development of these time series is explained in the following section.

The conversion of hourly data to daily data was performed by the HEC-DSS Vue software function that averages the hourly data in to a daily time series. **Figure 4-13** shows the time series of CDEC data converted from hourly to daily time step for stage in the Sacramento River at Fremont and Fremont Weir spills into the Yolo Bypass.

The longest continuous recording station applicable to this study was found for the Sacramento River at Verona USGS gage. This time series was used to compare the current and proposed configurations of the Fremont Weir over a much longer period of record than exists directly at the Fremont Weir site.

Data Development

Three time series were developed from Fremont hourly stage data and Fremont hourly spill data from CDEC. The following is a description of the process for utilizing and transforming the hourly CDEC data:

- Daily Fremont Stage: Computed from HEC-DSS Vue function that averages hourly time series into daily time series.
- Daily Sacramento River at Fremont flows: Computed using the daily Fremont stage time series and the synthetic rating curve for the Sacramento River at Fremont developed by the California Division of Flood Management (DFM) shown on **Figure 4-14**. Given the rating curve characteristics, records below 12 ft and above 45 ft were considered as missing values.
- Daily Fremont Spills: Computed from HEC-DSS Vue function that averages hourly time series into daily time series. Values described as below the rating table (BRT, code -9998) were considered as zero values and, above rating table (ART, code -9997) as missing values.

The Sacramento River at Fremont stage (converted from USED to NAVD88) time series of daily average data is presented on **Figure 4-15, Figure 4-16, and Figure 4-17** with the periods in which stage exceeded the Fremont Weir crest identified. The red bars on the figures represent the consecutive number of days for which there was flow over the Weir. The figures show that 28 such events were recorded between January of 1984 and December of 2007.

The computed Sacramento River at Fremont daily stage is plotted as a daily exceedance probability (**Figure 4-18**). **Figure 4-18** shows that under historical hydrology, the daily probability of stage greater than weir crest 33.5 ft USED is approximately 17% during January-May, but only 6% when evaluated for the entire year (i.e. stage is sufficient to generate Fremont Weir spills 17% of the days within the January – May period).

Figure 4-19 presents Fremont Weir daily spill probability of exceedance for the entire time series period (Jan 1984-Dec-2007). The figure shows that the Fremont Weir daily flows between 0 and 10,000 cfs occur approximately 14% of the time during January through May, The information provided by the **Figure 4-18 and Figure 4-19** was used to examine the frequency and magnitude of Fremont Weir spills to the Yolo Bypass. Also, the Sacramento River stage exceedance plot (**Figure 4-18**) was used to guide the selection of the bottom elevation for the proposed notch.

Proposed Modification to the Fremont Weir

Hydraulic Model Assumptions

To simulate a proposed notch in the Fremont Weir, the HEC-RAS hydraulic model was modified to include 12 new cross sections near the Fremont Weir representing the notch. The modified Fremont Weir would need to be able to convey, by gravity, the desirable flows into the Yolo Bypass. The initial assumption was to consider a new channel with invert at 17.53 ft NAVD 88 (18 ft USED). The 17.53 ft elevation was chosen as a function of two criteria, the terrain elevation between Fremont Weir and Tule Canal, and the Sacramento River flow at Fremont.

As a reference for the first criterion, **Figure 4-20** shows the surface profile for the cross section that represents a conservative alignment of the new structure going from Sacramento River (zero distance) to the beginning of the Tule Canal (approximately 10,000 ft) (see **Figure 4-1**). **Figure 4-20** also shows the estimated invert of Tule Canal (11.6 ft NAVD 88) and the new channel bottom elevation (17.5 ft NAVD 88). At the time of the HEC-RAS model development, the new channel alignment and Tule Canal invert elevations were considerably uncertain. Thus, a relatively simple conceptual channel above the assumed invert was utilized in the model to reflect this uncertainty and potential backwater effects. The modeling of this notch and connecting channels should only be considered conceptual at this point of development. Once the engineering teams further the design and biological teams better understand the requirements and limitations, a more refined weir notch and channel should be included in this modeling. .

A second criterion was used to evaluate whether the notch and canal would be sufficient to convey the target flows into the Yolo Bypass with a reasonable frequency. Historical Sacramento River flows at Verona were used to estimate a range of flows that may occur in the future. According to **Figure 4-21**, daily flows exceeding the range of 20,000 to 40,000 cfs would occur around 50% of the days within the January to March time period. This flow range was used in the initial elevation setting of the proposed notch. This flow range at Verona roughly correlates to 18,000 to 28,000 cfs at Fremont and roughly 19.5 to 24.5 ft NAVD88 at Fremont Weir.

Once the elevation and flow conditions at Fremont were better understood, the cross section dimensions for the notch were approximated. **Figure 4-22** presents the dimensions for the trapezoidal channel structure connecting the Fremont Weir to the Tule Canal. The figure shows the channel with bottom length of 225 ft, side slopes of 2:1 and top length of 287 ft. The channel dimensions were estimated to avoid channel velocities greater than 3 ft/s. It was assumed that the new structure would operate most of the time conveying flows below 10,000 cfs.

Potential Fremont Weir Notch Rating Curve

A rating curve for the modified Fremont Weir was developed from the HEC-RAS results and shown in **Figure 4-23** and **Table 4-4**. These results are used in the CALSIM model using Sacramento Flow at Verona as a trigger for the Fremont Weir modification. The curves presented on **Figure 4-21**, show that within a defined range of Verona flows (30,000 cfs -50,000 cfs), that represents approximately the area between the 50th and the 75th percentile of flows during February and March, will result in a flow of 1,000 cfs or greater into the Yolo Bypass.

Model Sensitivity

Since the actual design of the modified Fremont Weir is unknown and is beyond the scope of this study, an analysis was conducted to evaluate whether the frequency and magnitude of flows could be increased by enlarging the channel bottom width from 225 ft to 450 ft. Initially, it was expected that the ability to convey flow on a wider channel would increase significantly. The expected increase in channel capacity is presented in **Figure 4-24**, where T 225 ft and T 450 ft are theoretical channels with constant bottom slope, constant dimensions, same manning coefficient, and flowing at normal depth. Through greater examination of the model cross-sections, an area approximately 32,000 ft downstream from the Fremont Weir into the Yolo bypass that serves as a hydraulic constriction was identified, especially at low flows. This terrain elevation condition limits the effectiveness of a wider channel capacity to provide more flow. An improved high-resolution elevation data set would assist in identifying whether this area truly acts in this fashion. This kind of investigation, however, is beyond the scope of this study.

Comparison between Current and Proposed Fremont Weir Configurations

The two scenarios, current and proposed Fremont Weir configurations, were analyzed over a nearly 80-year (October 1929 – July 2008) reconstructed daily flow sequence using the hydrologic data sets, spill flow equations, and the rating curves described in previous sections. The correlation equations developed to extend the Sacramento River flows at Fremont are based on flows below 90,000 cfs (approximately 37,000 cfs of Fremont weir spills). The probability of occurrence of spills over the Fremont Weir significantly increases with the proposed notch. **Figure 4-25** and **Figure 4-26** show the exceedance plots for current and modified Fremont Weir, respectively. With the modified Fremont Weir it is expected that daily flows during the Jan-May period will exceed 3,000 cfs more than 46% of the time in contrast to less than 14% of the time with the current configuration. The months of January, February, and March will have significantly higher chances of sufficient daily flows as compared with April and May. This analysis assumed a maximum of 10,000 cfs could be passed through the modified weir.

Figure 4-27 through **Figure 4-29** show the events producing discharges greater than 3,000 cfs for the existing and proposed Fremont Weir. The periods greater than 30 days are indicated in the call-outs. The time series line represents stage at Sacramento River at Fremont. The bars represent when a continuous flow (up to a week no flow gap) of more than 3,000 cfs was simulated to spill into the Yolo bypass. The graphs show clearly that January through March is a critical period for spills into the bypass. The maximum number of days that continuous flows greater than 3,000 cfs would be observed with an unrestricted modified weir is 189 days in 1998. A more realistic operation of the proposed modified Weir structure (notch and gate) would only permit flows during the January 1 through April 15 period and limit notch flows up to the 3,000 - 6,000 cfs range. This operation is shown in **Figure 4-27** through **Figure 4-29** as green bars.

Table 4-5 presents a summary of the change in events that produce flows greater than 3,000 cfs over the Fremont Weir (current conditions and proposed notch). The table presents the results for the period 1984-2007 (observed flow period) and 1929-2007 (longer reconstructed flow period) and indicates that the proposed notch would more than double the number of events that are deemed biologically significant.

Hydrological Modeling Summary

Several broad conclusions can be made from this initial study. First, the creation of a notched low flow channel through the Fremont Weir has the potential to significantly increase the frequency of inundation of the Yolo Bypass. The frequency of providing biologically-important flows is doubled as compared to the current configuration. It appears that the increase in frequency is a more robust result than the increase in magnitude of flows. Second, the hydraulics in the upper reach are important. The profile suggests that low flows may be affected by downstream hydraulic controls. Higher resolution elevation mapping, cross-sections, and more detailed modeling would be important to better understand these conditions. Finally, the modeling has shown that sufficient velocities, depths, and general residence times could be achieved from flows in the range of 3,000-6,000 cfs. The modeling has assumed that the Yolo Bypass would not be altered. It is likely that land use and other concerns will require that certain lands be inundated, while adjacent lands are not. When these decisions are made, it will be important to verify the hydraulic conditions to ensure that conditions both upstream and downstream are suitable for the habitats of concern.

Modeling Limitations

The present model is suitable for a coarse-level feasibility analysis of a modified Fremont Weir. The intent of this study is to show the range of Sacramento River flows at which a modified Fremont Weir becomes feasible and the degree and extent of increased inundation. Another major goal of this analysis was to develop an approximate rating curve for the modified Fremont Weir that could be used in other water resources models like CalLite and CALSIM. Additional study would be required to gain greater insight and begin to identify design-level conditions.

For the above mentioned goals of this study, it was acceptable to utilize the USACE elevation from the Yolo Bypass model (USACE, 2007). A detailed Yolo bypass hydraulic model would require a refinement on the number of cross sections used by the model. More cross sections would clarify possible problems like the flow on cross section at 32,000 ft downstream of the Fremont Weir (cross section 47428.85), where an apparent berm acts as a hydraulic constriction. A more refined model would also use different Manning’s coefficients as a function of land use or satellite data and would include additional low flow calibration at various locations along the Yolo Bypass.

Although a 2-D hydraulic model of the Yolo Bypass (USACE, 2007) is available from the USACE, the model was designed for high flows in the range of 343,000 cfs and 500,000 cfs. The model documentation reports that it will not reliably simulate lesser discharges. In addition to this model limitation, the computational requirements of this model and resources necessary to adapt the mesh for this analysis are beyond the scope of this task.

For the design of the modified weir, a more refined analysis on the missing flow and stage data would be desirable, a detailed survey of the area close to the weir would be necessary and more detailed assumptions would have to be defined like maximum depth and width of the channel.

Coarse satellite images were used to estimate flooded areas (300x300 m resolution) and not enough time was spent on defining the correlation between Fremont Weir flows, time of travel and floodplain area inundated. However, in the future this technique could be refined and be used as a calibration tool for the model.

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Table 4-1: HEC-RAS model results for depth, area mean velocity and travel time for different flows at the modified Fremont Weir

Flow (Q) cfs	**Mean Depth for the Entire Yolo Bypass** (D) ft	**Surface Area (from GIS mapping)** (A) Acres	**Mean Velocity** (V) ft/s	**Travel Time** (t) day
1,000	5.9	4,100	1.66	8.8
2,000	5.3	5,700	1.94	4.9
3,000	3.9	11,000	1.77	4.2
4,000	2.8	15,900	1.49	4.2
5,000	2.6	18,600	1.32	4.0
6,000	2.6	21,500	1.26	3.9
7,000	2.6	23,100	1.19	3.7
8,000	2.6	24,600	1.20	3.6
9,000	2.7	25,900	1.20	3.5
10,000	2.8	27,100	1.20	3.4

Table 4-2: Estimated flooded area from satellite images and the respective previous 7 day average of Fremont flows. Values rounded to the thousands.

Date	**Flow – HEC-RAS**[1] **(cfs)**	**Area – satellite image**[2] **(acres)**	**Area – HEC-RAS** **(acres)**
6-Mar-1998	48,000	51,000	45,000
15-Jan-2003	13,000	32,000	27,000
8-Feb-2006	14,000	36,000	31,000
13-Apr-2006	72,000	48,000	49,000

[1] Estimated flow based on Fremont Gage for the previous five days. May underestimate since tributary flow is not included.

[2] Estimated acreage based on rough delineation from 300mx300m satellite image.

Table 4-3. Data sources used for the Fremont Weir analysis

Location	**Type of Data**	**Hourly Data**			**Daily Data**		
		Source	**From**	**To**	**Source**	**From**	**To**
Sacramento River at Fremont	Stage (USED)	CDEC FRE	1/1/1984	Current	Computed from hourly	1/1/1984	12/31/2007
Sacramento River at Fremont	River Flow	NA	NA	NA	Computed using daily stage and DFM rating curve	1/1/1984	12/31/2007
Sacramento River at Fremont	Spill into Yolo	CDEC FRE	1/1/1984	Current	Computed from hourly	1/1/1984	12/31/2007
Sacramento River at Fremont	Spill into Yolo	NA	NA	NA	USGS 11391021	1/1/1947	9/30/1975
Sacramento River at Verona	River Flow	NA	NA	NA	USGS 11425500	10/1/1929	Current

Table 4-4. Summary table for the new structure diversion to be used with CalLite and Calsim models

Sacramento River at Fremont Stage ft (NAVD 88)	**Notch Flow: Unrestricted (cfs)**	**Notch Flow: Proposed Limits (cfs)**	**Sacramento River at Fremont Flow (cfs)**	**Sacramento River at Verona Flow (cfs)**
17.5	0	0	14600	23100
18.6	100	100	17200	25700
19.2	250	250	17700	27200
19.8	500	500	18600	28600
20.7	1000	1000	20200	31000
21.8	2000	2000	22200	34100
22.7	3000	3000	24000	36500
23.4	4000	4000	25300	38500
23.9	5000	5000	26300	39900
24.5	6000	6000	27700	41600
24.9	7000	6000	28900	42700

Sacramento River at Fremont Stage ft (NAVD 88)	Notch Flow: Unrestricted (cfs)	Notch Flow: Proposed Limits (cfs)	Sacramento River at Fremont Flow (cfs)	Sacramento River at Verona Flow (cfs)
25.3	8000	6000	29900	43900
25.7	9000	6000	31000	45100
26.0	10000	6000	31900	46000

Table 4-5. Number of events with consecutive spills producing more than 3,000 cfs over Fremont Weir under current and proposed notch conditions

Number of events with consecutive days of spills (max 7 day gap to count as new event) that produced more than 3,000 cfs	**Count of events between 1984-2007**		**Count of events between 1929-2007**	
	Current Weir	**Proposed Notch**	**Current Weir**	**Proposed Notch**
Less than 30 days	18	41	48	137
Greater than 30 days	9	19	11	70
Greater than 45 days	4	11	5	46

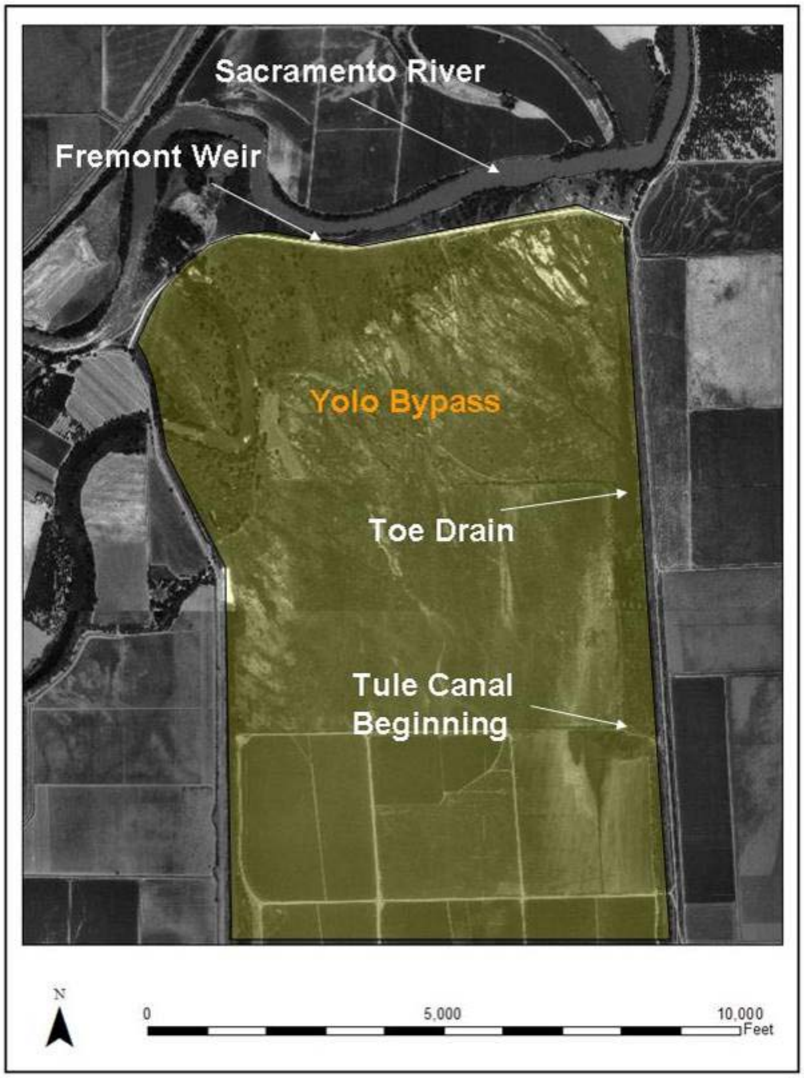


Figure 4-1. Aerial view of the Fremont Weir and Yolo bypass location

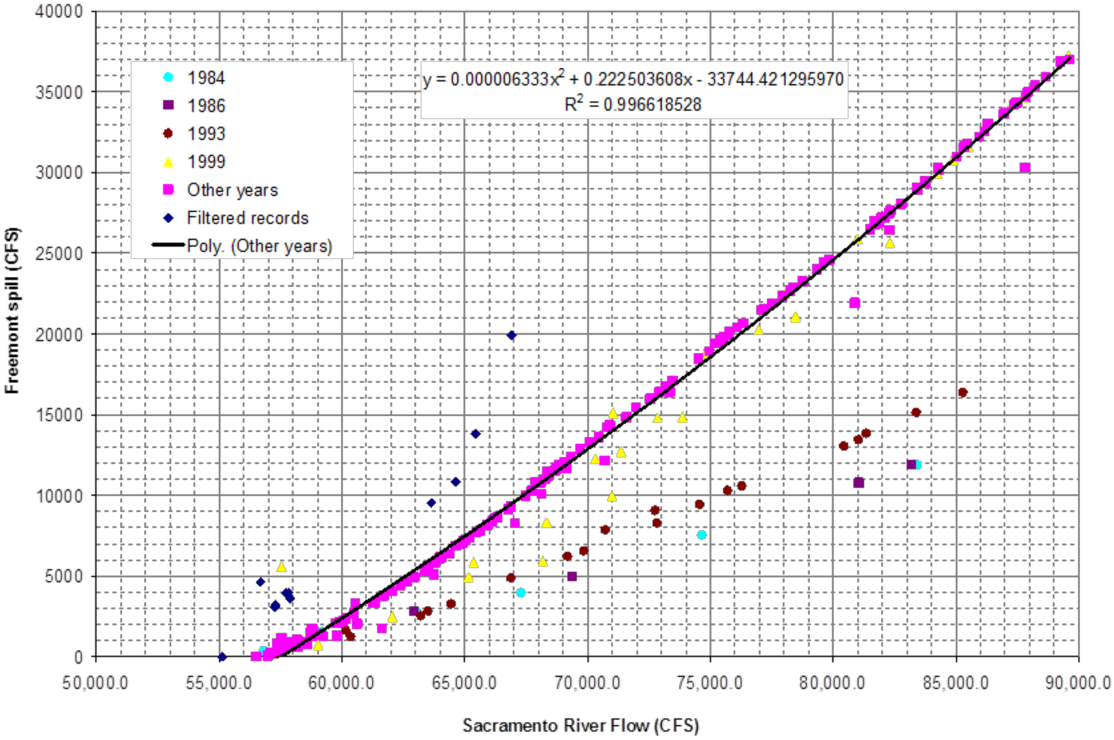


Figure 4-2. Fremont Weir spills curve for Sacramento flows from 50,000 to 90,000 cfs

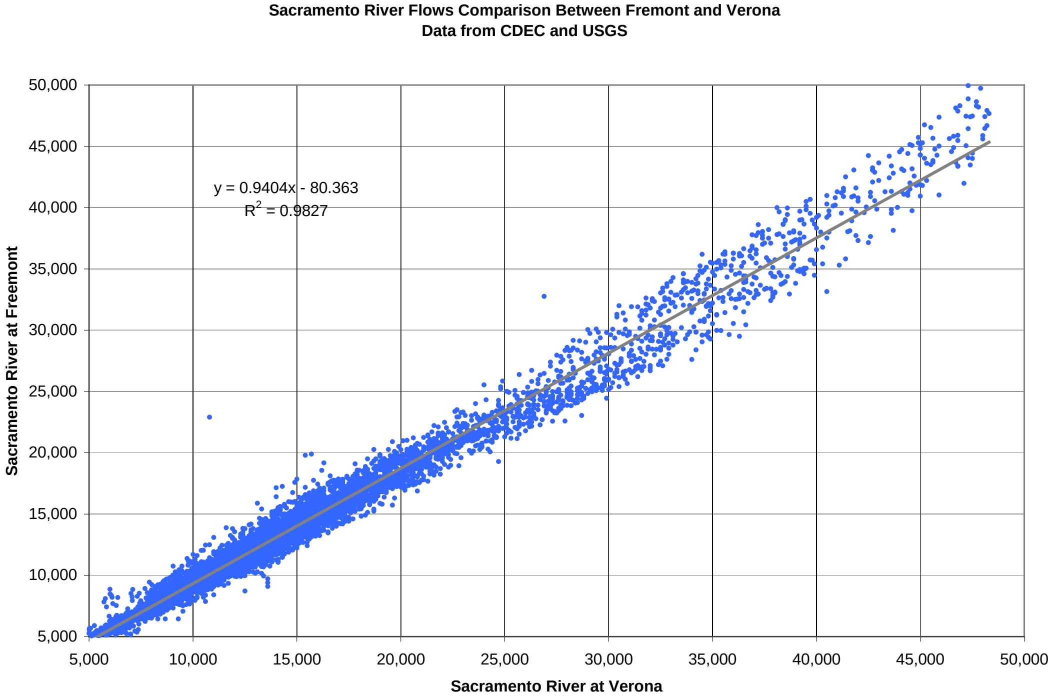


Figure 4-3. Correlation between Sacramento River at Verona and Sacramento River at Fremont for flows below 50,000 cfs

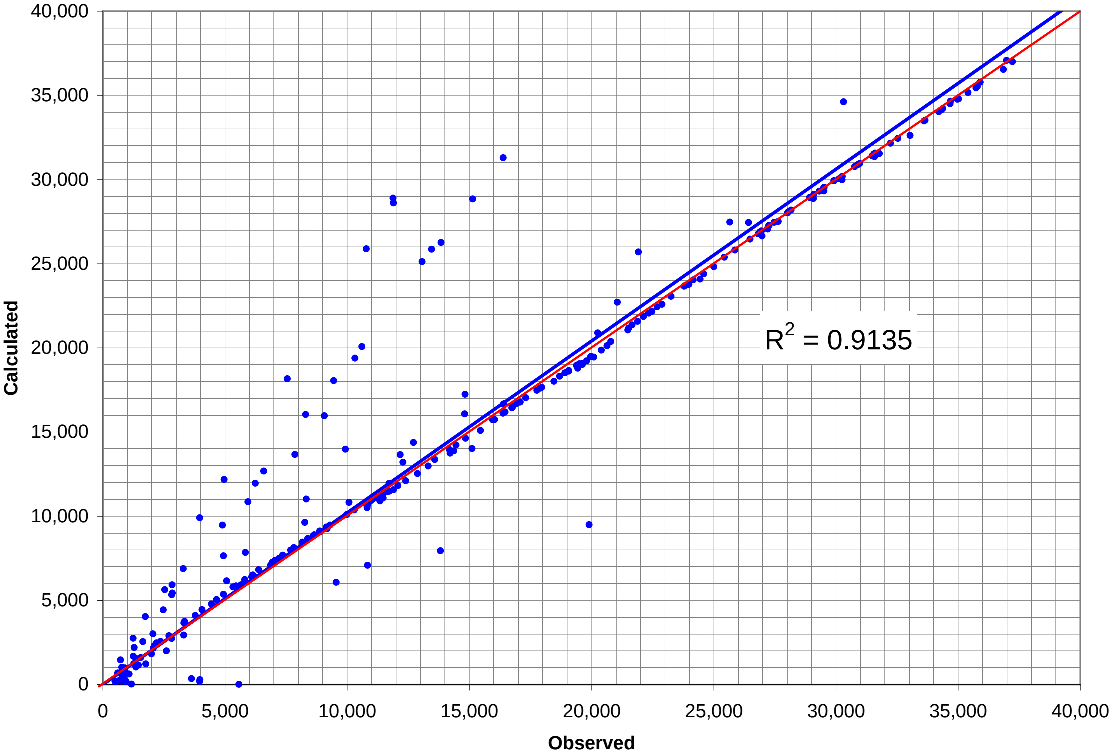


Figure 4-4. Observed and calculated Fremont Weir spill correlation

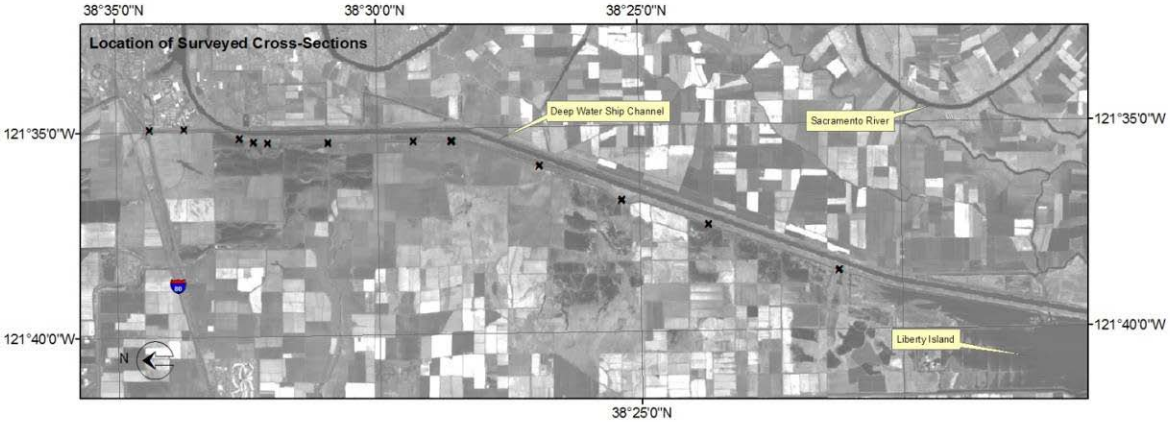


Figure 4-5. Location of surveyed Yolo bypass East Toe Drain cross sections (DWR unpublished data)

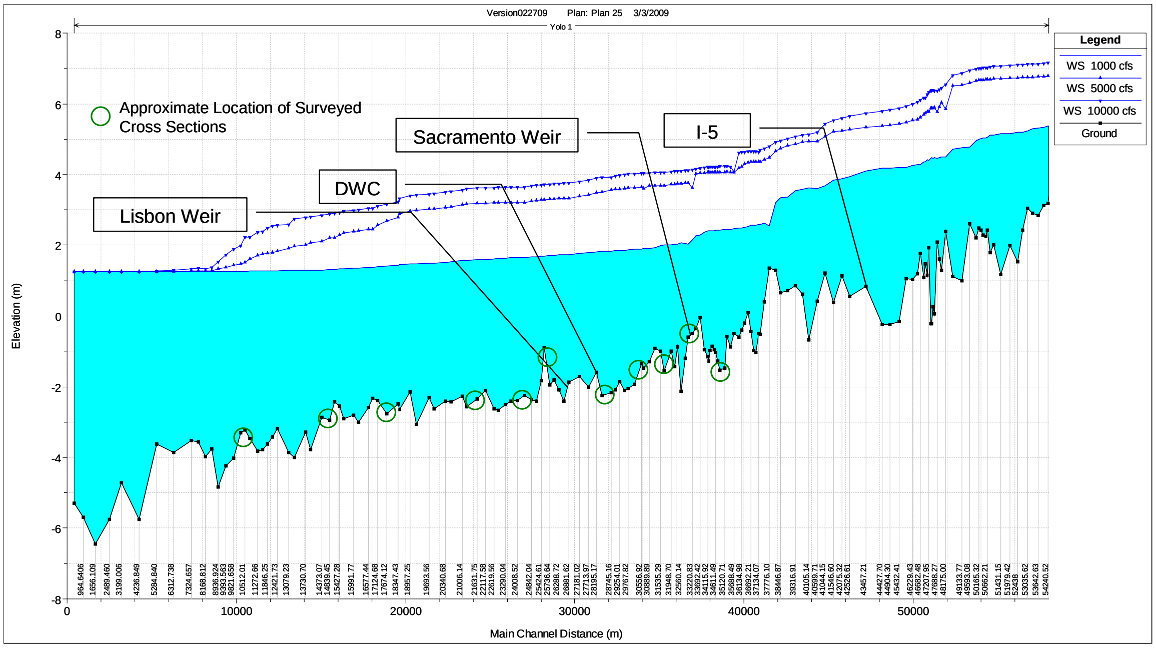


Figure 4-6. Yolo bypass profile for the deepest point of each cross section. Values in metric units from HEC-RAS analysis

Figure 4-7. Photos taken February 18 2009 between 1:45 - 2:00 pm downstream of the Lisbon Weir. Stage approx. 7.4 ft NAVD88. Flows were 1982 cfs at 13:45 and 1943 at 14:00 (DWR unpublished data)

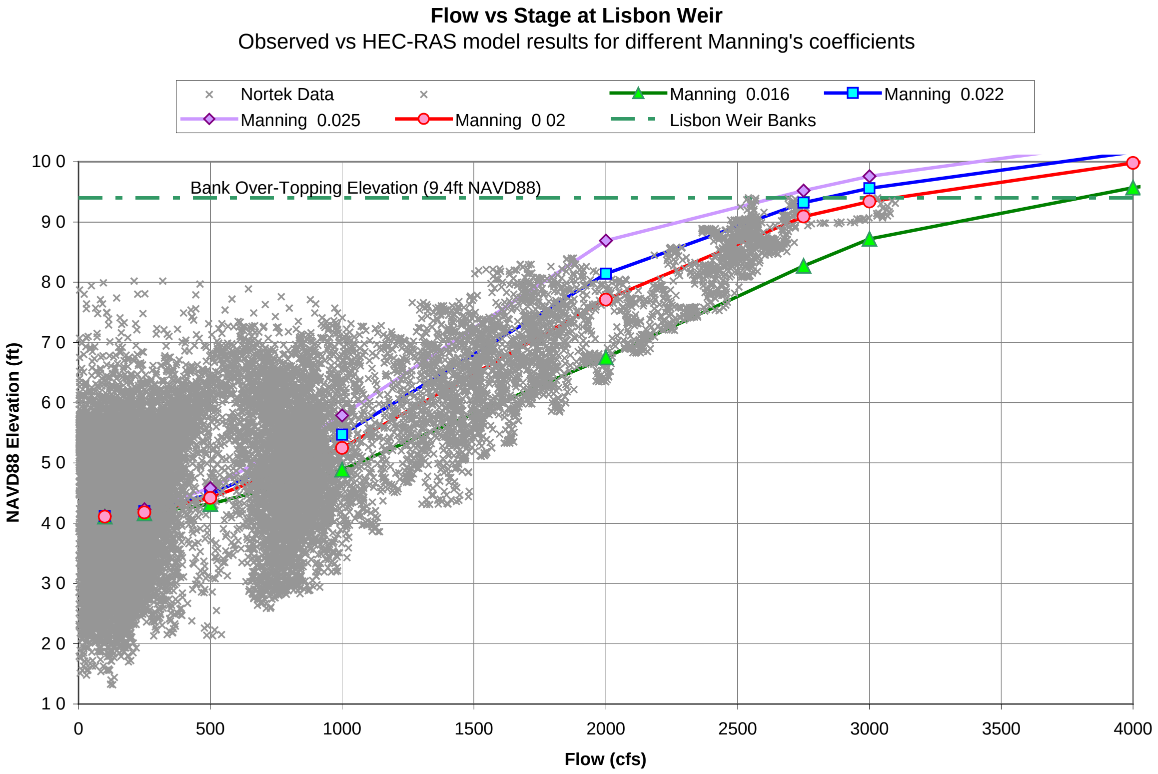
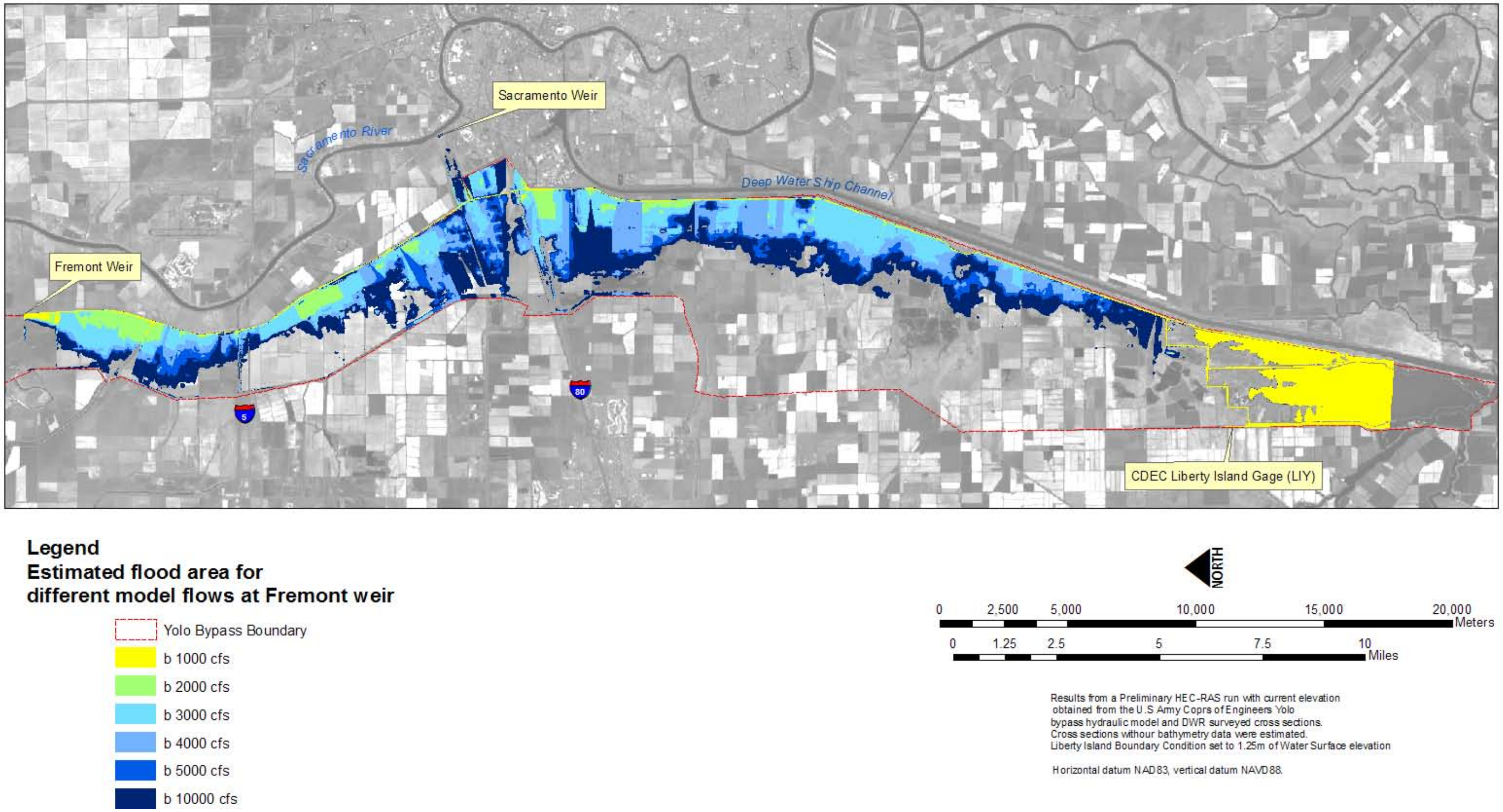


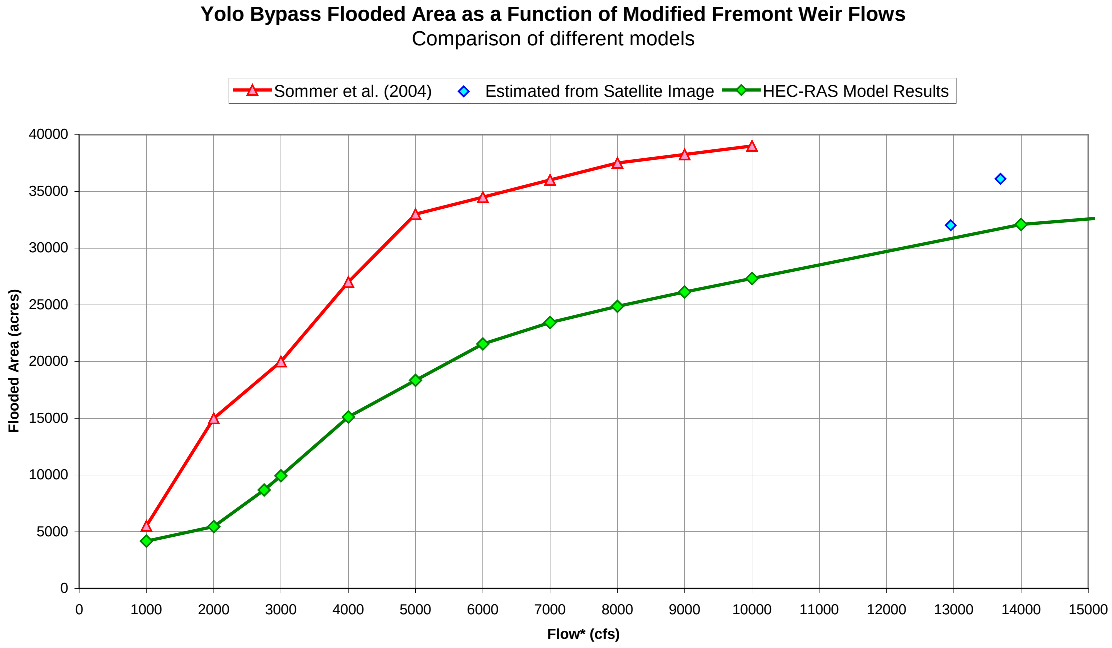
Figure 4-8. Historical flow vs elevation at Lisbon Weir and HEC-RAS model results at different Toe Drain Manning's coefficients. (Unpublished data from DWR)



Results from a Preliminary HEC-RAS run with current elevation
obtained from the U.S Army Coprs of Engineers Yolo
bypass hydraulic model and DWR surveyed cross sections.
Cross sections withour bathymetry data were estimated.
Liberty Island Boundary Condition set to 1.25m of Water Surface elevation

Horizontal datum NAD83, vertical datum NAVD88.

Figure 4-9. HEC-RAS modeling results showing flooded areas at different Fremont Weir notch flows



*HEC-RAS model assumes flows only from Fremont weir and Sommer et al.(2004) assumes all flows that enter the Yolo Bypass

Figure 4-10. Comparison of flooded area for different models and models assumptions.

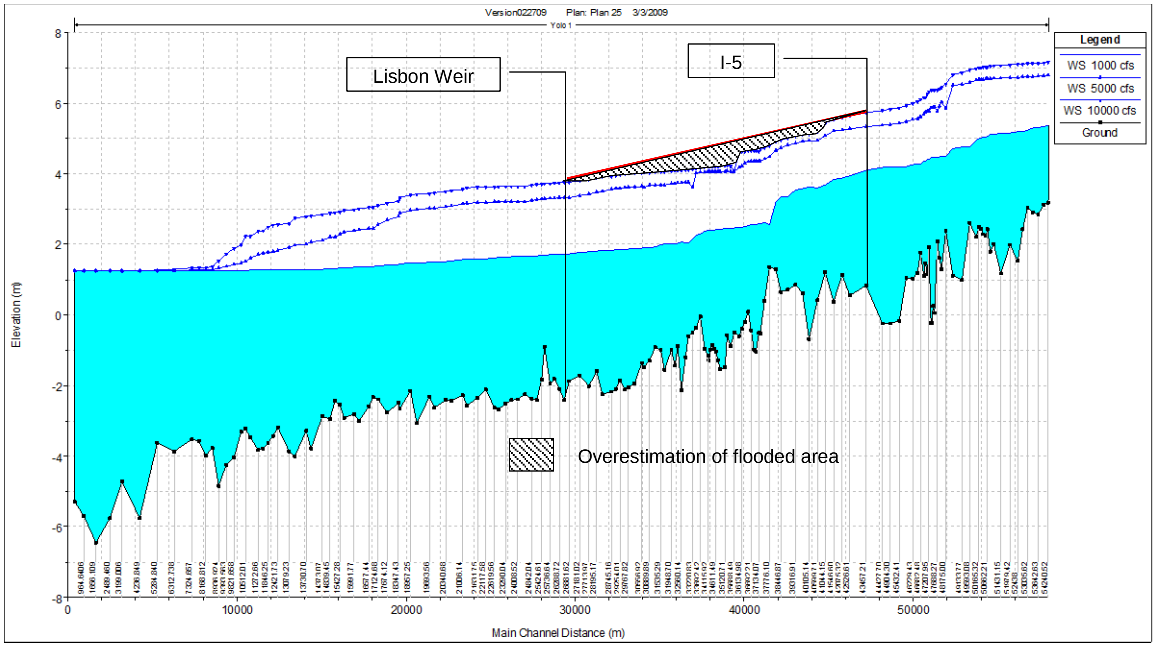


Figure 4-11. Possible overestimation of flooded areas using a linearization of water surface between two stations.

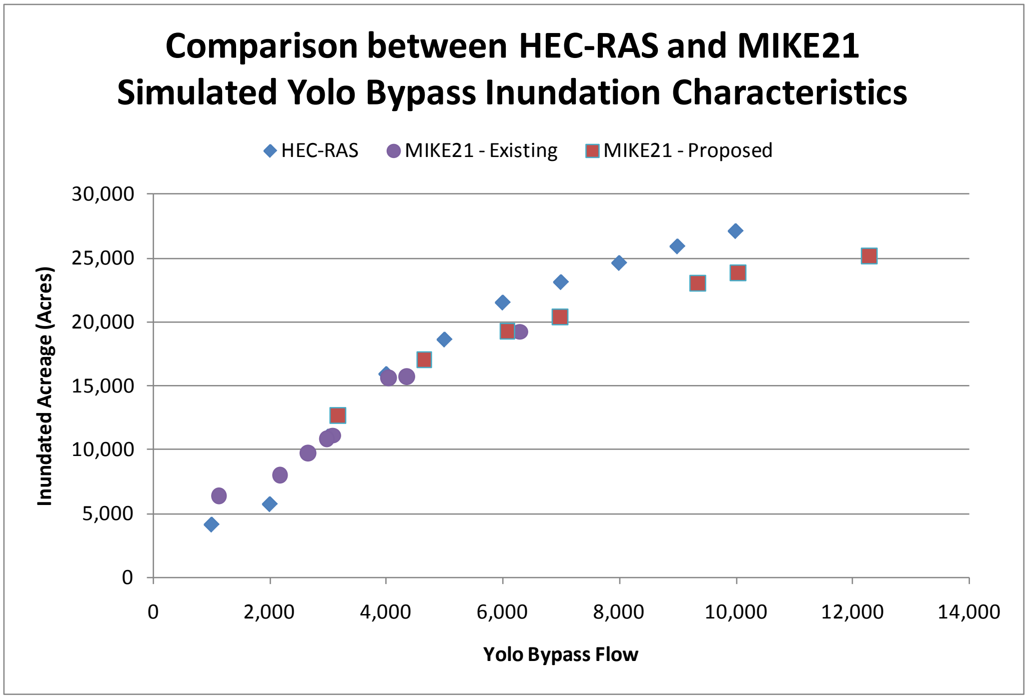


Figure 4-122. Comparison of HEC-RAS and MIKE21 simulated Yolo Bypass inundation characteristics.

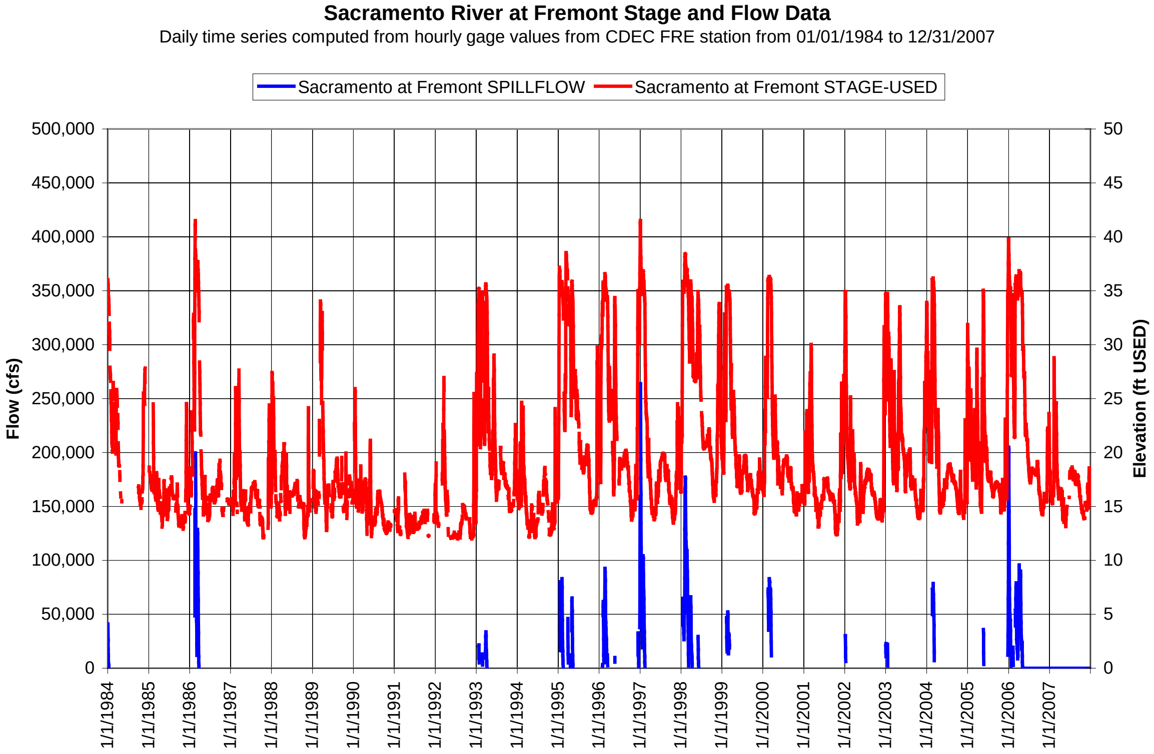


Figure 4-133. CDEC daily time series for stage and flow at Fremont Weir. Data converted from hourly to daily

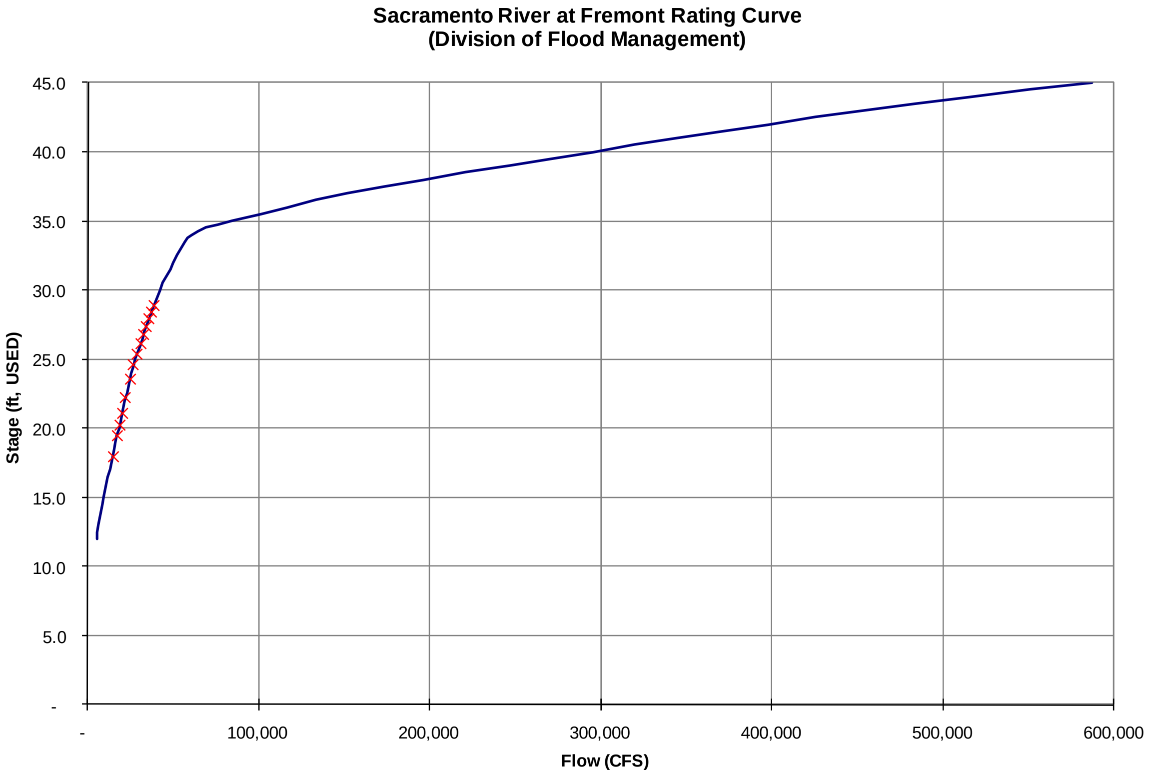


Figure 4-144. Sacramento River at Fremont rating curve (Source: California Division of Flood Management)

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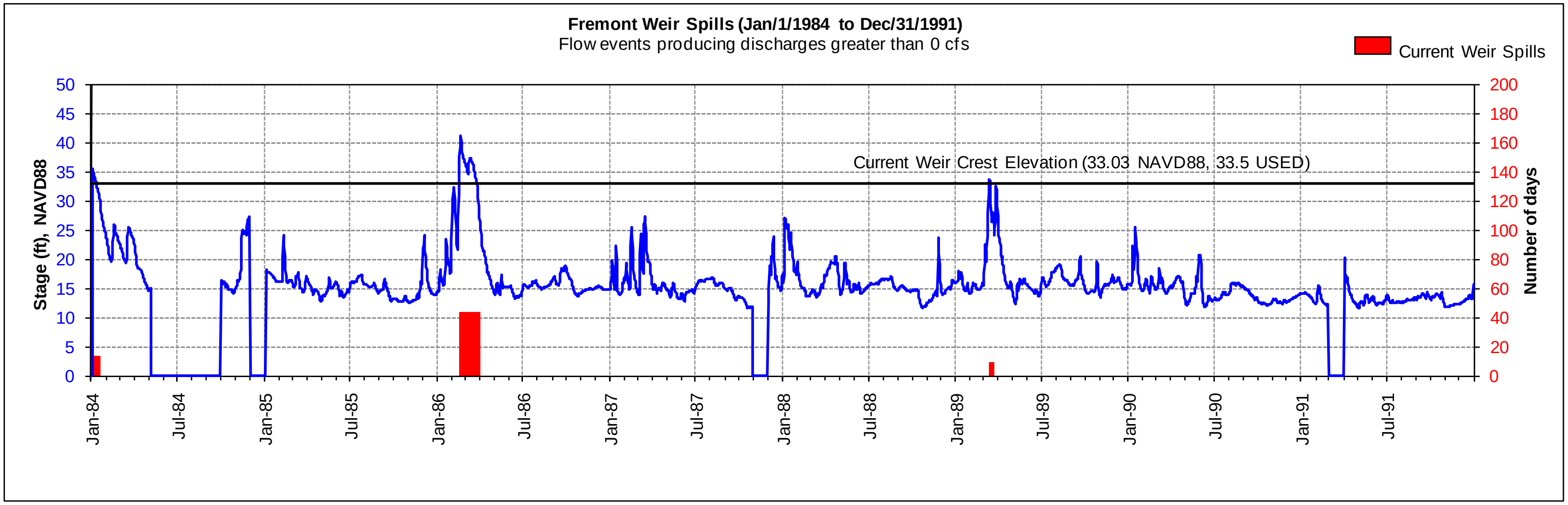
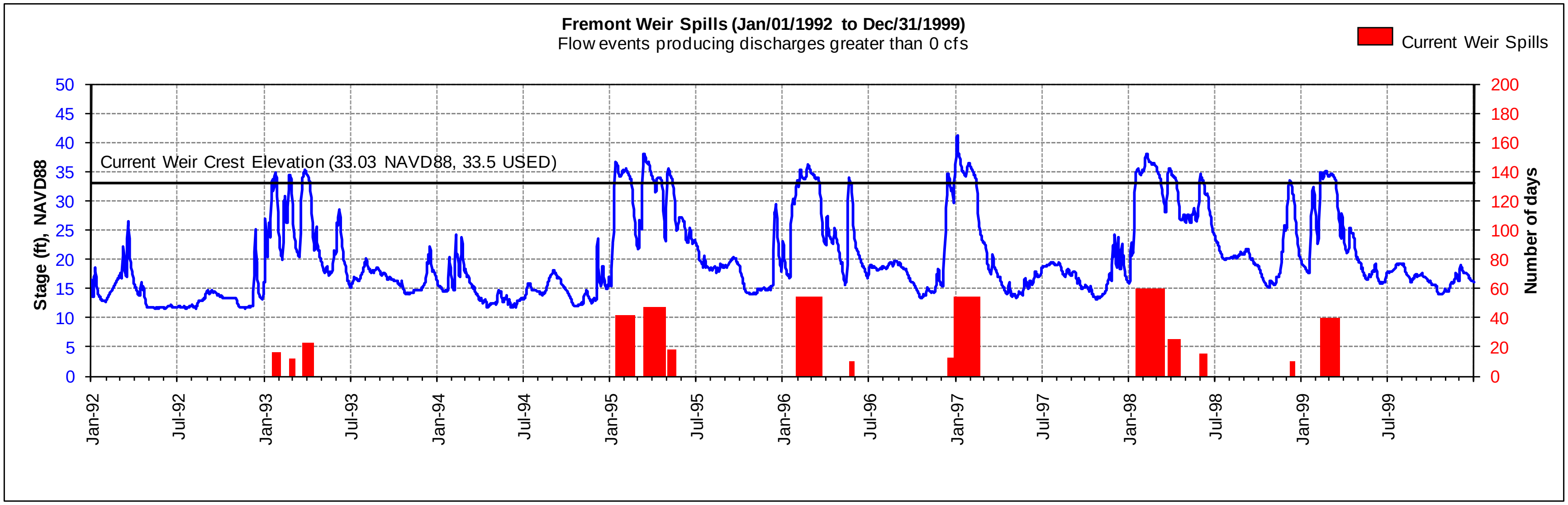
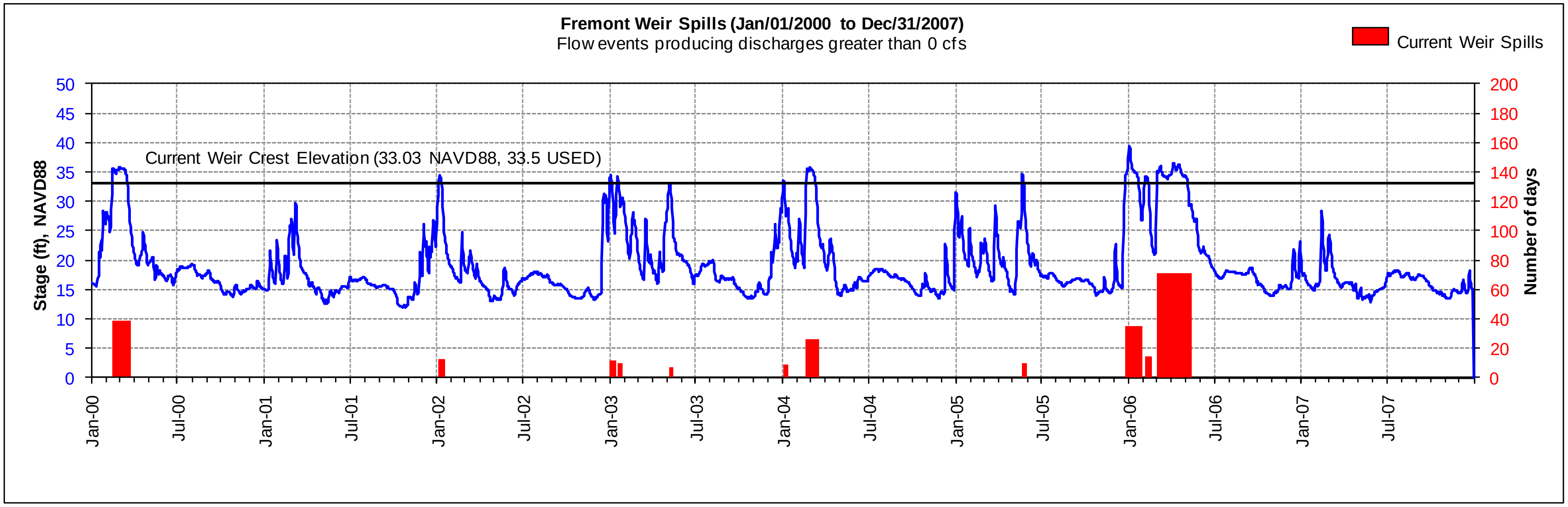


1
2 Figure 4-155. Observed Fremont Weir spills and duration (Jan 1984 to Dec 1991)



3
4 Figure 4-166. Observed Fremont Weir spills and duration (Jan 1992 to Dec 1999)



1
2 Figure 4-177. Observed Fremont Weir spills and duration (Jan 2000 to Dec 2007)

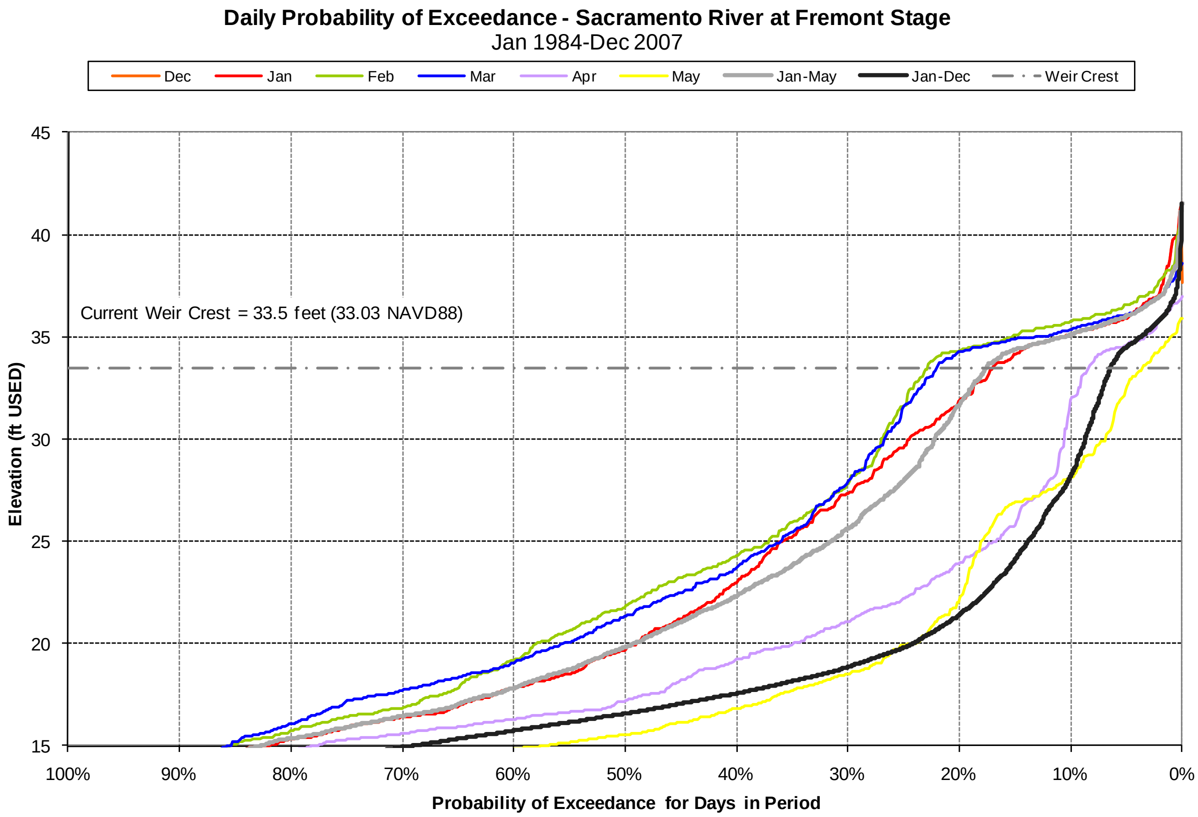


Figure 4-188. Sacramento River at Fremont stage probability exceedance plot, daily average (1984-2007)

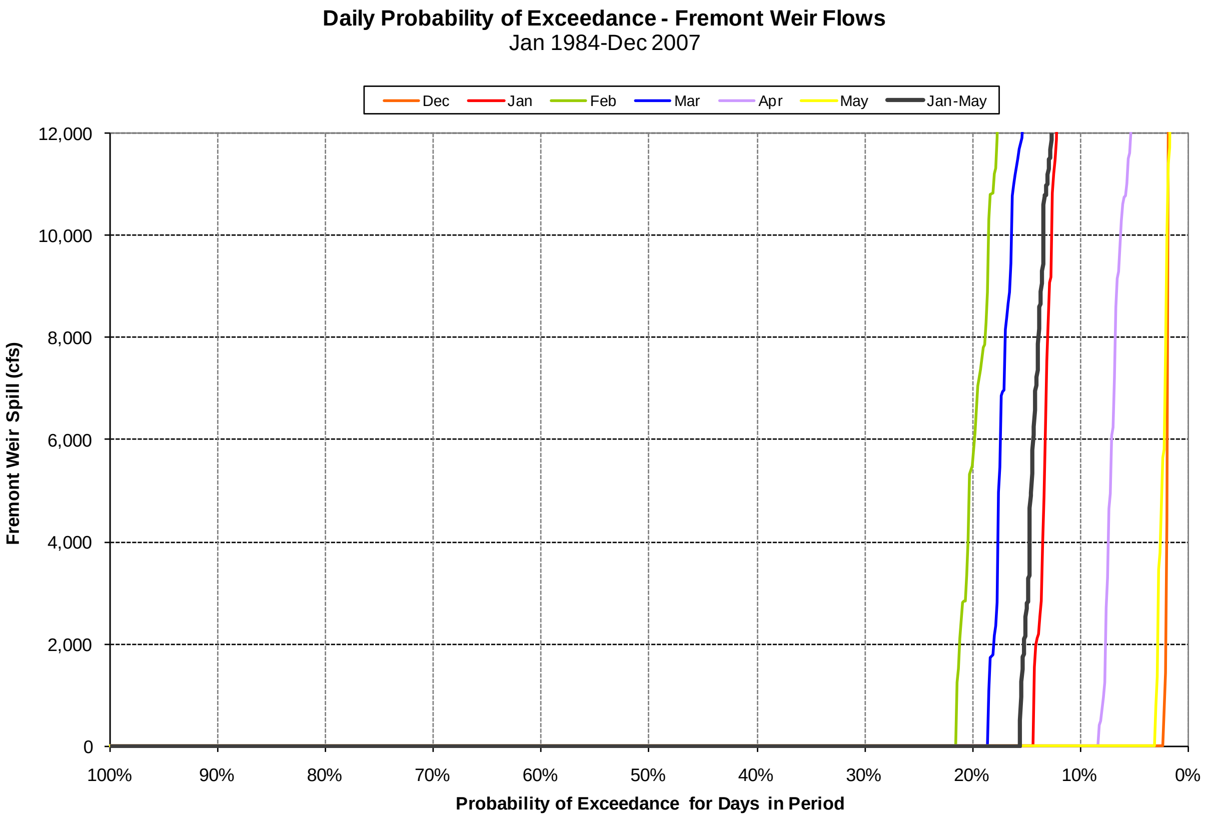


Figure 4-199. Fremont Weir spills probability of exceedance plot, daily average (1984-2007)

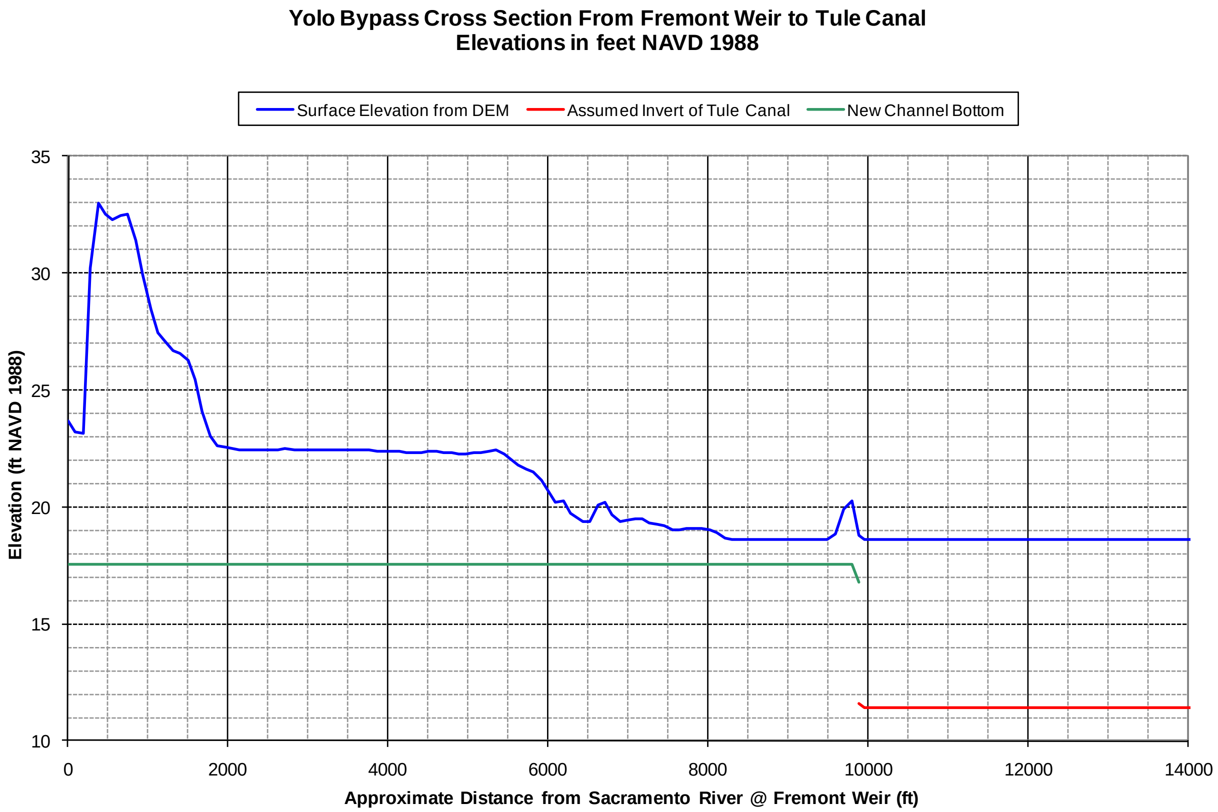
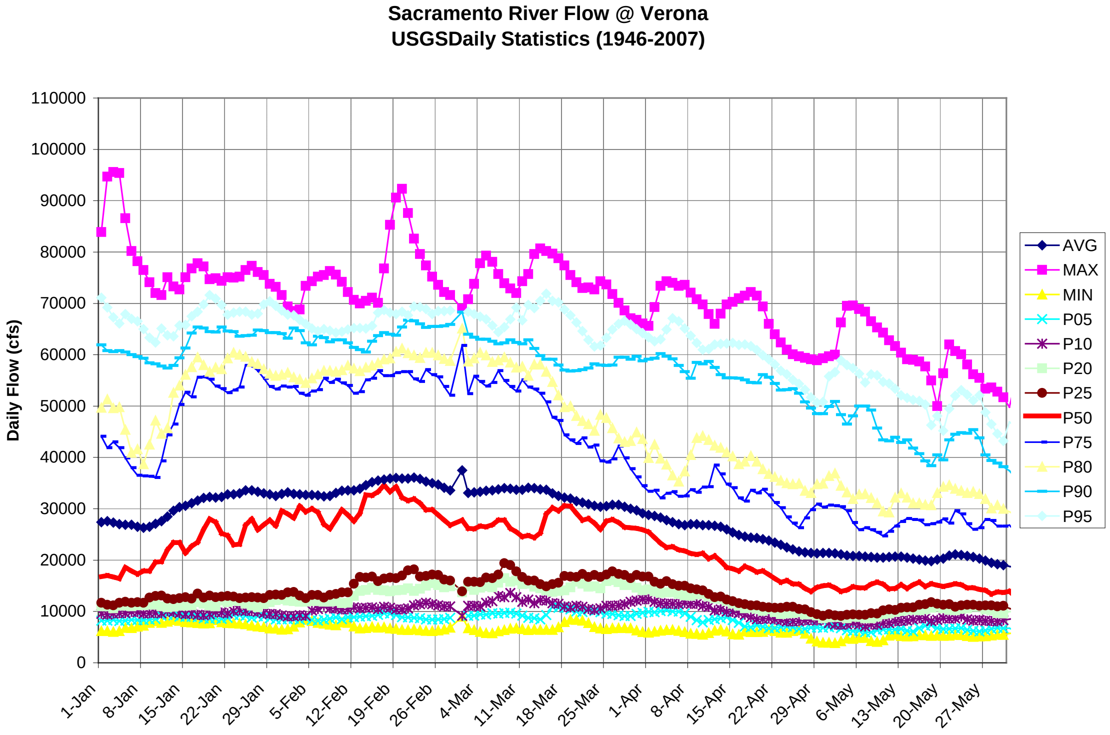
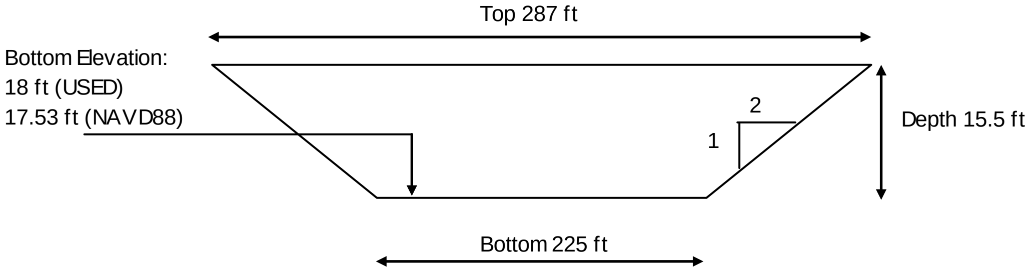


Figure 4-20. Yolo Bypass Profile from Sacramento River at Fremont Weir to Tule Canal

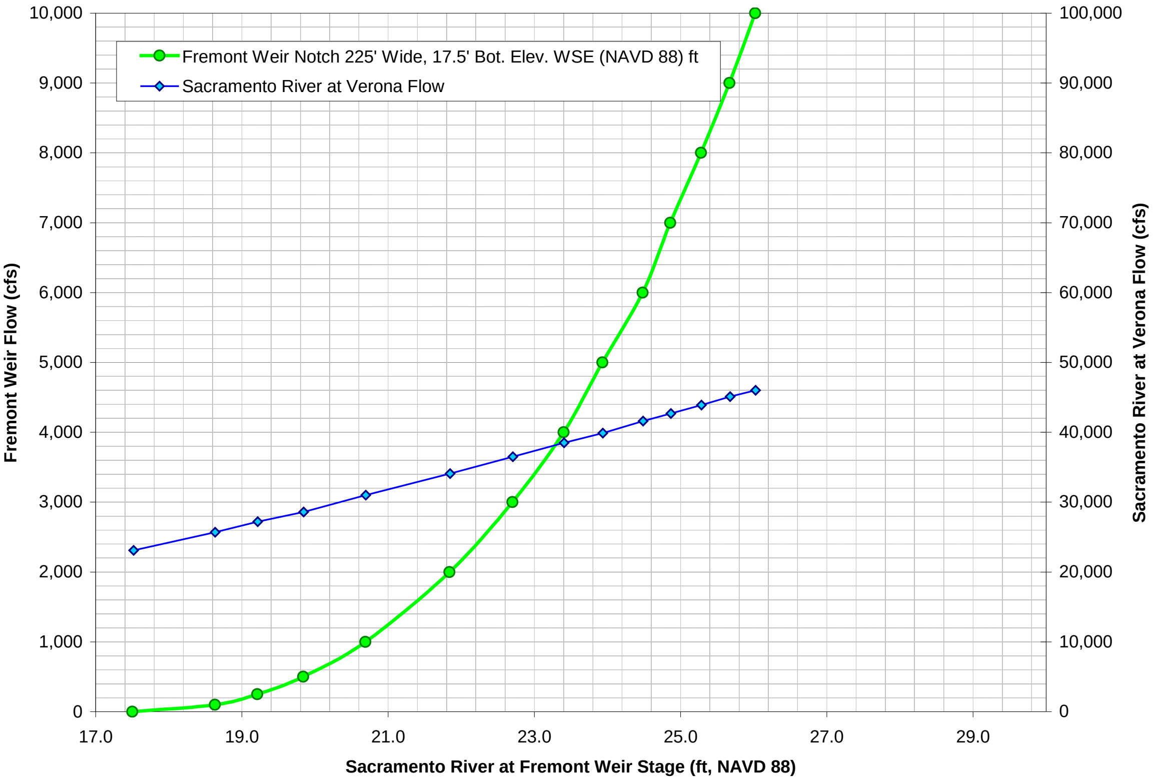


1 Figure 4-201. Daily statistics data from USGS for Sacramento River at Verona



2

3 Figure 4-212. Dimensions for the channel connecting the Fremont Weir to the Tule Canal at the Yolo
4 Bypass



5

6 Figure 4-223. Rating curves for the modified Fremont Weir and Sacramento River flow at Verona

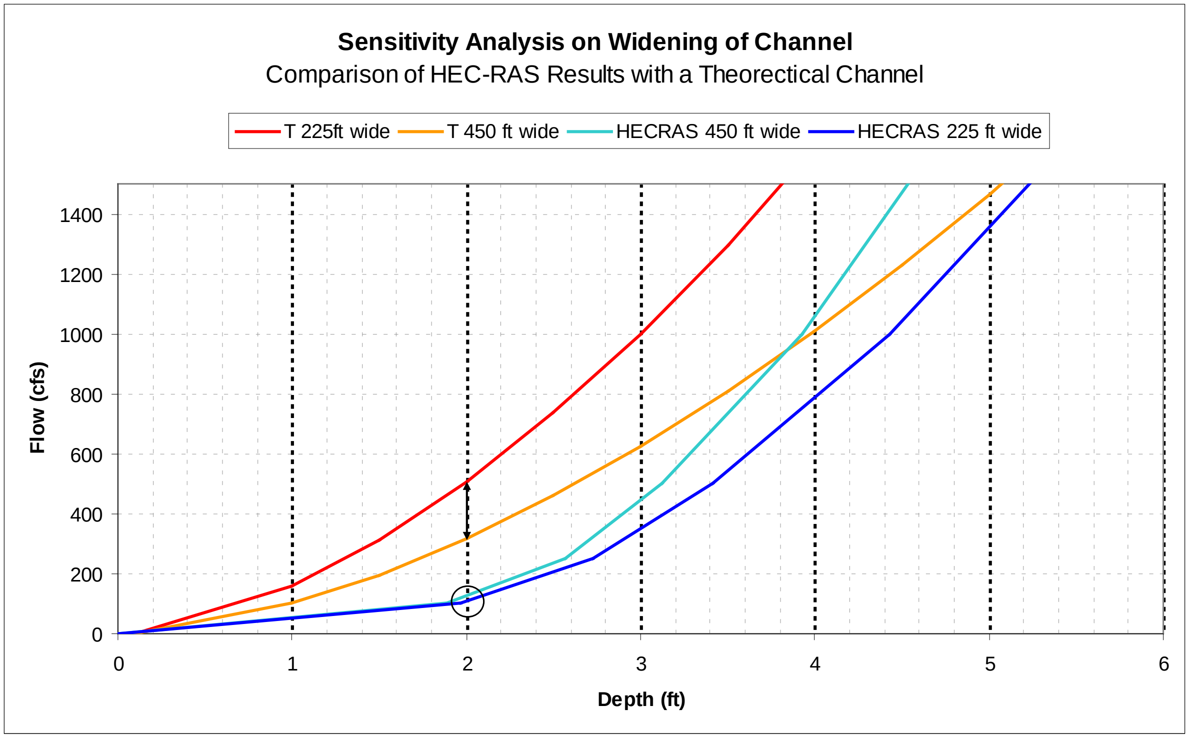


Figure 4-234. Sensitivity analysis on the effects of widening the spill channel

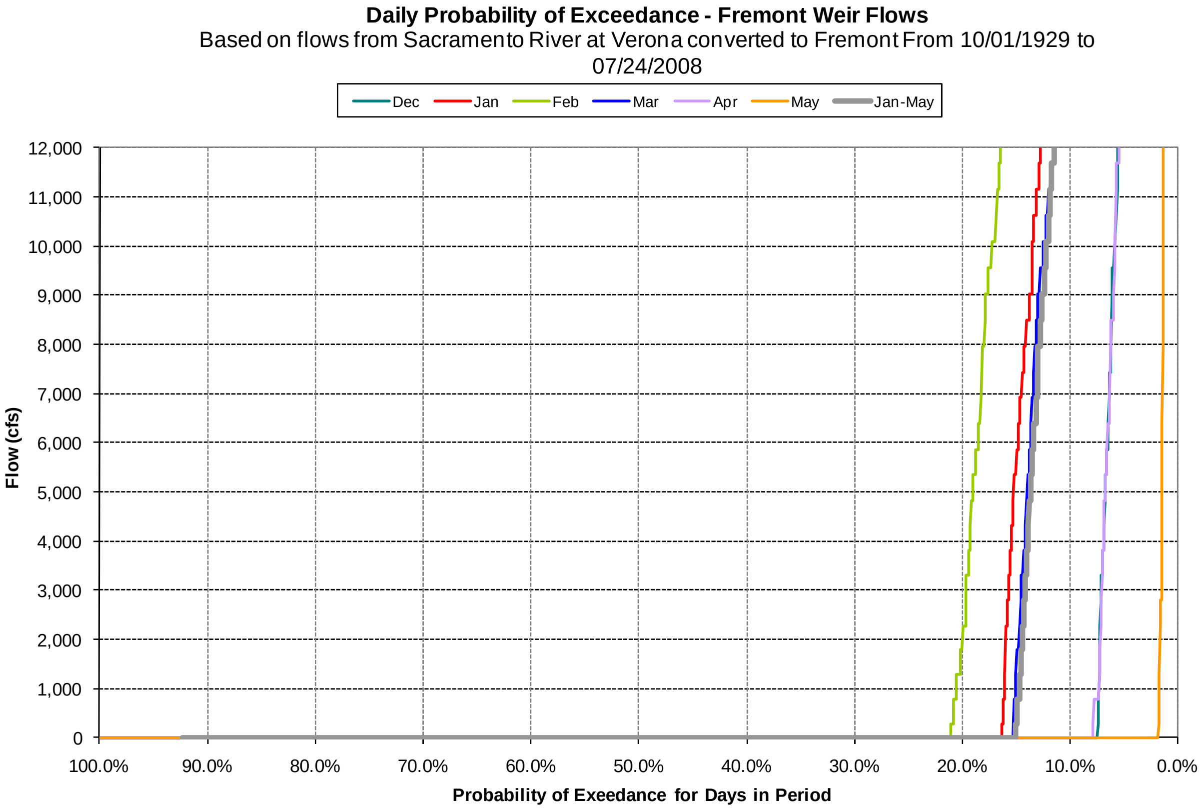
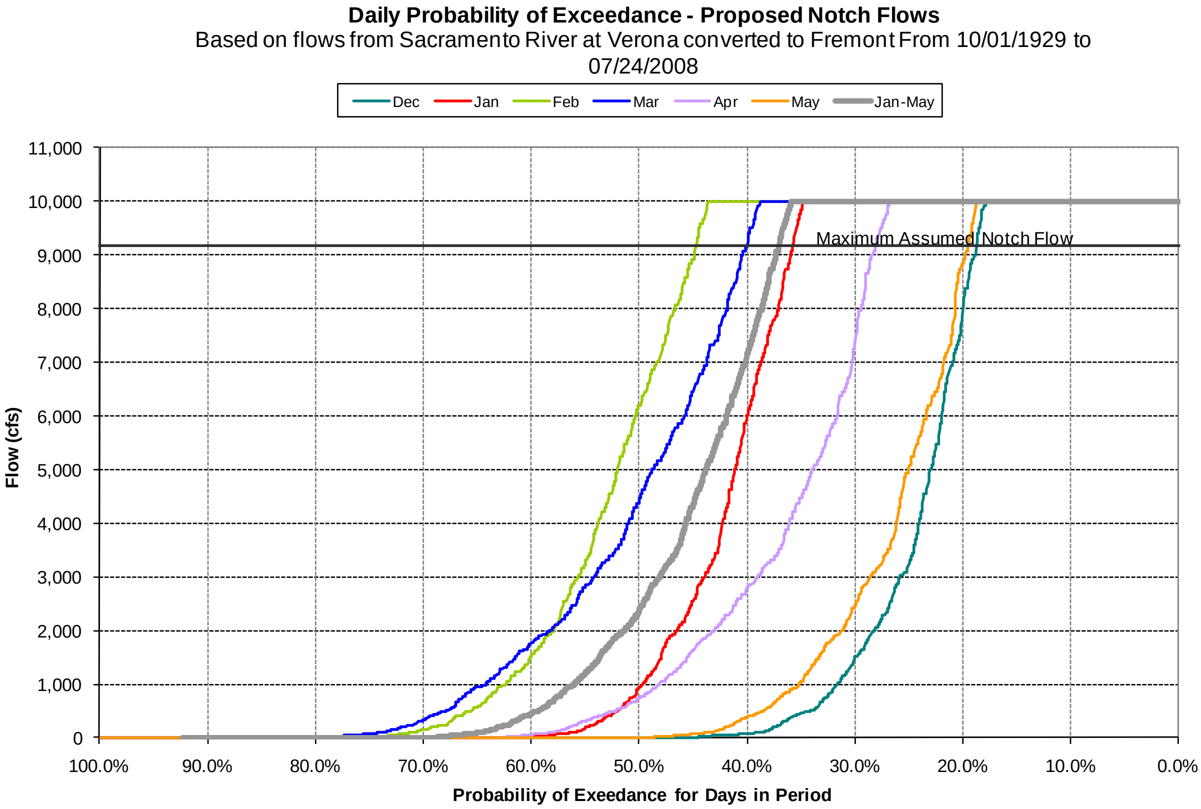


Figure 4-245. Exceedance plot for current Fremont Weir flows for selected months



1

2 Figure 4-256. Exceedance plot for modified Fremont Weir for selected months

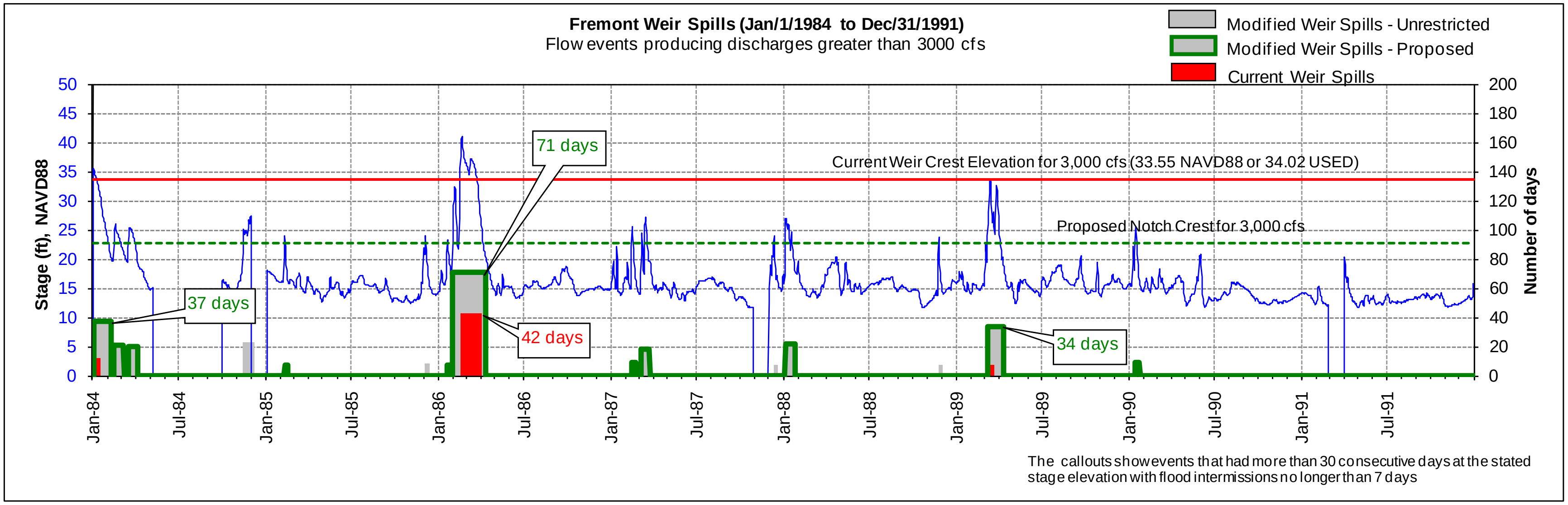


Figure 4-267. Events producing discharges greater than 3000 cfs for more than 30 days (1984-1991)

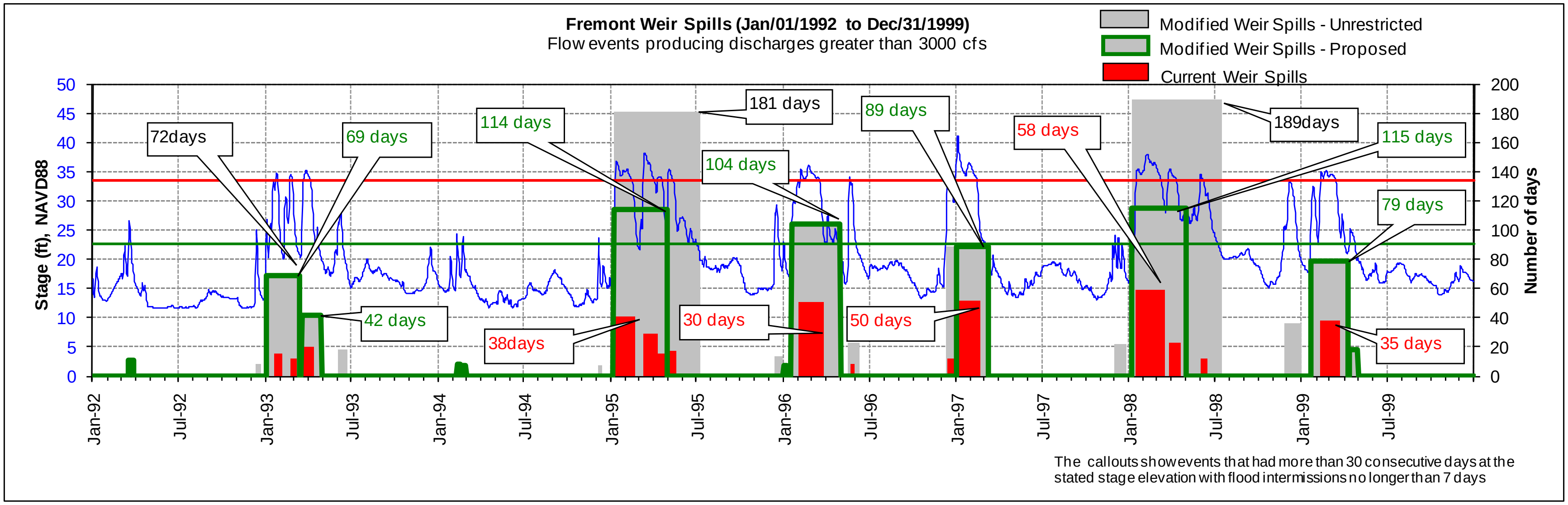


Figure 4-278. Events producing discharges greater than 3000 cfs for more than 30 days (1992-1999)

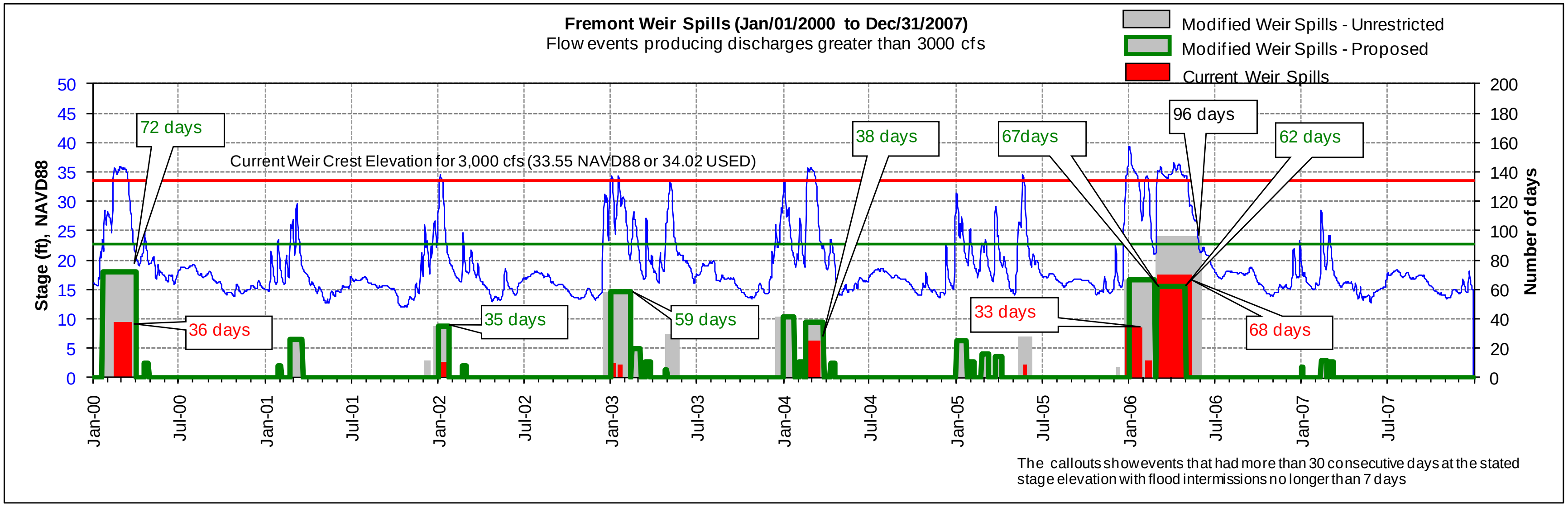


Figure 4-289. Events producing discharges greater than 3000 cfs for more than 30 days (2000-2007)

D.5. DSM2 Recalibration for Bay-Delta Conservation Plan

DWR's DSM2 is the primary analytical tool used to evaluate the changes to Delta hydrodynamics and water quality associated with the proposed elements of the BDCP Alternatives. The ability to accurately simulate tidal flows and salt transport in the northern Delta and Cache Slough region is of particular importance for the BDCP considering the proposed diversion intakes on the Sacramento River and large-scale tidal marsh restoration. In preparing the analytical tools for use in the BDCP modeling, DSM2 model was recalibrated using recent historical flow, stage and salinity data in the Delta. The DSM2 grid was modified to include recent morphological changes such as the flooded Liberty Island, in addition to some updated bathymetric data in the north Delta region. The recalibration effort significantly improved DSM2's simulation of the observed tidal stage, flows and salt transport in the Delta. Detailed description of the recalibration process and results are included in a technical report previously documented for the BDCP Effects Analysis. This technical report is included as the Attachment 1 to the Section D (separate PDF file).

D.6. Evaluation of Tidal Marsh Restoration using RMA Bay-Delta Model

BDCP proposes large-scale tidal marsh restoration in various regions of the Delta to improve habitat diversity and food availability for covered species. Two-dimensional RMA Bay-Delta Model was used to provide an assessment of tidal marsh restoration effects on flows, stage, velocity and EC for areas throughout the Delta at Near-term (NT) with 14,000 acres of restoration, Early Long-term (ELT) with 25,000 acres of restoration and Late Long-term (LLT) with 65,000 acres of restoration. A technical report prepared for the BDCP Effects Analysis summarizes the evaluation of tidal marsh restoration under the three time-step scenarios with historical boundary conditions using the RMA model. This technical report is included as the Attachment 2 to the Section D (separate PDF file).

The results from this evaluation were used to corroborate the simulation of tidal marsh restoration effects on the Delta hydrodynamics and salinity transport using one-dimensional DSM2 model as described in Section D.8.

D.7. Evaluation of Sea Level Rise Effects using UNTRIM San Francisco Bay-Delta Model

BDCP analyses consider the effects of future projections of sea level rise on the hydrodynamics and salinity intrusion in the Sacramento-San Joaquin Delta. For the selected sea level rise scenarios, three-dimensional UnTRIM Bay-Delta model was simulated to evaluate the Delta hydrodynamic and salinity conditions under historical conditions. UnTRIM results were used in corroborating the hydrodynamics and salinity results from the one-dimensional DSM2 model (described in Section D.8) and two-dimensional RMA Bay-Delta model for projected 15 cm sea level rise at the Early Long-Term and 45 cm rise at Late Long-Term. A technical report prepared for the BDCP Effects Analysis summarizes the UnTRIM results for various projections of sea level rise values. This technical report is included as the Attachment 3 to the Section D (separate PDF file).

Even though, BDCP analyses used 15 cm sea level rise at ELT and 45 cm rise at LLT, several other values were simulated using UnTRIM to capture the range of uncertainty in the sea level rise projections and to understand the potential impact on the CVP-SWP operations. UnTRIM was simulated for sea level rise values including 15 cm, 30 cm, 45 cm, 60 cm, 140 cm and 140 cm with 5% tidal range amplification. UnTRIM results for the simulated sea level rise scenarios are included in the Section D Attachment 3.

D.8. DSM2 Corroboration for Modeling Tidal Marsh Restoration and Sea Level Rise Effects in the Sacramento-San Joaquin Delta

In the analysis of the BDCP alternatives, simulation of the effects related to the projected sea level rise and the proposed restoration areas are integral parts of the physical modeling to understand the effects. BDCP Alternatives evaluation requires long-term analysis of hydrodynamics and water quality in the Delta resulting from the proposed physical and operational changes. DSM2 is an appropriate model for this type of analysis. It has been successfully used in analyzing several projects in the Delta. However, DSM2 has a limited ability to simulate two-dimensional features such as tidal marshes and three-dimensional processes such as gravitational circulation which is known to increase with sea level rise in the estuaries. Therefore, it is imperative that DSM2 be recalibrated or corroborated based on a dataset that accurately represents the Delta conditions under restoration and sea level rise.

Since the proposed conditions are hypothetical, the Delta hydrodynamics conditions under the proposed conditions were estimated by simulating higher dimensional models, which can resolve the two- and three-dimensional processes well, over a short time period. The results from the higher dimensional models provided the data sets needed to corroborate or recalibrate DSM2 under the proposed conditions so that the hydrodynamics and salinity transport in the Delta can be simulated with reasonable accuracy.

DSM2 was corroborated using results from the three-dimensional UnTRIM model for 15cm and 45cm sea level rise scenarios. DSM2 was corroborated using the results from two-dimensional RMA Bay-Delta Model (RMA2) for three restoration scenarios corresponding to Near-Term (NT), Early Long-Term (ELT) and Late Long-Term (LLT) time phases. DSM2 was also corroborated using the results from RMA2 model for two integrated restoration and sea level rise scenarios, representing the proposed restoration and assumed sea level rise at ELT and LLT time phases. Detailed descriptions of the corroboration process and results are included in a technical prepared for use in the BDCP Effects Analysis. This technical report is included as the Attachment 4 to the Section D (separate PDF file).

D.9. Incorporation of Daily Variability in the Bay-Delta Conservation Plan Modeling

CALSIM II is the primary model that integrates all the proposed BDCP elements, with existing system and regulatory framework. It provides operational decisions on a monthly timestep. The operation of some of the proposed BDCP elements including the modified Fremont Weir and the north Delta intakes were found to be sensitive to the daily variability of flows. This section summarizes the approach used to incorporate daily variability in the Sacramento River flows into CALSIM II and DSM2 modeling performed for BDCP.

This section includes a technical memorandum previously documented for use in the BDCP Effects Analysis.

TECHNICAL MEMORANDUM

Incorporation of Daily Variability in BDCP Modeling

PREPARED FOR: Jennifer Pierre/ICF

PREPARED BY: CH2M HILL

DATE: August 27, 2013

In reality, daily operations in the overall CVP-SWP system that affect Delta flows depend on daily decisions under unique conditions, occasionally through consultation between several agencies. As the spatial extent of the system increases, the permutations of possible daily outcomes increase so much that it is difficult to assume rules to implement such decisions in a long-term planning model such as CALSIM II. For the BDCP modeling, updates were implemented for new BDCP facilities that are sensitive to daily river flow pattern. Monthly river flows were downscaled to represent daily variability using historical data. The daily downscaling did not require any operational decisions. Daily modeling for Delta would require several assumptions on daily operations that cannot be modeled, and therefore, was not attempted. Most of the current Delta standards are 14-day average or monthly. Sub-monthly requirements have been attempted to be addressed conservatively at a monthly time step in CALSIM II.

This technical memorandum summarizes the approach used to incorporate daily variability into CALSIM II and DSM2 modeling performed for BDCP. CALSIM II results are based on operational decisions on a monthly timestep. It is important to note that this daily mapping approach does not in any way represent the flows resulting from operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from CALSIM II’s monthly operational decisions.

Sacramento River Daily Variability in CALSIM II

The operation of the modified Fremont Weir and the diversion/bypass rules associated with the proposed North Delta intakes are sensitive to the daily variability of flows. Short duration, highly variable storms are likely to cause Fremont Weir spills. However, if flows are averaged for the month, as is done in a monthly model, it is possible to not identify any spill. Similarly, the operating criteria for the north delta intakes include variable bypass flows and pulse protection criteria. Storms as described above may permit significant diversion but only for a short period of time. Initial comparisons of monthly versus daily operations at these facilities indicated that weir spills were likely underestimated and diversion potential was likely overstated using a monthly time step.

Figure 1 shows a comparison of observed monthly averaged Sacramento River flow at Freeport and corresponding daily flow as an example. The figure shows that the daily flow exhibits significant variability around the monthly mean in the winter and spring period while remaining fairly constant in summer and fall months. Figure 2 shows the daily historical patterns by water year type. It shows that daily variability is significant in the winter-spring while the summer flows are holding fairly constant in the most water year types. The winter-spring daily variability is deemed important to species of concern.

In an effort to better represent the sub-monthly flow variability, particularly in early winter, a monthly-to-daily flow mapping technique is applied directly in CALSIM II for the Fremont Weir, Sacramento Weir, and the North Delta intakes. The technique applies historical daily patterns, based on the hydrology of the year, to transform the monthly volumes into daily flows. Daily patterns are “borrowed” from the observed DAYFLOW period of 1956-2008. In all cases, the monthly volumes are preserved between the daily and monthly flows. It is important to note that this daily mapping approach does not in any way represent the flows resulting from operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from CALSIM II’s monthly operational decisions.

Observed Daily Patterns

CALSIM II hydrology is derived from historical monthly gauged flows for 1922-2003. This is the source data for monthly flow variability. DAYFLOW provides a database of daily historical Delta inflows from WY 1956 to present. This database is aligned with the current Delta infrastructure setting. Despite including the historical operational responses to various regulatory regimes existed over this period, in most winter and spring periods the reservoir operations and releases are governed by the inflows to the reservoirs. It is likely that the unimpaired daily patterns are preserved in these seasons in most years.

Daily patterns from DAYFLOW used directly for mapping CALSIM II flows for water years 1956 to 2003. For water years 1922 to 1955 with missing daily flows, daily patterns are selected from water years 1956 to 2003 based on similar total annual unimpaired Delta inflow. The daily pattern for the water year with missing daily flows is assumed to be the same as the daily pattern of the identified water year. Correlation among the various hydrologic basins is preserved by selecting same pattern year for all rivers flowing into the Delta, for a given year in the 1922-1955 period. Table 1 lists the selected pattern years for the water years 1922 to 1955 along with the total unimpaired annual Delta inflow.

Thus, for each month in the 82-year CALSIM II simulation period, the monthly flow is mapped onto a daily pattern for computation of spills over the Fremont Weir and Sacramento Weir and for computing water available for diversions through the North Delta intakes. A preprocessed timeseries of daily volume fractions, based on Sacramento River at Freeport observed flows, is input into CALSIM II. The monthly volume as determined dynamically from CALSIM II then is multiplied by the fractions to arrive at a daily flow sequence. The calculation of daily spills and daily diversions are thus obtained. In the subsequent cycle (but still the same month), adjustments are made to the daily river flow upstream of the Sacramento Weir and the North Delta intakes to account for differences between the monthly flows assumed in the first cycle and the daily flows calculated in subsequent cycles. For example, if no spill over Fremont was simulated using a monthly flow, but when applying a daily pattern spill does occur, then the River flow at the Sacramento Weir is reduced by this amount. In this fashion, daily balance and monthly balance is preserved while adding more realism to the operation of these facilities.

North Delta Diversion Operations

Most BDCP EIR/EIS Alternatives include new intake(s) on Sacramento River upstream of Sutter Slough, in the north Delta. Each intake is proposed to have 3,000 cfs maximum pumping capacity. It is also proposed that the intakes will be screened using positive barrier fish screens to eliminate entrainment at the pumps. Water diverted at the intakes is conveyed to a new forebay in the south Delta via tunnels.

The BDCP proposes bypass (in-river) rules, which govern the amount of water required to remain in the river before any diversion can occur. Bypass rules are designed to avoid increased upstream tidal transport from downstream channels, to support salmonid and pelagic species transport to regions of suitable habitat, to preserve shape of the natural hydrograph which may act as cue to important biological functions, to lower potential for increased tidal reversals that may occur because of the reduced net flow in the River and to provide flows to minimize predation effects downstream. The bypass rules include three important components:

1. a constant low level pumping of up to 300 cfs at each intake depending on the flow in the Sacramento River,

2. an initial pulse protection, and

3. a post-pulse operations that permit a percentage of river flow above a certain threshold to be diverted (and transitioning from Level I to Level II to Level III).

The bypass rules are simulated in CALSIM II using daily mapped Sacramento River flows as described above to determine the maximum potential diversion that can occur in the north Delta for each day. The simulation identifies which of the three criteria is governing, based on antecedent daily flows and season. An example of the north delta flows and diversion is illustrated in Figure 3. As can be seen in this figure, bypass rules begin at Level I in October until the Sacramento River pulse flow develops. During the pulse flow, the constant low level pumping (Level 0) is permitted, but is limited to a certain percentage of river flow. After longer periods of high bypass flows, the bypass flow requirements moves to Level II and eventually Level III which permit greater potential diversion. CALSIM II uses the monthly average of this daily potential diversion as one of the constraints in determining the final monthly north Delta diversion.

Daily Hydrologic Inputs in DSM2

DSM2 is simulated on a 15-minute time step to address the changing tidal dynamics of the Delta system. However, the boundary flows are typically provided from monthly CALSIM II results. In all previous planning-level evaluations, the DSM2 boundary flow inputs were applied on a daily time step but used constant flows equivalent to the monthly average CALSIM II flows except at month transitions. In an effort to better represent the sub-monthly flow variability, particularly in early winter, a monthly-to-daily flow mapping technique is applied to the boundary flow inputs to DSM2.

The daily mapping also helps in refining the monthly CALSIM II operations by providing a better estimate of the Fremont and Sacramento weir spills which are sensitive to the daily flow patterns. It also allows in providing the upper bound of the available North Delta Diversion in the BDCP Alternatives. The daily mapping approach used in CALSIM II and DSM2 are consistent.

It is important to note that this daily mapping approach does not in any way represent the flows resulting from operational responses on a daily time step. It is simply a technique to incorporate representative daily variability into the flows resulting from CALSIM II’s monthly operational decisions.

Observed Daily Patterns

CALSIM II hydrology is derived from historical monthly gaged flows 1922-2003. Main Delta inflows are Sacramento River, San Joaquin River, Yolo Bypass, Mokelumne River, Cosumnes River and Calaveras River. All the monthly river inflows to Delta resulting from CALSIM II are mapped according to “borrowed” observed daily patterns in this approach.

DAYFLOW provides a database of daily historical Delta inflows from WY 1956 to present. This database is aligned with the current Delta infrastructure setting. Even though it includes the historical operational responses to various regulatory regimes existed over this period, in most winter and spring periods the reservoir operations and releases are governed by the inflows to the reservoirs. It is likely that the unimpaired daily patterns are preserved in these seasons in most years.

Daily patterns from DAYFLOW used directly for mapping CALSIM II flows for water years 1956 to 2003. For water years 1922 to 1955 with missing daily flows, daily patterns are selected from water years 1956 to 2003 based on similar total annual unimpaired Delta inflow. The daily pattern for the water year with missing daily flows is assumed to be the same as the daily pattern of the identified water year. Correlation among the various hydrologic basins is preserved by selecting same pattern year for all rivers flowing into the Delta, for a given year in the 1922-1955 period. Table 1 lists the identified pattern years for the water years 1922 to 1955 along with the total unimpaired annual Delta inflow.

Daily Patterning of Delta River Inflows

Based on the pattern years identified for WY 1922-1955 and the DAYFLOW data for WY 1956-2003, daily flow timeseries are prepared for all the observed Delta inflows for the 82-year period. Based on the 82-year daily timeseries, monthly average timeseries are computed for all the observed Delta inflows over the 82-year period. When preparing the 82-year daily and monthly observed database, adjustments may be needed for February months. If a water year is a leap year and the corresponding selected pattern water year is not, then March 1st flow in the selected pattern year is used to compute the monthly average flow for February and to pattern the flow on the 29th day of February. Converse to that if the selected pattern year is a leap year and the water year is not, then the February average for the selected pattern year is computed from the first 28 days in February. Table 2 shows the years with adjustments made to February monthly averages.

The 82-year observed daily flows are scaled based on the ratio of simulated to observed monthly flows.

i. Adjustment factor is calculated based on monthly average flows:

$$f_{adj} = Q_{monthly\ simulated} / Q_{monthly\ observed}$$

ii. Simulate daily flows are estimated by scaling the observed daily flows using the adjustment factor:

$$q_{simulated} = f_{adj} * q_{observed}$$

Under some extreme observed flow conditions that are not present in the simulated flows, the patterning produces unrealistic swings in daily flows and corrections to constant patterns were implemented. In order to reduce this effect, a set of criteria was introduced for each boundary flow. The criteria allow daily mapping only when the simulated monthly flow is greater than a minimum flow target and the adjustment factor is falling within a certain range reducing the risk of introducing unrealistic variability into daily mapped flows. If either criterion is not met the mapping is not performed and constant monthly average flow is assigned to all the days in the month. The observed daily river flow record used for mapping each simulated monthly Delta inflow is listed in the Table 3 below along with the criteria for the daily mapping. As with CALSIM II, in all cases the monthly flows and diversions are maintained as the daily mapping is implemented.

Sacramento River

Daily mapping of Sacramento River flow is performed in CALSIM II using the approach described above. The daily Sacramento River flow simulated in CALSIM II is used to map the monthly C169 output from CALSIM II for use in DSM2. The Freeport Regional Water Project (FRWP) diversions from CALSIM II (D168B and D168C) are added to the daily mapped C169 as FRWP diversion is explicitly simulated in DSM2.

Yolo Bypass

Yolo Bypass receives water from the Sacramento River via Fremont Weir and Sacramento Weir spills and other local flows such as Knight’s Landing Ridge Cut, Cache Creek, Willow Slough and Putah Creek. The daily flow values for Fremont Weir and Sacramento Weir spills are simulated directly in CALSIM II based on the daily mapped Sacramento River flows. The Yolo Bypass flow from local sources, computed from monthly CALSIM II results by subtracting spills (D160 and D166A) from Yolo Bypass flow into Delta (C157), are mapped using the daily residuals computed from QYOLO and observed Fremont and Sacramento Weir spills. For observed Fremont weir spill CDEC FRE gage data is used for 1984 – 2003 period. The missing values were filled based on a flow correlation with Sacramento at Verona (USGS 11425500, 1929-2009) using 2006 weir rating curve. For observed Sacramento Weir spill USGS 11426000 gage data is used.

Finally, the simulated daily Fremont Weir and Sacramento Weir spills from CALSIM II are added to the daily mapped Yolo Bypass local flows to estimate the daily inflow for Yolo Bypass into the Delta.

San Joaquin River

Monthly San Joaquin River flow at Vernalis simulated in CALSIM II (C639) is mapped using QSJR daily flow pattern from DAYFLOW. The daily mapping is not performed if C639 is less than 2,000 cfs or if the adjustment factor is not within 0.25 and 7.0 for all months except April and May. The minimum flow target for April and May months is dependent on the 60-20-20 Water Year Type for San Joaquin River Valley. Table 4 shows the long-term minimum flow target to be used for daily mapping of San Joaquin River flow at Vernalis in April and May. The higher minimum flow targets are used to ensure that the daily flows do not fall below the values shown in the Table 4.

The daily mapped C639 flows are then added to R644 return flow from CALSIM II to estimate the daily inflow for San Joaquin River at Vernalis boundary.

Eastside Streams

Monthly Mokelumne River inflow (C603) to Delta from CALSIM II is estimated by subtracting Cosumnes River flow (C601) from C604 flow. It is mapped using the 82-year daily flow pattern prepared from QMOKE data from DAYFLOW. Monthly Cosumnes River (C601) is mapped using the daily flow pattern based on the CSMR data from DAYFLOW.

Monthly Calaveras River flow from CALSIM II (C508) is mapped based on the daily pattern of QMISC data from DAYFLOW. The daily pattern for Calaveras inflow from WY 1956-1960 was based on the CALR daily flow data from the 1930-1960 DAYFLOW dataset and based on QMISC daily flow data from the current DAYFLOW dataset for WY 1960 - 2003. The reason for this is that the current DAYFLOW QMISC data set records reports monthly averages for WY 1956 – 1960 as shown in the Figure 4. The daily patterned C508 data is added to the R514 return flow from CALSIM II to estimate the daily inflow for Calaveras River into the Delta.

Daily Patterning of North Delta Diversion

Daily mapping of the Sacramento River flow in CALSIM II allows to accurately implementing the bypass rules proposed in the BDCP so that a refined estimate of potential north Delta diversion can be estimated. Daily north Delta diversion flows used in DSM2 are estimated by patterning the actual monthly north Delta diversion (D400) from CALSIM II based on the potential daily north Delta diversion from CALSIM II operations. Adjustment factors are computed as the ratio of simulated north Delta diversion in CALSIM II (D400) and the monthly average of potential daily north Delta diversion from CALSIM II. The daily CALSIM II outputs for potential north Delta diversion are then scaled using the adjustment factor to compute the initial estimate of the daily north Delta diversion boundary condition for DSM2.

The final north Delta diversion is computed by adjusting its initial estimate using the daily south Delta exports and constraining the total daily pumping (combined north and south) to the available maximum total pumping capacity of 14,900 cfs. The north Delta diversion is adjusted by reallocating the amount of total daily pumping in excess of 14,900 cfs to the days when the total pumping is less than 14,900 cfs within each month while making sure that daily Sacramento River flow if at least 5,000 cfs. The monthly averages of the final daily north Delta diversion are checked against the CALSIM II (D400) results to ensure the mass balance.

Daily Patterning of South Delta Exports

The initial estimate of the daily south Delta exports at Jones Pumping Plant and Banks Pumping Plant is simply setting all the days in a month equal to the constant monthly average values from CALSIM II (D418_TD and D419_TD). The initial estimates are then adjusted by constraining combined north and south Delta pumping at Jones to 4,600 cfs (maximum pumping capacity at Jones Pumping Plant) and by constraining combined north and south Delta pumping at Banks to 10,300 cfs (maximum pumping capacity at Banks Pumping Plant). The daily Jones and Banks components in the north Delta are computed from initial estimate of the daily north Delta diversion using the monthly fractional volumes from CALSIM II (D418_IF and D419_IF).

The initial daily south Delta export at Jones is adjusted by reallocating the amount of daily combined Jones pumping in excess of 4,600 cfs to the days when total Jones pumping is less than 4,600 cfs within each month. Similarly, the initial south Delta export at Banks is adjusted by reallocating the amount of daily combined Banks pumping in excess of 10,300 cfs to the days when total Banks pumping is less than 10,300 cfs within each month. The monthly averages of the final south Delta exports at Jones and Banks Pumping Plants are checked against the CALSIM II (D418_TD and D419_TD) results to ensure the mass balance. It is important to note that in the absence of the north Delta diversion as in the case of No Action scenario this approach results in constant monthly south Delta exports across all the days in the month similar to the traditional method.

Daily Patterning of DCC Gate Operations

DCC gate operations are determined based on the CALSIM II output “//DXC/GATE-DAYS-OPEN//1MON//”, which provides the number of days DCC gates are open for each month in the 82-year period. For the months where GATE-DAYS-OPEN is zero, the gate operation is set to close on all the days in the month. For the months where GATE-DAYS-OPEN is greater than zero, the gate operation is determined based on daily Sacramento River flow upstream of the Delta Cross Channel estimated from daily mapped Sacramento inflow and subtracting the north Delta diversion from it. From beginning of the month, the gates are set to open on the days if Sacramento River flow upstream of the Delta Cross Channel is less than 25,000 cfs, otherwise the gates are assumed to be closed. The cumulative sum of the number of days with the gates open is tracked. If the number of the days specified by CALSIM II is met in a month, then the gates are closed for the rest of the month.

The monthly total number of days with DCC gates open is computed from the final daily timeseries and compared to the CALSIM II result. This approach could result in discrepancy with CALSIM II result if daily Sacramento River flow is greater than 25,000 cfs while the monthly average in CALSIM II was not. The discrepancy was not corrected since the daily approach is more realistic.

End-of-month Smoothing

The daily mapped Delta inflows are smoothed at the month transition to avoid abrupt change in flow. The smoothing approach used computes 4-day forward moving average and 4-day backward moving average and averages the two moving averages in the last 5 days of a month and the first 5 days of the next month. Once the smoothing is performed the resulting daily timeseries is scaled to conserve the monthly average of the inflow.

Smoothing is performed on all the main Delta River inflows. Sacramento River is an exception since the daily pattern needs to be consistent with the daily mapping of Sacramento River flow in CALSIM II as the north Delta diversion is mapped based on the daily potential estimated in CALSIM II. There is a chance that with smoothing the daily Sacramento flow could change from the CALSIM II pattern and may not be sufficient to meet the daily north Delta diversion.

TABLE 1

Identified "Pattern" Water Year for the Water Years 1922 to 1955 with Missing Daily Historical Flows

Water Year	Total Annual Unimpaired Delta Inflow (TAF)	Selected "Pattern" Water Year	Total Annual Unimpaired Delta Inflow (TAF)
1922	32,975	1975	31,884
1923	23,799	2002	23,760
1924	8,174	1977	6,801
1925	26,893	1962	25,211
1926	18,534	1959	17,967
1927	38,636	1984	38,188
1928	26,363	1962	25,211
1929	12,899	1994	12,456
1930	20,326	1972	19,863
1931	8,734	1977	6,801
1932	24,179	2002	23,760
1933	14,126	1988	14,019
1934	12,895	1994	12,456
1935	28,486	2003	28,228
1936	30,698	2003	28,228
1937	25,448	1962	25,211
1938	56,949	1998	56,482
1939	12,743	1994	12,456
1940	37,185	1963	36,724
1941	46,746	1986	46,602
1942	42,301	1980	41,246
1943	36,870	1963	36,724
1944	17,158	1981	17,131
1945	26,757	1962	25,211
1946	28,823	2003	28,228
1947	16,206	2001	15,460
1948	23,741	1979	22,973
1949	19,176	1960	19,143
1950	23,272	1979	22,973
1951	39,110	1984	38,188
1952	49,270	1986	46,602
1953	30,155	2003	28,228
1954	26,563	1962	25,211
1955	17,235	1981	17,131

TABLE 2

Adjustment in Number of Days to Calculate February Monthly Average in the Selected Pattern Years

Water Year	Selected Pattern Water Year	Water Year Days in February	Pattern Year Days in February	Adjustment (days)
1922	1975	28	28	0
1923	2002	28	28	0
1924	1977	29	28	1
1925	1962	28	28	0
1926	1959	28	28	0
1927	1984	28	29	-1
1928	1962	29	28	1
1929	1994	28	28	0
1930	1972	28	29	-1
1931	1977	28	28	0
1932	2002	29	28	1
1933	1988	28	29	-1
1934	1994	28	28	0
1935	2003	28	28	0
1936	2003	29	28	1
1937	1962	28	28	0
1938	1998	28	28	0
1939	1994	28	28	0
1940	1963	29	28	1
1941	1986	28	28	0
1942	1980	28	29	-1
1943	1963	28	28	0
1944	1981	29	28	1
1945	1962	28	28	0
1946	2003	28	28	0
1947	2001	28	28	0
1948	1979	29	28	1
1949	1960	28	29	-1
1950	1979	28	28	0
1951	1984	28	29	-1
1952	1986	29	28	1
1953	2003	28	28	0
1954	1962	28	28	0
1955	1981	28	28	0

TABLE 3

DSM2 Boundary Flow, CALSIM II Output Used, Observed DAYFLOW Record Used for Daily Mapping and Applicable Constraints

DSM2 Boundary Flow	CALSIM Output	Observed DAYFLOW Records	Constraints [2]
Sacramento River at Freeport	C169	QSAC	None
Yolo bypass flow not including Fremont and Sacramento Weir Spills	(C157 – D160 – D166A)	QYOLO minus Historic Fremont and Sacramento Weir Spills	Allowed range for adjustment factor is 0.25 to 7.0
Cosumnes River	C501	CSMR	Allowed range for adjustment factor is 0.25 to 7.0
Mokelumne River	(C504 – C501)	QMOKE	Allowed range for adjustment factor is 0.25 to 7.0
Calaveras River at Stockton	C508	QMISC	Allowed range for adjustment factor is 0.25 to 7.0
San Joaquin River at Vernalis	C639	QSJR	Allowed range for adjustment factor is 0.25 to 7.0; Minimum flow target for simulated monthly flow is 2,000 cfs in most months [1]

Notes:

[1] In April and May months the minimum target flow to allow daily mapping for San Joaquin River is determined based on San Joaquin River 60-20-20 Water Year Type. Minimum target flow for Wet and Above Normal Years 7,000 cfs, Below Normal Years 5,500 cfs, Dry Years 4,000 cfs and Critical Years 2,500 cfs.

[2] Daily mapping is not performed and constant monthly average flow is assigned to all the days in the month if the listed criteria is not met

TABLE 4

San Joaquin River at Vernalis Minimum Flow Target in April and May for Daily Mapping

San Joaquin River Index (60-20-20)	Long-term Flow Target at Vernalis (cfs)
1	7,000
2	7,000
3	5,500
4	4,000
5	2,500

Notes: 2,000 cfs is used as the minimum flow target for other months

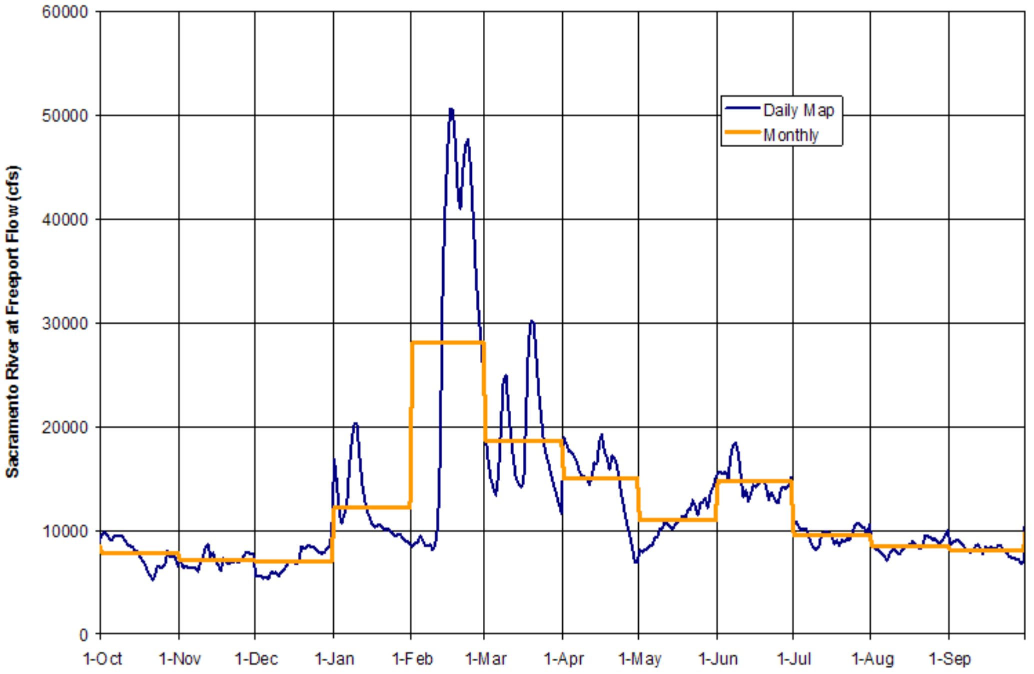


Figure 1: Example monthly-averaged and daily-averaged flow for Sacramento River at Freeport

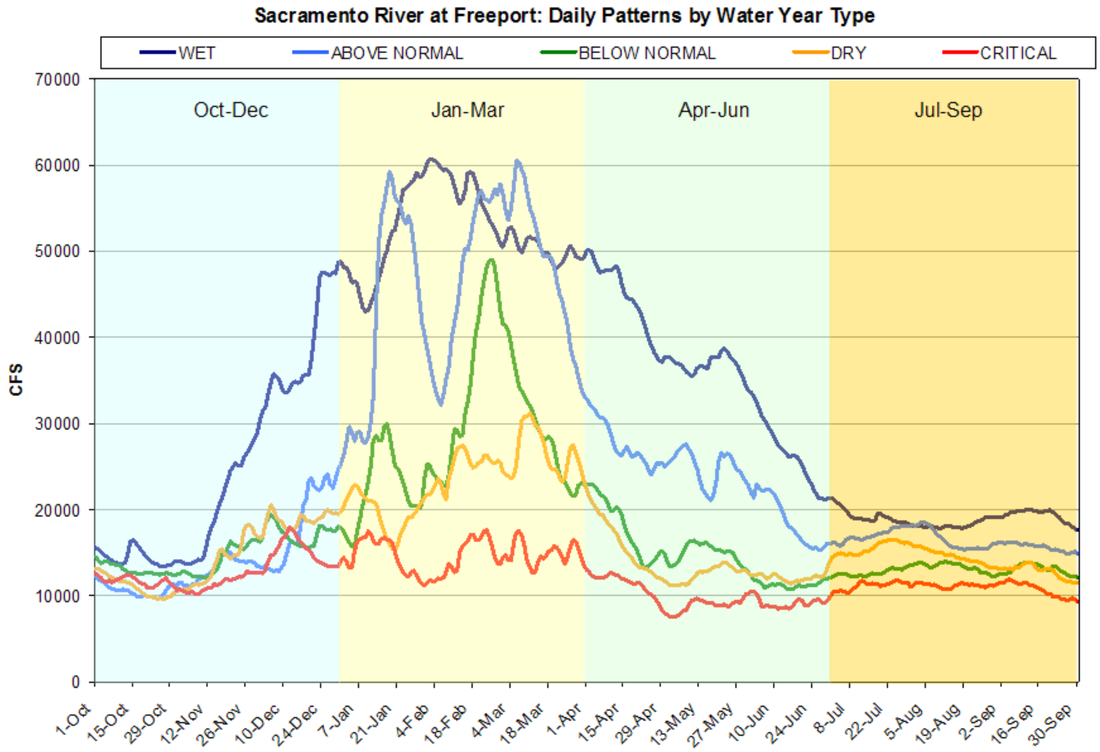


Figure 2: Mean daily flows by Water Year Type for Sacramento River at Freeport

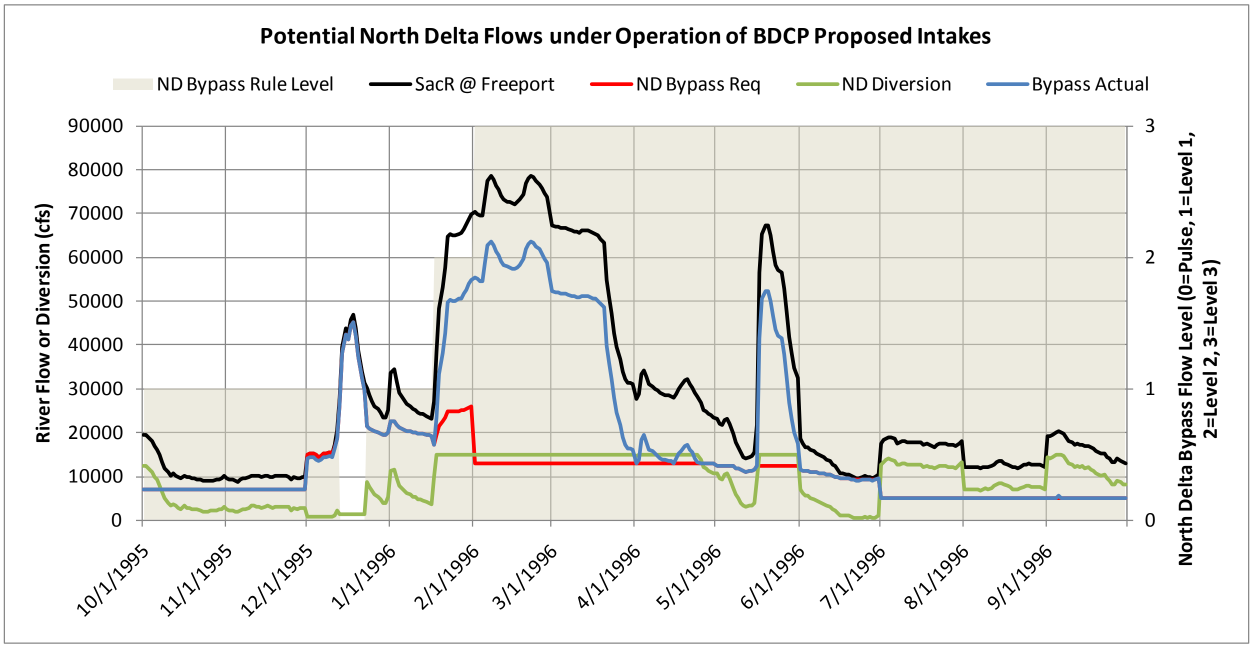


Figure 3: Example year daily patterns and operation of the North Delta intakes. Note: the grey shading indicates the active bypass rule (0=pulse/low level pumping, 1=level I, 2=level II, and 3=level III).

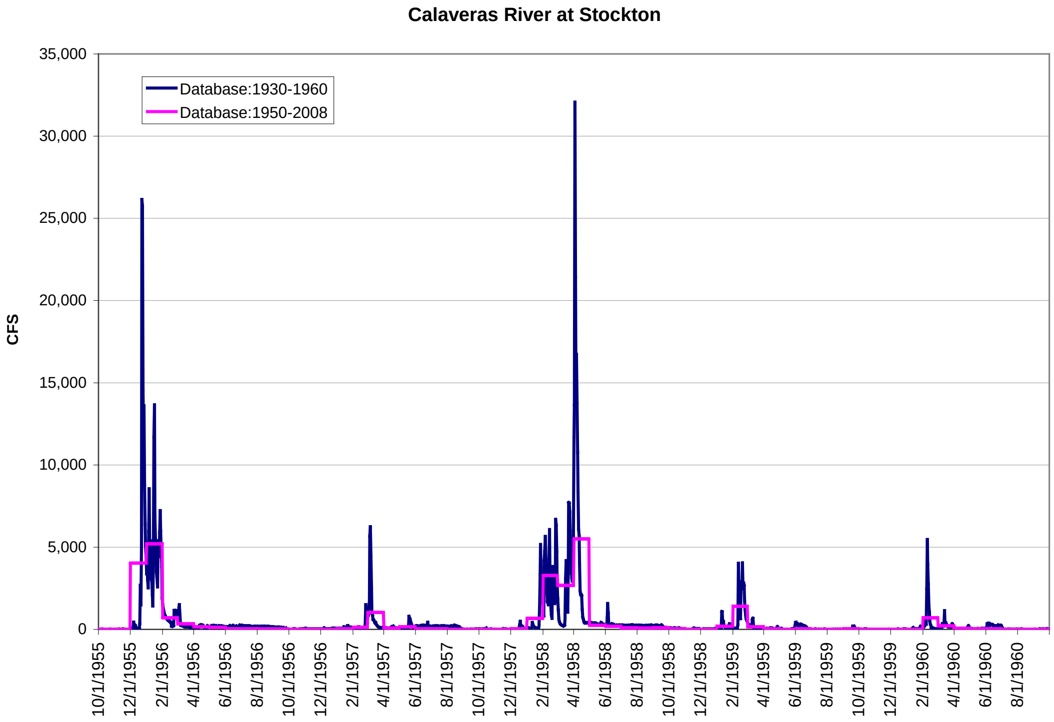


Figure 4: Calaveras River flow from 1930-1960 DAYFLOW and QMISC daily flow from the Current DAYFLOW Datasets

D.10. Additional Sensitivity Analyses for Bay-Delta Conservation Plan

This section compiles information from key sensitivity analyses performed in support of the BDCP planning process. This section is a compilation of various technical memoranda and PowerPoint slides previously prepared for use in various BDCP lead agency or stakeholder discussions.

As noted earlier, Reclamation's 2008 OCAP BA Appendix W included a comprehensive sensitivity analysis of CALSIM II results relative to the uncertainty in the inputs. This appendix provides a good summary of the key inputs that are critical for largest changes in several operational outputs. Understanding the findings from this appendix may help bracket the range of uncertainty in the CALSIM II results.

D.10.1. D-1641 Export/Inflow Ratio in BDCP

Modeling of BDCP Alternatives included two differing approaches in computing the export/inflow ratio. This section summarizes the effects of the two approaches on key flow and storage results.

This section includes a technical memorandum previously documented for use in the BDCP Effects Analysis.

TECHNICAL MEMORANDUM

D-1641 Export/Inflow Ratio in BDCP

PREPARED FOR: ICF

PREPARED BY: CH2M HILL

DATE: September 5, 2013

Background

Export/Inflow (E/I) ratio is one of the D1641 criteria used to govern allowed Delta exports. E/I Ratio limits were established under SWRCB D1641 to reduce fish, egg, and larvae entrainment and mortality at the south Delta intakes. Under BDCP, entrainment at the south Delta intakes is minimized by specific measures such as shifting exports to north Delta intakes and by operating south Delta intakes to meet defined Combined Old and Middle River (OMR) flow criteria dependent on water year types and the San Joaquin River inflow. At the north Delta intakes BDCP bypass flows are designed to minimize entrainment of the fish into Central Delta, and provide sufficient protection for migrating fish. Additional BDCP criteria related to Delta Outflow ensures the incidental benefits that E/I ratio is expected to provide.

E/I Ratio in BDCP Modeling

Modeling of the BDCP decision tree scenarios included two ways of calculating the inflow and export values in the E/I ratio based on the timing of when the modeling was performed. The initial modeling of the decision tree scenarios including the Low Outflow Scenario [LOS] and the scenario with high Fall outflow and low Spring outflow [original Alternative 4] each did not consider the diversion at the proposed north Delta intakes as part of the computation of the E/I ratio. In other words, the modeling for these two scenarios included measurement of the ‘Sacramento River inflow’ component downstream of the new North Delta intakes, and the diversion at the south Delta intakes. However, the decision tree scenarios that were modeled later including the High Outflow Scenario (HOS) and the scenario with high Spring outflow and low Fall outflow accounts for the north Delta diversion as part of both the inflow and export calculations as recommended by NMFS. In other words, the E/I calculation in the latest approach included Sacramento River inflow measured upstream of the north Delta intakes and the exports included the total diversion at the north Delta intakes and the south Delta intakes.

D1641 states that Sacramento River inflow is as measured at Freeport. It also states that the exports are the total of the inflow into Clifton Court Forebay and the pumping at Tracy Pumping Plant. Initial BDCP modeling adhered to this definition of the E/I ratio. However, NMFS Comment 1.12 (on the February 2012 draft) expressed concern with the calculation of the inflow below the North Delta diversion, and subsequent progress report (on March 2013 draft) noted concern with the inconsistencies arising from the two different applications of the E/I ratio in the decision tree branches. Similar concerns were raised through the EIR/EIS review.

E/I Ratio Sensitivity Analysis

A sensitivity analysis was performed to determine potential differences in the modeling results that may arise with the two different approaches of computing the E/I ratio. The primary objective of this analysis was to provide information to the lead agencies that would help in ascertaining if the two approaches result in similar operations results and the biological effects are adequately captured in the current effects analysis.

CALSIM II models for the LOS and the scenario with high Fall outflow and low Spring outflow (ESO) at Early Long-Term (ELT) were simulated using the E/I ratio calculation recommended by NMFS. The results from the sensitivity analysis were compared to the results used in the effects analysis, to determine the differences in key flows and storage operations. Some of the key results are summarized below. For the ease of reading only the results from the ESO scenario are presented in here. CALSIM II results from the sensitivity run, Alternative 4 ESO at ELT with E/I ratio per NMFS recommendation [A4_ESO_ELT (NMFS)], are compared to No Action Alternative at ELT [NAA_ELT], Alternative 4 HOS at ELT [A4_HOS_ELT], and Alternative 4 ESO at ELT [A4_ESO_ELT] presented in the effects analysis.

Figures 1, 2 and 3 show the probability of exceedance of the E/I ratio with diversion at the north Delta intakes as part of the E/I calculation, during April, May and June months. For April, E/I ratio values in both A4_ESO_ELT and A4_ESO_ELT (NMFS) runs are below the required 0.35. For May, except for two years under A4_ESO_ELT scenario, the E/I ratio values are at or below the required 0.35. For June, using the initial approach in computing the E/I ratio (as shown by A4_ESO_ELT curve) resulted in 40% of the years with higher E/I ratio than the required 0.35 value, as computed per NMFS approach.

Long-term average monthly pattern of the north Delta bypass flows are shown in Figure 4. Both the A4_ESO_ELT runs are resulting in similar bypass flows in all months except during June through August, where the run with NMFS approach is resulting in slightly higher flows than the run with initial approach. Figure 5 shows the probability of exceedance of resulting north Delta bypass flows during the month of June. A4_ESO_ELT (NMFS) run shows higher bypass flow in June in 20% of the years compared to the A4_ESO_ELT run. June bypass flows are between 10000 cfs to 20000 cfs in the years where there is a difference between the two approaches. The minor changes in July and August bypass flows are related to the changes in the Delta exports.

Figure 6 shows the long-term average monthly pattern of the total Delta exports. Once again both the A4_ESO_ELT runs are resulting in similar Delta exports in all months except during June and July. Exports from June are shifted to July, under the run with NMFS approach. As shown in Figure 7, however, the annual total Delta exports under the both runs remain similar. Both the ESO runs differ by only 11 TAF. Figure 7 also shows about 50 TAF shift in exports from the north Delta intakes to the south Delta intakes.

Figure 8 and 9 show the comparison of the end of September carryover storage in Shasta and Oroville Reservoirs. The change in the E/I approach resulted in similar storage conditions under the two A4_ESO_ELT runs at both Shasta and Oroville. At Folsom, however, the end of September carryover storage under the A4_ESO_ELT (NMFS) run is slightly lower than the A4_ESO_ELT run, as shown in Figure 10. This is primarily due to the shift in exports from June to July under the NMFS approach run, and the associated carriage water cost required to maintain the Delta salinity control requirements in July. This change in the Folsom storage condition is not apparent at the end of May, which is representative of the available cold water pool, as shown in Figure 11. Both A4_ESO_ELT simulations resulted in similar results for the other flow and storage operations.

Summary

In summary, the results from the sensitivity run for A4_ESO_ELT with E/I ratio approach recommended by NMFS showed that on a long-term average, there are minor changes in the flow and storage operations compared to the A4_ESO_ELT results included in the current effects analysis. The north Delta bypass flows and Delta outflow are increasing slightly in June using the NMFS recommended approach. Annual Delta exports remained similar between both approaches. However, Delta exports are shifted slightly from May-June to July-August using the NMFS recommended approach, which may be resulting in a slight reduction in the Folsom carryover storage conditions. Other flow and storage operations were found to be similar between the runs with the two E/I ratio computation approaches.

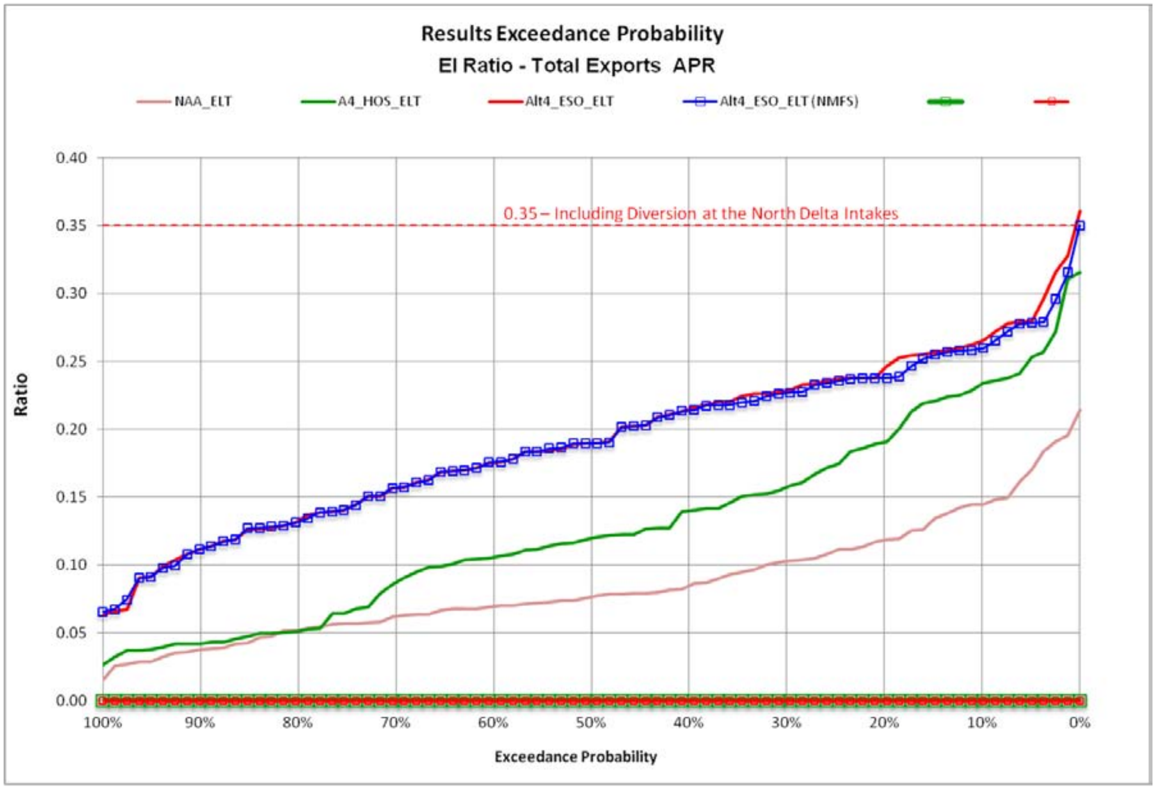


Figure 1: Comparison of probability of exceedance of E/I ratio in the month of April. E/I ratio values computed using Sacramento River inflow upstream of the north Delta intakes and the total Delta exports. 0.35 is the SWRCB D-1641 E/I ratio requirement for the month of April.

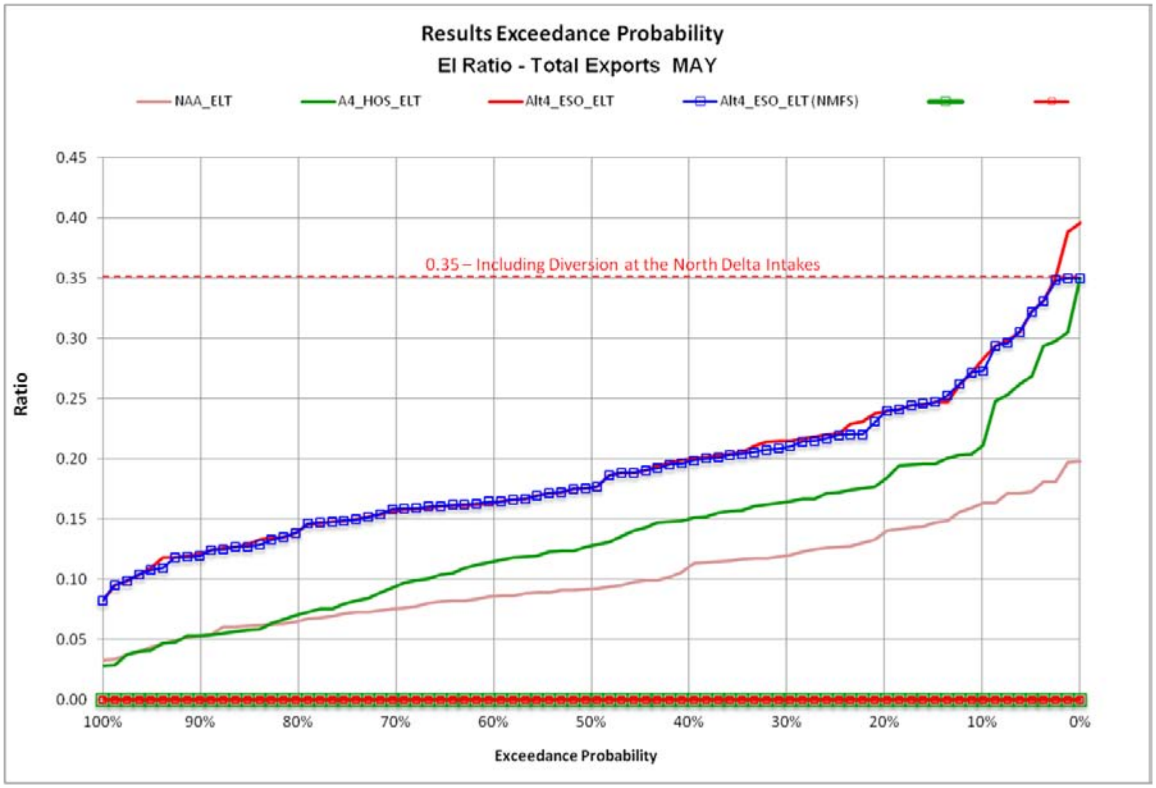


Figure 2: Comparison of probability of exceedance of E/I ratio in the month of May. E/I ratio values computed using Sacramento River inflow upstream of the north Delta intakes and the total Delta exports. 0.35 is the SWRCB D-1641 E/I ratio requirement for the month of May.

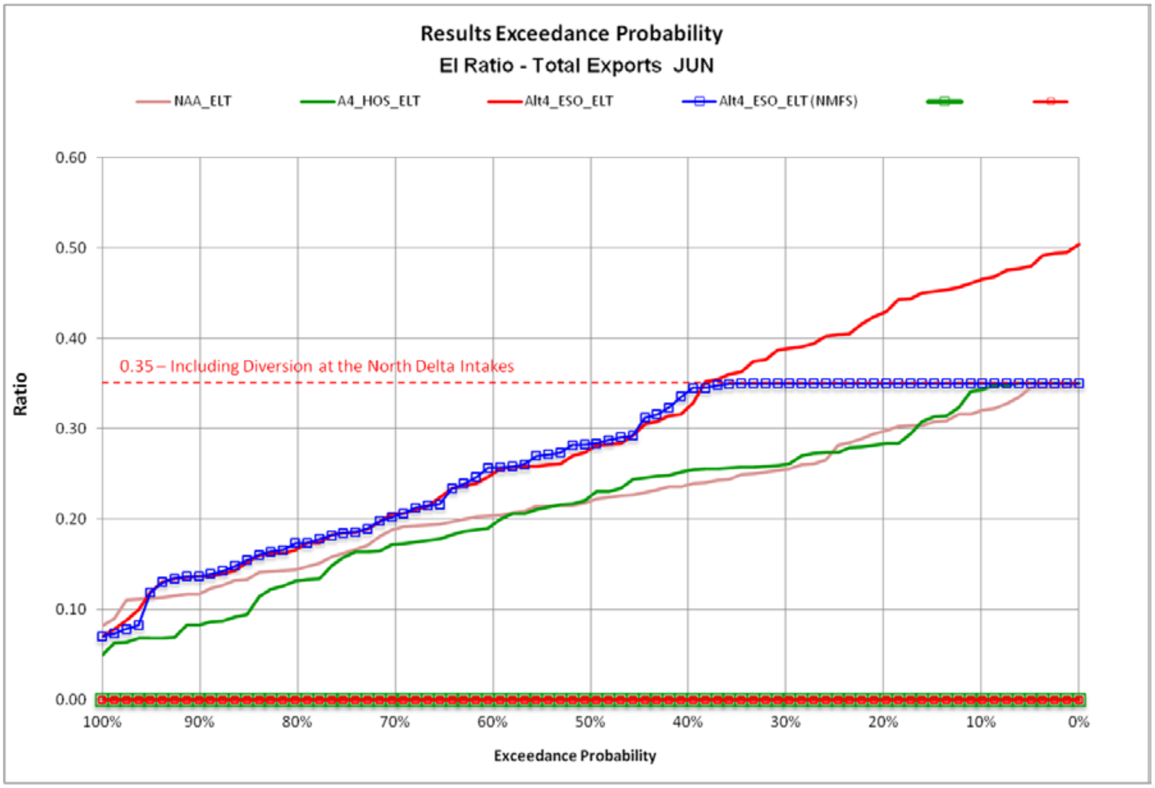


Figure 3: Comparison of probability of exceedance of E/I ratio in the month of June. E/I ratio values computed using Sacramento River inflow upstream of the north Delta intakes and the total Delta exports. 0.35 is the SWRCB D-1641 E/I ratio requirement for the month of June.

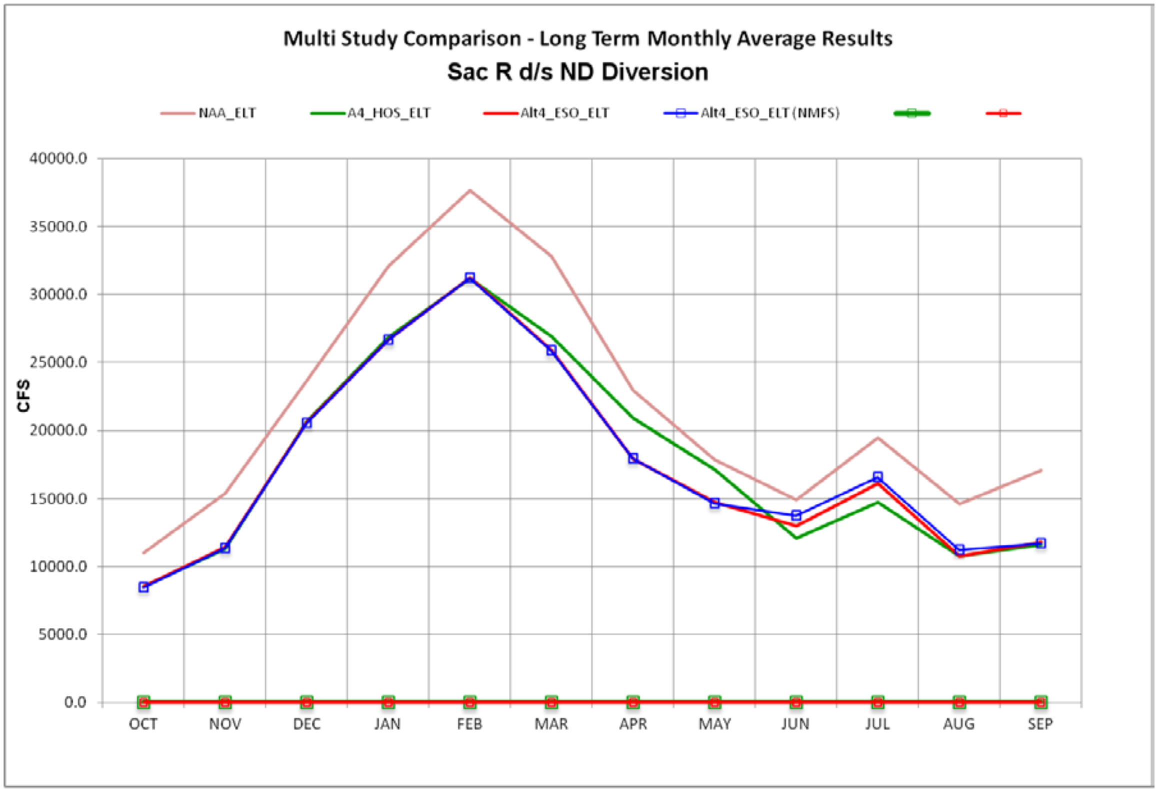


Figure 4: Comparison of long-term average monthly patterns of the north Delta bypass flows.

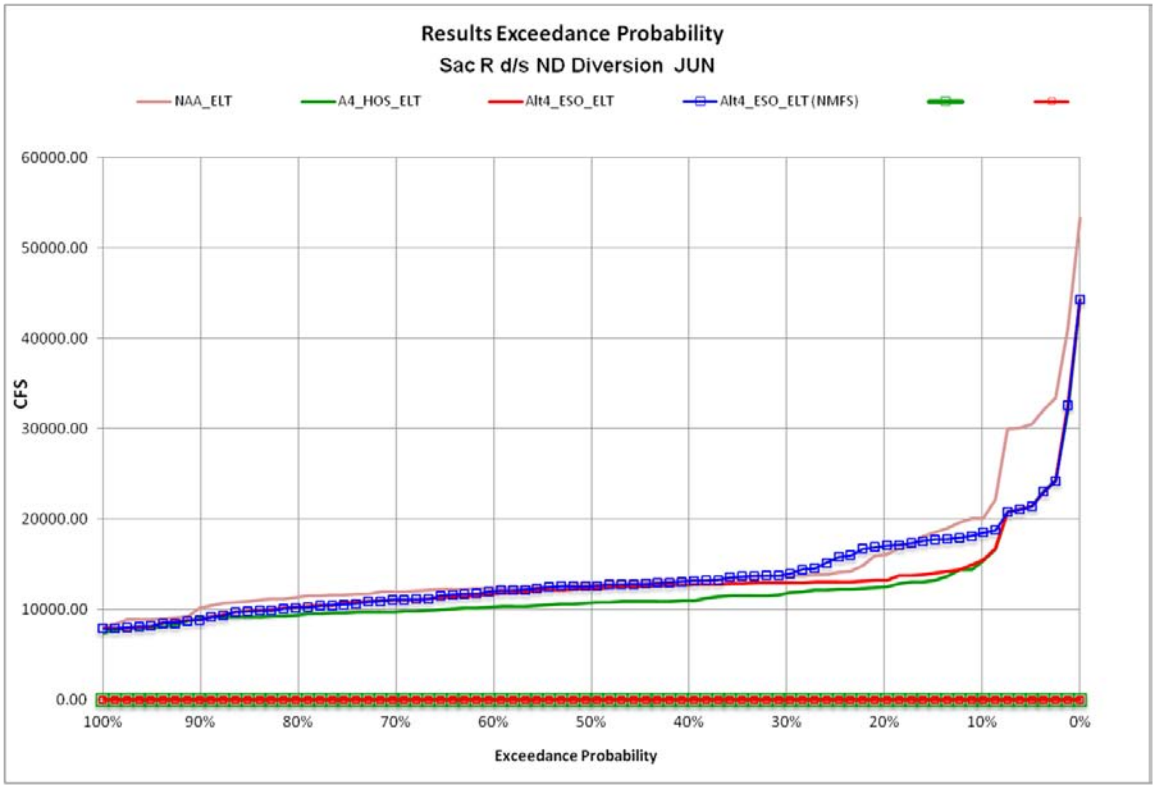


Figure 5: Comparison of probability of exceedance of the resulting north Delta bypass flows in the month of June.

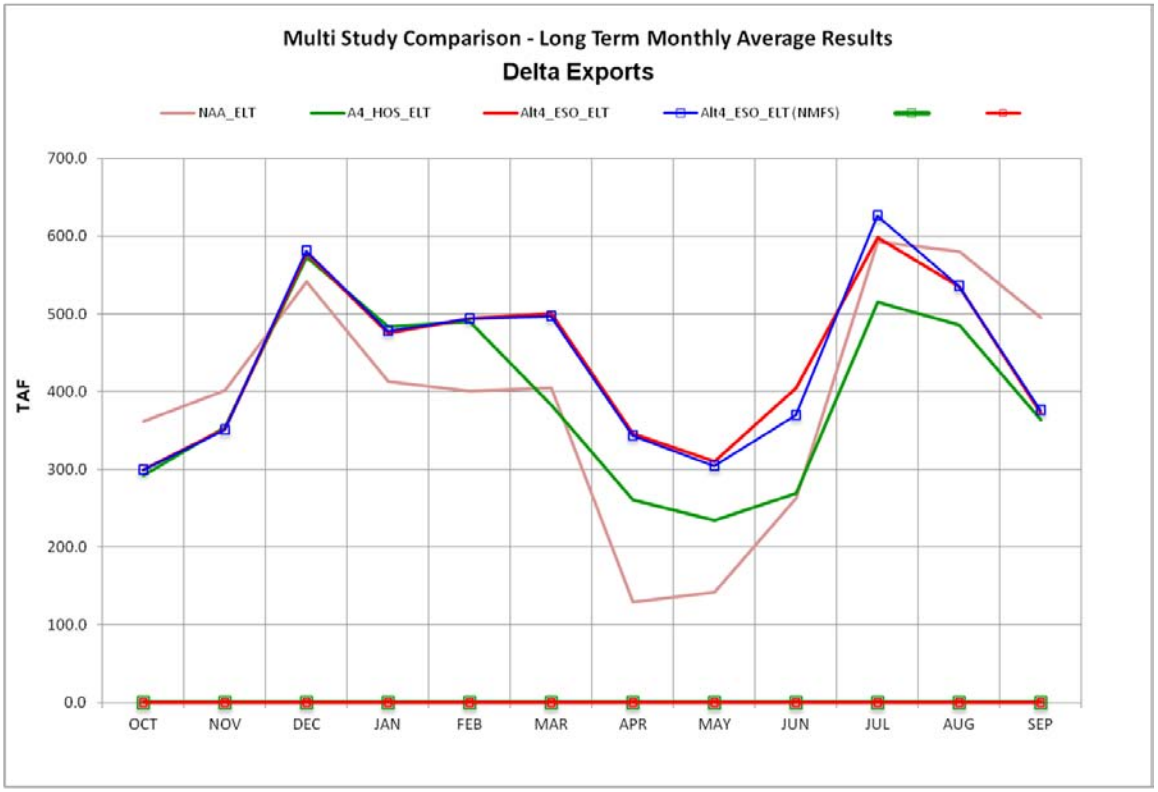


Figure 6: Comparison of long-term average monthly patterns of the total Delta exports.

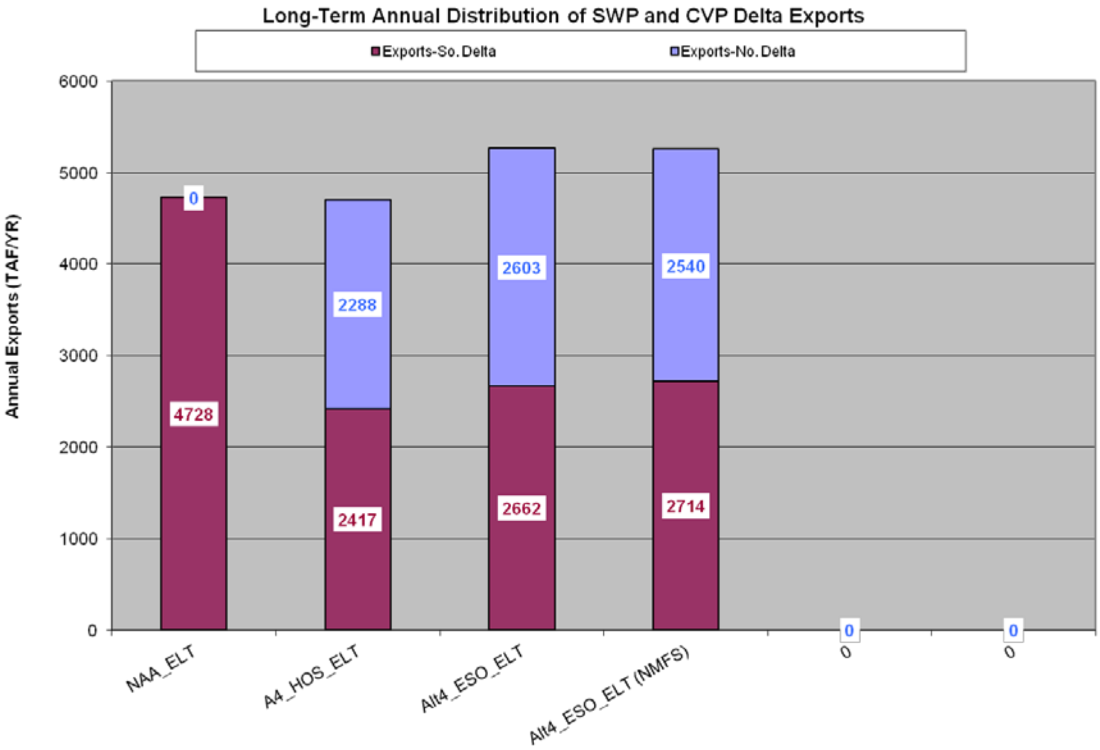


Figure 7: Comparison of long-term average Delta exports at the north Delta intakes and the south Delta intakes.

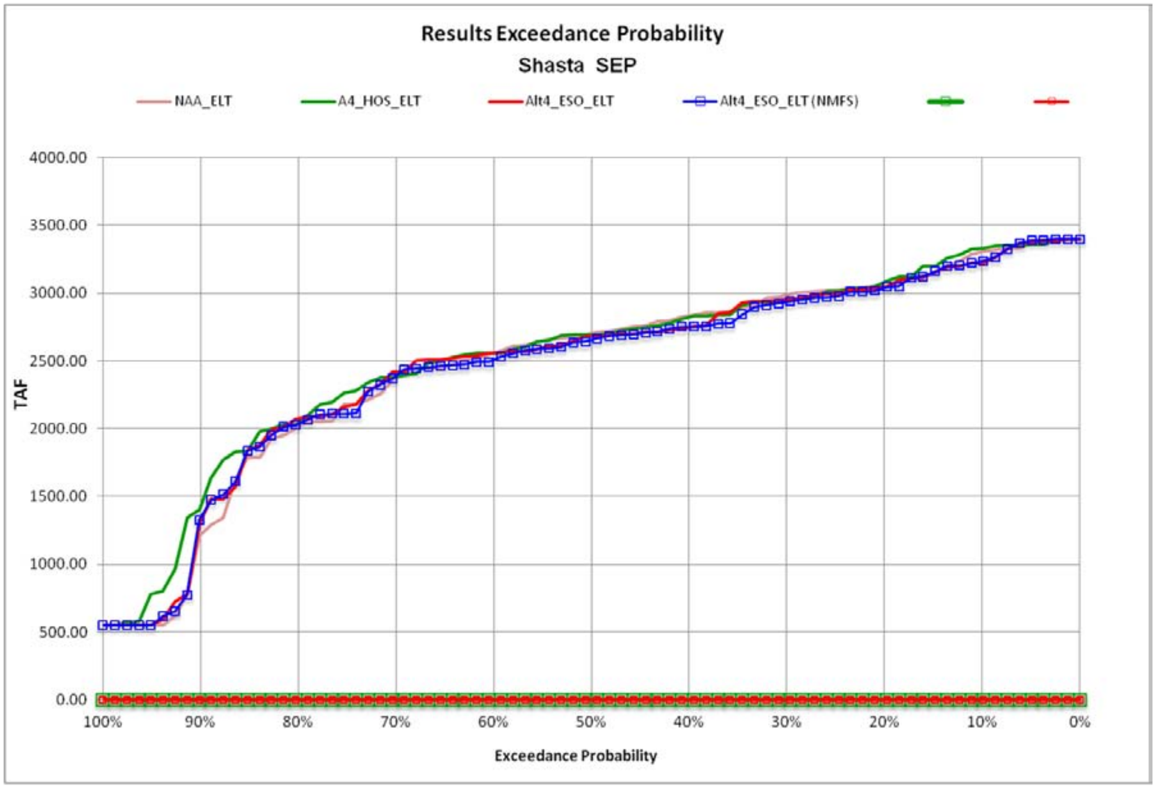


Figure 8: Comparison of probability of exceedance of the resulting end-of-September carryover storage in the Shasta Reservoir.

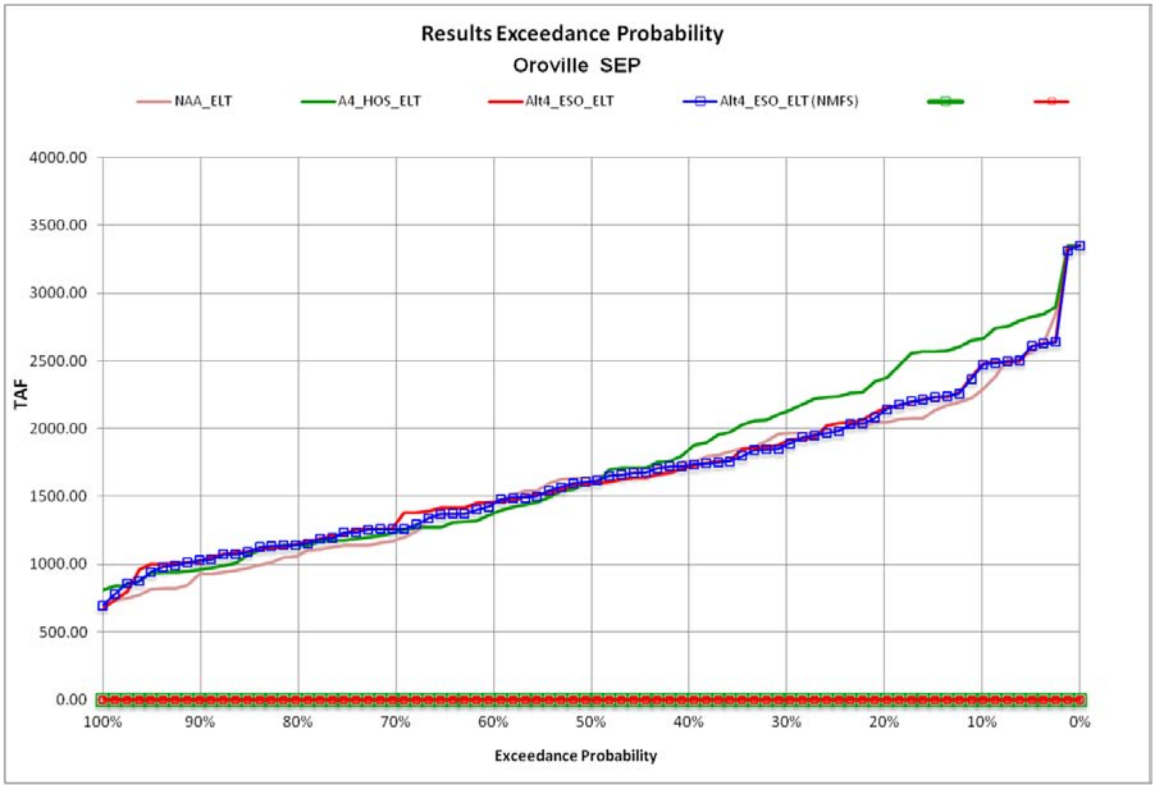


Figure 8: Comparison of probability of exceedance of the resulting end-of-September carryover storage in the Oroville Reservoir.

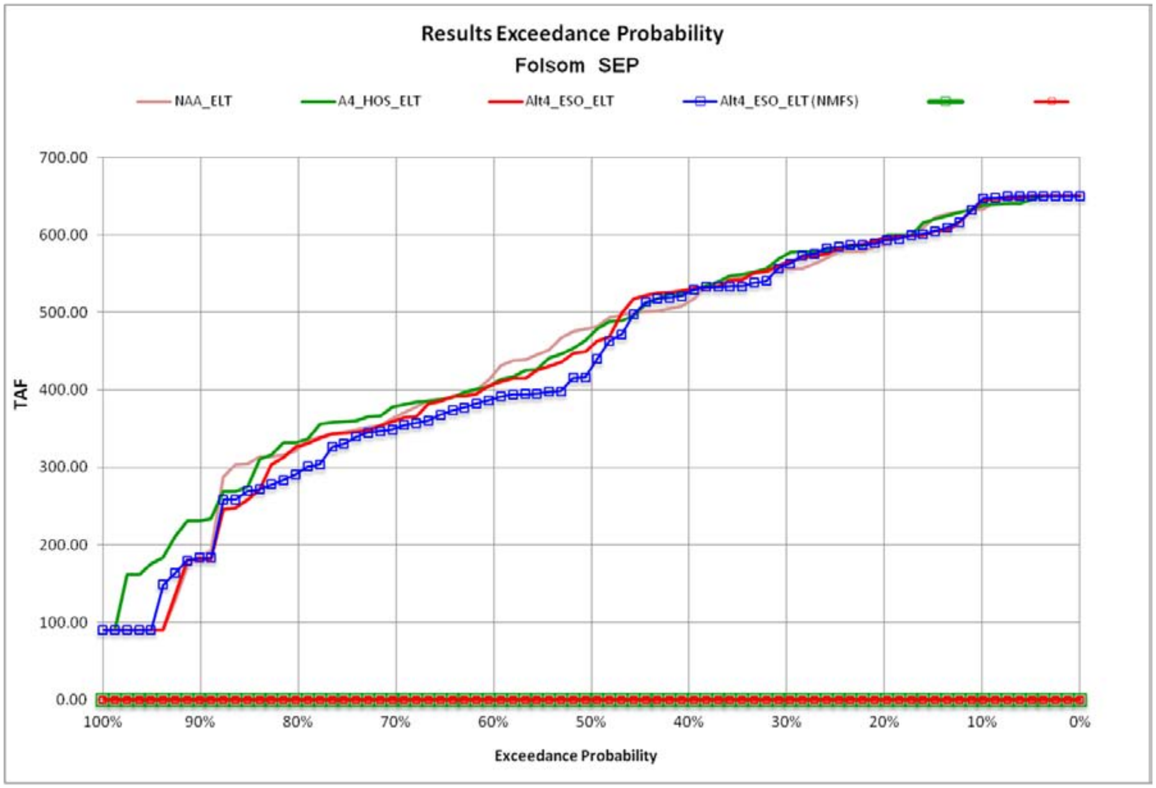


Figure 9: Comparison of probability of exceedance of the resulting end-of-September carryover storage in the Folsom Reservoir.

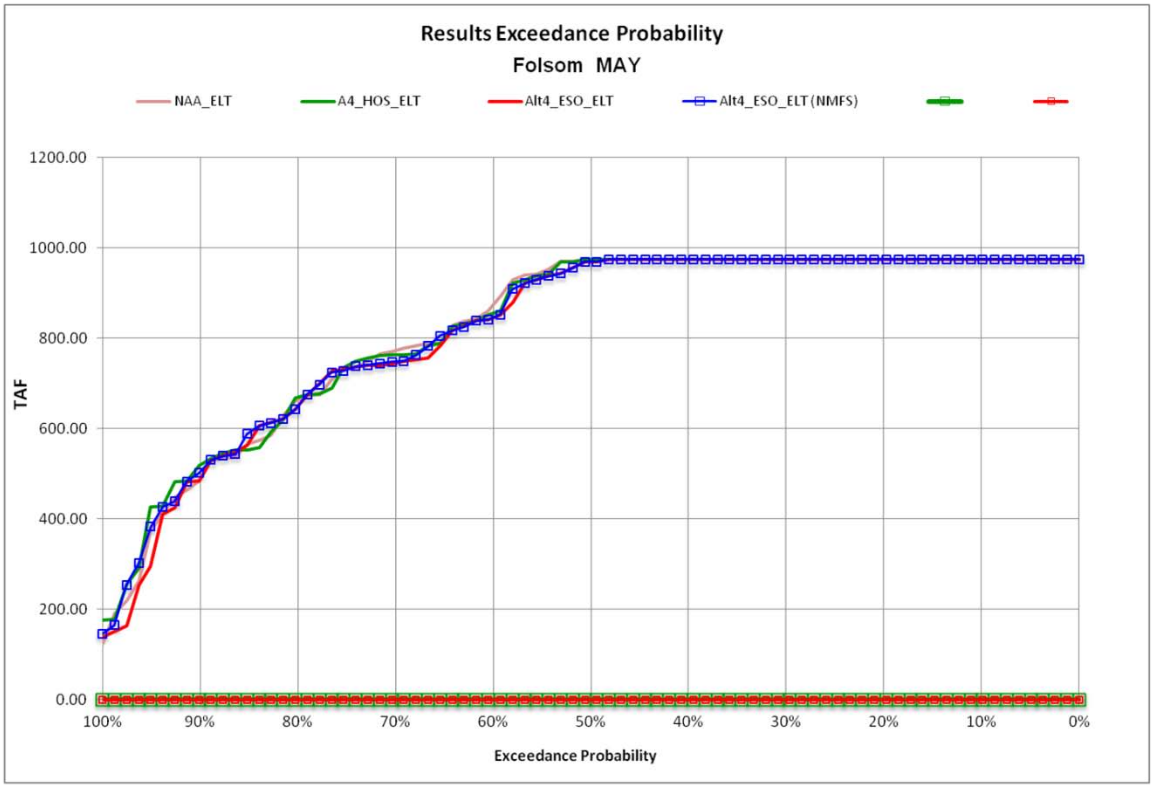


Figure 10: Comparison of probability of exceedance of the resulting end-of-May storage in the Folsom Reservoir.

D.10.2. Incremental Effects of Climate Change, Sea Level Rise, and Restoration on Operations

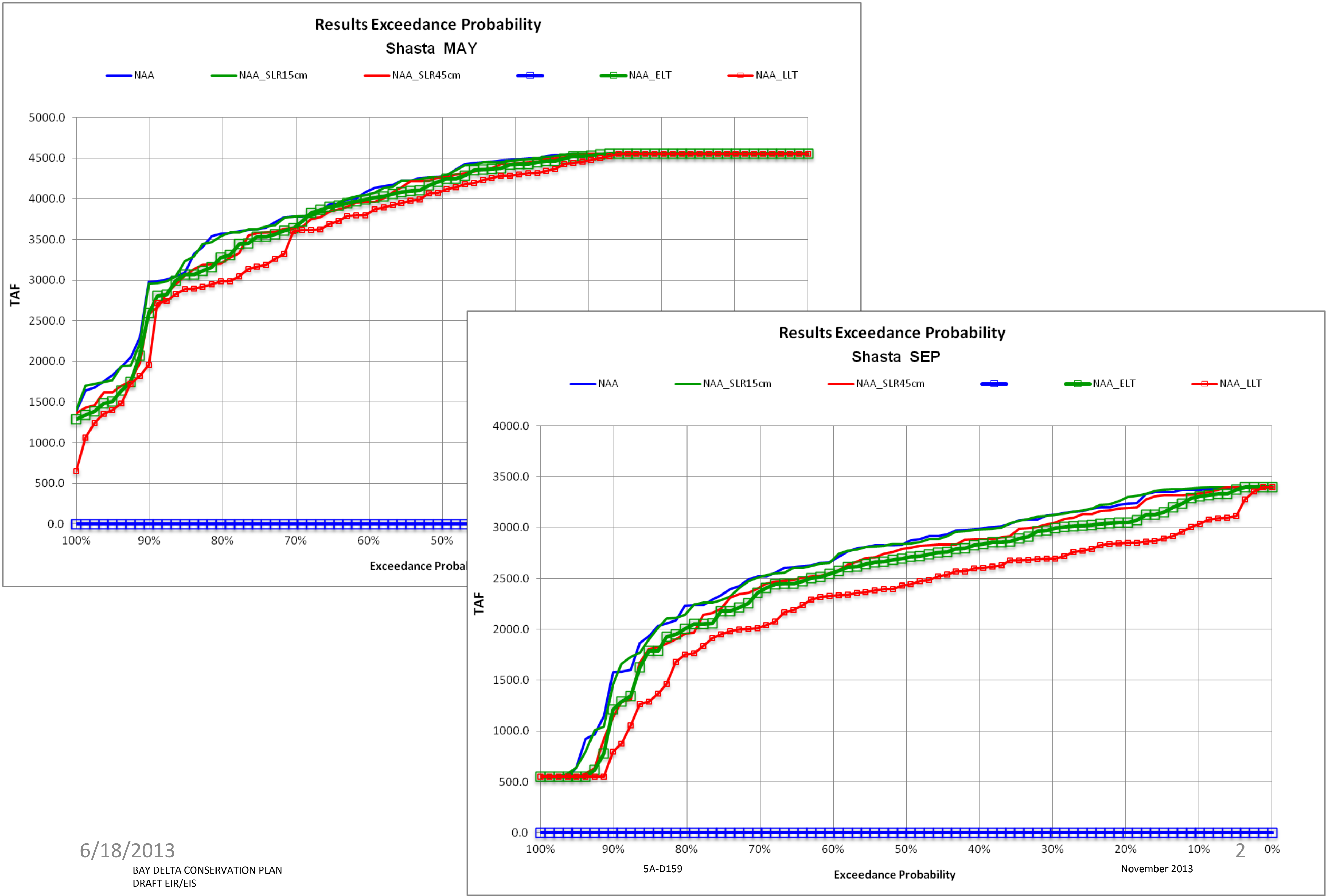
The modeling performed for the BDCP EIR/EIS Alternatives included the combined effects of the various proposed elements under BDCP, integrated with the projected climate change and sea level rise. Additional simulations were conducted to understand the incremental effects of proposed BDCP operations without restoration, climate change and sea level rise effects. This section includes a few key results from this incremental analysis presented at a BDCP stakeholder engagement meeting.

The results show that the effects on the upstream operations are primarily due to the climate change effect on the reservoir inflows, river temperatures, and the increased salinity intrusion in the Delta due to the projected sea level rise. The proposed BDCP operations did not impact the upstream reservoir conditions, both at end-of-May and end-of-September, because of the increased flexibility in the system. The proposed restoration under BDCP has limited effect on the overall system operations.

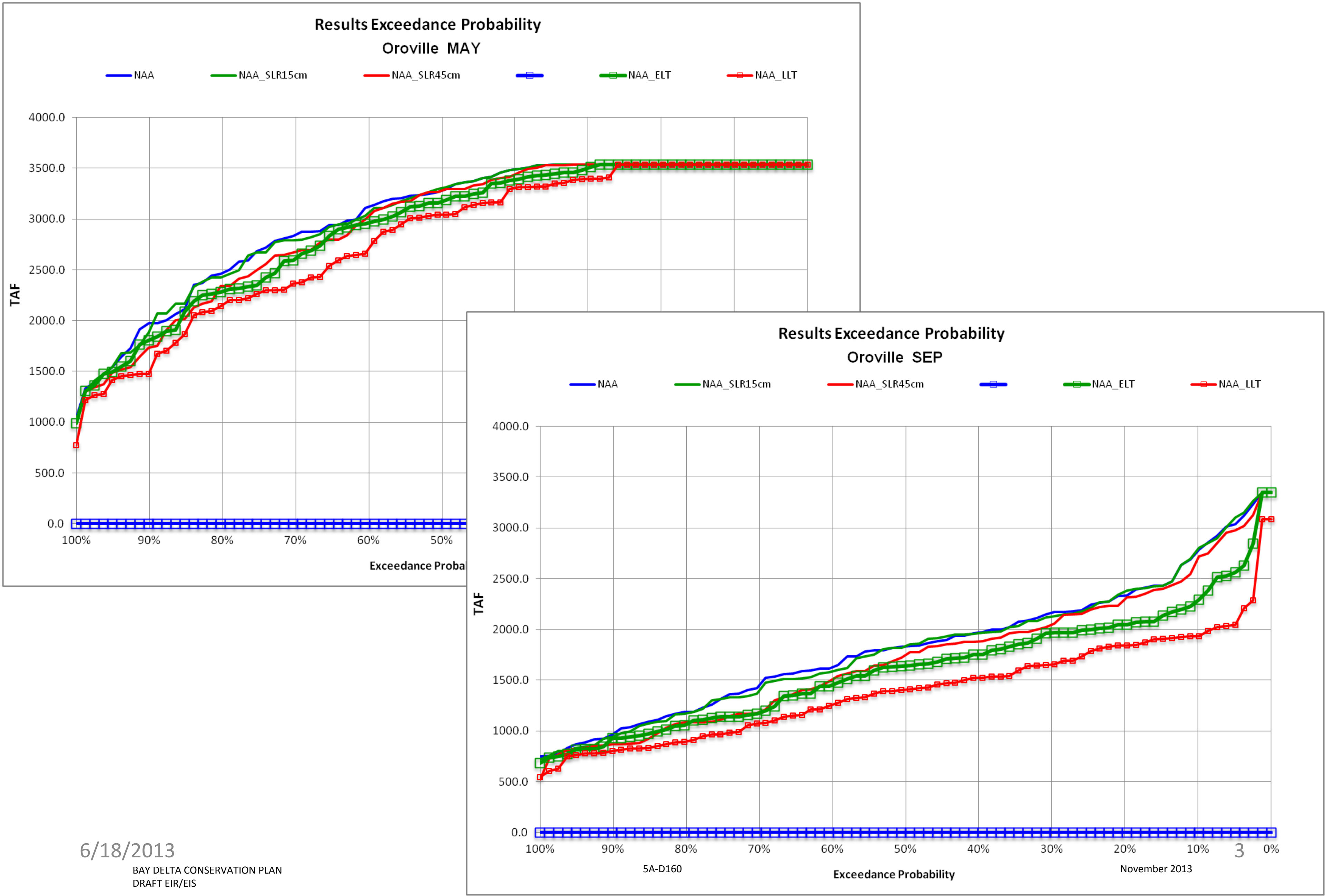
Incremental Effects of Sea Level and Climate Change

- NAA
- NAA with 15 cm SLR
- NAA with 45 cm SLR
- NAA with 15 cm SLR and Climate Change at 2025
- NAA with 45 cm SLR and Climate Change at 2060

Shasta Storage



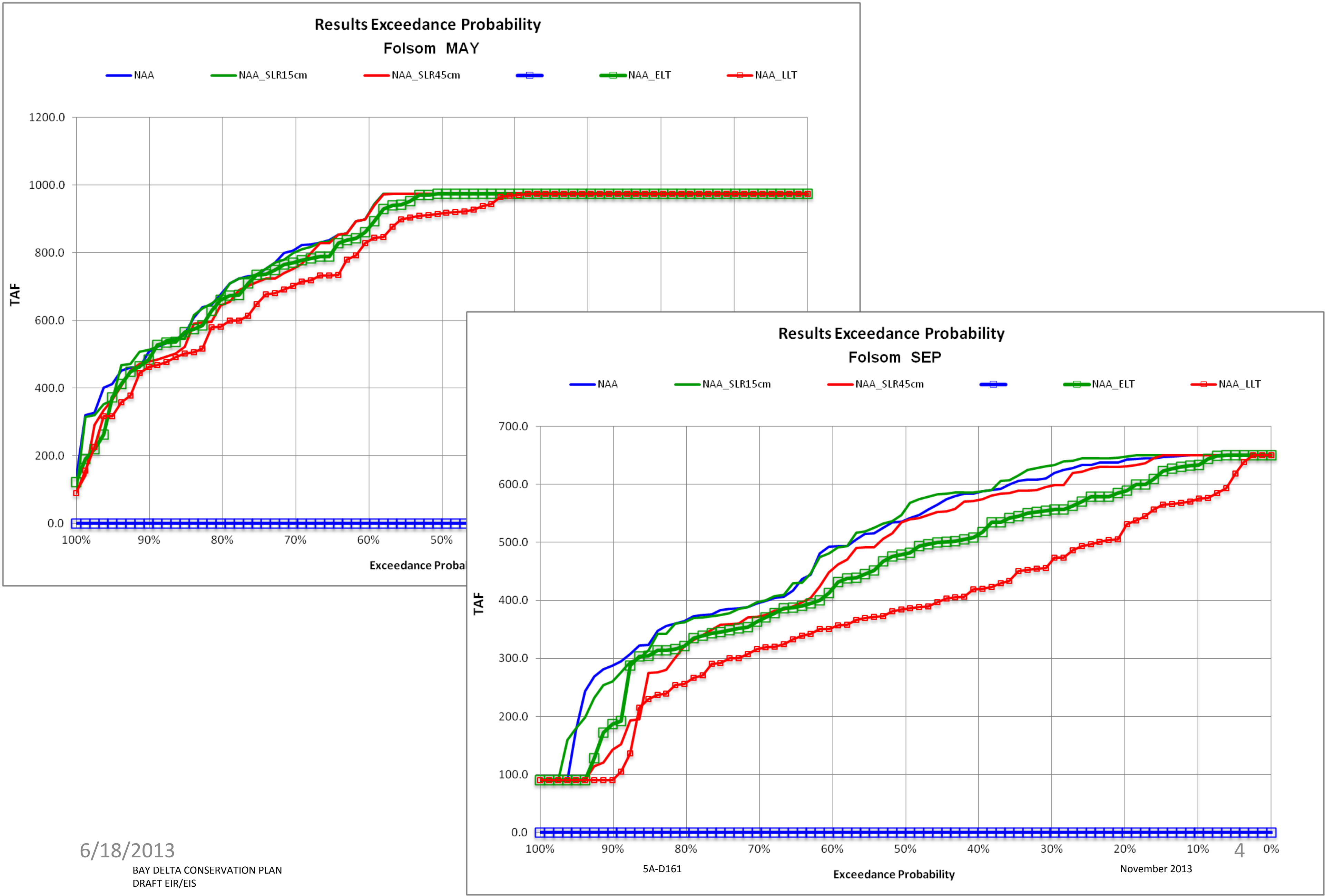
Oroville Storage



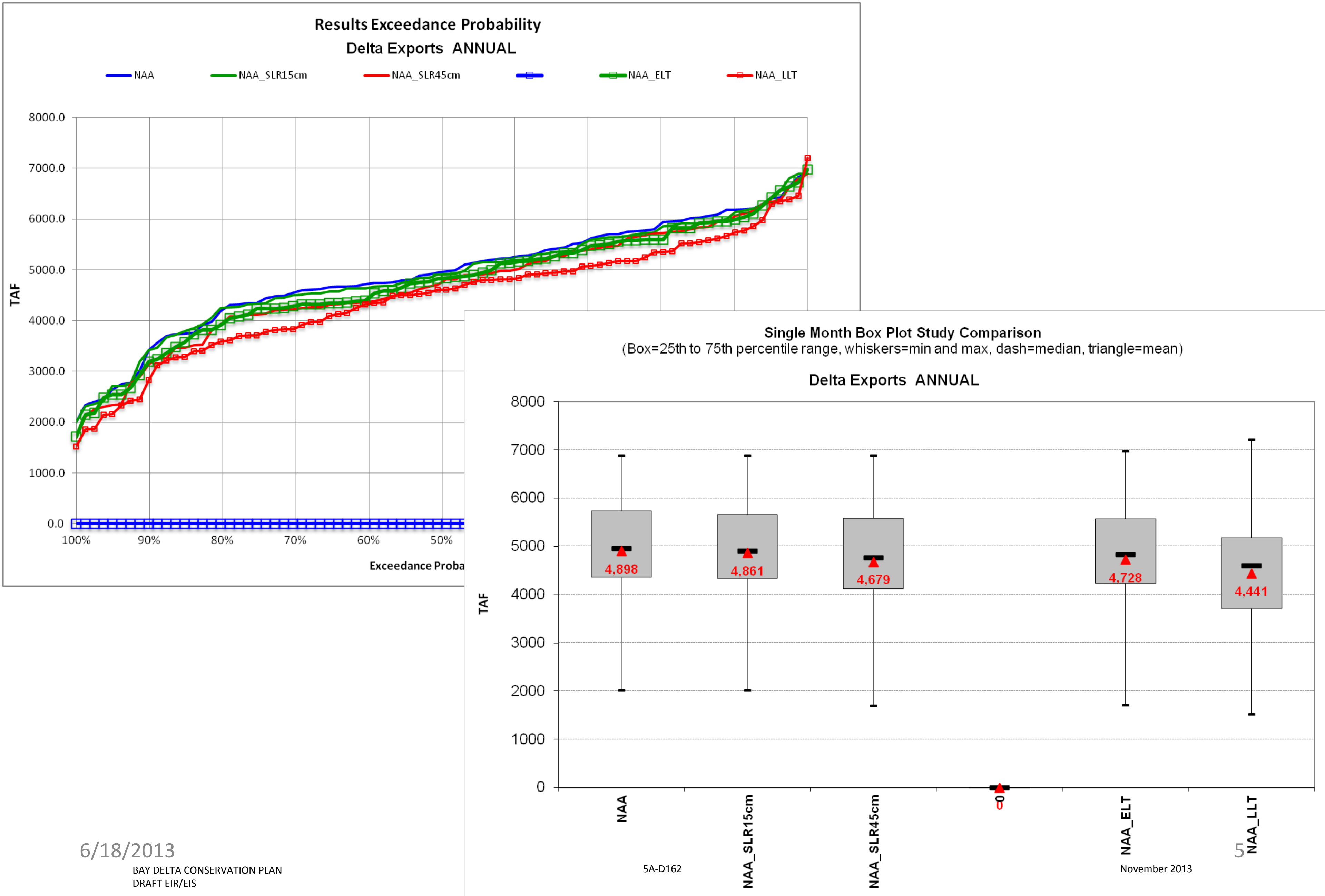
Results Exceedance Probability
Oroville MAY

Results Exceedance Probability
Oroville SEP

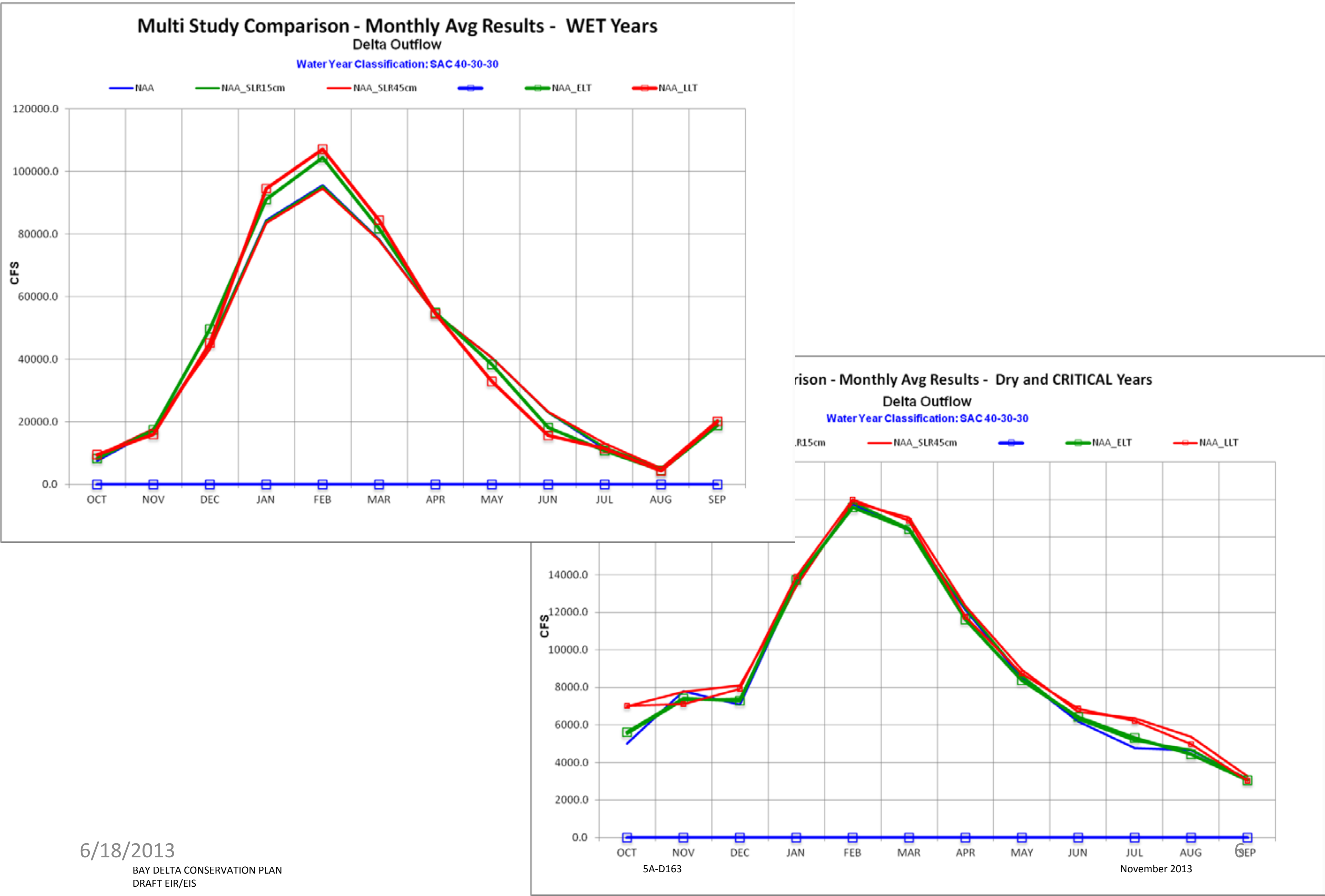
Folsom Storage



Delta Exports



Delta Outflow

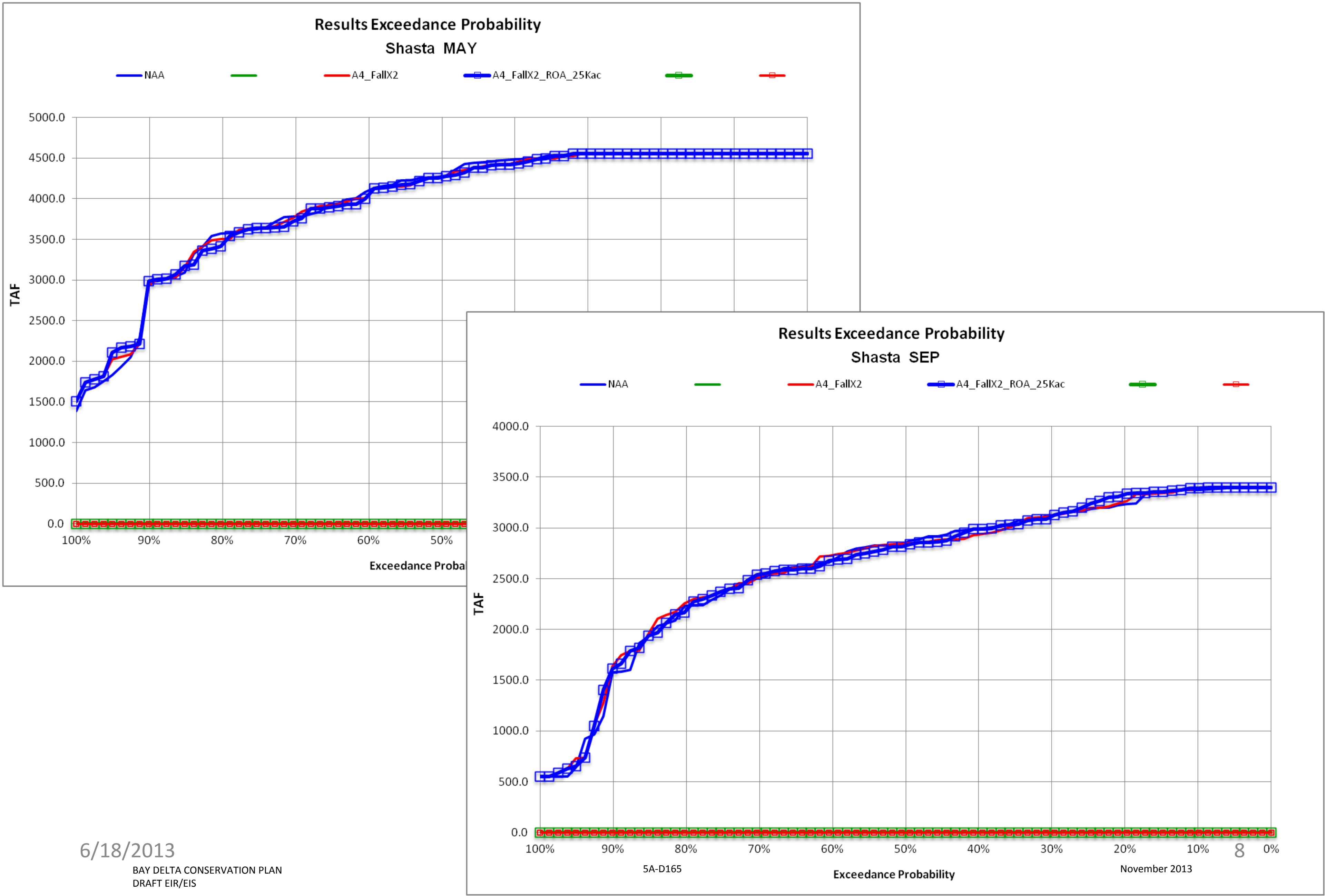


Incremental Effects of Conveyance and Restoration

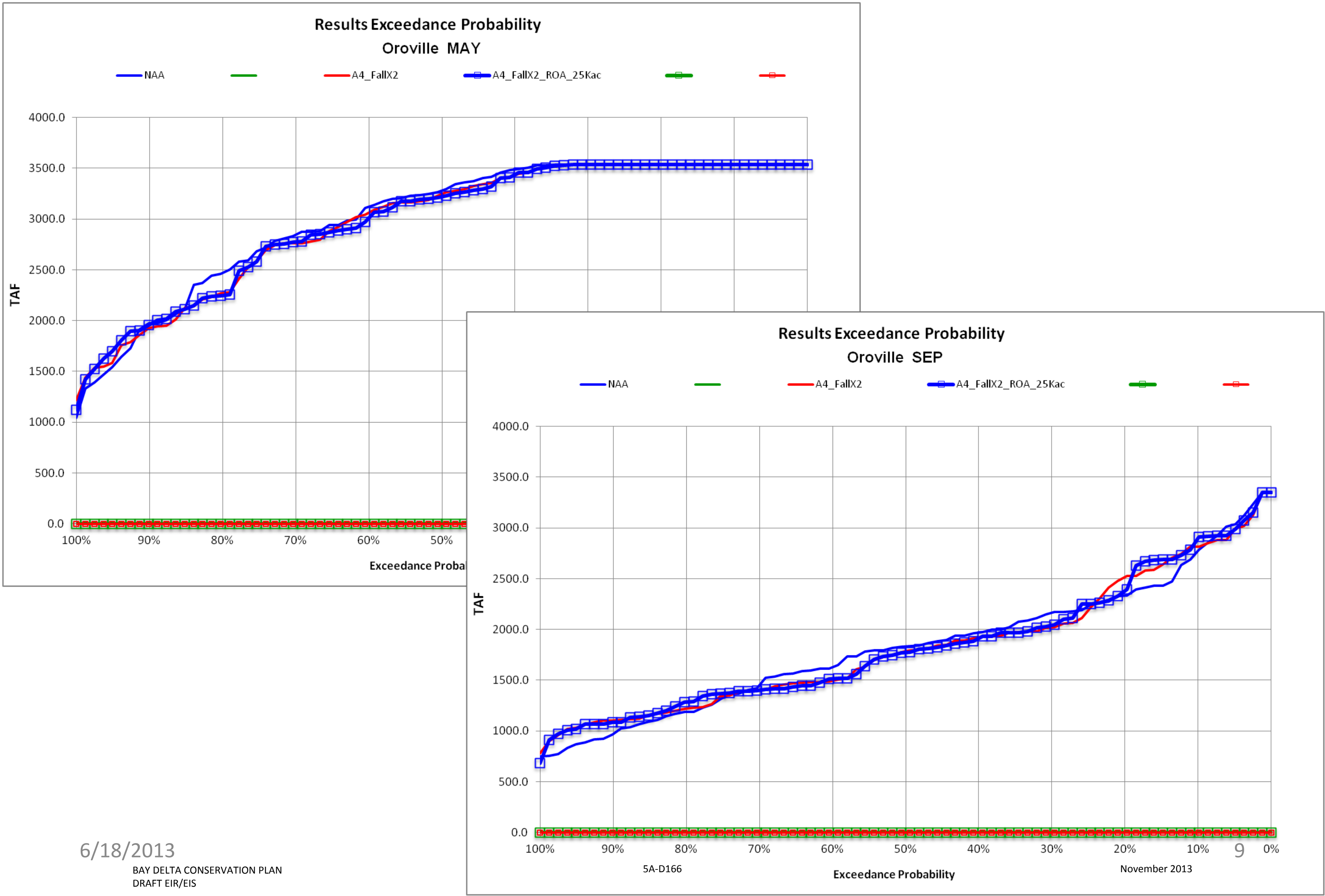
- NAA
- Alt4 with FallX2
- Alt4 with FallX2 and 25,000 ac Tidal Wetlands Restoration

6/18/2013

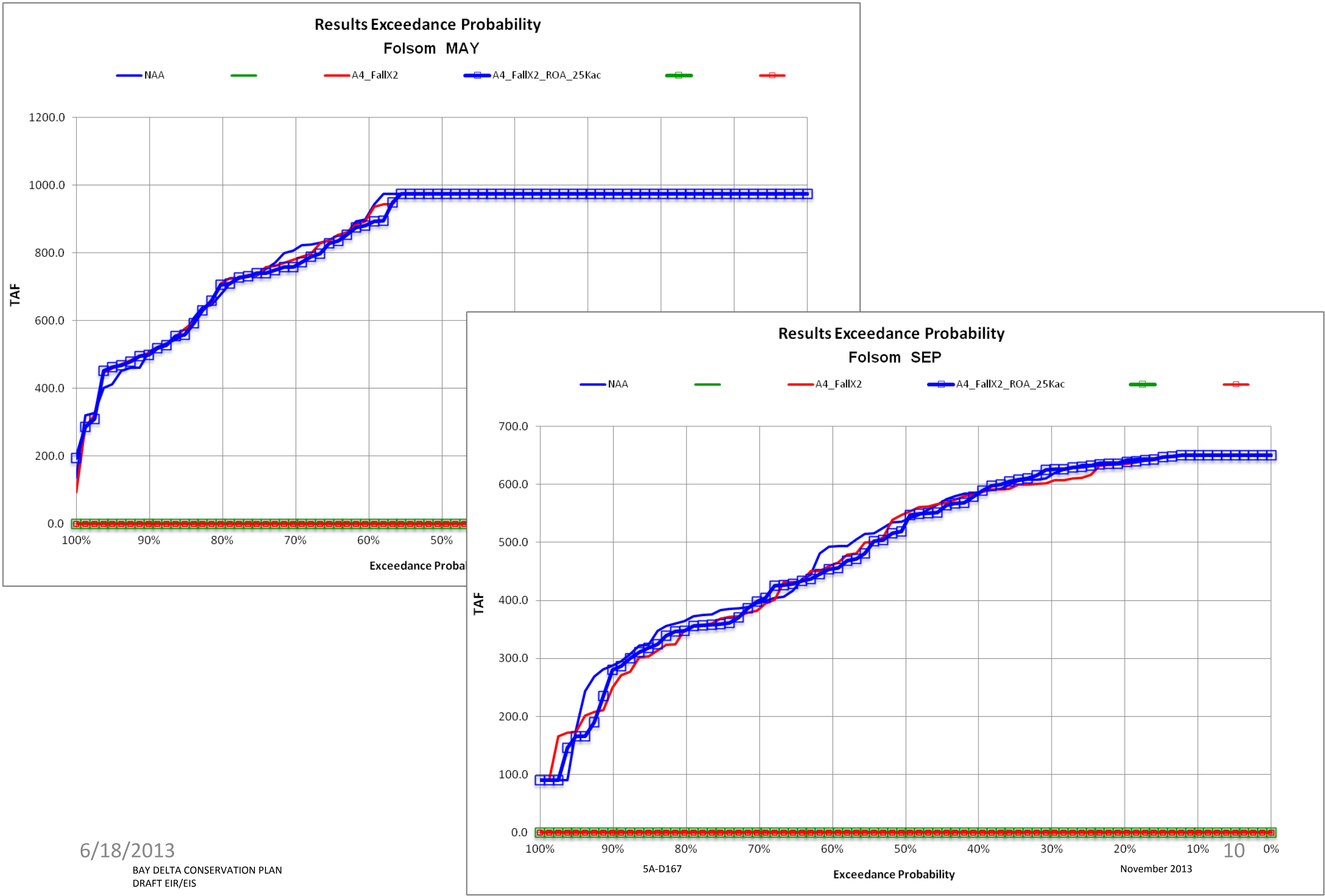
Shasta Storage



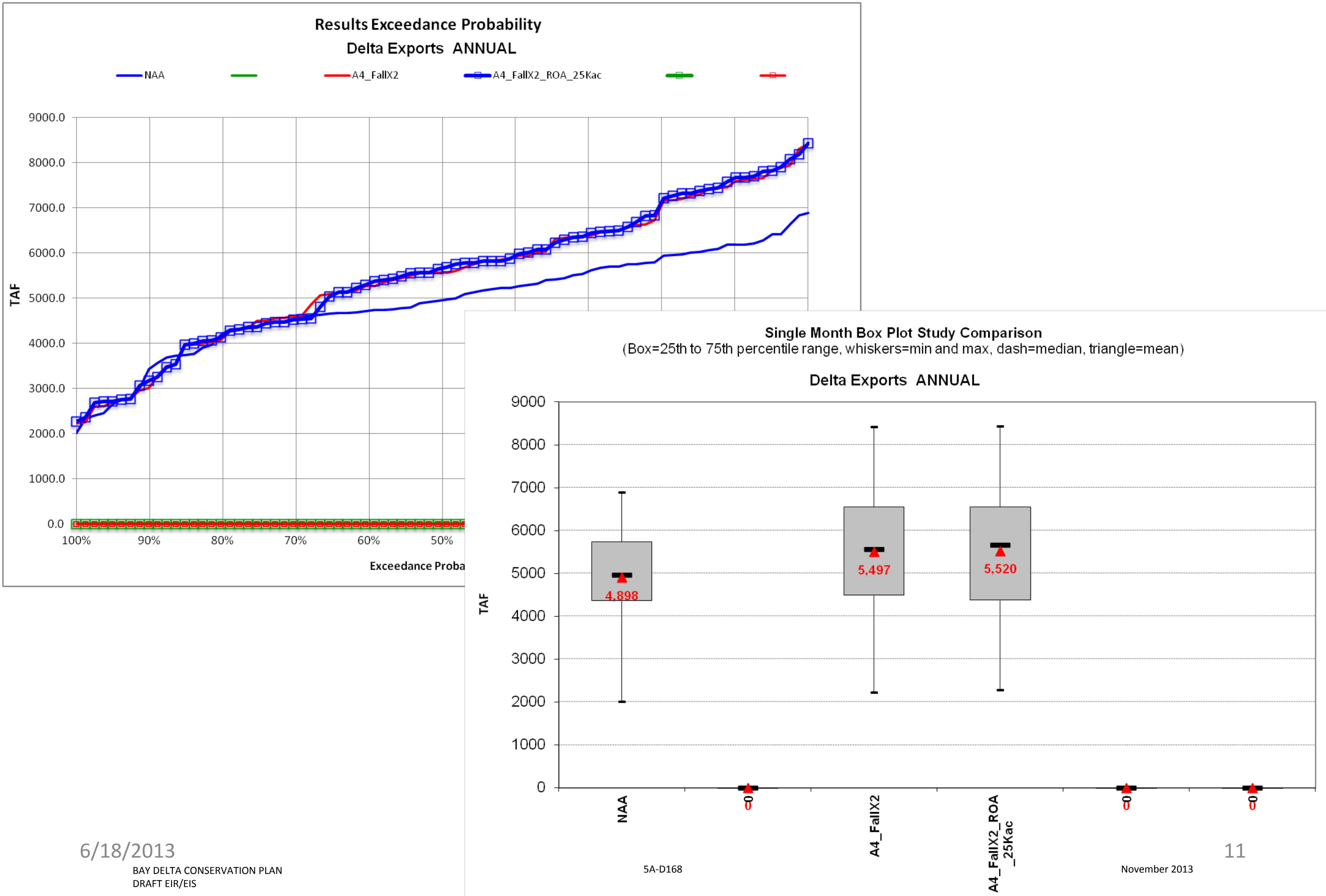
Oroville Storage



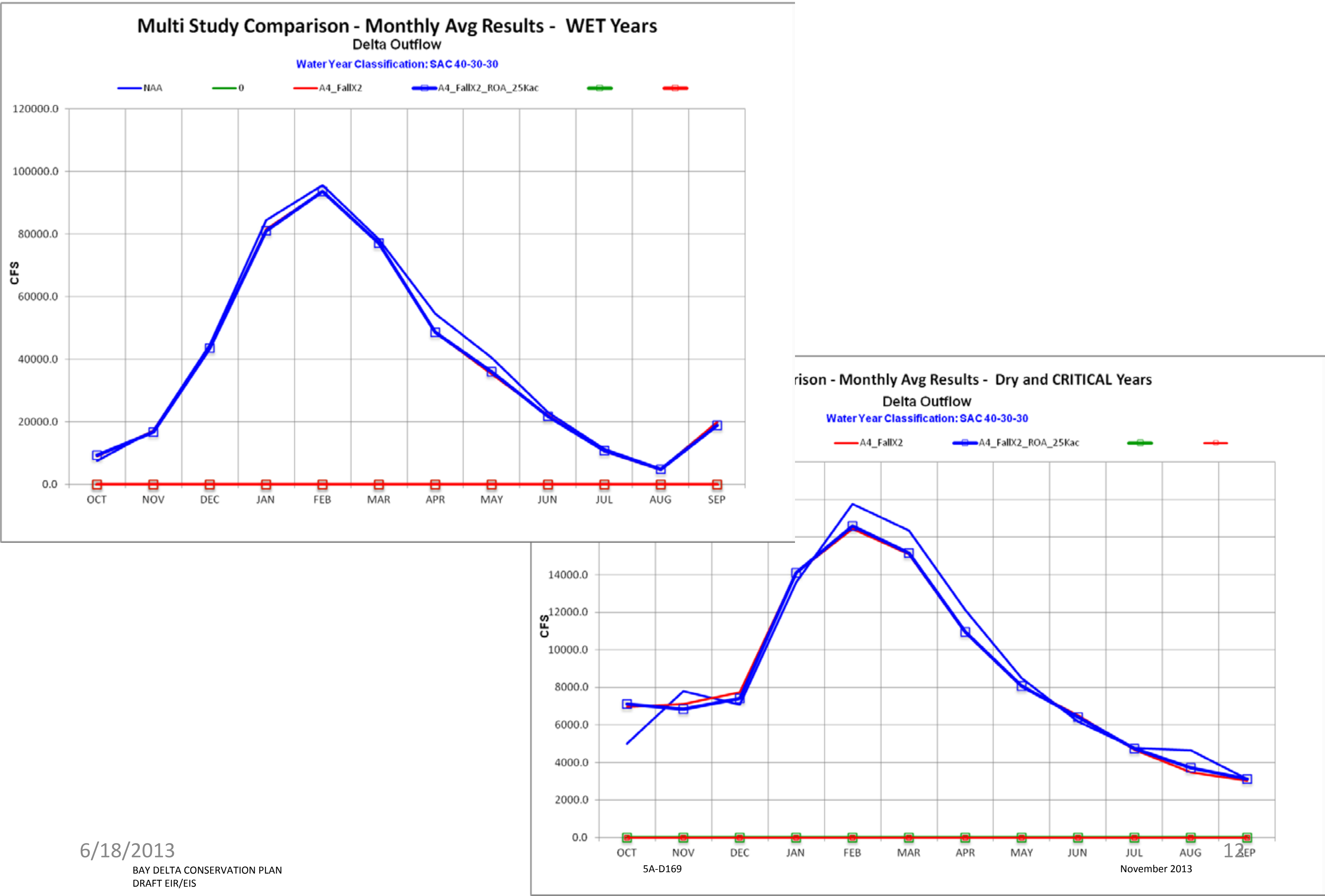
Folsom Storage



Delta Exports



Delta Outflow



Multi Study Comparison - Monthly Avg Results - WET Years

Delta Outflow

Water Year Classification: SAC 40-30-30

rison - Monthly Avg Results - Dry and CRITICAL Years

Delta Outflow

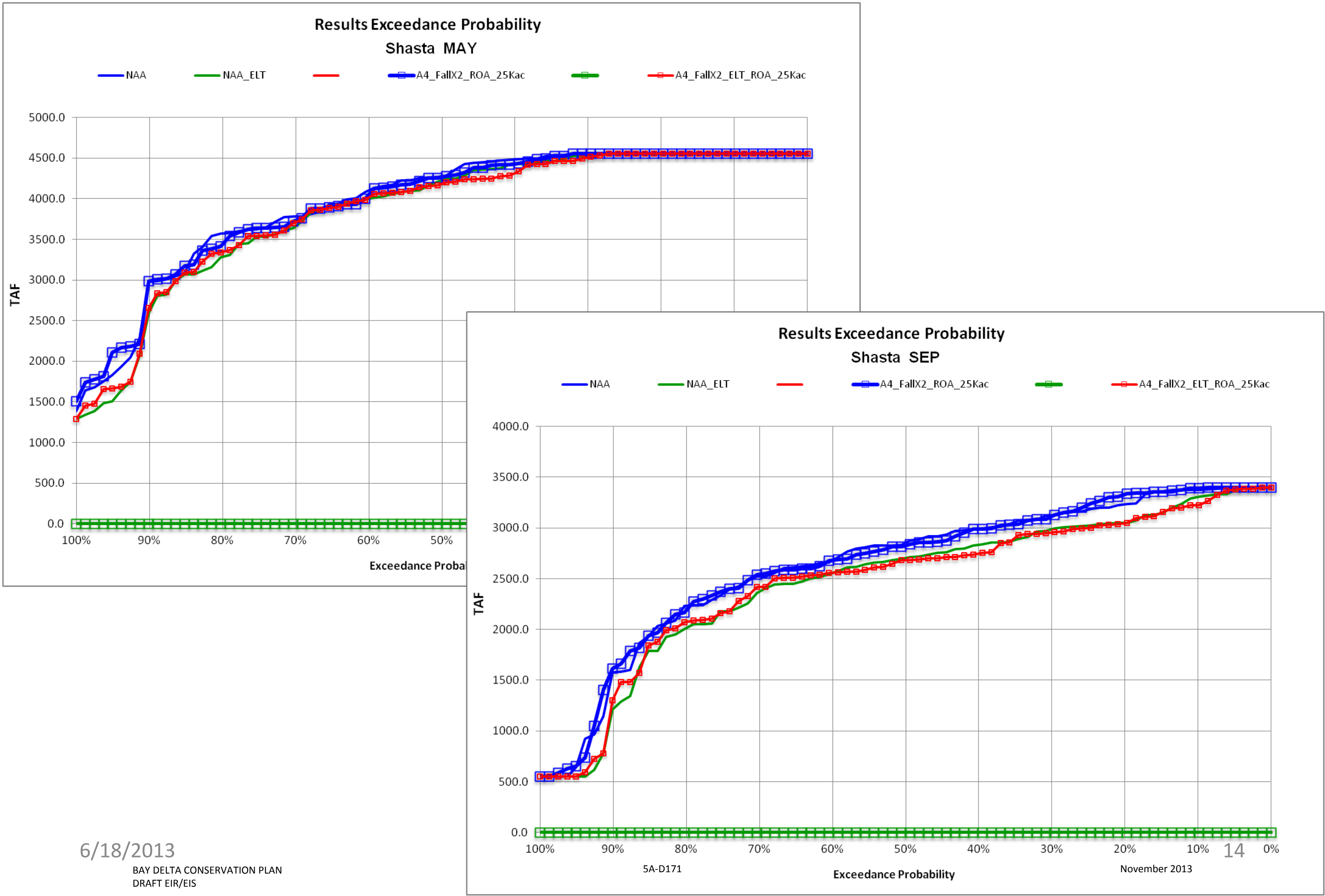
Water Year Classification: SAC 40-30-30

Incremental Effects of Conveyance, Restoration, Sea Level Rise and Climate Change

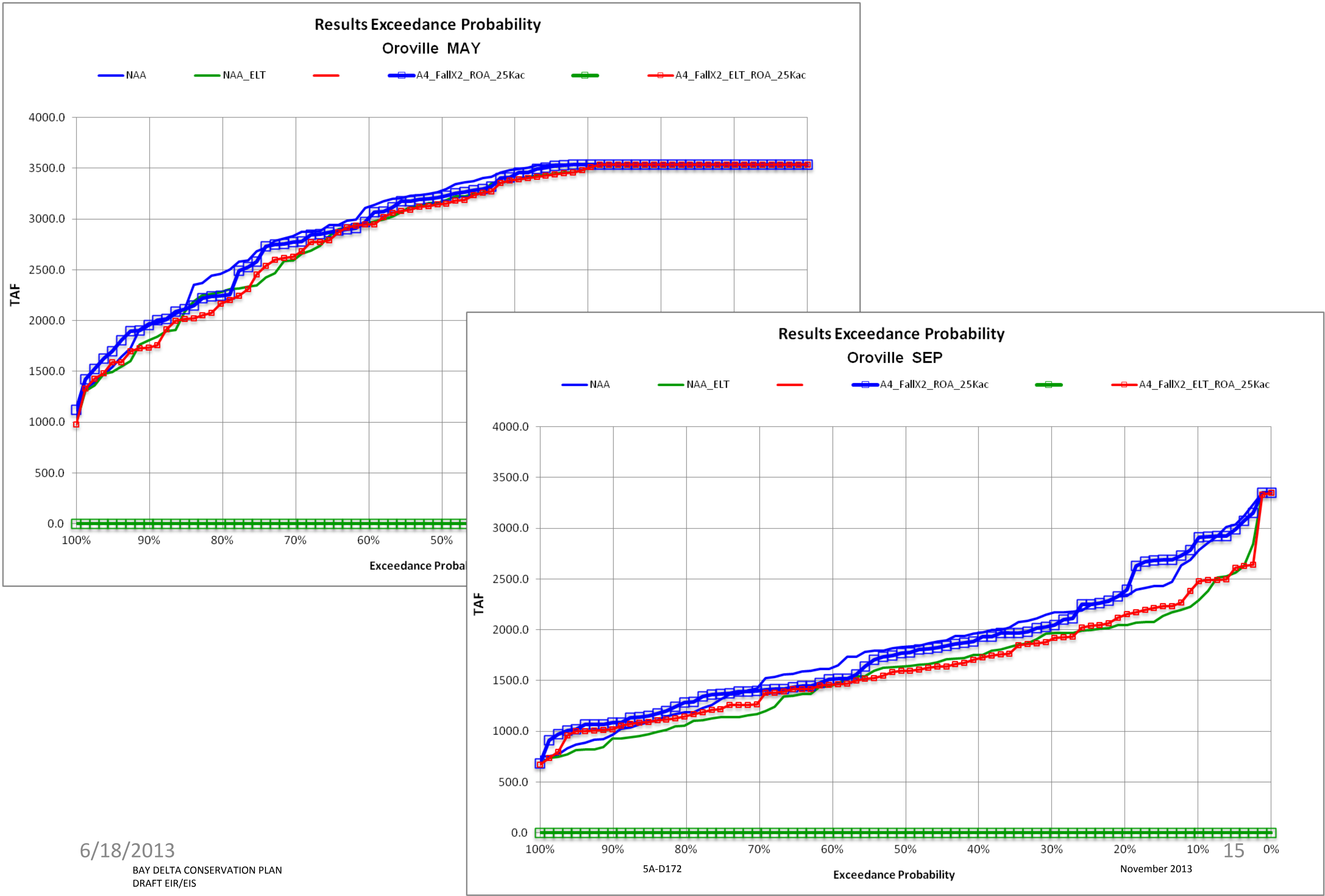
- NAA
- NAA_ELT
- Alt4 with FallX2
- Alt4 with FallX2 and 25,000 ac Tidal Wetlands Restoration
- Alt4 with FallX2 including 25,000 ac Tidal Wetlands Restoration, 15 cm Sea Level Rise and Climate Change at 2025

6/18/2013

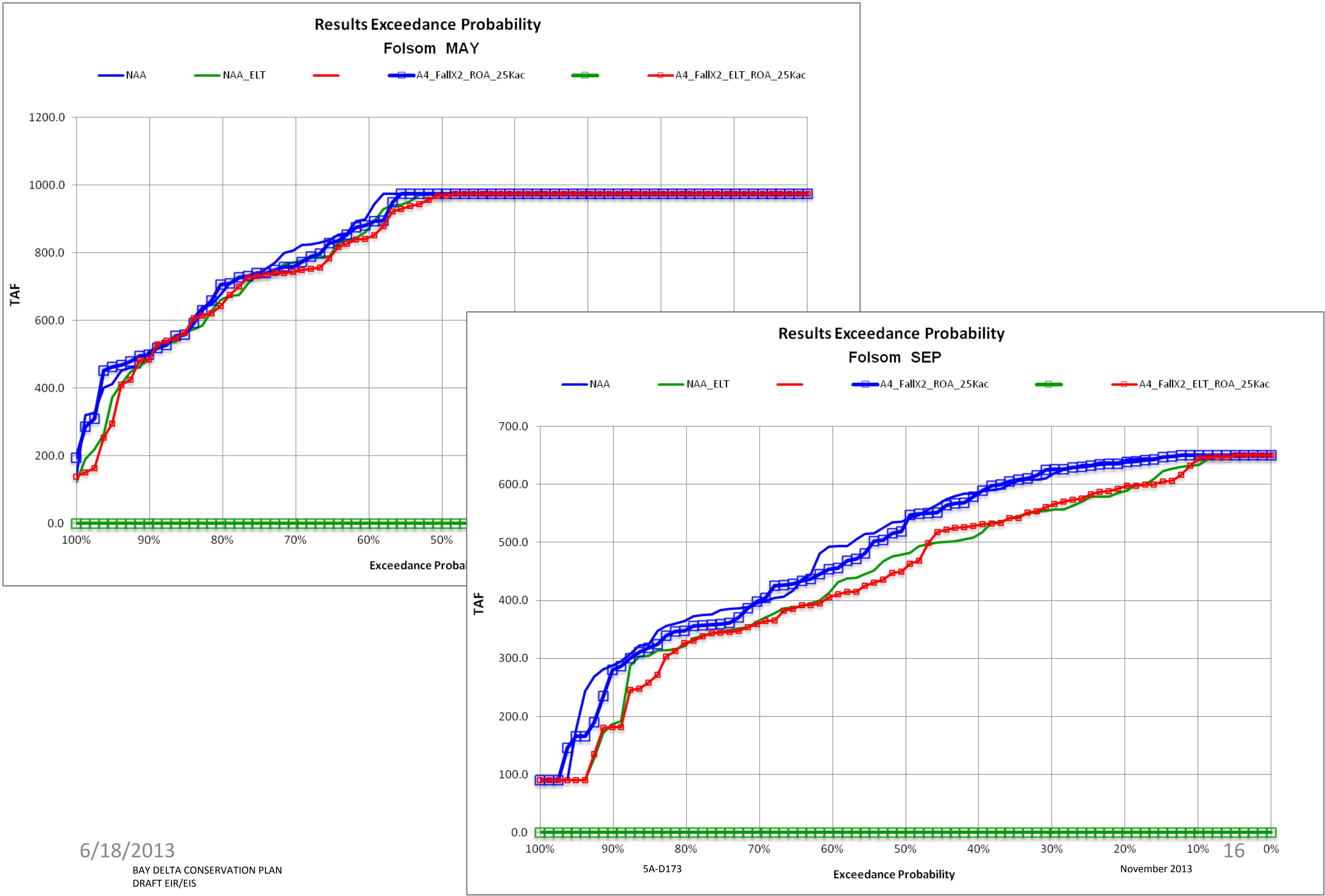
Shasta Storage



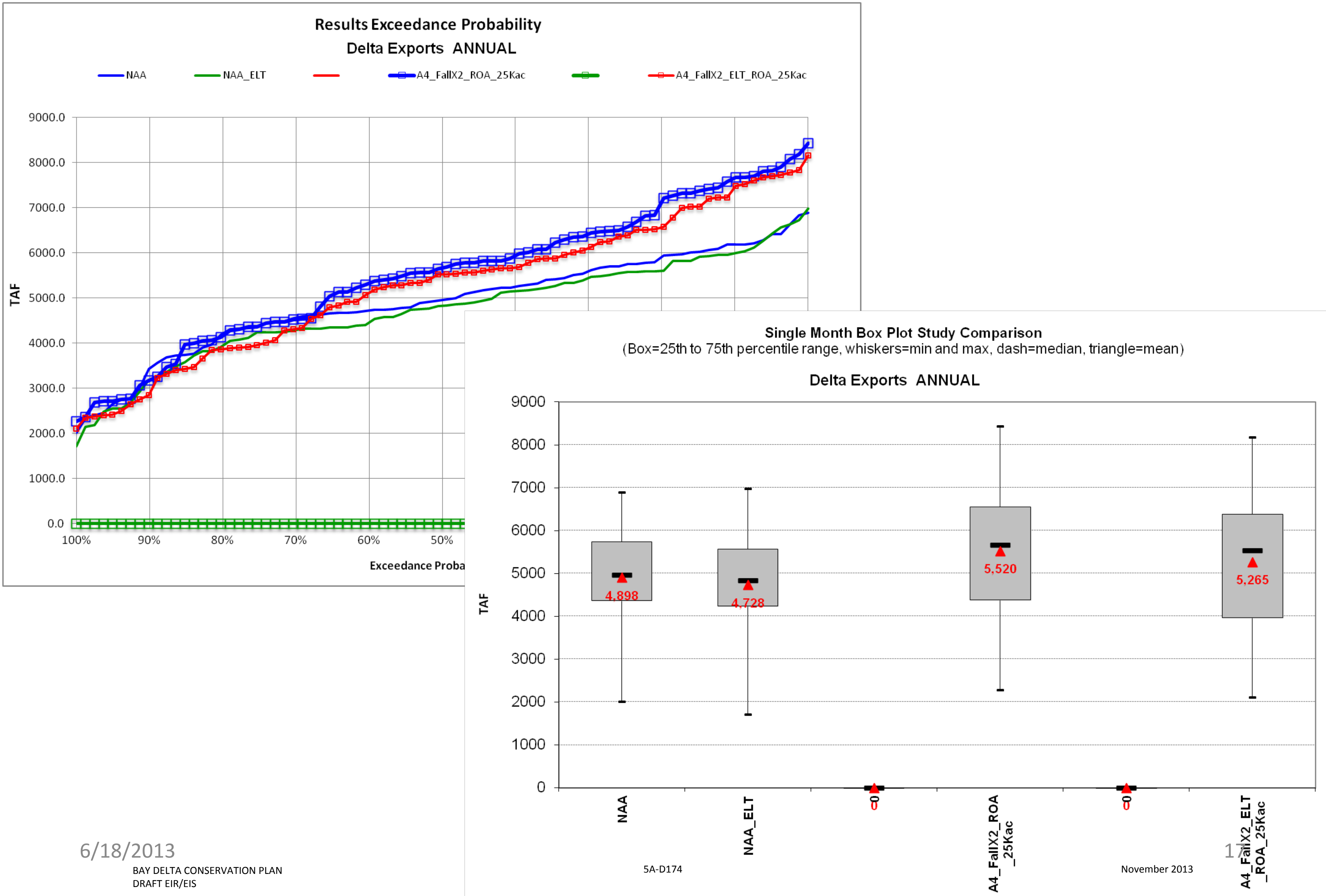
Oroville Storage



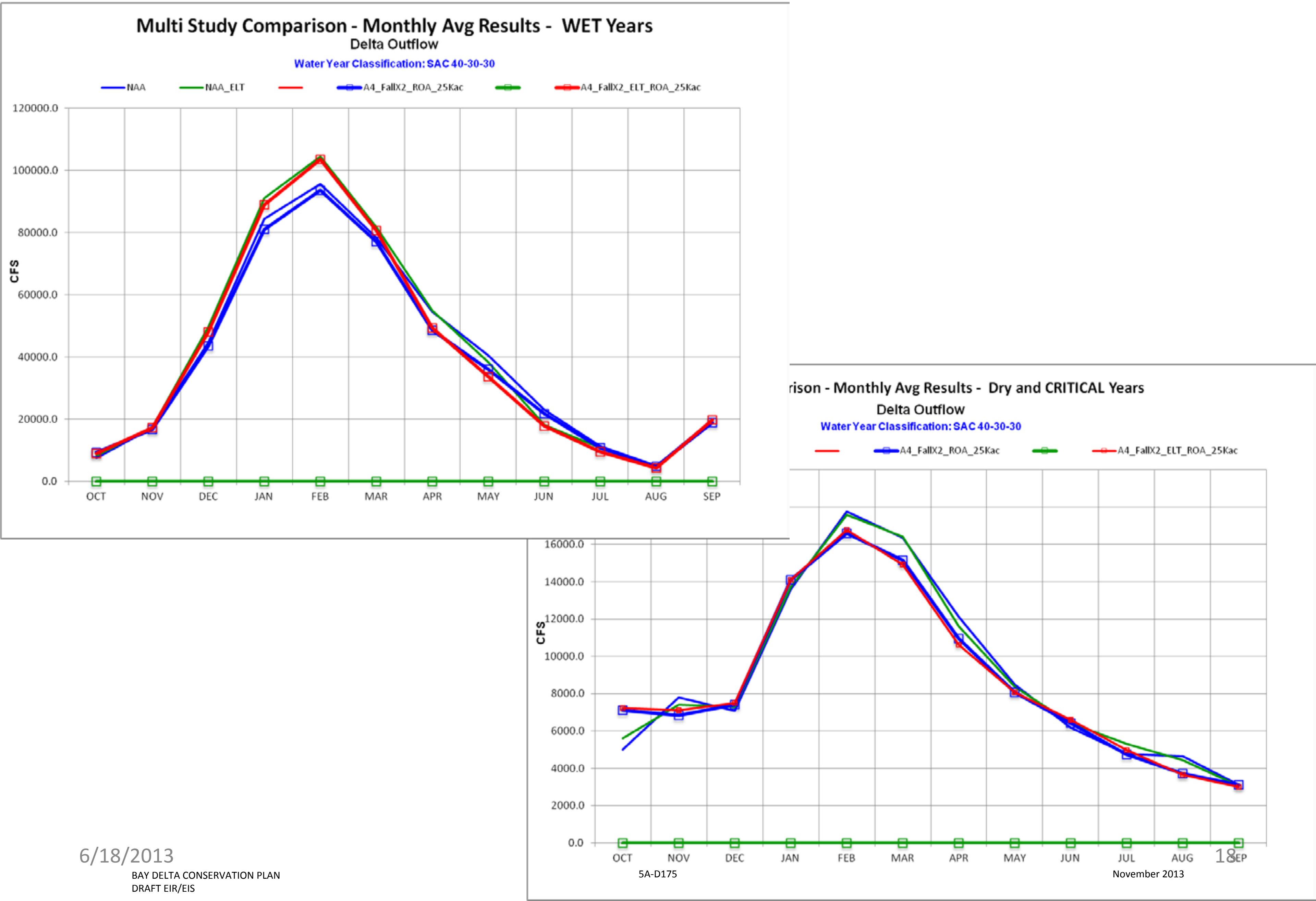
Folsom Storage



Delta Exports



Delta Outflow



D.10.3. BDCP CALSIM II Results under Current Climate and Sea Level

The modeling performed for the BDCP EIR/EIS Alternatives included the effects of climate change and sea level rise. Additional simulations were performed to understand the effects of BDCP without considering the projected climate change and sea level rise. This section presents a few key results from this analysis. This section includes a few key results from this sensitivity analysis presented at a BDCP stakeholder engagement meeting.

The incremental changes between the No Action Alternative and the BDCP Alternative 4 without considering the projected changes in climate and sea level were found to be similar to the results presented in the EIR/EIS, which included the climate change and sea level rise effects.

BDCP Modeling Update

CALSIM II Results without Climate Change and Sea Level Rise

August 7th, 2013

Outline

- Background
- No Climate Change Scenarios
- Storage Results
- Delta Exports
- Deliveries

BDCP CM1 Developed through Interagency and Stakeholder Coordination Processes

2007

- Initial Options Report

2008

- Conveyance Working Group with several sub-teams (e.g. HOTT, HRT, Other Stressors etc) explored potential restoration footprints, operational components
- Using feedback from CWG, Integration Team identified initial restoration and operational assumptions

2009

- DRERIP, Mini-Effects Analysis helped refine the initial operations

2010

- BDCP Steering Committee PP
- Finalize Effects Analysis Methods and Results for 2010 PP

2011

- Improvements to South Delta operations (Scenario 6)

2012

- CS5 process leading to the latest PP with Decision Tree
- Revised Effects Analysis Methods and Results for 2012 PP

Scenario Definitions

- **EX**: Existing Conditions
  - 2009 Level of Development; No Fall X2
  - Climate change and sea level rise effects **not** included

- **NAA**: No Action Alternative
  - 2030 Level of Development; 443 TAF/year increase in NOD demand
  - Climate change and sea level rise effects **not** included

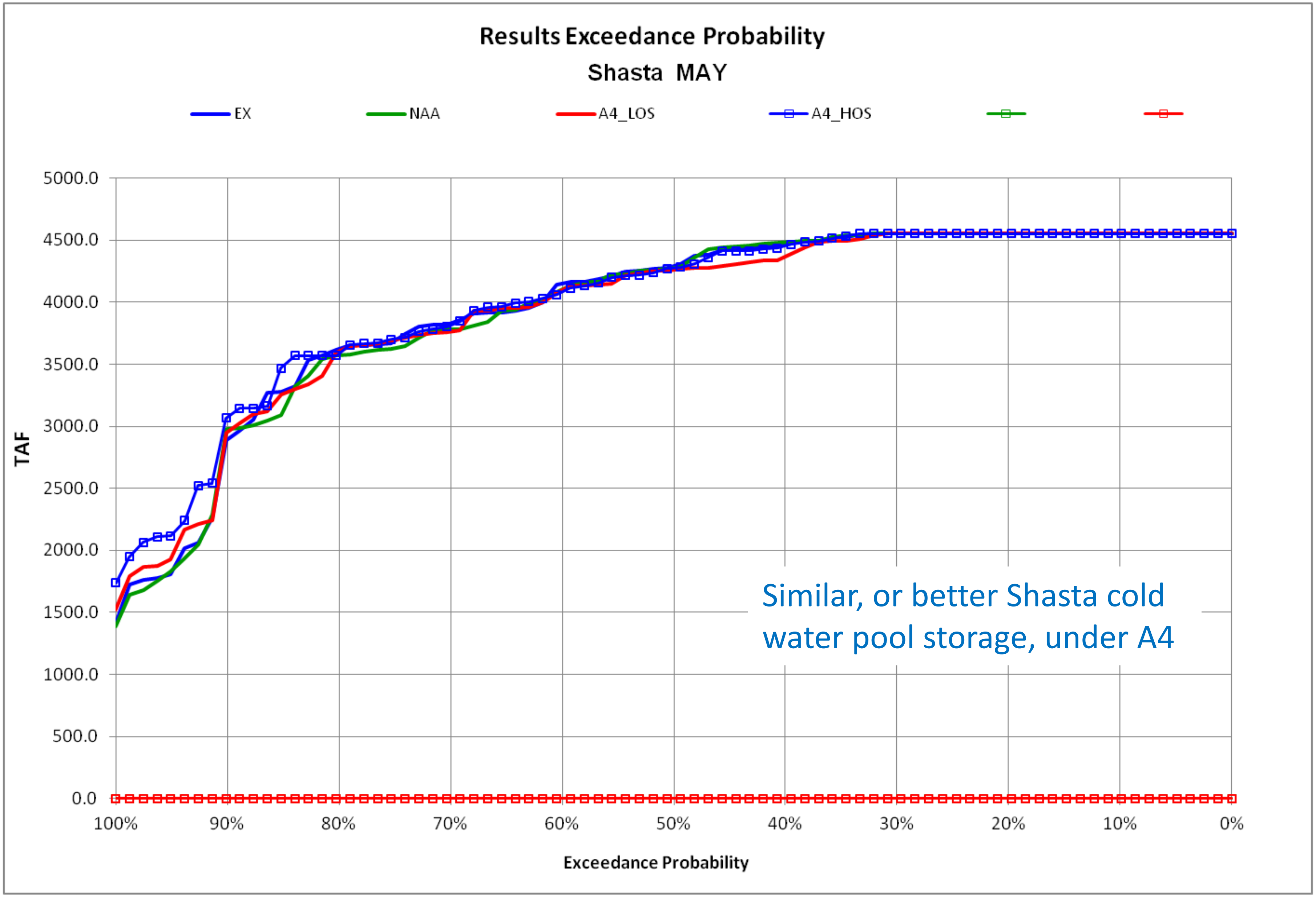
- **A4_LOS**: BDCP Alternative 4 Low Outflow Scenario
  - 2030 Level of Development; 443 TAF/year increase in NOD demand
  - Dual conveyance with proposed 9,000 cfs North Delta diversion
  - Includes 65,000ac restoration effects at LLT
  - Climate change and sea level rise effects **not** included

- **A4_HOS**: BDCP Alternative 4 High Outflow Scenario
  - 2030 Level of Development; 443 TAF/year increase in NOD demand
  - Dual conveyance with proposed 9,000 cfs North Delta diversion
  - Includes 65,000ac restoration effects at LLT
  - Climate change and sea level rise effects **not** included

Differences in Existing and No Action Assumptions

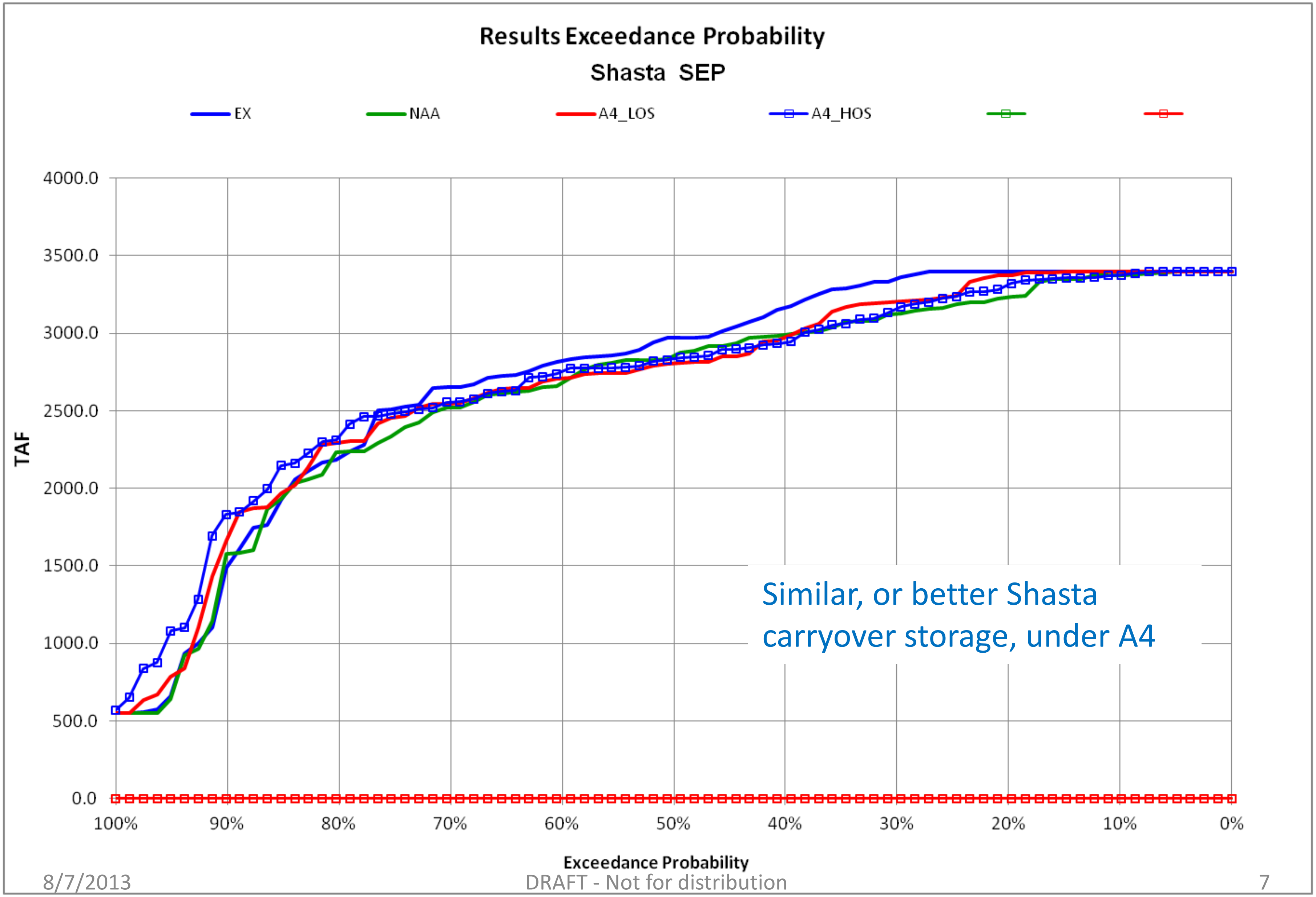
- **Increase in demands and build out of facilities associated with water rights and CVP/SWP contracts**
  - About 443 TAF per year increase in north of Delta at the future level of development.
  - Increase in CVP M&I service contracts (253 TAF per year) and water rights (184 TAF per year) related primarily to urban M&I use, especially in the communities in El Dorado, Placer, and Sacramento Counties.
- **Increase in demands associated with SWP contracts south of Delta**
  - SWP M&I demands, which under the existing level of development vary on hydrologic conditions between 3.0 and 4.1 MAF per year, under the future condition are at maximum contract amounts in all hydrologic conditions.
- **New urban intake/Delta export facilities:**
  - Freeport Regional Water Project
  - City of Stockton Delta Water Supply Project
  - Delta-Mendota Canal–California Aqueduct Intertie
  - Contra Costa Water District Alternative Intake
  - South Bay Aqueduct rehabilitation, to 430 cfs capacity, from the junction with California Aqueduct to Alameda County Flood Control and Water Conservation District Zone 7.
- **Small increases in demand for wildlife refuges including Firm Level 2 supplies**
  - About 8 TAF per year increase in the future level of development
  - Shift in refuge demands from south to north (24 TAF per year reduction in south of Delta and 32 TAF per year increase in north of Delta).
- **No Action Alternative also includes implementation of the Fall X2 standard**
  - Requires additional water releases in wet and above normal years to meet X2 targets in the Delta in September and October, plus additional releases in November to augment Delta outflow.

Shasta End of May Storage



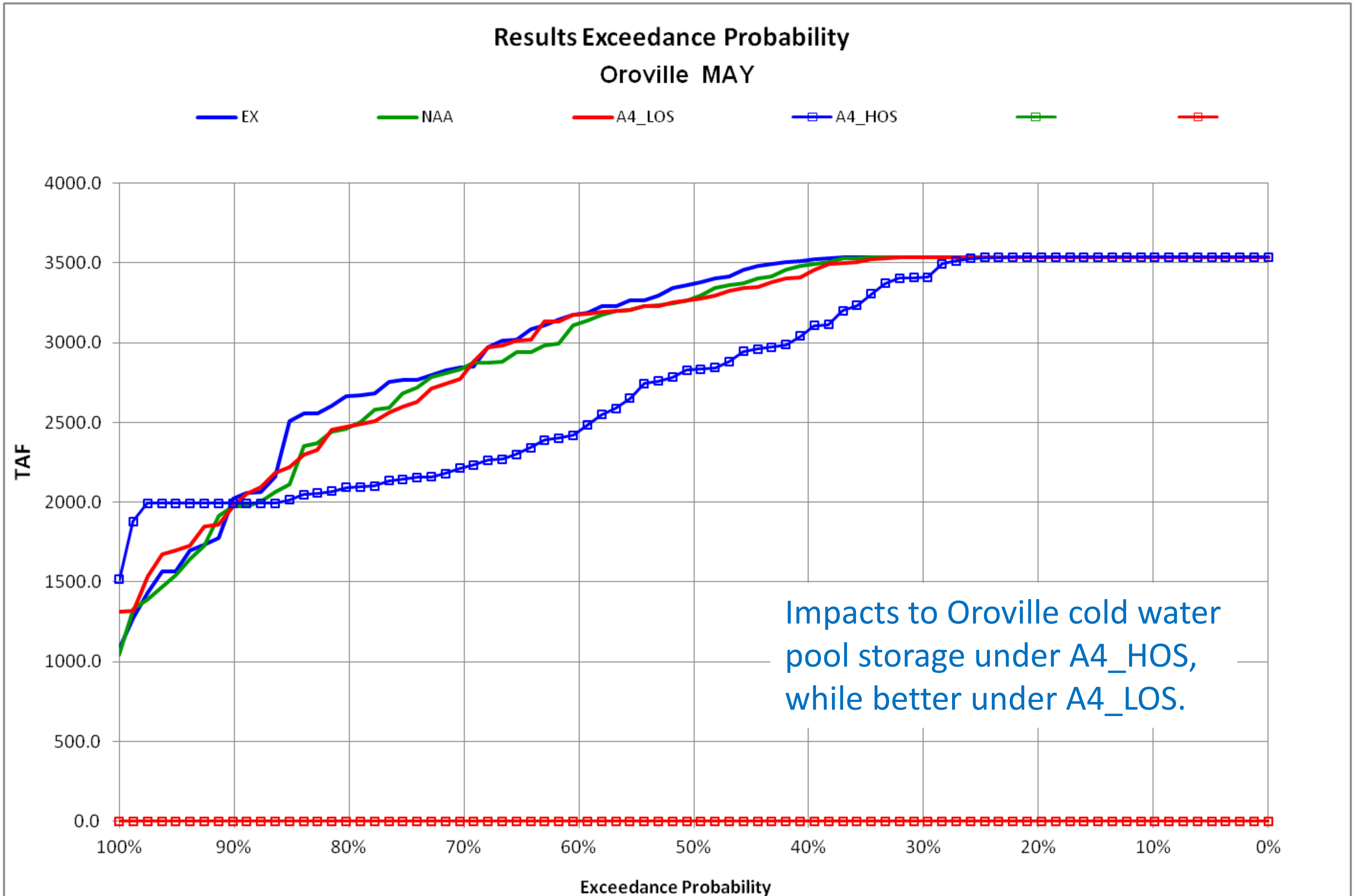
Similar, or better Shasta cold water pool storage, under A4

Shasta End of September Storage



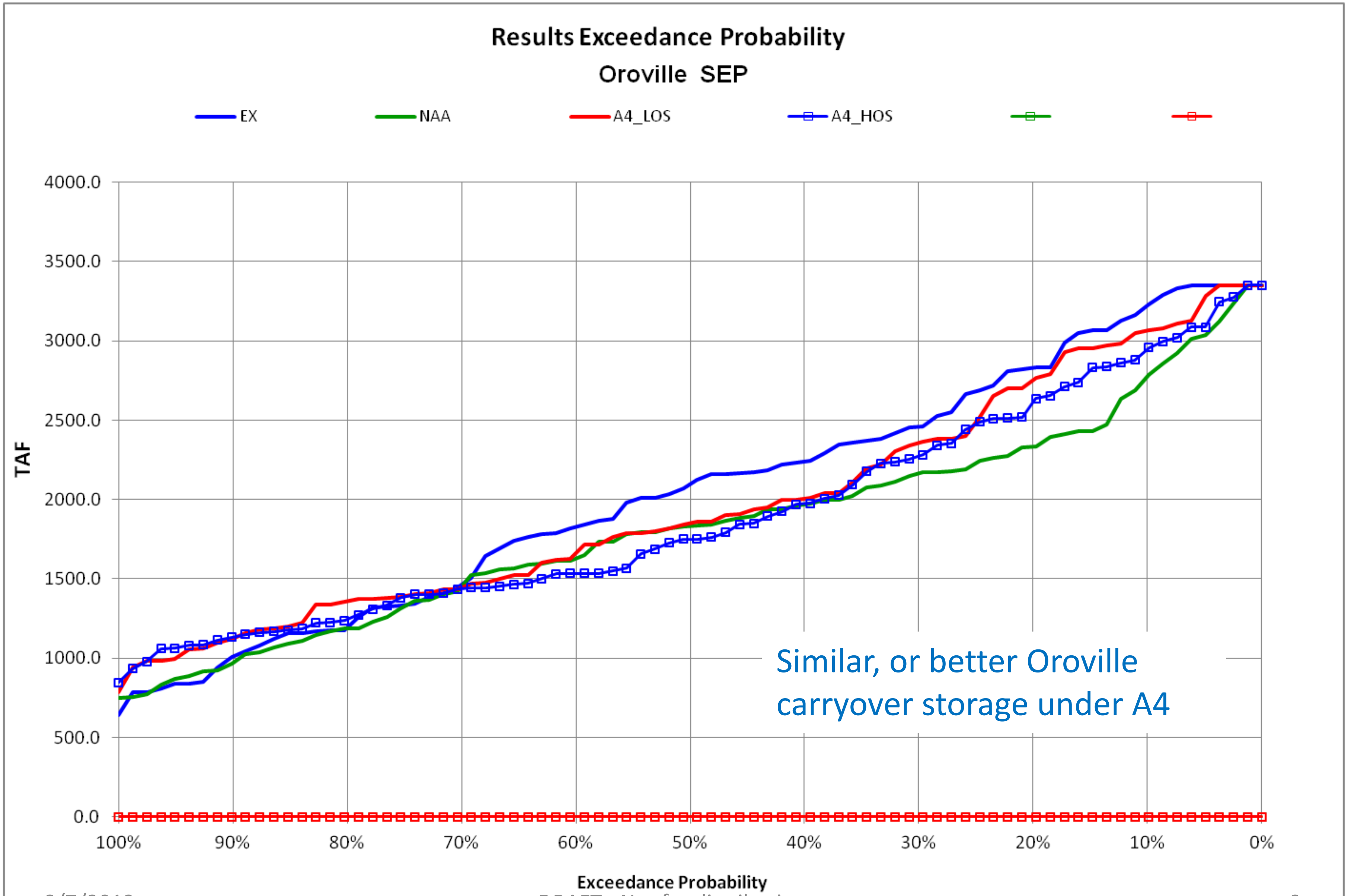
Similar, or better Shasta carryover storage, under A4

Oroville End of May Storage



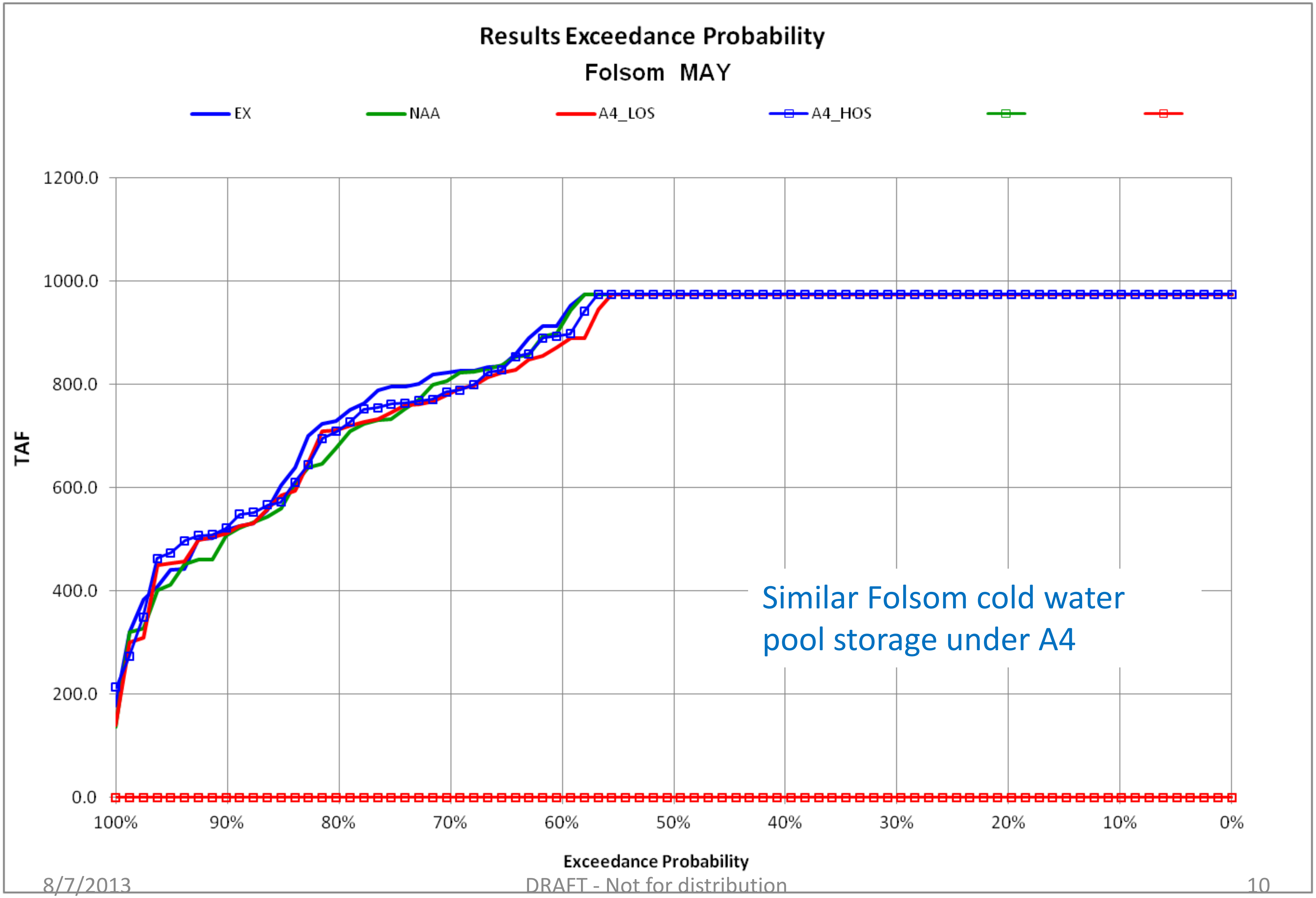
Impacts to Oroville cold water pool storage under A4_HOS, while better under A4_LOS.

Oroville End of September Storage



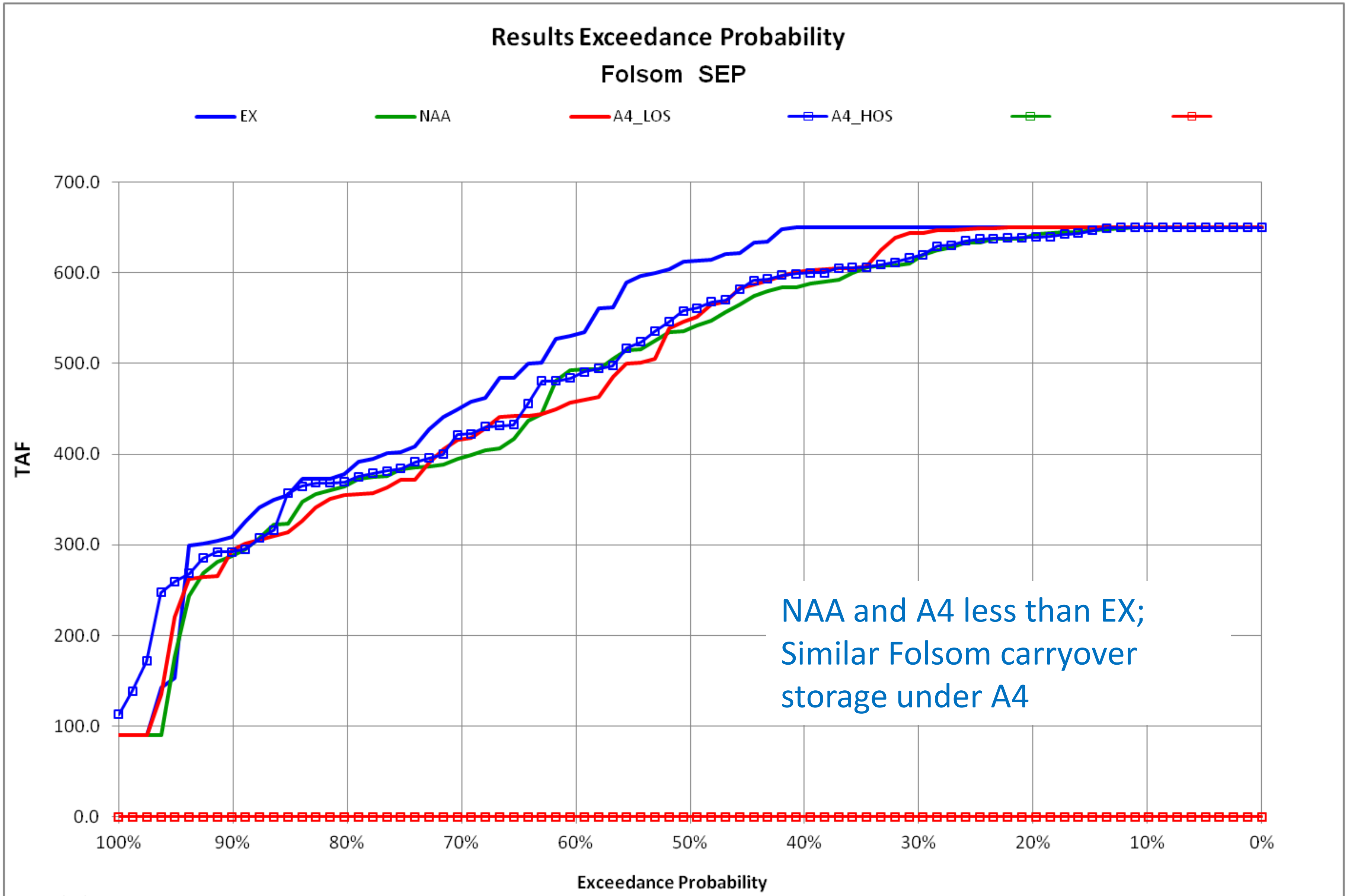
Similar, or better Oroville carryover storage under A4

Folsom End of May Storage



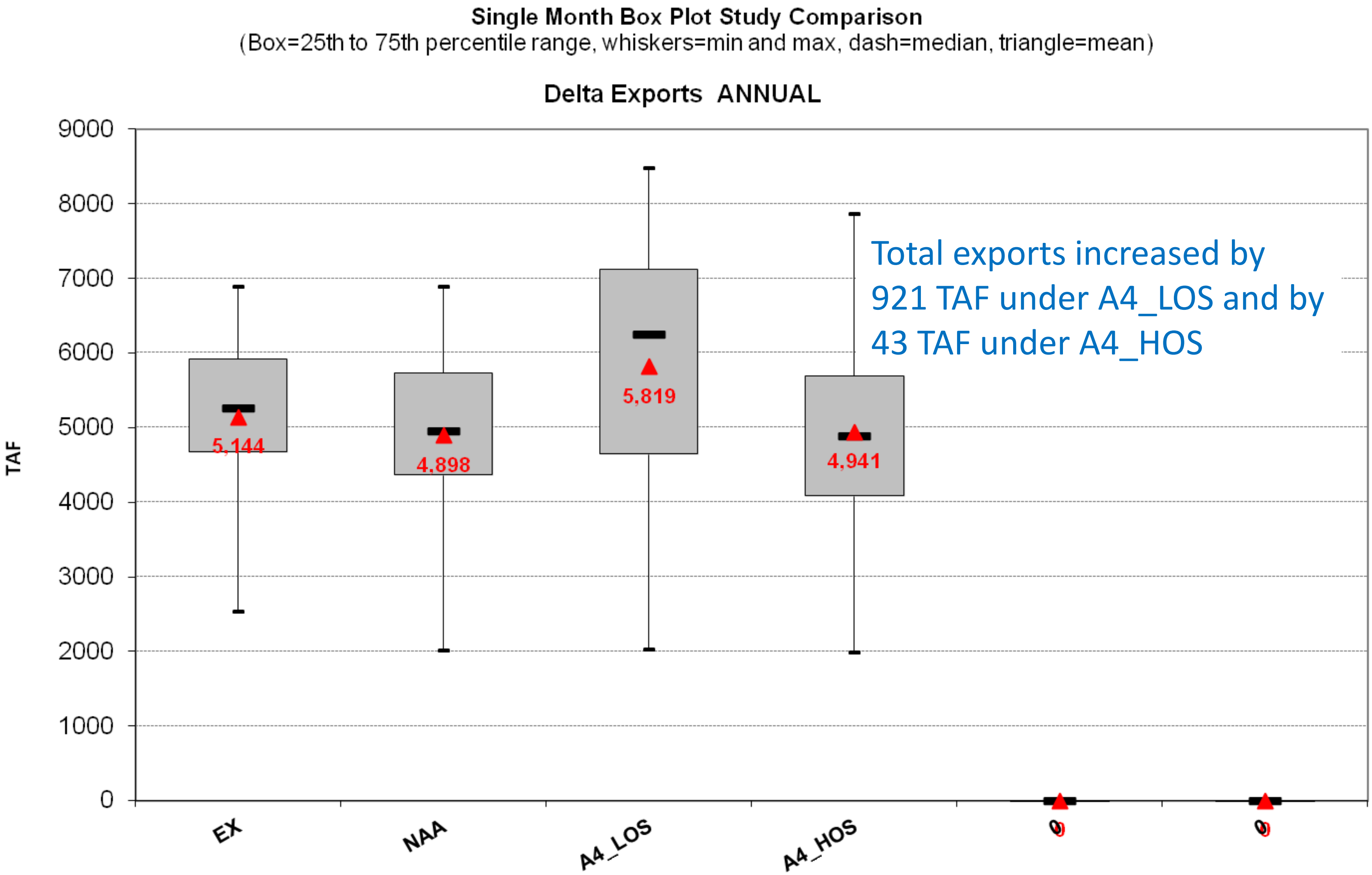
Similar Folsom cold water pool storage under A4

Folsom End of September Storage



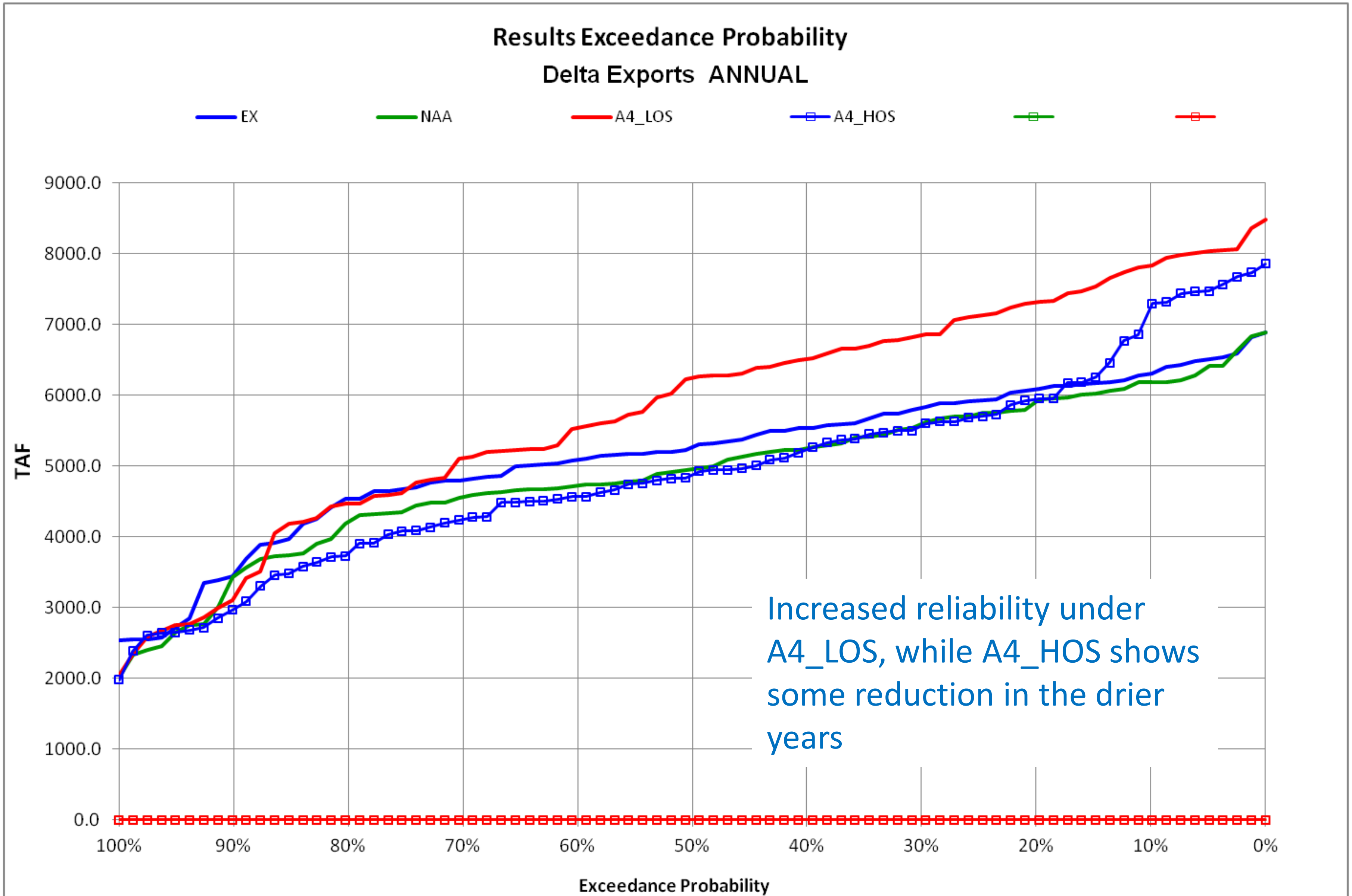
NAA and A4 less than EX; Similar Folsom carryover storage under A4

Annual Delta Exports



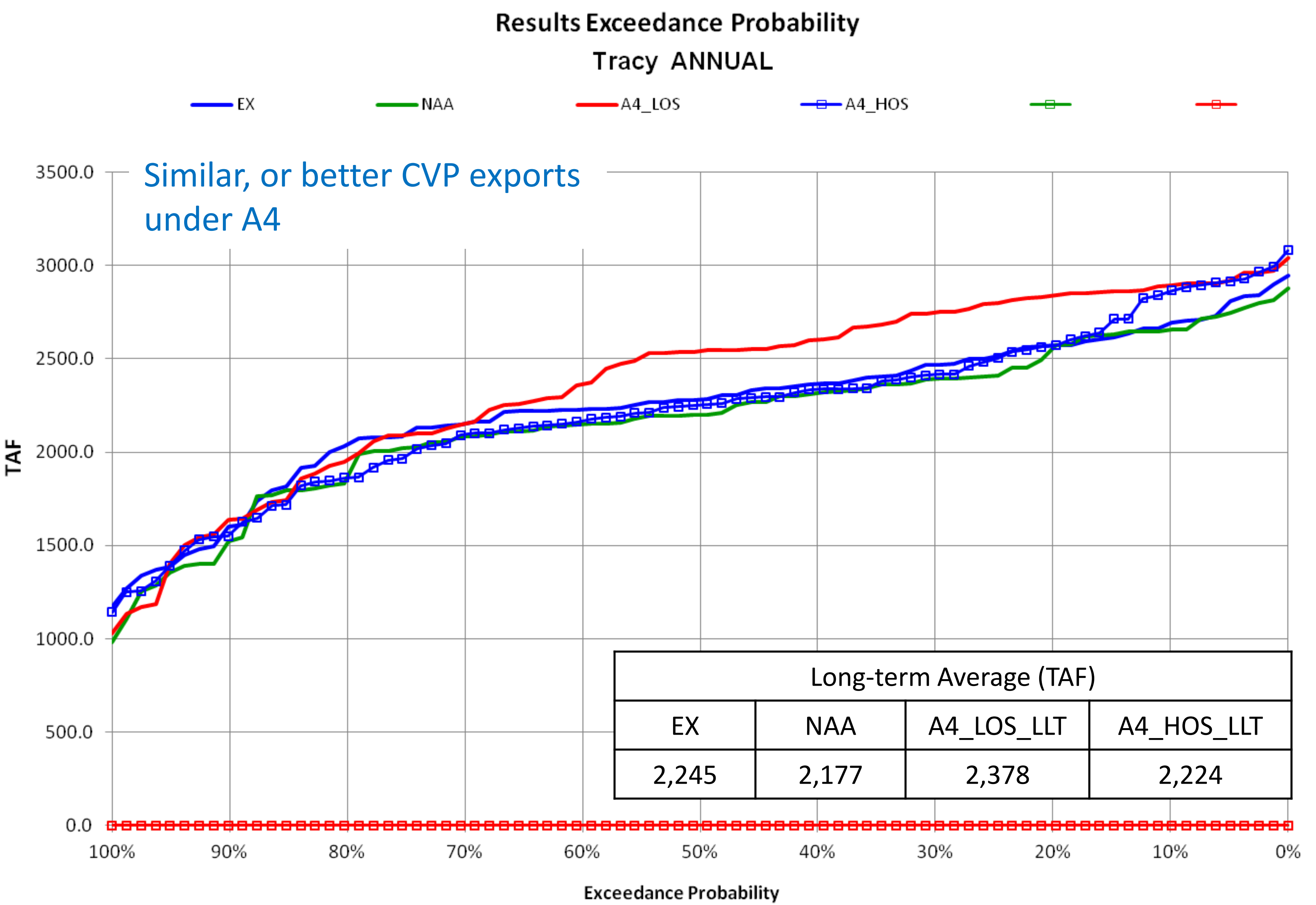
Total exports increased by 921 TAF under A4_LOS and by 43 TAF under A4_HOS

Delta Exports Reliability



Increased reliability under A4_LOS, while A4_HOS shows some reduction in the drier years

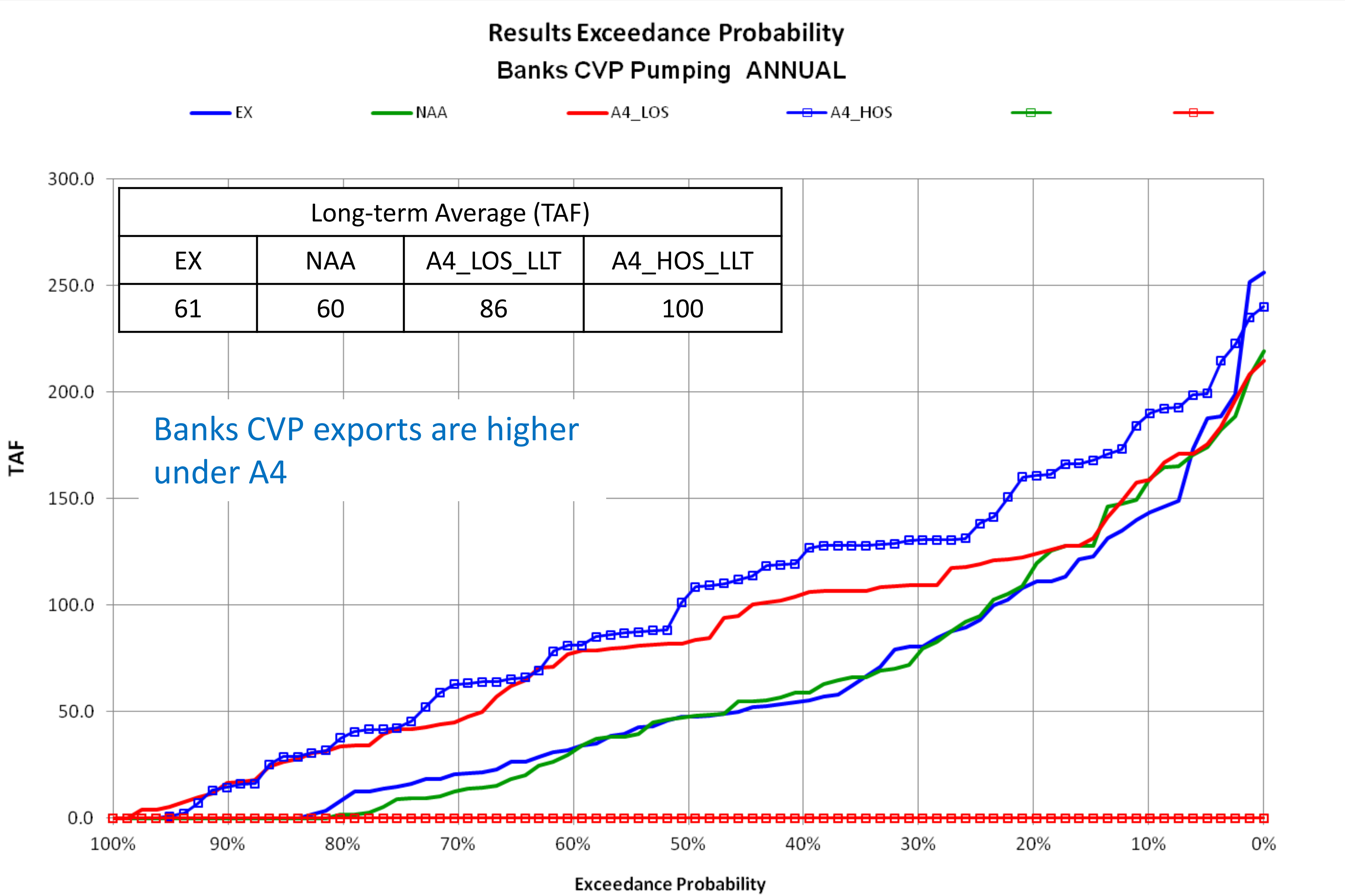
Total Jones Annual Pumping



Similar, or better CVP exports under A4

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
2,245	2,177	2,378	2,224

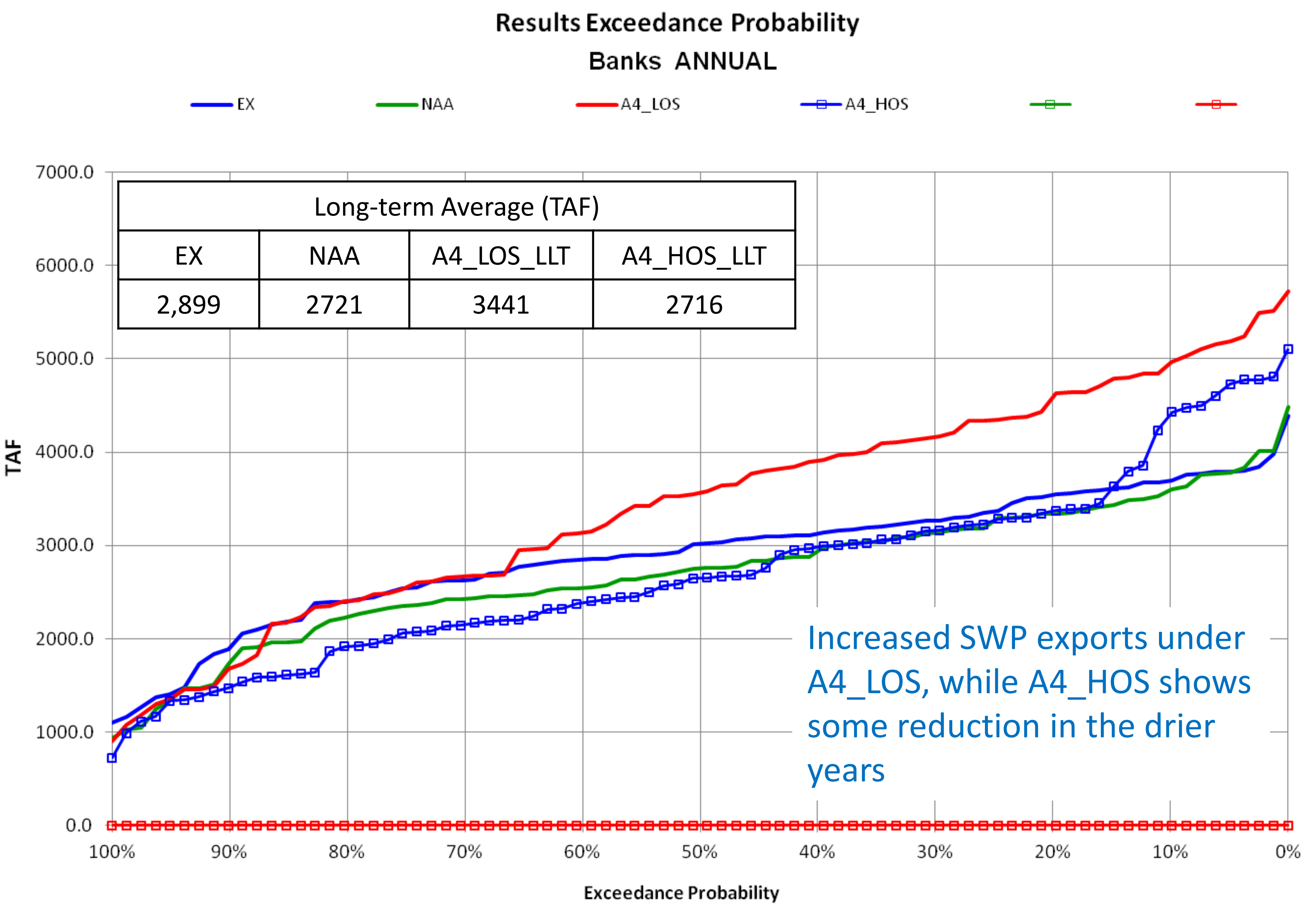
Banks CVP Annual Pumping



Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
61	60	86	100

Banks CVP exports are higher under A4

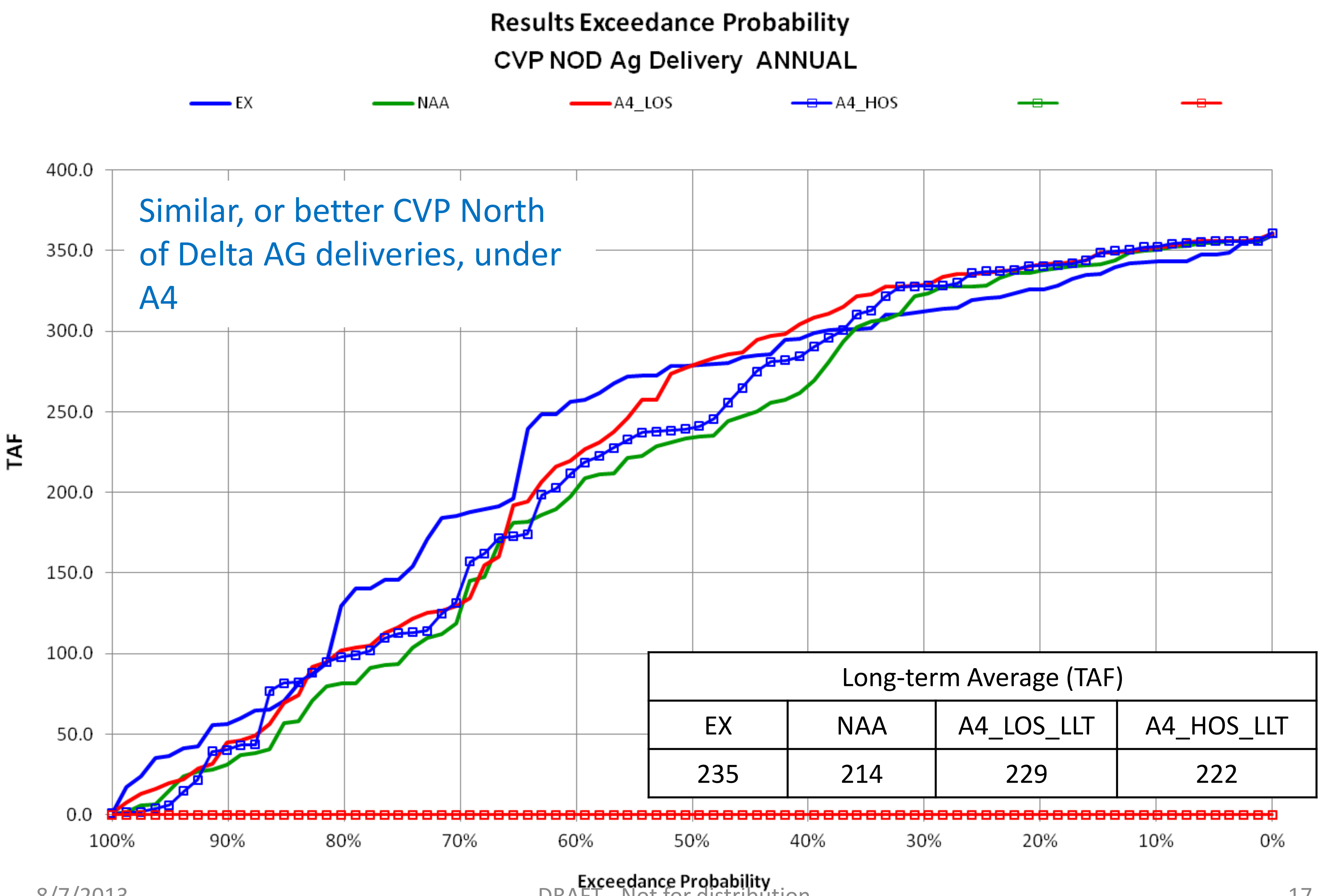
Total Banks Annual Pumping



Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
2,899	2721	3441	2716

Increased SWP exports under A4_LOS, while A4_HOS shows some reduction in the drier years

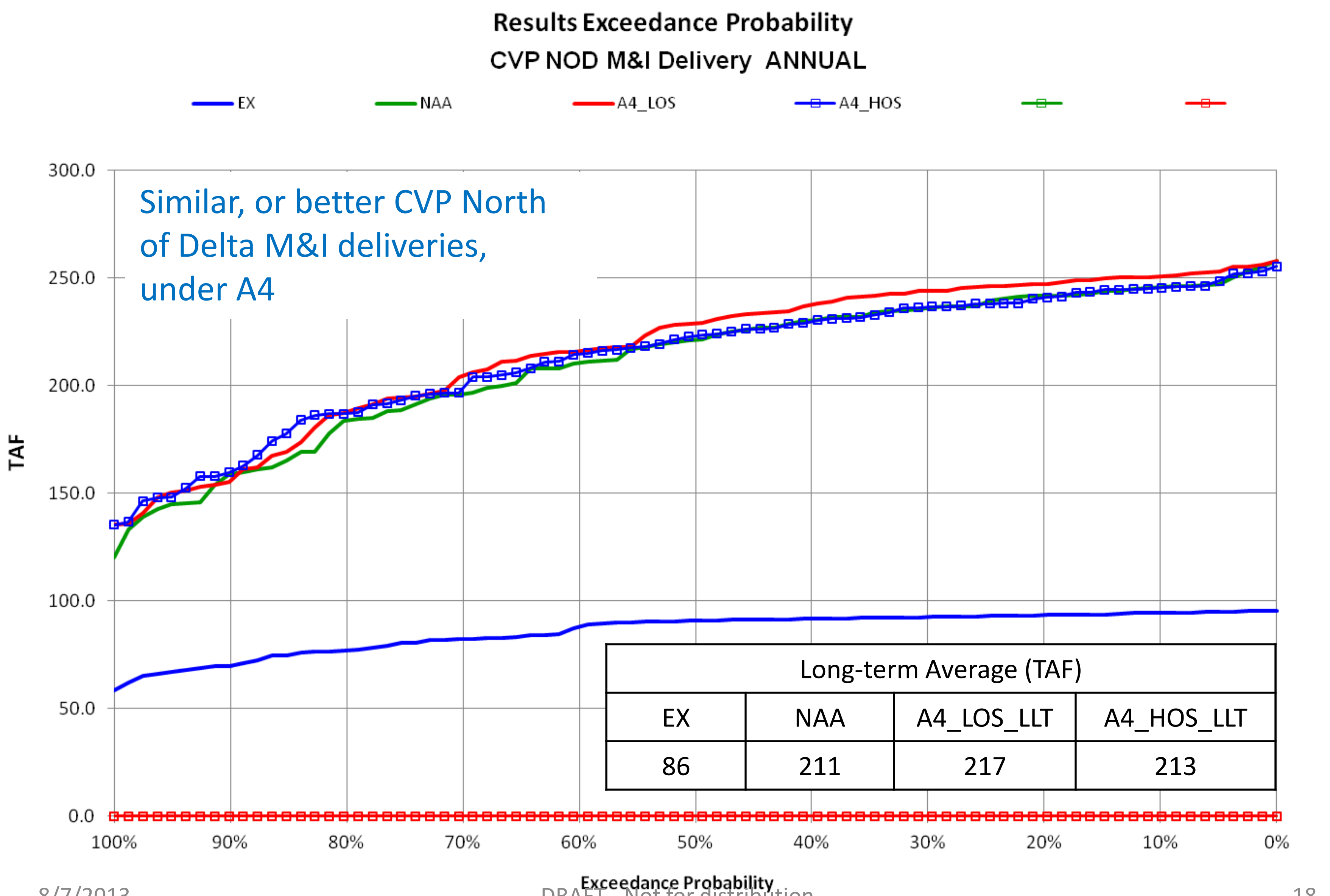
CVP NOD Ag Service Contracts Annual Deliveries



Similar, or better CVP North of Delta AG deliveries, under A4

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
235	214	229	222

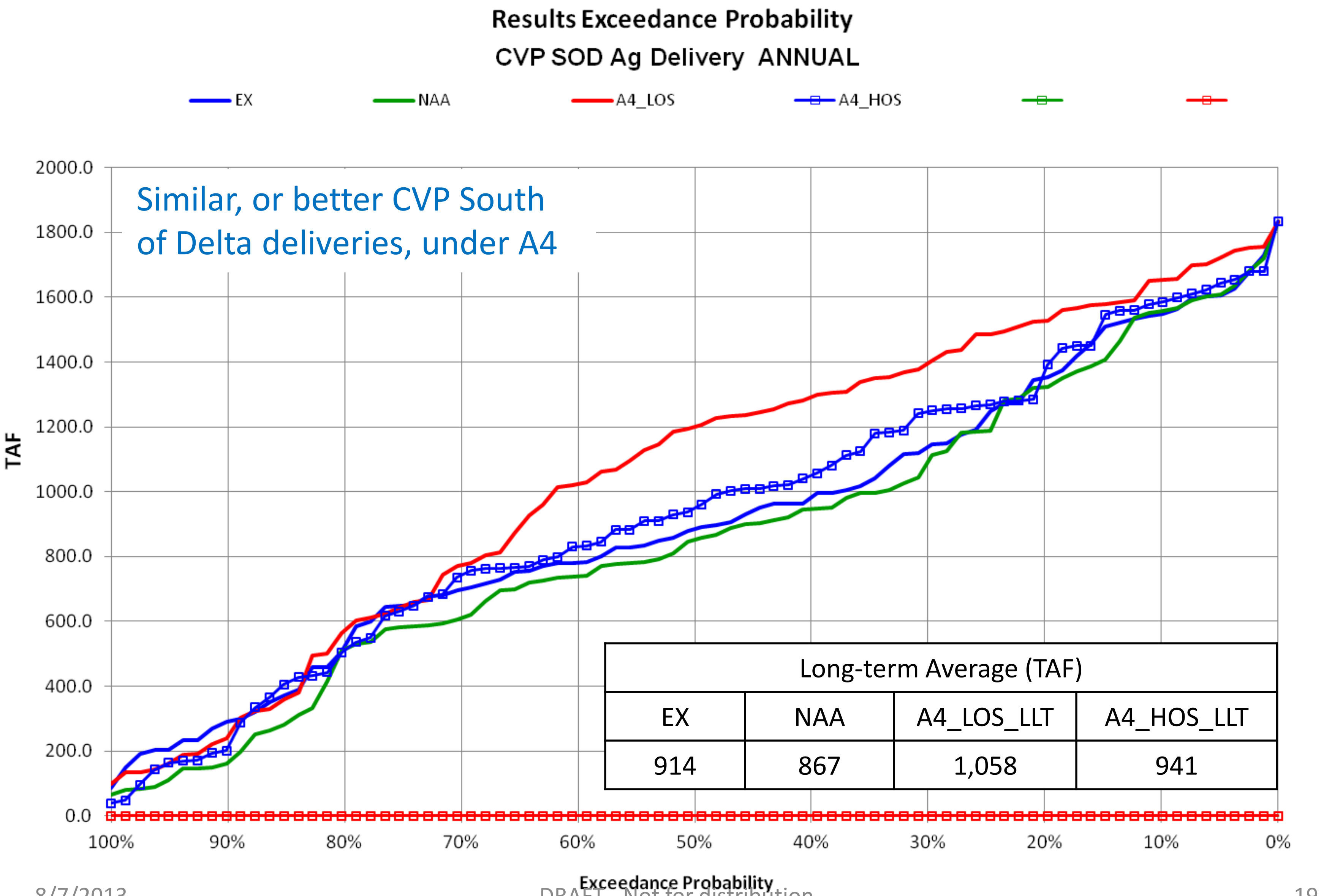
CVP NOD M&I Service Contracts Annual Deliveries



Similar, or better CVP North of Delta M&I deliveries, under A4

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
86	211	217	213

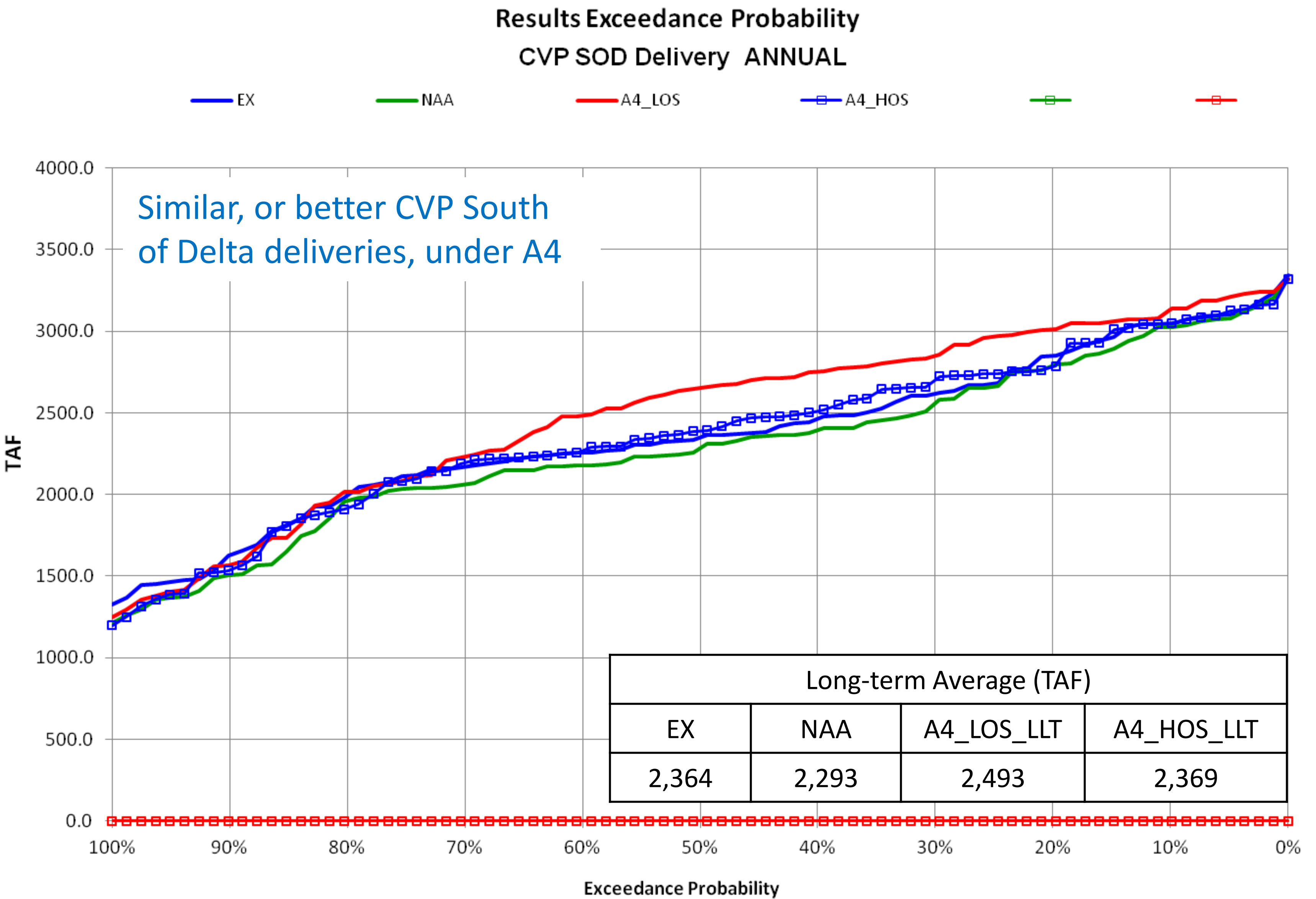
CVP SOD Ag Service Contracts Annual Deliveries



Similar, or better CVP South of Delta deliveries, under A4

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
914	867	1,058	941

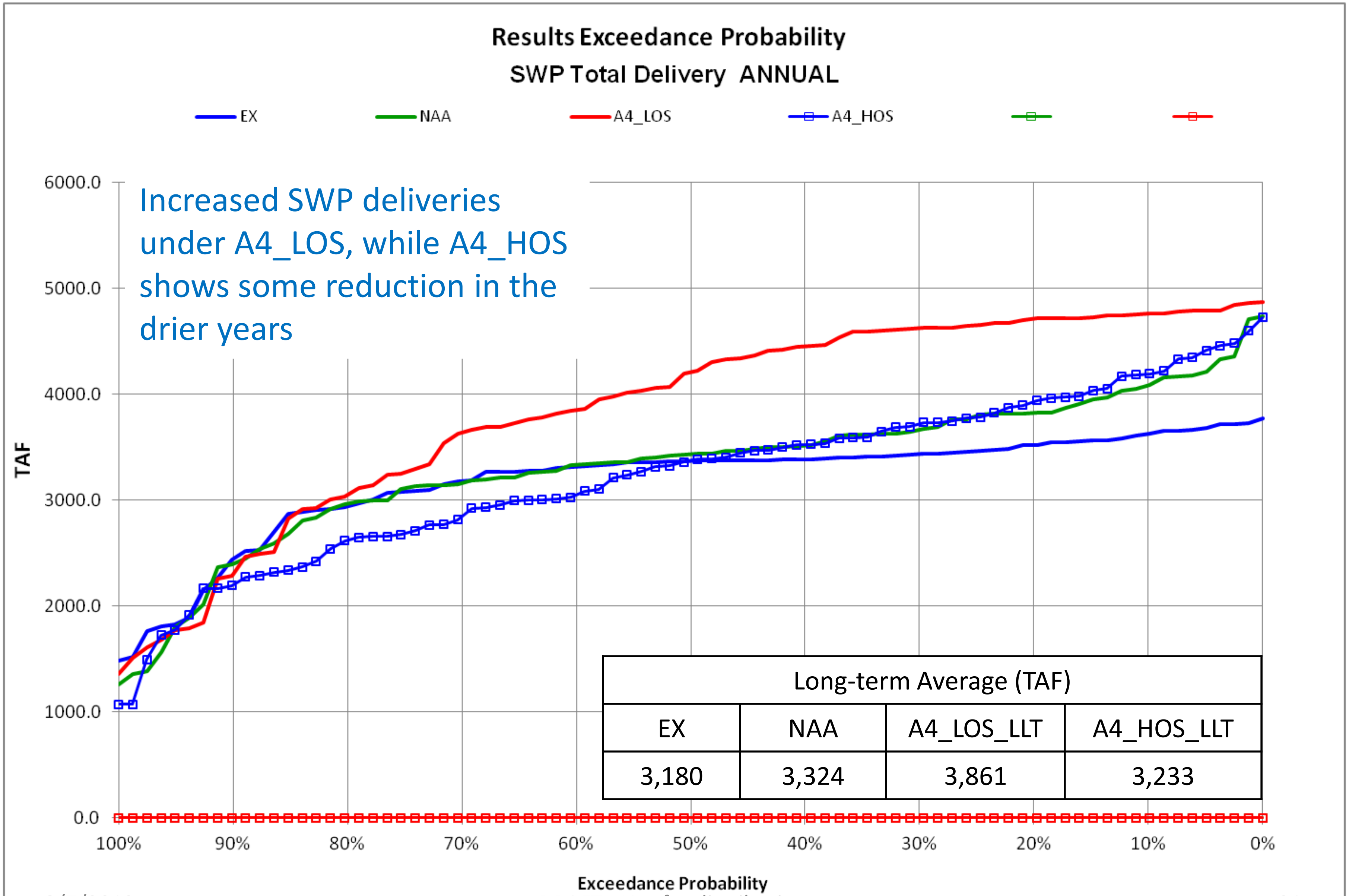
CVP SOD Annual Deliveries



Similar, or better CVP South of Delta deliveries, under A4

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
2,364	2,293	2,493	2,369

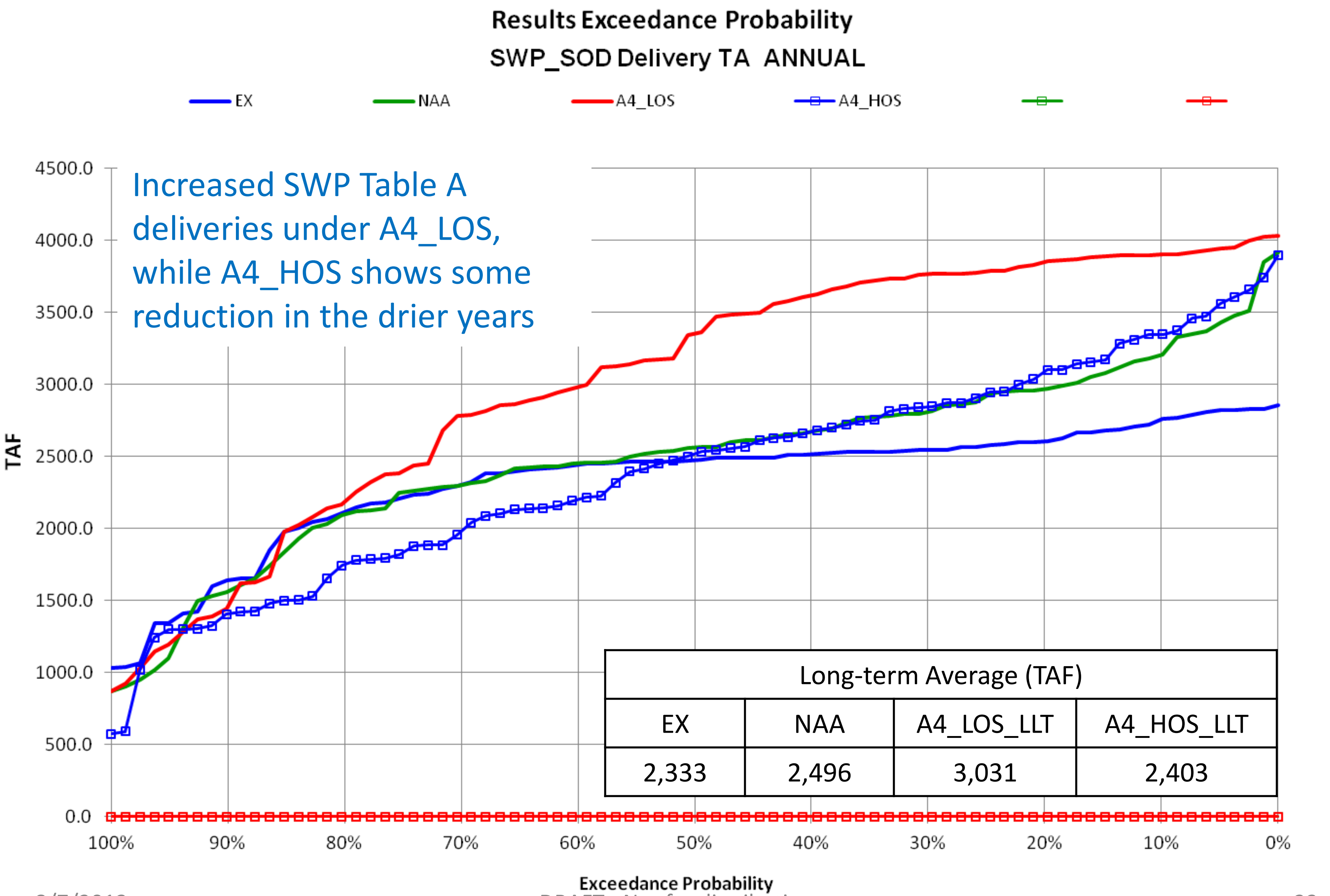
SWP Total Annual Deliveries



Increased SWP deliveries under A4_LOS, while A4_HOS shows some reduction in the drier years

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
3,180	3,324	3,861	3,233

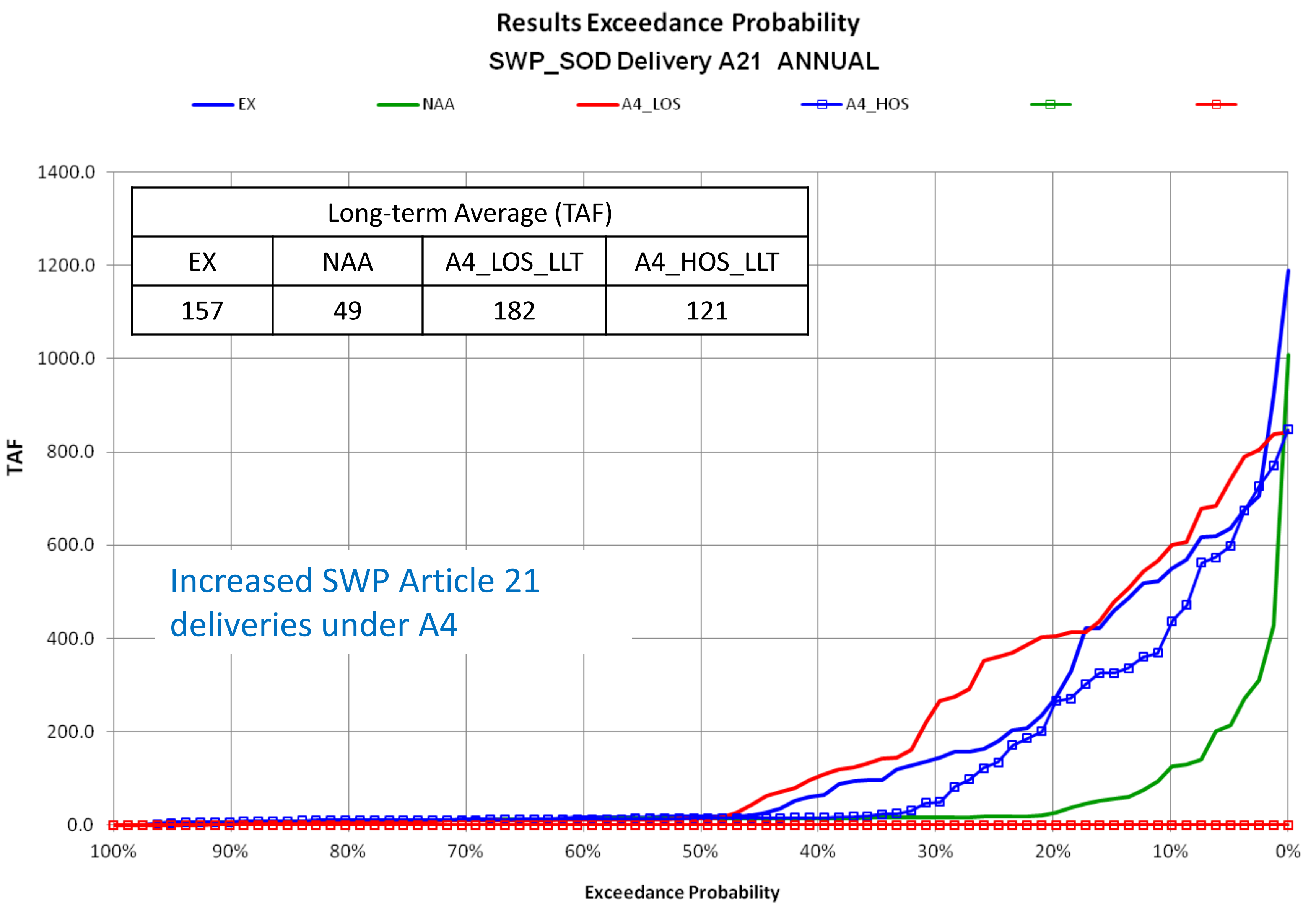
SWP Annual Table A Deliveries



Increased SWP Table A deliveries under A4_LOS, while A4_HOS shows some reduction in the drier years

Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
2,333	2,496	3,031	2,403

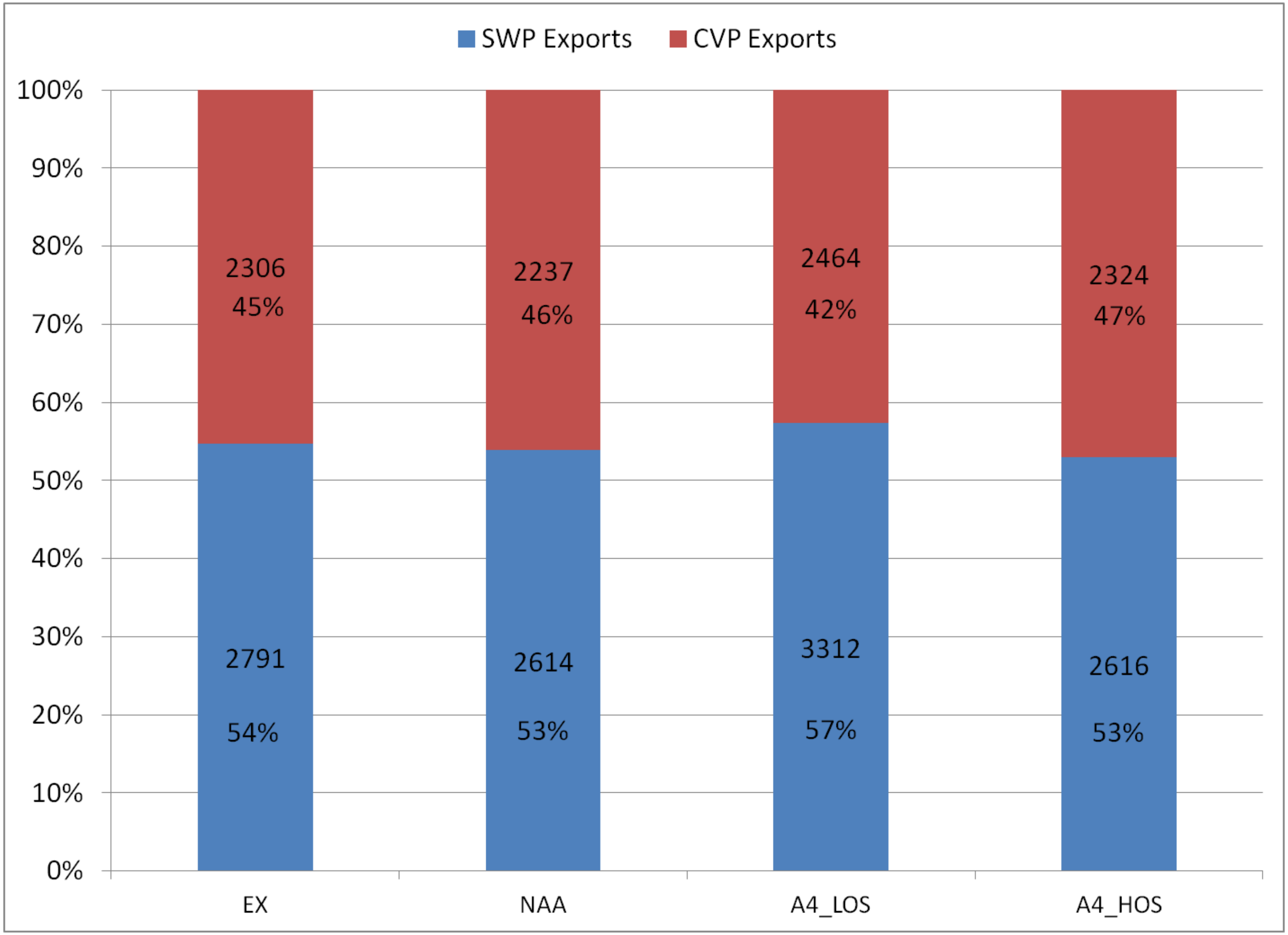
SWP Annual Article 21 Deliveries



Long-term Average (TAF)			
EX	NAA	A4_LOS_LLT	A4_HOS_LLT
157	49	182	121

Increased SWP Article 21 deliveries under A4

SWP and CVP Export Split



- *CVP exports include pumping at Jones Pumping Plant and Joint Point Diversion*
- *SWP exports do not include pumping for water transfers*

Water Deliveries

CALSIM II Water Supply Metrics				NAA	A4_LOS	A4_HOS	A4_LOS minus NAA	A4_HOS minus NAA
Sacramento River Hydrologic Region								
CVP Settlement	Contract Delivery (annual average)	(TAF/year)	Long Term	1,860	1,859	1,858	-1	-1
			Dry and Critical	1,839	1,839	1,840	0	1
CVP Refuge Level 2	Contract Delivery (annual average)	(TAF/year)	Long Term	153	163	154	10	1
			Dry and Critical	136	139	134	3	-2
CVP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	210	217	213	7	3
			Dry and Critical	173	179	181	6	7
CVP Ag	Contract Delivery (annual average - does not include Settlement contractors)	(TAF/year)	Long Term	212	227	221	15	8
			Dry and Critical	92	104	101	13	9
SWP FRSA	Contract Delivery (annual average)	(TAF/year)	Long Term	950	951	953	1	3
			Dry and Critical	901	905	909	4	8
SWP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	23	28	22	5	-1
			Dry and Critical	16	17	13	1	-3
San Joaquin River Hydrologic Region (not including Friant-Kern and Madera Canal water users)								
CVP Exchange	Contract Delivery (annual average)	(TAF/year)	Long Term	852	852	852	0	0
			Dry and Critical	814	814	814	0	0
CVP Refuge Level 2	Contract Delivery (annual average)	(TAF/year)	Long Term	261	261	261	0	0
			Dry and Critical	249	249	249	0	0
CVP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	16	17	16	1	1
			Dry and Critical	13	14	13	1	0
CVP Ag	Contract Delivery (annual average; does not include Exchange contractors)	(TAF/year)	Long Term	289	350	313	61	24
			Dry and Critical	134	165	151	31	16
SWP Ag	Contract Delivery (including Article 21) (annual average)	(TAF/year)	Long Term	4	4	3	1	0
			Dry and Critical	3	3	2	0	0

Water Deliveries

CALSIM II Water Supply Metrics				NAA	A4_LOS	A4_HOS	A4_LOS minus NAA	A4_HOS minus NAA
San Francisco Bay Hydrologic Region								
CVP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	290	297	292	7	2
			Dry and Critical	318	322	320	4	2
CVP Ag	Contract Delivery (annual average)	(TAF/year)	Long Term	36	43	39	8	3
			Dry and Critical	16	20	19	4	2
SWP M&I	Contract Delivery (including Article 21, includes transfers to SWP contractors) (annual average)	(TAF/year)	Long Term	199	246	195	47	-3
			Dry and Critical	142	150	118	8	-25
Central Coast Hydrologic Region								
SWP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	44	54	43	10	-1
			Dry and Critical	31	33	25	1	-6
Tulare Lake Hydrologic Region (not including Friant-Kern Canal water users)								
CVP Refuge Level 2	Contract Delivery (annual average)	(TAF/year)	Long Term	12	12	12	0	0
			Dry and Critical	11	11	11	0	0
CVP Ag	Contract Delivery (annual average - includes Cross Valley Canal)	(TAF/year)	Long Term	598	733	654	135	56
			Dry and Critical	279	344	313	65	34
SWP M&I	Contract Delivery (annual average)	(TAF/year)	Long Term	84	104	81	20	-3
			Dry and Critical	60	63	48	3	-12
SWP Ag	Contract Delivery (including Article 21) (annual average)	(TAF/year)	Long Term	658	917	693	259	35
			Dry and Critical	461	484	369	23	-92
South Lahontan Hydrologic Region								
SWP M&I	Contract Delivery (including Article 21) (annual average)	(TAF/year)	Long Term	267	324	253	57	-14
			Dry and Critical	198	216	160	19	-38
South Coast Hydrologic Region								
SWP M&I	Contract Delivery (including Article 21, includes transfers to SWP contractors) (annual average)	(TAF/year)	Long Term	1,352	1,637	1,287	285	-65
			Dry and Critical	992	1,069	806	77	-186
SWP Ag	Contract Delivery (including Article 21) (annual average)	(TAF/year)	Long Term	8	11	8	3	0
			Dry and Critical	6	6	5	0	-1

Water Deliveries

CALSIM II Water Supply Metrics				NAA	A4_LOS	A4_HOS	A4_LOS minus NAA	A4_HOS minus NAA
Total For All Regions								
Total Supplies	Contract Delivery (CVP, SWP and other) (annual average)	(TAF/year)	Long Term	8,377	9,307	8,423	930	46
			Dry and Critical	6,885	7,146	6,599	261	-286

D.10.4. Tidal Marsh Restoration Sensitivity Analysis

BDCP assumes up to 65,000 acres of tidal marsh restoration. As part of the modeling of the BDCP EIR/EIS Alternatives, a hypothetical footprint of the tidal marsh restoration was developed in various regions of the Delta, to incorporate the effects of the proposed large-scale restoration in the analyses. To understand the range of uncertainty associated with the assumed restoration, several two-dimensional RMA Bay-Delta Model simulations were performed for several other hypothetical restoration footprints. The goal of this effort is to bracket the range of potential changes in the Delta hydrodynamics and salinity conditions under varied restoration footprint assumptions. Sensitivity of hydrodynamics and salinity conditions in the Delta was evaluated for three factors shown below. The sensitivity scenarios included variations in footprints to reflect these factors.

- Tidal marsh restoration acreage assumed in one region of the Delta versus other
- Available channel conveyance leading to the breach
- Location of the breach

All the simulations were performed from April 2002 to December 2002 period, using historical flow, tide and salinity boundary conditions. The sensitivity scenarios include:

Factor	BDCP Base Scenario	Sensitivity Scenario
Tidal marsh restoration acreage assumed in one Restoration Opportunity Area (ROA) versus other	ELT	Maximize restoration acreage in Suisun ROA while reducing the acreage in Cache Slough ROA, keeping the total tidal marsh restoration equal to ELT levels
	LLT	No tidal marsh restoration in No South Delta ROA.
Available channel conveyance leading to the breach	LLT	Increase conveyance in the Middle River Channel leading to the Union Island breach in the South Delta ROA.
	LLT	Suisun Scour simulation representing the channel scour and tidal marsh evolution in Suisun Marsh at LLT.
Location of the breach	ELT	Remove the breach to the Prospect Island along Miner Slough.
	LLT	Remove the breach to Little Egbert Island along Cache Slough.
	LLT	Relocate the Sherman Island breach on Threemile Slough to San Joaquin River

A technical report with detailed results and a summary of the findings from the tidal marsh sensitivity analysis, and their likely implications on the physical modeling results is included as the Attachment 5 for Section D.

D.11. CALSIM II and DSM2 Schematics used for Bay-Delta Conservation Plan Modeling

CALSIM II schematic and DSM2 grid representing the version of the models used for the BDCP modeling are included in the Attachment 6 for Section D (separate PDF file).

The version of CALSIM II schematic included in the Section D Attachment 6 is dated April 1, 2010, and is consistent with the CALSIM II model used for BDCP.

The primary DSM2 grid included in the Section D Attachment 6 is DWR's Version 2.0, which is based on the 2000 calibration of the DSM2 model. Majority of the Version 2.0 DSM2 grid remained unchanged under BDCP. Only parts of the grid were modified for BDCP. These modifications are shown separately in the Section D Attachment 6. The specific modifications to the DSM2 grid are related to:

- BDCP recalibration
- Representation of the north Delta intakes under each BDCP Alternatives 1 – 8
- Representation of the BDCP tidal marsh restoration areas at Late Long-Term

D.12. DSM2 16 Year Planning Simulation versus 82 Year Planning Simulation

This section includes a technical memorandum prepared by DWR comparing and contrasting the DSM2 planning simulations performed over the 16 year period (WY 1976 – 1991) versus the simulations performed over the 82 year period (WY 1922 – 2003).

OFFICE MEMO

TO: Cathy Crothers	**DATE:** 8-22-13 DRAFT
FROM: Parviz Nader-Tehrani, Erik Reyes, Francis Chung, Tara Smith	**SUBJECT:** CalSim II and DSM2 Modeling for BDCP (16-years versus 82-years)

SUMMARY FOR CONSULTANT REVIEW

I. Introduction

Contra Costa Water District (CCWD) raised concerns that the CalSim Artificial Neural Network (ANN) results showed that BDCP Alternatives increased chlorides at CCWD's intake locations at Rock Slough, Old River south of Highway 4, and Victoria Canal when compared against a No Action Alternative. DWR technical staff has confirmed modeled increase in chlorides (salinity). However, the CalSim ANN water quality results are only used as guidelines to drive project operations, such as changes in export levels. Instead, the better tool to use is DSM2, which produces results that more accurately reflect the actual water quality impacts that might occur due to project operations. DWR staff reviewed the DSM2 results and found that there was a chloride increase, averaged over 16-years[1], but it was smaller than the increase seen in the average CalSim ANN results, which rely on data from an 82-year time period.

All of the existing analysis for the BDCP Draft EIR/S has used 16-year DSM2 results. CCWD's inquiry led DWR staff to investigate whether 82-year DSM2 results showed greater changes in chlorides, or salinity, than the 16-year results. DWR staff ran an 82-year DSM2 simulation for the No Action Alternative and for Alternative 4 to examine if there are indeed significant differences in chlorides when comparing 82-year results against 16-year results. DWR staff found that there is at times greater increases in chlorides in the 82-year simulation period than there are in the 16-year period when looking at the average monthly results. Even so, DWR staff believes that the conclusions based on the 82-year time period do not add any additional accuracy or value to the analysis. In fact, the hydrology that is used in the CalSim simulations that provides input to DSM2 is not as accurate as in the 16-year period. This memo briefly describes CalSim and DSM2 and their appropriate applications and addresses whether CalSim and DSM2 82-year simulations are the "best available model" for the BDCP process. Also discussed at the end of this memo are the Potential impacts to BDCP and other DWR efforts if there is a move to DSM2 82-year simulations. The points below summarize the findings and are explained in the following text.

- 82-year CalSim simulations were designed to evaluate system performance from a probabilistic perspective, whereas 16-year DSM2 simulations are designed to investigate the detailed physics of the hydrodynamics and water quality, such as the

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[1] DSM2 uses Electrical Conductivity (EC) to model salinity. The simulated EC values are converted to chlorides using empirical relationships developed from historical data at various locations in the Delta.

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movement of chlorides, in the estuary system. In other words, DSM2 can show salinity (chloride) changes in all of the Delta channels in short time steps (daily or less) in relation to changes in flows and tidal movement of water, which can help understand how salinity moves within the system with more accuracy than CalSim.

16-year DSM2 simulations have adequate data (over half a million time-steps) to evaluate the detailed physics of the system. 82-year DSM2 simulations do not appear to add any value to these evaluations and are less accurate due to a less accurate hydrology in the earlier historical periods.

- The use of 16 year DSM2 simulations can be analogized to the use of a microscope that renders a close examination of a focus area, the Delta, on a fine time scale, 15 minutes.

- The distribution of year types in the 16-year period is similar to the distribution in the 82-year period (i.e., a wide range of hydrological conditions is reflected in both data sets).

- Data to develop DSM2 Boundary conditions is more readily available for the 16-year period because the time period is more recent.

  Historic data of more recent periods is of better quality when used to develop the historic hydrology used in CalSim and DSM2. Data representing historic flows, tidal stages, and water quality, etc. for periods before the 1950's is often estimated rather than from recorded gage data.

- The 16-year simulation period for DSM2 contains the driest two-year drought and also an extended drought (1987 – 1991), and provides sufficient information for necessary confidence in the modeling results.

- 16-year DSM2 simulations have been used for several programs, including SDIP, Franks Tract, Storage Investigations, and OCAP.

- An 82-year DSM2 simulation was developed to look at expanded Los Vaqueros storage investigations and was an appropriate use of the model for that specific analysis. A longer simulation period was needed to properly evaluate salinity results over the time needed to fill the reservoir. Since filling the reservoir occurs over a number of years, 16 years was too short to properly look at how the water quality in the reservoir might change over time due to variable hydrologic conditions.

- 82-year DSM2 simulations need additional development if they are to be used for constituents other than salinity, such as organic carbon, dissolved oxygen, or temperature.

- Choosing 16-, 82-, 25-, or 50-year simulation periods will generally provide different period average results despite them having similar year type distributions. This is because the sequence of years plays a large role in physical and operational system responses. However, the difference in length of the modeling period may not add value or confidence in results.

II. CalSim and DSM2

(What is CalSim II and for what purposes is it used? What is DSM2 and for what purposes is it used?)

CalSim and DSM2 focus on different aspects of the system, with different levels of detail in relation to project operations. In Appendix 5A of the BDCP documentation, section A.3 (pages A-10 through A-23) has a detailed description of CalSim II (input and output) along with the assumptions and how it was used to simulate the system operations. In section Section A.5 (Pages A-32 through A-49), there is a detailed description of DSM2 (input and output) and how it was used to simulate the hydrodynamics and water quality in the Sacramento San Joaquin Delta. For reference, both of these sections are attached to the end of this memo.

CalSim II uses a monthly time step for inflows and exports. CalSim II looks at system performance over larger time scales and thus 82 years of data enhances the evaluation process. DSM2 is a hydrodynamic[2] and water quality model and looks at finer details of the physical system and uses a 15-minute time–step, for such functions as salinity, water levels, flows, organic carbon, and dissolved oxygen. CalSim II is run at a monthly time-step for a total of 984 time-steps in an 82-year simulation period. DSM2 runs at a 15 minute time-step for a total of 560,640 time-steps in a 16-year simulation period. For an existing condition simulation, CalSim uses historical hydrologic data as its input and applies current water regulatory requirements and level of development in order to determine the operation of the state and federal projects. DSM2 is calibrated[3] using historical data at several locations in the Delta. For planning studies, its inflow and export input come from CalSim's monthly output. Because DSM2 is a model of the physical system, if actual flows into and exports and diversions from the system matched that of CalSim, DSM2 would be able to determine water levels, flow patterns, and salinity throughout the channels in the Delta within the confidence levels as determined by the historical calibration. CalSim can only determine salinity at select locations in the Delta. This is explained more fully in the paragraph below.

A. CalSim

1. Artificial Neural Network

The Artificial Neural Network in CalSim is the module that calculates the amount of

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[2] A hydrodynamic model is a tool that is able to describe or represent the motion of water using numerical solutions to the complex governing equations of conservation of momentum and mass within a fluid.

[3] In Calibration, model parameters (knobs) are adjusted in order for model output to match observed data. Validation of the model follows. In validation, another historical time period is chosen, the model is run again and the results of the simulation are matched with observed data without adjusting the model parameters.

water needed to be released into the Delta or exported in order to meet the water quality objectives in the Delta at a few specific locations. The CalSim ANN does not adjust the flows to meet water quality levels in other Delta locations. The CalSim ANN is not a physics-based model, but a mathematical model that finds patterns in data and is trained to fit those patterns with equations that provide the best estimate of salinity, using output from DSM2. The inputs into ANN include major inflows, tidal magnitudes, cross-channel operation and Delta-wide consumptive use. The inputs for training do not include salts coming from agricultural returns. Because of this lack of detailed input for land salts and regional diversion and returns, the ANN is limited in its accuracy to represent the physical system.

Appendix 5A, Section C, starting from page B-185, includes specific CalSim II and DSM2 Modeling results. End of Month Storage values at major reservoirs are analyzed in detail for each of the listed BDCP alternatives. These include Trinity, Shasta, Oroville, Folsom, San Luis, and New Melones. Los Vaqueros storage, however, has traditionally never been a part of the standard CalSim II output. In summer of 2009, at the request of CCWD, DWR agreed to allow Dan Easton (MBK) to insert the LV (Los Vaqueros) module inside BDCP CalSim studies. According to CCWD, this addition would allow a better representation of CCWD operations of its three intakes (Rock Slough, Old River, and Victoria Canal). The accuracy of the LV module relied on the accuracy of the ANNs developed for these three intakes. DWR has been in charge of developing ANNs for all the scenarios studied for BDCP. Although DWR has routinely generated ANNs designed to simulate water quality conditions at 11 locations (including all the three CCWD intakes), we performed a "ANN Full Circle Analysis" only for the four major locations; Emmaton, Jersey Point, Old River Rock Slough, and Collinsville. These were the locations that primarily affected the operations (such as reservoir releases or export levels) simulated within CalSim II. In addition, it has always been understood that ANNs perform the best[4] when the ocean salt is the primary source of the salt. As a result, the accuracy of the ANNs to simulate water quality conditions at the other two CCWD intakes (Old River and Victoria Canal) should be considered questionable. In fact, in an E-mail exchange in October 29, 2009, Matt Moses (CCWD) acknowledged that "**Use of ANN to estimate water quality at CCWD intakes can at times result in operational flutter between cycles and inaccurate estimates of CCWD delivered water quality. CCWD will likely use pre-processed water quality time series input for CalSim studies related to Los Vaqueros Expansion".**

2. CalSim II Daily Data

CalSim II has routines for estimating Fremont Weir flows and North Delta Diversions that transform monthly flows into daily historic patterns. The daily historic patterns provide for better estimates of flow and diversion at the Fremont Weir and North Delta Diversion facilities. Daily historic patterns are assumed[5] from recorded gage data for Sacramento River at

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[4] When performing best, salinity determined by the CalSIM ANN more closely matches the DSM2 simulated salinity for the same conditions.

[5] CalSim II is a monthly model and for most locations assumes that flow is uniform for every day in a given simulation month. Two places that are different are the Fremont Weir and the Hood NDD. At these locations it was necessary to introduce the daily variability of real-time hydrographs to get more realistic estimates of flow over the weir and diverted at Hood NDD. Daily variability is introduced into the model by assuming that the monthly water volume at Fremont weir occurs on a daily pattern that matches the daily pattern that occurred historically.

Freeport for the period of 1955 – 2003. There is insufficient gage data for the period of 1922 – 1954 and thus the daily patterns here are estimated from daily patterns of years with gage data (1955 – 2003) for years in 1922 - 1954 that are hydrologically similar. The period with gage data is obviously a more accurate depiction of daily flows and thus gives more accurate results that feed into DSM2. From an accuracy and quality of data point of view, the 16-year period of 1976 – 1991 is better than the 82-year period of 1922 – 2003.

3. CalSim II Hydrology Data

Similar to the point above, in general the quality of hydrologic data is less reliable the further back in time one goes. The input hydrology for the 82-year CalSim simulation period consists of good gage data from about the 1950’s to 2003; however, this data only provides a “best estimate” of data from the 1950’s back to 1922. For CalSim, which is run on a monthly time-step and analyzes system performance, it helps to have more data with which to evaluate the performance. Traditionally, the early period has been thought to be desirable to simulate for the evaluation of system performance because it contains an extended drought period (1928 – 1934). There is also, however, an extended drought period (1987 – 1991) in the more recent years with more accurate gage data, which is used in DSM2 as discussed above. The driest two-year drought also occurs in the later period with more accurate gage data. Thus, while using estimated input data allows for longer simulations, the data for the early years of simulation (1922 – 1950’s) is acknowledged to be of lower quality. In contrast, DSM2 models the 16-year period with recent high quality data and includes hydrologic variability similar to the 82-year period, as discussed above.

B. DSM2

1. Historical Development of Delta Simulation Model Planning Studies

The modeling purpose of the operation model is to show system-wide changes to flow and exports related to SWP and CVP operational scenarios. The modeling purpose of the hydrodynamic and water quality models is to show more detailed changes to physical constituents, such as salinity, in the Delta due to the changes in flows from the operations model (CalSim), tidal variations, gate operations, structural changes (such as a tunnel) and in-Delta diversions and returns. Flows from the systems operations models, such as DWRSIM and CalSim, have been used as input to Delta hydrodynamic models, such as DSM (a predecessor to DSM2), since the early 1990s. DSM used flow and export output from DWRSIM to make analysis for various DWR programs, including the North and South Delta Programs. At that time, computing power was expensive, so running several years of time, such as 16 years, could take up to two weeks of computer run time. Years simulated represented various year types in order to allow modelers to see the impact of proposed changes to the Delta on the hydrology and salinity in the Delta.

DSM2 modeling uses daily and 15 minute data from 16 years, 1976 –1991. CalSim modeling uses monthly data from 82 years, 1922-2003. Because the hydrodynamic models and the operations models have different purposes and use different temporal types of data (monthly versus daily or less), the length of the time period to use in the model must be chosen in consideration of the data available during the time period. This is an important consideration because the quality of the input data affects the confidence to be given in the modeling results. Section II.A.2 and II.A.3 above discusses the quality/resolution of flow data from

CalSim that is used as input to DSM2. Available data, purpose of modeling, and representative hydrologic time periods are all factors that determine the best available model to use in an analysis, as discussed further below.

2. DSM2 16-Year and 82-Year Planning Studies

a) DSM2 16-year-Year Planning Studies

In 1998, DWR released DSM2, which was an improvement over DSM in several respects, including improved channel bathymetry and the use of a real tide that included spring neap variations[6]. One of the first studies for which DSM2 was used was evaluating the CALFED alternatives. At that time, the operations model provided output, for use as input to DSM2, through 1994. The engineers making the simulations chose a series of years that represented the full spectrum of year types: Wet, Above Normal, Below Normal, Dry, and Critical. The years 1976-1991 fit the spectrum of year types and also were contained in a continuous series of years that could be run as one study. Since hydrodynamics and water quality from one year affect the results of the following year, a sequence of years that contained all needed year types was chosen. The sequence of years was bracketed on either side by two critical years, 1976 and 1977 at the beginning of the sequence of years and 1990 and 1991 at the end of the sequence of years. Critically dry years are an area of focus when looking at alternatives due to potentially larger impacts to water quality. The table below shows the relationship in year types between the 16 years and 82 years.

	82 Year - year type percentage	16 Year - year type percentage	82 Year - number of years in year type	16 Year - number of years in year type
Wet	32	25	26	4
Above Normal	15	13	12	2
Below Normal	17	6	14	1
Dry	22	25	18	4
Critical	15	31	12	5

The DSM2 16-year simulation period has an ample amount of data to look at the finer details of the physical system. The 16-year period contains the driest two-year drought on record and it also has an extended drought period (1987 – 1991). There is adequate variation of year types and drought periods to evaluate the physical system and the impacts of operational and structural changes to that system. The accuracy of the model would not be improved with the addition of more years. It is important to understand the processes causing the differences in water quality between alternatives. DSM2, with 16 years, is able to do that due to a finer scale time step and a simulation that models the physical movement of water

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[6] Prior to using a Spring Neap tide, DWR used a 19-year mean tide that repeated every 25 hours with the range of water levels being somewhere in-between the Spring and Neap ranges. Spring tide is the highest energy tide that contains the widest range of water levels. It is caused by the sun and the moon being aligned and creating a greater force. The neap tide contains the smallest range and occurs when the moon and the sun are at 90 degrees and the solar force partially cancels out the moon's force.

and salinity. Accuracy of the model would not be improved with additional years because 16 years contains the variability in year types and enough data to determine why there are differences in water quality results.

In putting together DSM2, DWR developed boundary conditions, which are not provided by operation models. These boundary conditions include water levels at Martinez, salinity at Martinez, and multiple agricultural diversions, drainages, and water quality. In order to develop some of these boundary conditions, historical data was necessary. A more complete set of historical data for development for the 16 years was available due to the facts that the period chosen was more recent and that the data was available in a public data base. Since 1998, DSM2 16-year simulations have been used for several programs, including the following:

- South Delta Improvements Program (http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfmhttp://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm),

- Franks Tract (http://www.water.ca.gov/frankstract/) ,

- Surface Storage Investigations (http://www.water.ca.gov/storage/common_assumptions/index.cfm)
    - including the In-Delta Storage (http://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfmhttp://baydeltaoffice.water.ca.gov/sdb/sdip/index_sdip.cfm),

- and Operations Criteria and Plan (OCAP) biological assessments (http://www.usbr.gov/mp/cvo/ocap_page.html).

b) DSM2 82-Year Planning Studies

DSM2 82-year simulations were also developed as part of the Surface Storage Investigations work to look at the salinity in the expanded Los Vaqueros Reservoir as it was filled. Due to the filling taking several years, 16-year simulations were not sufficient to do the analysis. A longer simulation period was needed to properly evaluate salinity results over the time needed to fill the reservoir. Since the filling of the reservoir occurs over a number of years, 16 years was too short to properly look at how the water quality in the reservoir might change over time due to variable hydrologic conditions. As part of this effort, boundary water levels at Martinez were developed for the 82-year simulation. These water levels were adjusted to account for sea level rise. Additionally, gate/barrier operations and agricultural diversions and returns were developed over the 82-year period. Simulations had to be run in sections covering shorter periods due to file size limitations and increases in computer run time over the 16-year simulation

3. Are 82-year DSM2 simulations right for BDCP?

a) Is more better?

Although the DSM2 was able to look at 82-year simulations for the above Surface Storage Investigation work, the question is whether the 82-year DSM2 simulation is the best available model for all analyses for the BDCP?

In modeling, it is not appropriate to assume that using more years in the model is necessarily better. It is more important to determine the requirements of the project first before determining the best available model. Often, when the amount of input used by a model is increased beyond what is needed or beyond the capability of the model, people reviewing the modeling results may wrongly assume they are more accurate or dependable than they really are. The following illustrates these points for the analysis of BDCP alternatives:

- Different hydrologies (all year types) are represented in the 16-year studies in a daily time-step.

  The process causing the difference in EC between alternatives is understood. With low export pumping in the south Delta in Alternative 4 , land salts are not quickly removed from the system after a dry year. Salinity levels in the south Delta will increase due to higher San Joaquin salinity, higher salinity in agricultural returns and/or lower flows in the San Joaquin River. Higher agricultural return salinity, representing leaching of fields, can also occur during winter months impacting water quality. Project exports, when high enough will remove that concentrated salinity from the south Delta. The exports also bring fresher Sacramento water into the south Delta area. In Alternative 4, since there are less exports than in the No Action Alternative, flows from the San Joaquin River and salinity due to concentrated agricultural returns make up a greater portion of the water diverted by Contra Costa Water District.

- The magnitude of the differences will vary due to different factors:

  - Different year types following each other will impact the magnitude. Whether it is 16 years, 25 years, 30 years, or 82 years, there is not a pattern of year types that history follows. Because of this fact, it is not a good assumption that the magnitude of the difference in EC levels would follow the 82-year average in the future. It could be more or it could be less. What is important is to determine what is behind the increase in EC and understand how that magnitude would be affected by that physical process. In this situation, the physical process is the higher concentration of land salts (from agricultural drainage) as compared to ocean salt, that is causing the increase in salinity.

  - The magnitude of the difference is affected by how ocean salts and land salts are modeled. In the case that is examined here (higher salinity from a dryer year followed by lower exports), land salt is not moved out of the system as quickly as in the base condition.

Because the salt coming from agricultural returns is estimated and not measured, there is uncertainty in values produced in studies that will affect the proper interpretation of the difference in water quality magnitude between No Action Alternative and Alternative 4. Agricultural water quality and diversions and drainages are boundary conditions for DSM2 and are supplied by another model, the Delta Island Consumptive Use (DICU) model, because measured values are not available. Calibration of DSM2 using historical conditions has shown that when DSM2 is not matching salintity well in the south Delta (in dry periods), it is due to the lack of adequate boundary conditions from agricultural boundary conditions. So when land salts become an important factor in the water quality results, care should be taken with interpreting the resolution and accuracy of results.

The physical processes behind the water quality differences between the No Action Alternative and Alternative 4 are understood. In this particular case, the differences are primarily due to agricultural diversions and returns. Because of this understanding of the impact of agriculture and because of understanding the relative accuracy of this impact, the accuracy of the DSM2 results cannot be improved by increasing the number of years of simulation. Thus, the 16-year DSM2 model is the best available model for the BDCP analysis. 82-year DSM2 results will not add additional value to this project.

b) DSM2 82-year simulations need additional development

82-year simulations of other constituents, such as organic carbon, dissolved oxygen, or temperature in the Delta, have not been developed. Additionally, the likelihood of developing boundary conditions for these constituents with an acceptable level of confidence is very small due to the limited amount of historical data. The further in time one gets away from the availability of data, the accuracy of the results becomes worse because an estimation is used instead of actual data. In developing the 82-year simulations for salinity, relationships for boundary conditions for Martinez and inflows could be more easily developed. Other constituents do not follow easily defined patterns and are much more difficult to develop.

4. Model Run time

In making a decision for the best available model, run time for obtaining results is a factor. One reason for using a combination of multi-dimensional[7] (multi-D) models with DSM2 in BDCP was because the multi-D models could not perform studies quickly enough to model 16 years. For example, to complete a 16-year study using the multi-D model RMA without combining it with DSM2 would have taken a computer run time of approximately one month. In addition to this practical concern of model run time, 16-year long multi-D model simulations are not deemed to produce additional or useful findings that are not afforded by 16-year DSM2 simulations. However, for a refined detailed analysis, refined both in space and in time, multi-D models have a place and have been deployed as an industry standard. For instance, multi-D models were needed and used to model flow into the habitat areas because the multi-D models were better in generating necessary information than DSM2. Information

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[7] Mult-Dimensional models model flow in two or three dimensions. In DSM2, a one dimensional model, flow is modeled as either moving upstream or downstream. In a two dimensional model, flow directions and magnitudes in a wide but shallow channel can be modeled.

from those multi-D runs modeling the habitats was fed into DSM2. Each alternative in this process is often run several times due to new changes in how that alternative is configured based on dialogue between stakeholders or technical problems in running the study. Model run time, in addition to the time it takes to process and analyze the information, has to be considered. If using a multi-D model does not provide added value to the studies and is more cumbersome, then using the simpler model is better.

For 82 years, the current run time for DSM2 is one day (24 hours), so run time is not the issue. It is a little more cumbersome to process the results due to the increased output per study (about 5 GB output for 16 years and 20 to 25 GB for 82 years), but that cumbersomeness also is not the main concern. The concern is that the additional years added would not add value to the analysis in all cases , so that the time added to run and process the results, even if not overly burdensome, would not be justified.